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Lifecycle Carbon Reduction and Net Zero Pathway Modeling Using LEED, EDGE, and SBTI Frameworks in Developing Economy Industrial Buildings

Mukut Kanti Barua[1];

[1]. *Operation Manager (Bangladesh)-Commodities, Industry and Facilities Division (CIF), Bureau Veritas, Dhaka, Bangladesh; Email: immukut@gmail.com*

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Abstract

This study examined lifecycle carbon reduction and net zero pathway modeling using LEED, EDGE, and SBTi frameworks in developing economy industrial buildings. The problem addressed in this research is that many industrial buildings in developing economies remain highly dependent on fragmented sustainability practices, limited lifecycle carbon accounting, weak green finance readiness, and insufficient integration between building certification, resource efficiency, and science-based emissions targets. The purpose of the study was to assess how LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned target setting, and integrated framework adoption influence lifecycle carbon reduction and net zero pathway readiness. A quantitative, cross-sectional, case-based research design was adopted, using industrial enterprise building cases such as manufacturing plants, warehouses, processing facilities, logistics buildings, and industrial parks. The sample included 180 valid respondents, consisting of engineers, facility managers, sustainability consultants, project managers, energy auditors, construction managers, and industrial owners or developers. The key variables were LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned target setting, lifecycle carbon reduction, LEED-EDGE-SBTi integration, and net zero pathway readiness. Data were analyzed through descriptive statistics, Cronbach's alpha reliability testing, Pearson correlation, and multiple regression modeling. The findings showed strong reliability across all constructs, with alpha values ranging from 0.82 to 0.89. EDGE-based resource efficiency recorded the highest mean score of 4.18, followed by lifecycle carbon reduction at 4.11, LEED-based sustainability practices at 4.05, and net zero pathway readiness at 3.98. Correlation results showed that lifecycle carbon reduction was strongly associated with net zero readiness, $r = 0.71$, $p < 0.01$. Regression analysis showed that LEED, EDGE, and SBTi jointly explained 58.4% of lifecycle carbon reduction variance, while lifecycle carbon reduction and framework integration explained 62.7% of net zero readiness variance. The study implies that integrated sustainability frameworks can strengthen industrial decarbonization, improve resource efficiency, and support measurable net zero transition planning.

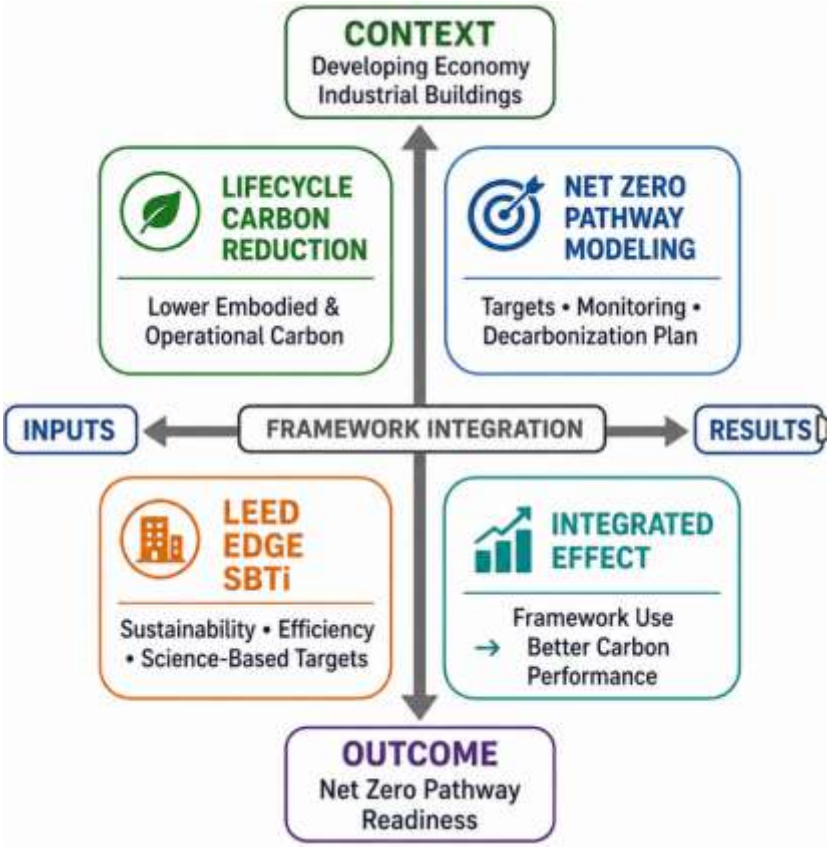
Keywords

Lifecycle carbon reduction; Net zero pathway readiness; LEED; EDGE; SBTi.

INTRODUCTION

Lifecycle carbon reduction refers to the systematic reduction of greenhouse gas emissions generated across the complete life cycle of a building, including raw material extraction, manufacturing, transportation, construction, operation, maintenance, refurbishment, demolition, and end-of-life treatment. In industrial buildings, this concept becomes especially significant because such facilities combine conventional building-related emissions with production-support energy demand, mechanical systems, process-related utilities, cooling loads, lighting, ventilation, water use, material flows, and long-term operational intensity (Sartori & Hestnes, 2007). . Lifecycle carbon is usually divided into embodied carbon and operational carbon. Embodied carbon refers to emissions associated with building materials, construction activities, maintenance, repair, replacement, and disposal, while operational carbon refers to emissions generated through electricity consumption, heating, cooling, ventilation, lighting, equipment use, and building services during the use phase. A lifecycle perspective is necessary because carbon emissions are distributed across multiple stages rather than being limited to the operational phase alone. Earlier building lifecycle studies have emphasized that environmental assessment must include both operational and embodied dimensions because design choices, material selection, construction processes, system boundaries, and service-life assumptions strongly influence total carbon performance.

Figure 1: Integrated Framework for Lifecycle Carbon Reduction and Net Zero Pathway Readiness



Similar evidence has shown that embodied energy measurement requires careful identification of the parameters that influence building-related emissions (Dixit et al., 2010). The importance of whole-building life cycle energy analysis has also been supported in studies that connect operational and embodied energy as part of total building performance (Ramesh et al., 2010). Life cycle assessment has therefore become a key analytical approach for evaluating the environmental burden of buildings because it connects material production, construction, use, maintenance, and end-of-life impacts into one comprehensive assessment structure (Ortiz et al., 2009). The relevance of life cycle assessment for building-sector carbon evaluation has also been emphasized in broader reviews of building energy and

environmental impacts (Cabeza et al., 2014). Life cycle carbon emissions assessment has further been recognized as a necessary approach for understanding building-related environmental performance across multiple stages (Chau et al., 2015). In the present study, lifecycle carbon reduction is defined as the measurable improvement of whole-building carbon performance through low-carbon materials, efficient design, energy optimization, resource-efficient operation, carbon accounting, and structured net zero planning. This definition is particularly relevant to industrial facilities because the reduction of operational energy demand may increase the relative importance of embodied and recurrent emissions across the total building life cycle (Dixit et al., 2012). Embodied energy studies have also shown that building case studies must consider lifecycle contributions beyond operational energy alone (Chastas et al., 2016). The need to investigate embodied energy parameters across residential and building contexts has further strengthened the relevance of lifecycle carbon analysis (Dixit, 2017). The international importance of lifecycle carbon reduction is linked to the global role of buildings and construction in energy consumption, resource extraction, and emissions generation. In developing economies, the issue becomes more urgent because industrial expansion, infrastructure development, manufacturing growth, and urbanization continue to increase the demand for new industrial buildings with measurable carbon reduction capacity.

Net zero pathway modeling refers to the structured identification, measurement, sequencing, and evaluation of actions required to move a building, facility, or organization from its current emissions baseline toward a net zero carbon condition. In industrial buildings, such a pathway includes energy demand reduction, efficient envelope design, high-performance mechanical and electrical systems, lower-carbon material selection, improved water efficiency, renewable energy planning, emissions monitoring, and alignment with measurable carbon reduction targets. Net zero is not limited to lower utility costs or green building certification; it requires a planned carbon pathway in which emissions baselines, reduction strategies, monitoring procedures, reporting systems, and target milestones are connected to verifiable climate-aligned outcomes. Studies on lifecycle assessment have shown that net zero modeling becomes more credible when embodied and operational emissions are assessed together because an intervention that reduces one emissions category may change the relative contribution of another across the whole building life cycle (Bribián et al., 2011). This integrated view of building life cycle assessment has also been supported by research emphasizing the relationship between building systems, energy use, and environmental burden (Cabeza et al., 2014). The need to reduce embodied carbon within the built environment has further been emphasized as an important part of carbon mitigation strategy (Pomponi & Moncaster, 2016). This issue is highly relevant for industrial buildings, where operational carbon may be dominant due to energy-intensive use, while embodied carbon may also be substantial because of large structural systems, concrete, steel, envelope materials, industrial flooring, equipment replacement, and maintenance cycles. Research on building lifecycle energy and carbon assessment indicates that low-energy and high-performance buildings require careful embodied carbon accounting because operational reductions can make material-related impacts proportionally more significant (Sartori & Hestnes, 2007). Building life cycle energy analysis has also shown that operational and embodied components must be examined together to understand total building energy demand (Ramesh et al., 2010). Studies on embodied energy in buildings have further shown that lifecycle energy contributions may vary depending on design choices, building type, and material systems (Chastas et al., 2016). In this study, net zero pathway modeling is treated as a measurable quantitative construct represented by indicators such as carbon baseline availability, lifecycle carbon accounting, renewable energy readiness, science-based target alignment, green finance capacity, emissions monitoring, management commitment, and operational decarbonization planning. This approach is consistent with corporate climate-target literature, which emphasizes that emissions reduction goals become more credible when they are connected to climate science and transparent target-setting methods (Krabbe et al., 2015). Corporate greenhouse gas target-setting methods have also been shown to support more structured organizational emissions planning (Faria & Labutong, 2019). Recent evidence on science-based targets has further emphasized the need to evaluate whether private-sector commitments are aligned with climate goals (Bjørn et al., 2022). In developing economy industrial buildings, net zero pathway modeling functions as a bridge between building-level sustainability actions and organization-level carbon governance because the building must not only

perform efficiently but also contribute to wider emissions reduction targets.

LEED, EDGE, and SBTi represent three complementary frameworks for examining lifecycle carbon reduction and net zero readiness in industrial buildings. LEED, or Leadership in Energy and Environmental Design, is a green building rating system that evaluates sustainability performance through categories such as energy, water, materials, site design, indoor environmental quality, innovation, and regional priorities. EDGE, or Excellence in Design for Greater Efficiencies, is a resource-efficiency certification framework designed to support measurable reductions in energy use, water use, and embodied energy in materials, with strong relevance for developing and emerging markets because of its practical focus on efficiency and cost-sensitive design. SBTi, or the Science Based Targets initiative, is a corporate climate target-setting framework that guides organizations in aligning greenhouse gas reduction targets with climate science and global temperature goals. The integration of these three frameworks is central to this study because each framework contributes a different dimension to industrial building decarbonization. LEED provides a broad sustainability assessment structure, EDGE provides a resource-efficiency and developing-market practicality structure, and SBTi provides a science-aligned emissions target-setting structure. Green building research has shown that rating systems can influence design decisions, increase sustainability awareness, support market recognition, and organize environmental performance assessment, while measured performance may vary across buildings and contexts depending on operation, building type, user behavior, and energy systems (Newsham et al., 2009). The debate on whether LEED-certified buildings always save energy has also shown the importance of measuring actual building performance rather than relying only on certification status (Scofield, 2009). Green building research has further demonstrated that the field has expanded across certification, sustainability assessment, and building performance concerns (Zuo & Zhao, 2014). Comparative research on green building rating tools indicates that assessment schemes differ in scope, weighting, regional adaptability, and performance emphasis, making the selection and integration of frameworks important for specific building categories and national contexts (Doan et al., 2017). EDGE is highly relevant to developing economy industrial buildings because practical savings in energy, water, and materials may be more feasible than complex or expensive sustainability interventions. SBTi is also relevant because building-level carbon actions need to connect with organization-level emissions reduction commitments. Corporate emissions research shows that science-based targets require transparent allocation methods, emissions scopes, decarbonization pathways, and climate-aligned reduction trajectories (Krabbe et al., 2015). Research on science-based corporate greenhouse gas target-setting methods has also shown that target credibility depends on structured methodological choices (Faria & Labutong, 2019). Evidence on corporate Paris alignment has further shown that science-based targets require careful assessment rather than general climate claims (Bjørn et al., 2022). Therefore, this study does not treat LEED, EDGE, and SBTi as separate sustainability concepts. Instead, it examines them as measurable and potentially integrated predictors of lifecycle carbon reduction and net zero pathway readiness in industrial building contexts.

The international significance of this research is grounded in the global movement toward low-carbon construction, industrial decarbonization, resource-efficient building design, and accountable corporate climate action. Buildings and construction activities influence global emissions through energy consumption, material production, land development, infrastructure expansion, supply chains, waste generation, and long service lives. Industrial buildings occupy a distinctive position within this challenge because they are both physical infrastructure and operational platforms for manufacturing, processing, storage, logistics, and production support. Their carbon performance is shaped by building design, structural materials, equipment loads, heating and cooling requirements, ventilation systems, lighting systems, renewable energy readiness, maintenance practices, and operational management. The literature has repeatedly emphasized that lifecycle thinking is necessary for understanding building-related environmental impacts because operational energy, embodied energy, material choices, service-life assumptions, replacement cycles, and end-of-life scenarios all affect total lifecycle performance (Ortiz et al., 2009). The comparative analysis of building materials has also shown that energy and environmental impacts vary considerably across material choices and lifecycle stages (Bribián et al., 2011). Building-sector life cycle assessment research has further confirmed that life cycle energy and environmental analysis are important for understanding the building sector's broader

sustainability performance (Cabeza et al., 2014). Life cycle carbon emissions assessment has also been identified as a useful method for evaluating building-related carbon performance (Chau et al., 2015). Studies on embodied energy measurement further show that inconsistent system boundaries, data sources, geographic assumptions, emission factors, and calculation methods can produce wide variation in building carbon results, making empirical measurement and construct reliability essential for carbon-related research (Dixit et al., 2010). The need for a consistent embodied energy measurement protocol has also been emphasized in building research (Dixit et al., 2012). A conceptual model for defining system boundaries has further clarified why building carbon studies require transparent methodological decisions (Dixit et al., 2013). This issue becomes more important in developing economies, where local lifecycle databases, environmental product declarations, emissions benchmarks, technical expertise, and carbon accounting systems may be less developed than in high-income settings. Green building adoption research also indicates that sustainability implementation is influenced by policy pressure, financial incentives, market demand, professional knowledge, owner commitment, perceived business value, and institutional support (Ahn et al., 2013). Incentive-based research has also shown that green building adoption depends partly on policy and financial support mechanisms (Olubunmi et al., 2016). Empirical review evidence has further shown that drivers of green building adoption include market, regulatory, organizational, and professional factors (Darko et al., 2017). Within this international context, the present study focuses on how recognized sustainability and carbon-target frameworks can support measurable lifecycle carbon reduction in developing economy industrial buildings. A quantitative, cross-sectional, case-study-based approach is appropriate because it allows the study to examine the level of LEED, EDGE, and SBTi adoption, measure relationships among variables, and test whether framework integration statistically predicts lifecycle carbon reduction and net zero readiness.

Developing economy industrial buildings create a specific research context because sustainability decisions in these settings are shaped by rapid industrial growth, infrastructure expansion, cost constraints, energy-system limitations, uneven regulatory enforcement, limited green finance, technical capacity gaps, and varying levels of professional exposure to carbon accounting. Industrial facilities in these economies often need to expand production capacity, control operational costs, satisfy buyers or investors, respond to environmental requirements, and remain competitive in regional or global supply chains. These conditions make carbon reduction both a technical issue and an organizational issue. Sustainable construction and green building adoption studies show that stakeholders are influenced by regulatory expectations, market reputation, owner commitment, project cost, payback concerns, technical expertise, and institutional pressure (Ahn et al., 2013). Empirical research on green building drivers has also shown that adoption is shaped by professional awareness, market demand, policy requirements, and perceived sustainability benefits (Darko et al., 2017). Green building incentives and certification systems may support adoption when they are connected with financial feasibility, policy support, professional capability, and measurable performance outcomes (Olubunmi et al., 2016). Comparative analysis of rating tools has also shown that green building systems must be interpreted according to context, scope, and performance priorities (Doan et al., 2017). For this reason, developing economy industrial buildings require a framework that does not reduce sustainability to a single certification label. LEED can support broad sustainability assessment, EDGE can support affordable resource-efficiency improvements, and SBTi can support climate-aligned target setting and emissions governance. Corporate climate-target literature explains that credible emissions reduction requires the translation of global climate goals into organizational targets using science-based methods, sectoral allocation logic, and transparent emissions accounting (Krabbe et al., 2015). Research on corporate greenhouse gas target-setting methods has also shown that methodological clarity is necessary for credible science-based targets (Faria & Labutong, 2019). In industrial building contexts, this means that building-level practices should be linked to wider organizational emissions responsibilities, including direct fuel-related emissions, purchased electricity emissions, and relevant supply-chain or material-related emissions. Lifecycle carbon assessment studies support this broader perspective because emissions are distributed across multiple actors and stages, including material suppliers, designers, developers, contractors, operators, owners, and end-of-life managers (Ramesh et al., 2010). Building life cycle assessment research has also shown that building-related environmental impacts are shaped by

energy use, materials, and system boundaries (Cabeza et al., 2014). Embodied carbon reduction research has further emphasized that carbon mitigation in the built environment depends on practical evidence across design, material, and construction decisions (Pomponi & Moncaster, 2016). The developing economy context therefore strengthens the need for a quantitative model that can examine whether LEED adoption, EDGE-based resource efficiency, SBTi alignment, and integrated framework use are statistically associated with lifecycle carbon reduction performance and net zero pathway readiness.

The academic motivation for this study arises from the need to integrate three major streams of research that are often examined separately: lifecycle carbon assessment, green building certification, and science-based corporate target setting. Lifecycle assessment literature provides the technical foundation for measuring embodied and operational emissions across building stages, while many studies in this area focus on calculation methods, carbon inventories, materials, operational energy, service life, and system boundaries (Dixit et al., 2010). Building material lifecycle assessment research has also shown that environmental evaluation requires attention to energy, carbon, and eco-efficiency across materials and stages (Bribián et al., 2011). Building-sector assessment reviews have further emphasized the need to connect life cycle assessment and life cycle energy analysis in building research (Cabeza et al., 2014). Life cycle carbon emissions assessment has also been recognized as an important approach for evaluating building performance across multiple environmental dimensions (Chau et al., 2015). Green building literature examines certification systems, adoption drivers, market value, energy performance, sustainability assessment tools, and barriers to implementation, while these studies may not always connect certification adoption with science-based net zero pathways at the building or facility level (Newsham et al., 2009). Research questioning the actual energy performance of LEED-certified buildings has also shown the importance of distinguishing certification from measured outcomes (Scofield, 2009). Reviews of green building research have further shown that the field includes certification, sustainability performance, stakeholder adoption, and research agenda issues (Zuo & Zhao, 2014). Comparative studies of green building rating systems have shown that assessment tools vary in criteria, weighting, and applicability across contexts (Doan et al., 2017). Corporate climate-target literature explains how organizations can align greenhouse gas reduction commitments with climate science, but many studies in this area are positioned at the company, sector, or portfolio level rather than at the level of industrial building case studies (Krabbe et al., 2015). Corporate target-setting research has also shown that science-based greenhouse gas methods require methodological consistency and emissions accountability (Faria & Labutong, 2019). Evidence on corporate climate commitments has further emphasized the need to evaluate whether private-sector targets are genuinely Paris-aligned (Bjørn et al., 2022). This research connects these three areas by treating LEED, EDGE, and SBTi as measurable explanatory constructs in a quantitative model. The five-point Likert-scale approach allows professionals involved in industrial building design, construction, facility management, sustainability consulting, engineering, and energy management to assess the extent to which these frameworks are adopted and integrated in real project settings. Descriptive statistics can identify the current level of adoption and readiness, reliability analysis can test the internal consistency of the measurement constructs, correlation analysis can assess the strength and direction of relationships among framework adoption and carbon outcomes, and regression modeling can evaluate whether LEED, EDGE, SBTi, and lifecycle carbon reduction predict net zero readiness. Survey-based quantitative methods are suitable for examining stakeholder perceptions, adoption drivers, barriers, and relationships among sustainability variables in green building research (Ahn et al., 2013). Empirical review evidence on green building drivers has also supported the use of stakeholder-based data to understand sustainability adoption (Darko et al., 2017). The measurement design also responds to lifecycle assessment literature showing that carbon results are sensitive to system boundaries, assumptions, data quality, and methodological definitions, which makes construct clarity and reliability necessary for trustworthy empirical analysis (Dixit et al., 2012). Research on embodied energy system boundaries has also strengthened the need for clarity in measurement definitions (Dixit et al., 2013). Critical reviews of building LCA have further emphasized the importance of methodological development and data quality in future building assessment research (Anand & Amor, 2017).

The present research is introduced as a quantitative, cross-sectional, case-study-based investigation of lifecycle carbon reduction and net zero pathway modeling using LEED, EDGE, and SBTi frameworks in developing economy industrial buildings. LEED-based sustainability practices are defined in this study as the extent to which industrial buildings apply recognized green building principles related to energy efficiency, water efficiency, sustainable materials, waste reduction, indoor environmental quality, innovation, and operational performance. EDGE-based resource efficiency is defined as the extent to which industrial buildings adopt practical measures that reduce energy consumption, water consumption, and embodied energy in materials. SBTi-aligned target setting is defined as the degree to which building owners, operators, or related organizations use science-based emissions baselines, reduction targets, monitoring systems, and climate-aligned planning. Lifecycle carbon reduction is defined as measurable improvement in embodied and operational carbon performance across the building life cycle, while net zero pathway readiness is defined as the preparedness of a building or organization to move from current emissions performance toward a structured, monitored, and verifiable net zero pathway. These constructs are grounded in the literature on building life cycle assessment, embodied energy measurement, green building systems, and science-based climate targets. Earlier lifecycle energy research has established the relevance of assessing energy use across the full life of buildings (Sartori & Hestnes, 2007). Construction industry LCA research has also shown that sustainability assessment requires attention to multiple building stages (Ortiz et al., 2009). Building life cycle energy analysis has further supported the need to connect embodied and operational energy in one assessment structure (Ramesh et al., 2010). Corporate climate-target research has established the relevance of aligning emissions reduction targets with climate goals (Krabbe et al., 2015). Embodied carbon mitigation research has also shown that reduction strategies in the built environment require evidence-based assessment (Pomponi & Moncaster, 2016). Science-based target-setting research has further emphasized the need for credible methods in corporate greenhouse gas reduction planning (Faria & Labutong, 2019). The study is designed to produce empirical evidence through descriptive statistics, reliability analysis, correlation analysis, and regression modeling. It will examine whether stronger LEED adoption is associated with lifecycle carbon reduction, whether EDGE adoption supports resource-efficiency-related carbon outcomes, whether SBTi alignment strengthens net zero pathway readiness, and whether an integrated LEED–EDGE–SBTi score explains carbon reduction outcomes more effectively than separate framework use. The focus on developing economy industrial buildings provides a specific setting in which sustainability frameworks must be examined through practical feasibility, resource constraints, institutional readiness, carbon data availability, and measurable building performance. This introduction establishes the core definitions, international significance, research context, framework logic, and quantitative direction of the study while maintaining the study's focus on lifecycle carbon reduction and net zero pathway modeling.

Background of the Study

Lifecycle carbon reduction has become a central concern in the design, construction, and operation of industrial buildings because these facilities consume large amounts of energy, materials, water, and operational resources throughout their service life. Industrial buildings in developing economies are especially important in this discussion because they support manufacturing, processing, warehousing, logistics, and production activities that are expanding rapidly with economic growth. These buildings are often designed to prioritize cost, space, productivity, and operational continuity, while carbon performance, material efficiency, and long-term emissions planning may receive limited attention during early project decision-making. Lifecycle carbon reduction focuses on the total carbon impact of a building from material extraction and construction to operation, maintenance, renovation, and end-of-life treatment. This makes it broader than traditional energy-efficiency planning because it includes both embodied carbon from materials and construction activities and operational carbon from electricity, fuel use, ventilation, cooling, lighting, and building services. In industrial buildings, carbon emissions are influenced not only by the building envelope and energy systems but also by equipment loads, production-support infrastructure, water use, waste handling, and facility management practices. Frameworks such as LEED, EDGE, and SBTi provide structured ways to address different parts of this challenge. LEED supports a broad sustainability assessment of buildings through criteria related to energy, water, materials, indoor quality, and innovation. EDGE focuses on measurable

resource efficiency in energy, water, and embodied energy in materials, making it highly relevant for developing economy contexts where affordability and practical performance improvements are crucial. SBTi supports science-based carbon target setting by helping organizations align emissions reduction goals with measurable climate pathways. The integration of these three frameworks offers a useful foundation for modeling net zero pathways in industrial buildings because it combines certification logic, practical efficiency improvement, and target-based carbon governance. Therefore, this study is grounded in the need to quantitatively examine how LEED, EDGE, and SBTi adoption can support lifecycle carbon reduction and improve net zero readiness in developing economy industrial buildings.

Problem Statement

Industrial buildings in developing economies are increasingly expected to reduce carbon emissions, improve energy performance, and align with net zero goals, yet many of these buildings still lack an integrated and measurable approach for lifecycle carbon reduction. Most industrial building projects continue to focus heavily on capital cost, production capacity, floor area, technical functionality, and short-term operational needs, while whole-life carbon performance is often treated as a secondary concern. This creates a major problem because carbon emissions are not limited to daily energy use; they also arise from construction materials, structural systems, equipment installation, maintenance, replacement cycles, water systems, waste flows, and end-of-life processes. Many industrial facilities may adopt isolated sustainability measures, such as efficient lighting, improved ventilation, water-saving fixtures, or selected green materials, without connecting these actions to a complete carbon reduction pathway. At the same time, LEED, EDGE, and SBTi are often treated as separate frameworks rather than as complementary tools that can jointly support building decarbonization. LEED may be used for sustainability certification, EDGE may be used for resource-efficiency assessment, and SBTi may be used at the corporate level for emissions targets, but limited empirical attention has been given to how these frameworks interact within industrial building cases in developing economies. This creates a research gap because decision-makers need quantitative evidence showing whether these frameworks actually relate to lifecycle carbon reduction and whether their combined use can predict net zero pathway readiness. Another problem is that developing economy industrial buildings face unique challenges such as limited carbon data, weak policy enforcement, cost constraints, low awareness of lifecycle assessment, restricted access to green finance, and limited technical expertise in carbon modeling. These conditions make it difficult to transfer sustainability practices directly from developed economy settings. Therefore, the central problem of this study is the lack of a quantitative, case-study-based model that explains how LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting influence lifecycle carbon reduction and net zero readiness in developing economy industrial buildings.

Objectives of The Study

The main objective of this study is to develop a quantitative understanding of how LEED, EDGE, and SBTi frameworks contribute to lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings. The study aims to examine the extent to which LEED-based sustainability practices influence carbon reduction across the building lifecycle, particularly through energy efficiency, water efficiency, material selection, waste reduction, indoor environmental quality, and operational performance improvement. It also aims to assess the role of EDGE-based resource efficiency in supporting practical and measurable reductions in energy use, water consumption, and embodied energy in construction materials within cost-sensitive industrial building environments. Another objective is to evaluate how SBTi-aligned target setting supports net zero pathway modeling by encouraging carbon baseline development, emissions monitoring, science-based reduction targets, and structured decarbonization planning. The study further seeks to measure the relationship between framework adoption and lifecycle carbon reduction performance by using descriptive statistics and correlation analysis. In addition, it aims to determine whether LEED, EDGE, and SBTi adoption can statistically predict lifecycle carbon reduction and net zero readiness through regression modeling. A further objective is to develop a LEED–EDGE–SBTi integration score that reflects the combined use of sustainability certification, resource efficiency, and science-based target alignment in industrial building decarbonization. The study also intends to create a net zero pathway readiness index that can classify industrial buildings according to their preparedness for carbon reduction, renewable energy

planning, emissions monitoring, green finance readiness, and long-term net zero transition. Through these objectives, the research will provide an empirical structure for understanding how developing economy industrial buildings can move from fragmented sustainability practices toward integrated carbon reduction planning. The study will also support the testing of hypotheses by using a five-point Likert-scale questionnaire, reliability analysis, descriptive statistics, correlation analysis, and regression modeling. Overall, the objectives are designed to connect building-level sustainability practices with organization-level carbon governance and to provide measurable evidence for lifecycle carbon reduction and net zero pathway modeling.

Research Hypotheses

The research hypotheses of this study are developed to test the statistical relationships among LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned target setting, lifecycle carbon reduction, and net zero pathway readiness in developing economy industrial buildings. Since the study follows a quantitative, cross-sectional, case-study-based design, the hypotheses are structured to examine both direct relationships and predictive effects among the main variables. The first hypothesis states that LEED-based sustainability practices have a significant positive effect on lifecycle carbon reduction in developing economy industrial buildings. This hypothesis assumes that buildings applying stronger LEED-related practices in energy, water, materials, waste, and operational performance are more likely to achieve better lifecycle carbon outcomes. The second hypothesis states that EDGE-based resource efficiency has a significant positive effect on lifecycle carbon reduction. This hypothesis reflects the expectation that practical improvements in energy use, water use, and embodied energy in materials can reduce both operational and material-related carbon impacts. The third hypothesis states that SBTi-aligned target setting has a significant positive effect on net zero pathway readiness. This means that industrial buildings or organizations with clearer carbon baselines, emissions targets, monitoring systems, and science-based planning are expected to show stronger readiness for net zero transition. The fourth hypothesis states that lifecycle carbon reduction has a significant positive effect on net zero pathway readiness, suggesting that actual carbon reduction performance strengthens the ability of industrial buildings to move toward structured net zero pathways. The fifth hypothesis states that the integrated adoption of LEED, EDGE, and SBTi significantly predicts lifecycle carbon reduction performance. This hypothesis is important because the study does not view the three frameworks as isolated systems but as complementary tools that can jointly support decarbonization. The sixth hypothesis states that the integrated adoption of LEED, EDGE, and SBTi significantly predicts net zero pathway readiness. These hypotheses allow the study to move beyond descriptive discussion and statistically examine whether framework adoption and integration are meaningfully connected to carbon reduction and net zero outcomes.

Significance of the Research

i. This study is significant because it provides a focused quantitative model for examining lifecycle carbon reduction in developing economy industrial buildings, a context where sustainability performance is often affected by cost limitations, limited technical capacity, weak carbon data systems, and increasing industrial growth.

ii. The study is significant for industrial building owners and developers because it shows how LEED, EDGE, and SBTi frameworks can be used not only as separate sustainability tools but also as an integrated approach for reducing carbon emissions and improving long-term building performance.

iii. The study is significant for engineers, architects, sustainability consultants, and project managers because it provides measurable constructs that can support design decisions, material selection, energy planning, water efficiency, emissions monitoring, and net zero pathway development in industrial building projects.

iv. The study is significant for policymakers in developing economies because it can help identify how certification systems, resource-efficiency standards, and science-based targets can support national and sectoral decarbonization goals within industrial infrastructure development.

v. The study is significant for academic researchers because it connects three important research areas: lifecycle carbon assessment, green building certification, and science-based emissions target setting. This integration gives the research a stronger theoretical and empirical foundation.

vi. The study is significant for green finance institutions and certification bodies because it can help

demonstrate which sustainability indicators are most strongly associated with carbon reduction and net zero readiness, supporting better investment screening, certification planning, and performance evaluation.

vii. The study is significant for facility managers and industrial operators because it emphasizes operational carbon reduction, resource efficiency, monitoring systems, and management commitment as measurable components of net zero readiness.

viii. The study is significant because it develops practical analytical tools such as a net zero pathway readiness index and a LEED–EDGE–SBTi integration score, which can make the results more specific, measurable, and useful for industrial building decarbonization.

ix. The study is significant because it supports evidence-based decision-making by using descriptive statistics, reliability testing, correlation analysis, and regression modeling rather than relying only on conceptual discussion or general sustainability claims.

LITERATURE REVIEW

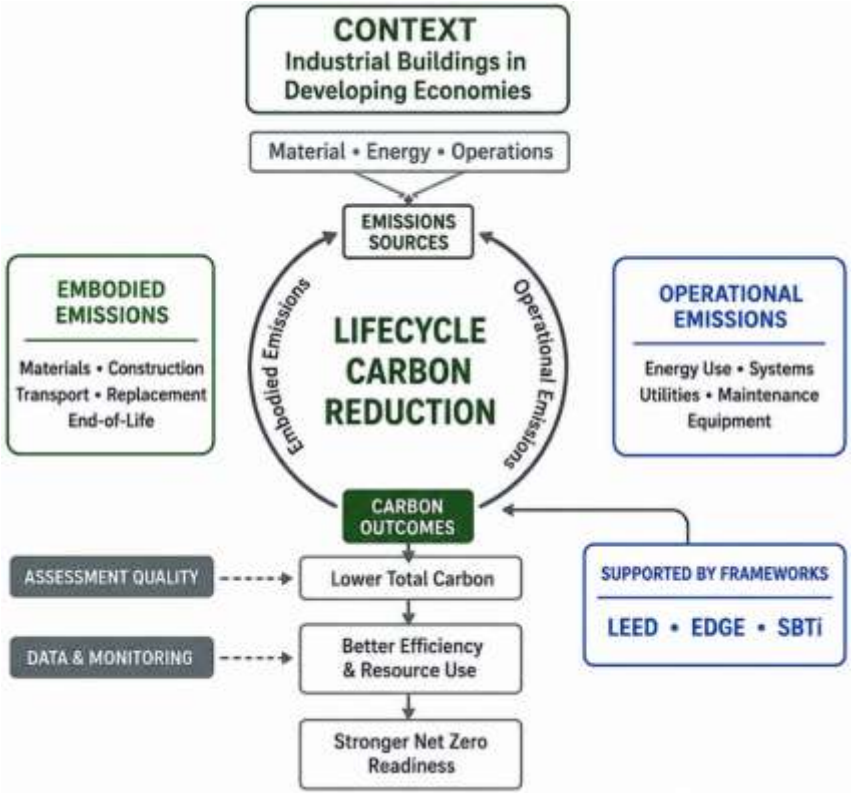
The literature on lifecycle carbon reduction and net zero pathway modeling in industrial buildings brings together several interconnected areas of sustainability research, including building life cycle assessment, embodied carbon reduction, operational energy efficiency, green building certification, resource-efficient design, corporate emissions target setting, and developing economy implementation challenges. Lifecycle carbon research emphasizes that buildings generate emissions across multiple stages, beginning with raw material extraction and product manufacturing and continuing through construction, use, maintenance, refurbishment, demolition, and end-of-life treatment. This perspective is important for industrial buildings because their carbon profile is shaped by both building-related systems and production-support activities, including mechanical systems, lighting, ventilation, cooling, equipment loads, water use, material flows, and facility operations. The literature on green building frameworks shows that certification systems can influence design quality, resource efficiency, environmental performance, and stakeholder awareness. LEED is widely discussed as a broad sustainability assessment framework that addresses energy, water, materials, indoor environmental quality, site planning, and innovation. EDGE is relevant to developing economy contexts because it emphasizes measurable reductions in energy, water, and embodied energy in materials through practical and cost-conscious design strategies. SBTi adds another dimension by shifting the focus from building certification alone to science-based carbon target setting, emissions baselines, reduction pathways, and organizational accountability. These three frameworks create a strong foundation for studying carbon reduction because they represent different but complementary layers of sustainability action. Existing literature also shows that developing economies face distinct barriers in implementing low-carbon building practices, including high upfront costs, limited access to green finance, lack of technical expertise, weak regulatory enforcement, limited carbon data, and inconsistent sustainability awareness. Therefore, the literature review for this study will examine lifecycle carbon reduction, net zero pathway modeling, LEED, EDGE, and SBTi framework adoption, theoretical explanations for sustainability adoption, the proposed conceptual framework, and the empirical research gap. This review will provide the foundation for developing the study's hypotheses, measurement constructs, and quantitative model.

Lifecycle Carbon Reduction in Industrial Buildings

Lifecycle carbon reduction in industrial buildings concerns the systematic decrease of carbon emissions generated from the production of materials, transportation, construction, facility operation, maintenance, replacement, and end-of-life processes. In industrial facilities, this issue is more complex than in many ordinary building types because the building is not only a shelter or workplace but also a platform for manufacturing, storage, processing, logistics, and utility-intensive operations. The carbon profile of an industrial building is therefore shaped by structural materials, envelope systems, mechanical and electrical services, ventilation demand, lighting loads, water systems, equipment support spaces, maintenance cycles, and energy management practices. A lifecycle view is essential because carbon reduction can be misunderstood when attention is limited to operational energy alone. Embodied emissions may be locked into the building before operation begins, while operational emissions continue throughout the service life. The relative importance of these two categories can also change when energy efficiency improves. As operational energy is reduced through better systems and

design, the carbon associated with materials, construction methods, and replacement cycles becomes more visible in total lifecycle performance. This makes lifecycle carbon reduction a useful foundation for this study because LEED, EDGE, and SBTi can be examined as frameworks that address different parts of the same carbon pathway. Material selection, efficient construction, operational energy reduction, and emissions monitoring become connected components rather than isolated sustainability actions. In industrial buildings within developing economies, this lifecycle perspective is particularly necessary because new industrial growth often requires large quantities of concrete, steel, cladding, mechanical equipment, and energy-consuming services. Carbon reduction must therefore be studied across the full building system, including embodied and operational emissions, rather than as a narrow energy-saving measure for facility cost control (Hammond & Jones, 2008; Ibn-Mohammed et al., 2013; Abdur & Iftekhar, 2021). These emissions directly shape long-term industrial sustainability performance overall.

Figure 2: Lifecycle Carbon Assessment and Reduction Framework for Industrial Buildings



A major theme in lifecycle carbon literature is that reliable carbon reduction depends on the quality of assessment boundaries, data sources, material assumptions, and the stages included in the analysis. Industrial buildings commonly have long service lives, repeated equipment upgrades, changing production requirements, and substantial maintenance demands, which means that carbon performance cannot be represented only by the initial construction phase or annual energy consumption. Lifecycle assessment provides a structured way to examine carbon consequences from cradle to grave, yet the literature also shows that results can vary widely when studies use different system boundaries, databases, service-life assumptions, or emission factors. This is important for the present research because developing economy industrial buildings may have limited access to local embodied-carbon databases, verified environmental product declarations, and detailed operational energy records. Under such conditions, stakeholder-based measurement through a Likert-scale instrument can help identify the perceived maturity of lifecycle carbon practices, carbon monitoring, material efficiency, and net zero readiness. Studies of building lifecycle assessment indicate that embodied carbon reduction can be achieved through alternative construction methods, low-carbon

materials, efficient structural systems, and improved design coordination. For example, modern methods of construction and material substitution can reduce embodied carbon when material quantities, production processes, and transport impacts are carefully evaluated. At the same time, broader lifecycle assessment studies warn that carbon policy or project decisions based on incomplete LCA evidence may produce unreliable conclusions. This makes reliability and validity testing highly important in a quantitative study that measures lifecycle carbon reduction as a construct. For industrial buildings, lifecycle carbon reduction should therefore include energy efficiency, material efficiency, resource efficiency, operational monitoring, and data quality as related dimensions within one measurement framework that reflects practical decarbonization decisions (Golam & Amir, 2022; Monahan & Powell, 2011; Säynäjoki et al., 2017). It also supports stronger statistical interpretation of framework effects.

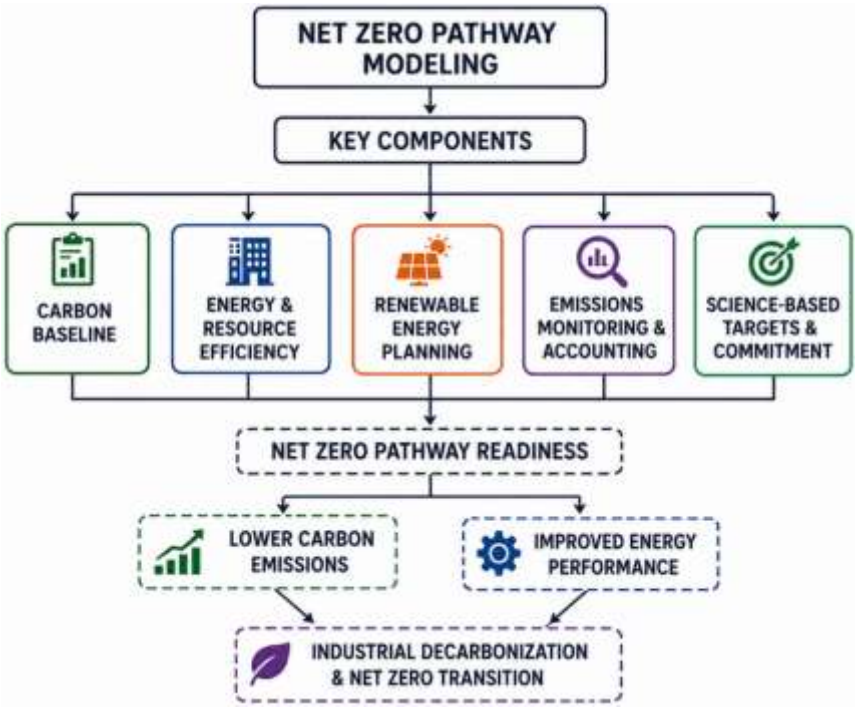
The relevance of lifecycle carbon reduction to this research also lies in its ability to connect building-level sustainability frameworks with organizational net zero planning. LEED can support lifecycle carbon reduction by encouraging better energy performance, efficient water use, material responsibility, waste reduction, and improved operational practices. EDGE can support lifecycle carbon reduction by focusing on measurable efficiency gains in energy, water, and embodied energy in materials, which is highly suitable for developing economy industrial buildings where affordability and practical savings are central concerns. SBTi can strengthen the carbon reduction process by encouraging organizations to set measurable emissions targets, define baselines, track progress, and connect building-level actions to wider decarbonization commitments. Lifecycle carbon reduction therefore becomes the technical bridge between certification-based practices and net zero pathway readiness. A comprehensive energy perspective also shows that the carbon performance of buildings should include not only operational demand but also embodied energy and other indirect energy requirements associated with construction, refurbishment, and user-related systems. This broader view is important in industrial buildings because operational efficiency improvements may reduce electricity or fuel-related emissions, while embodied emissions remain embedded in materials and infrastructure. For this reason, lifecycle carbon reduction should be treated as a multidimensional outcome rather than a single performance indicator. In the present study, this section supports the measurement of lifecycle carbon reduction as a dependent variable influenced by LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting. It also supports a net zero pathway readiness index, because stronger lifecycle carbon reduction should align with emissions monitoring, renewable energy planning, green finance readiness, and long-term decarbonization. In this way, lifecycle carbon reduction provides the empirical foundation for testing whether integrated framework adoption can predict carbon performance and net zero readiness in developing economy industrial buildings (Binayan & Shakhawat, 2022; Ibn-Mohammed et al., 2013; Säynäjoki et al., 2017; Stephan et al., 2012).

Net Zero Pathway Modeling in Developing Economy Building Sectors

Net zero pathway modeling refers to the structured process of identifying the technical, operational, financial, and organizational actions required to move buildings from current carbon-intensive performance toward a condition where annual emissions are reduced, balanced, or neutralized through efficiency, renewable energy, and verified carbon management. In the building sector, net zero modeling usually begins with a baseline of energy use and emissions, followed by staged interventions such as passive design, energy-efficient systems, electrification, renewable energy generation, carbon accounting, and long-term performance monitoring. For industrial buildings in developing economies, this modeling process is more complex because such facilities must support production, storage, processing, logistics, and utility-intensive operations while also responding to cost constraints and limited carbon data availability. Net zero pathway modeling therefore requires a clear definition of the balance boundary, the energy and carbon indicators used, and the relationship between demand reduction and renewable supply. Earlier net zero building literature shows that consistent definitions and calculation methods are essential because different interpretations of net zero can produce different design priorities, performance claims, and assessment outcomes (Hasan & Uddin, 2022; Marszal et al., 2011). This is highly relevant to developing economy industrial buildings, where building owners may adopt energy-saving technologies without linking them to a complete emissions pathway. A credible

pathway model must separate energy efficiency from carbon reduction because low energy use does not automatically mean low carbon performance when electricity grids depend heavily on fossil fuels. It must also consider whether the building's carbon pathway is measured at the facility level, project level, corporate level, or building-portfolio level. For this study, net zero pathway modeling is viewed as a measurable readiness process that includes carbon baseline development, resource-efficiency planning, renewable energy preparedness, emissions monitoring, science-based target alignment, and management commitment to long-term industrial decarbonization.

Figure 3: Net Zero Pathway Readiness Framework for Industrial Building Decarbonization



The literature on net zero and energy-efficient building design emphasizes that pathway modeling should prioritize demand reduction before renewable energy balancing. This means that a building should first reduce heating, cooling, lighting, ventilation, and equipment-related energy demand through passive design, efficient systems, control technologies, and better operational management before depending on renewable generation to offset remaining demand. Although much of the net zero building literature has focused on residential and commercial buildings, its principles are highly relevant to industrial buildings because industrial facilities require large, continuous, and often specialized energy loads. Energy-efficient design studies identify building orientation, envelope performance, insulation, glazing, ventilation strategies, natural lighting, passive cooling, high-efficiency systems, and integrated design as core factors that reduce energy consumption and improve decarbonization readiness (Pacheco et al., 2012; Hossain & Uddin, 2022). Net zero pathway modeling also requires simulation, optimization, and decision-support tools because multiple design alternatives may produce different energy, cost, and carbon outcomes. Building performance optimization literature shows that net zero design is strengthened when modeling tools evaluate trade-offs among energy performance, thermal comfort, cost, renewable energy options, and technology selection (Attia et al., 2013; Sany & Siful, 2022). In developing economy industrial buildings, these tools may be less available or less frequently used, which makes questionnaire-based assessment useful for measuring the extent to which professionals apply baseline analysis, energy modeling, carbon monitoring, and performance evaluation. For this research, the pathway concept is linked to LEED, EDGE, and SBTi because each framework supports a different part of the transition. LEED supports broad sustainability and performance assessment, EDGE supports measurable resource efficiency, and SBTi supports climate-aligned target setting. A pathway model becomes stronger when these frameworks are not

treated as isolated labels but as connected mechanisms for reducing energy demand, improving resource efficiency, defining emissions targets, and evaluating progress toward net zero readiness.

Net zero pathway modeling also requires attention to wider building-sector decarbonization conditions, especially in developing economies where electricity-grid emissions, material supply chains, policy enforcement, financing capacity, and technical expertise influence the feasibility of carbon reduction. Building-sector research shows that net zero outcomes depend on coordinated improvements in energy efficiency, renewable energy, building envelopes, low-carbon materials, retrofitting, electrification, and policy support, rather than on a single intervention (Binte & Iftekhar, 2022; Ürge-Vorsatz et al., 2020). This is directly relevant to industrial buildings because their carbon performance depends on the interaction between building systems and the external energy, material, and regulatory environment. Decarbonization pathway studies also show that scenario modeling can identify how different combinations of building efficiency, renovation levels, electrification, and clean electricity supply influence long-term emissions outcomes (Berrill et al., 2022; Taufiqur & Khalid, 2022). While those studies are often developed for national building stocks or residential sectors, the logic can be applied to industrial buildings by examining how alternative framework-adoption levels may predict lifecycle carbon reduction and net zero readiness. In developing economies, net zero pathway modeling must also account for practical barriers such as high upfront costs, limited incentives, insufficient technical knowledge, fragmented carbon data, and fossil-fuel-dependent grids. Therefore, this study treats net zero readiness as an empirical construct that can be measured through Likert-scale indicators rather than as a purely technical label. The model can include readiness dimensions such as emissions baseline availability, renewable energy planning, energy-efficiency implementation, lifecycle carbon accounting, green finance readiness, monitoring systems, and management commitment. By connecting LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting, this research positions net zero pathway modeling as a practical and statistical framework for examining how developing economy industrial buildings can move from scattered sustainability actions toward measurable carbon transition planning.

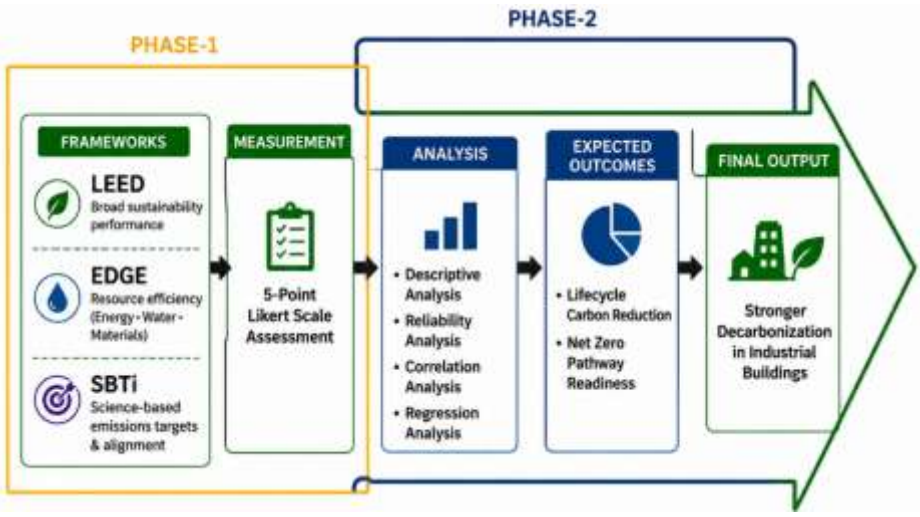
LEED, EDGE, and SBTi Frameworks for Building Decarbonization

LEED, EDGE, and SBTi represent three complementary frameworks for examining building decarbonization because each framework addresses a different but connected dimension of carbon reduction. LEED provides a broad green building certification structure that evaluates sustainability performance across areas such as energy efficiency, water management, materials, indoor environmental quality, site planning, innovation, and operational performance. For industrial buildings, LEED is useful because it encourages project teams to consider sustainability from the design and construction stages rather than treating environmental performance as an operational issue only. The strength of LEED lies in its ability to organize sustainability decisions into measurable credits, making it easier for designers, engineers, owners, and facility managers to translate environmental goals into design and management actions. However, the adoption of LEED also requires technical documentation, simulation, design coordination, and evidence-based performance evaluation. This is important in industrial buildings because energy demand, ventilation, process-support systems, material use, water use, and building service requirements are often more complex than in ordinary commercial buildings. Digital tools such as building information modeling can support LEED-related decision-making by helping project teams evaluate design options, energy performance, material choices, and certification requirements during early project planning. This indicates that LEED is not only a rating label but also a structured design-management process that can influence sustainability outcomes when it is integrated into preconstruction and design decision-making. In developing economy industrial buildings, LEED-based practices may support lifecycle carbon reduction by encouraging efficient building systems, improved material responsibility, better waste management, and stronger operational planning. For this study, LEED is therefore treated as one of the independent variables because its sustainability practices can be measured through a five-point Likert scale and statistically tested against lifecycle carbon reduction and net zero readiness outcomes (Azhar et al., 2011; Iftekhar & Binayan, 2023).

EDGE is particularly relevant to this research because it focuses on practical resource efficiency, especially energy use, water use, and embodied energy in materials. Unlike broader green building

rating systems that may include many categories, EDGE is highly focused on measurable savings and cost-sensitive strategies, making it suitable for developing economy contexts where affordability, simplicity, and implementation feasibility are major concerns. In industrial buildings, EDGE can support decarbonization by encouraging reduced energy demand, efficient lighting, improved ventilation, water-efficient systems, material optimization, and resource-conscious design. The importance of EDGE becomes clearer when green building rating systems are compared across different contexts. Studies on rating tools show that green building assessment systems differ in scope, credit weighting, environmental priorities, and regional suitability. This means that a framework useful in one region may require adaptation or careful interpretation in another context. For developing economies, certification tools must respond not only to environmental goals but also to cost, resource availability, technical capacity, market acceptance, and policy readiness. Comparative analysis of green building rating systems shows that systems such as LEED, BREEAM, GSAS, and Estidama prioritize sustainability categories differently, especially in relation to energy, water, materials, and environmental performance. This supports the need to examine EDGE alongside LEED rather than assuming that one certification framework can address all dimensions of carbon reduction. Recent research on EDGE-certified buildings also shows that the framework can support resource savings through an "efficiency first" logic, where reducing demand is emphasized before relying on advanced or costly technology. This is useful for industrial buildings in developing economies because carbon reduction must often be achieved through practical design choices, affordable technologies, and measurable efficiency improvements. In this study, EDGE-based resource efficiency is treated as a measurable construct that can help explain lifecycle carbon reduction performance and contribute to net zero pathway readiness through energy, water, and material savings (Awadh, 2017; Isimbi & Park, 2022; Hasan & Chapal, 2023).

Figure 4: Framework for Lifecycle Carbon Reduction and Net Zero Readiness Using LEED, EDGE, and SBTi



SBTi adds a different dimension to LEED and EDGE because it focuses on science-based emissions target setting rather than building certification alone. While LEED and EDGE mainly guide building-level sustainability and resource-efficiency actions, SBTi connects carbon reduction to organizational climate accountability, emissions baselines, target-setting methods, and Paris-aligned decarbonization pathways. This is important for industrial buildings because the building itself is usually part of a wider organizational system that includes manufacturing operations, purchased electricity, supply chains, logistics, procurement, and corporate sustainability reporting. Therefore, building-level carbon reduction becomes more meaningful when it is connected to organizational emissions targets. Research on green building rating criteria shows that rating systems use different credit structures and performance priorities, which makes it necessary to examine how certification-based actions connect

with broader carbon governance systems. This is where SBTi becomes valuable for the present study. It can help translate lifecycle carbon reduction into a structured pathway by encouraging baseline measurement, emissions monitoring, reduction targets, and progress evaluation. Science-based target research also shows that corporate Paris alignment requires strict measurement of emissions reduction pathways rather than general sustainability claims. For industrial buildings in developing economies, this connection is significant because many facilities may adopt green design or efficiency measures without linking them to measurable long-term carbon targets. The integration of LEED, EDGE, and SBTi therefore creates a stronger decarbonization model than any single framework alone. LEED can organize broad sustainability performance, EDGE can strengthen practical resource efficiency, and SBTi can align building-level carbon actions with science-based emissions targets. In this study, the LEED–EDGE–SBTi integration score is designed to measure this combined framework logic and test whether integrated adoption predicts lifecycle carbon reduction and net zero readiness. This supports the quantitative structure of the research by connecting certification, resource efficiency, and target alignment within one empirical model (Illankoon et al., 2017; Mahmuda, 2023; Rekker et al., 2022).

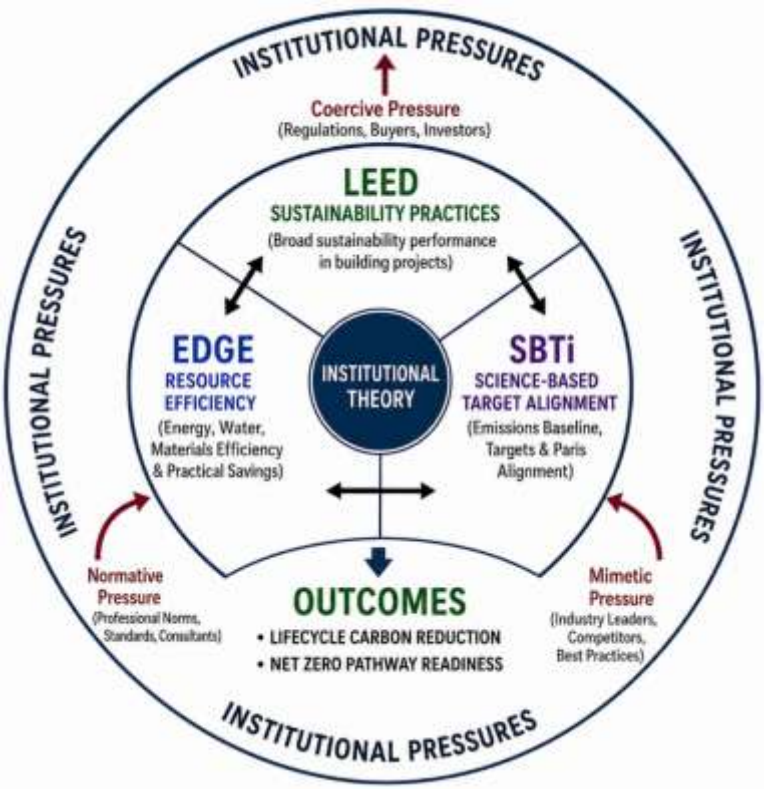
Theoretical Framework: Institutional Theory for Sustainability Adoption

Institutional Theory is the most suitable theoretical framework for this study because lifecycle carbon reduction and net zero pathway modeling in industrial buildings are not driven only by technical efficiency, engineering design, or financial calculation. They are also shaped by external pressures from governments, certification bodies, investors, clients, industry associations, sustainability consultants, international buyers, and professional communities. Institutional Theory explains how organizations adopt certain practices in order to gain legitimacy, comply with rules, respond to market expectations, and align with accepted professional norms. In the context of developing economy industrial buildings, this theory helps explain why building owners, developers, engineers, and facility managers may adopt LEED, EDGE, and SBTi-related practices even when carbon reduction is technically complex or financially demanding. Coercive pressure may come from environmental regulations, building codes, investor requirements, or buyer sustainability standards. Normative pressure may come from professional bodies, engineers, consultants, certification experts, and sustainability reporting expectations. Mimetic pressure may occur when organizations imitate leading industrial firms, certified buildings, multinational tenants, or competitors that have already adopted green building and carbon reduction practices. Institutional research shows that organizations exposed to environmental demands often respond differently depending on internal priorities, stakeholder influence, and managerial interpretation of external pressure (Delmas & Toffel, 2008; Aminul & Sheak, 2023). This is directly relevant to this study because two industrial buildings may face similar carbon expectations but adopt different levels of LEED, EDGE, or SBTi practices. Institutional Theory therefore provides a strong explanation for the variation in framework adoption among industrial buildings in developing economies. It also supports the quantitative structure of the study because institutional pressures can be reflected indirectly through measurable adoption of sustainability frameworks, resource-efficiency practices, science-based target alignment, and carbon reduction readiness.

Institutional Theory is especially relevant to carbon reduction because environmental practices are often adopted when organizations experience pressure to appear legitimate, responsible, competitive, and aligned with recognized standards. In industrial building projects, this pressure may influence material choices, energy-system design, water-efficiency planning, lifecycle carbon accounting, environmental documentation, certification decisions, and emissions target setting. The adoption of LEED can be interpreted as a response to institutional expectations for recognized green building performance. EDGE adoption can be interpreted as a response to practical market and policy expectations for measurable energy, water, and material efficiency. SBTi alignment can be interpreted as a response to global expectations for science-based corporate emissions reduction. Research on institutional pressures and environmental innovation indicates that regulatory and normative pressures can encourage firms to develop greener innovations and improve their environmental responses (Berrone et al., 2013; Shakhawat et al., 2023). Similarly, institutional-based research on green supply chain management shows that coercive, normative, and mimetic pressures can influence the adoption of environmental practices and related performance outcomes (Risha & Khalid, 2023; Zhu et al., 2013). This supports the logic of the present study because industrial buildings are connected to

wider supply chains, construction markets, certification systems, and corporate sustainability commitments. Institutional Theory also helps distinguish between symbolic adoption and substantive adoption. A building owner may pursue certification or target-setting for image and legitimacy, while another may deeply integrate the framework into design, operation, monitoring, and lifecycle carbon reduction. Studies on environmental management systems show that stakeholder pressures can encourage the internalization of environmental practices, but they may also create superficial adoption when organizations focus only on external appearance (Hossain & Binayan, 2023; Testa et al., 2018). Therefore, this theory supports the need to measure not only whether LEED, EDGE, and SBTi are known or mentioned, but also whether they are practically integrated into carbon reduction and net zero readiness.

Figure 5: Institutional Drivers of LEED, EDGE, and SBTi Adoption in Industrial Buildings



For this study, Institutional Theory will be applied through a quantitative model in which LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting represent institutionalized sustainability responses, while lifecycle carbon reduction and net zero pathway readiness represent performance-oriented outcomes of those responses. The theory assumes that stronger institutional adoption of recognized sustainability frameworks will increase the likelihood of measurable carbon reduction and stronger readiness for net zero transition. In construction and project-based environments, recent research shows that institutional pressures can improve environmental management performance when they influence project actors, behavioral responses, and decision-making systems (Sany & Uddin, 2023; Zhang et al., 2022). This supports the use of Institutional Theory in industrial building research because decarbonization requires coordination among owners, consultants, contractors, facility managers, suppliers, and regulators. The main formula that can be applied throughout this study is the LEED–EDGE–SBTi Net Zero Pathway Readiness Model:

$$NZPR_i = \beta_0 + \beta_1 LESI_i + \beta_2 LCR_i + \varepsilon_i$$

where $NZPR_i$represents net zero pathway readiness for respondent or case i, $LESI_i$represents the LEED–EDGE–SBTi integration score, LCR_irepresents lifecycle carbon reduction performance, $\beta_0$is the

constant term, $\beta_1$and $\beta_2$are regression coefficients, and $\varepsilon_i$is the error term. The integration score can be calculated as:

$$LESI_i = \frac{LEED_i + EDGE_i + SBTi_i}{3}$$

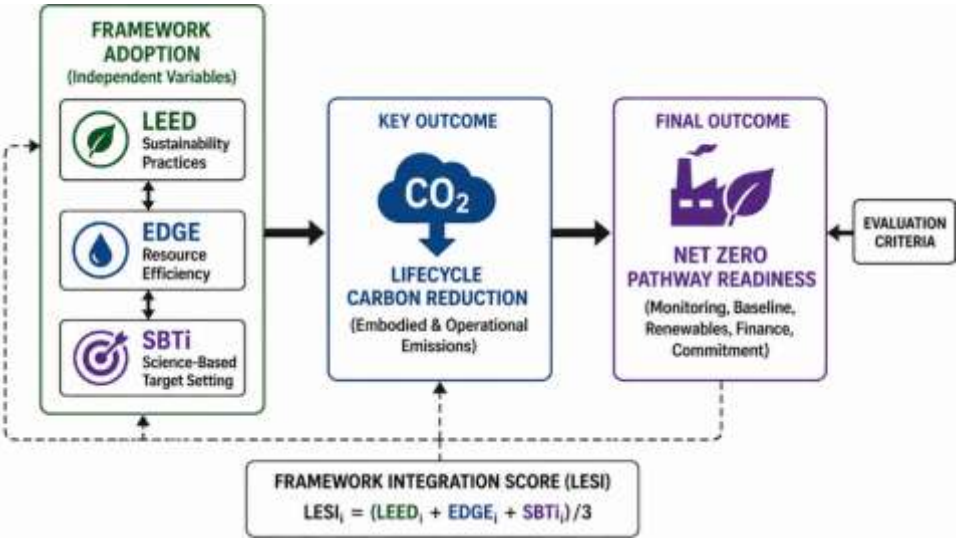
where $LEED_i$, $EDGE_i$, and $SBTi_i$represent the mean Likert-scale scores for LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting for respondent or case i. This formula is appropriate for the whole study because it connects the theoretical idea of institutionalized framework adoption with the empirical goal of predicting net zero readiness. It also allows the study to test whether integrated framework adoption has stronger explanatory value than isolated sustainability practices.

Conceptual Framework for LEED–EDGE–SBTi Integration and Net Zero Readiness

The conceptual framework of this study is developed to explain how LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting interact to influence lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings. A conceptual framework is necessary because lifecycle carbon reduction is not produced by one isolated action; it emerges from the combined influence of building design, resource efficiency, material selection, operational management, carbon accounting, and long-term emissions target setting. Green building assessment literature shows that sustainability rating systems help organize environmental performance into measurable categories, but each system differs in scope, emphasis, weighting, and applicability across contexts (Binayan, 2024; Haapio & Viitaniemi, 2008). This is important for the present study because LEED, EDGE, and SBTi do not perform the same function. LEED provides a broad sustainability structure for energy, water, materials, indoor environmental quality, site performance, and innovation. EDGE emphasizes measurable reductions in energy, water, and embodied energy in materials, making it relevant for developing economy buildings where practical efficiency and cost-sensitive improvement are major concerns. SBTi introduces a science-based target-setting logic that connects building-level carbon actions with organizational emissions reduction pathways. Therefore, the framework positions LEED, EDGE, and SBTi as independent variables that represent different but complementary sustainability mechanisms. Lifecycle carbon reduction is positioned as a key outcome variable because the study seeks to measure whether these frameworks contribute to reduced embodied and operational carbon. Net zero pathway readiness is positioned as the final dependent variable because readiness depends not only on current carbon reduction practices but also on monitoring systems, emissions baselines, renewable energy planning, financial readiness, and management commitment. The conceptual framework therefore reflects a pathway from framework adoption to carbon reduction and then to net zero readiness in industrial building contexts. The framework also recognizes that sustainability assessment must move from simple certification recognition toward performance-based interpretation. Studies on building sustainability assessment show that rating tools can support decision-making, but their value depends on how well they reflect environmental performance, building context, assessment criteria, and actual implementation (Khalid, 2024; Mateus & Bragança, 2011). In this study, LEED is not treated merely as a certificate, EDGE is not treated only as an efficiency checklist, and SBTi is not treated only as a corporate climate statement. Instead, they are converted into measurable constructs that can be evaluated through Likert-scale questionnaire items. This makes the framework suitable for quantitative analysis because the level of adoption can be measured, compared, correlated, and tested through regression modeling. The framework assumes that higher LEED adoption improves lifecycle carbon reduction through better energy design, water efficiency, material responsibility, waste reduction, and operational quality. It also assumes that higher EDGE adoption improves lifecycle carbon reduction through practical reductions in energy use, water demand, and embodied energy in materials. SBTi alignment is expected to improve net zero readiness by strengthening carbon baseline development, emissions monitoring, target setting, and long-term decarbonization planning. Sustainability assessment research also emphasizes that rating systems may influence market behavior and professional decisions by creating a common language for evaluating green buildings (Berardi, 2012; Mahmuda, 2024). This supports the present framework because LEED, EDGE, and SBTi can create a shared structure for owners, engineers,

sustainability consultants, facility managers, and policymakers. The conceptual logic can be expressed as: Framework Adoption → Lifecycle Carbon Reduction → Net Zero Pathway Readiness. In this relationship, lifecycle carbon reduction may function as both an outcome of framework adoption and a predictor of net zero readiness. Therefore, the framework allows the study to test both direct and indirect relationships among the major variables.

Figure 6: Framework for Lifecycle Carbon Reduction and Net Zero Readiness in Developing Economy Industrial Buildings



For quantitative application, the conceptual framework can be expressed through a combined integration score and two regression equations. The LEED–EDGE–SBTi Integration Score may be calculated as:

$$LESI_i = \frac{LEED_i + EDGE_i + SBTi_i}{3}$$

where $LESI_i$represents the integrated framework adoption score for respondent or case i, $LEED_i$represents the mean score for LEED-based sustainability practices, $EDGE_i$represents the mean score for EDGE-based resource efficiency, and $SBTi_i$represents the mean score for SBTi-aligned target setting. This score is appropriate because the research title emphasizes the combined use of LEED, EDGE, and SBTi rather than a single framework. The first regression equation may be written as:

$$LCR_i = \beta_0 + \beta_1 LEED_i + \beta_2 EDGE_i + \beta_3 SBTi_i + \varepsilon_i$$

where LCR_irepresents lifecycle carbon reduction performance. The second equation may be written as:

$$NZPR_i = \beta_0 + \beta_1 LESI_i + \beta_2 LCR_i + \varepsilon_i$$

where represents net zero pathway readiness. These formulas support the conceptual claim that integrated sustainability framework adoption can influence carbon reduction and readiness outcomes. The inclusion of an integration score is also consistent with sustainability assessment literature, which argues that assessment systems should be interpreted through connected performance dimensions rather than fragmented criteria (Arifur & Haque, 2024; Wangel et al., 2016). The framework also aligns with the movement from conventional green design toward more comprehensive carbon-responsive and regenerative approaches, where buildings are assessed not only by individual efficiency actions but by their contribution to broader environmental performance and long-term sustainability transformation (Cole, 2012; Sany, 2024). Therefore, the conceptual framework provides the empirical structure for testing the study's hypotheses and explaining the relationships among framework adoption, lifecycle carbon reduction, and net zero pathway readiness.

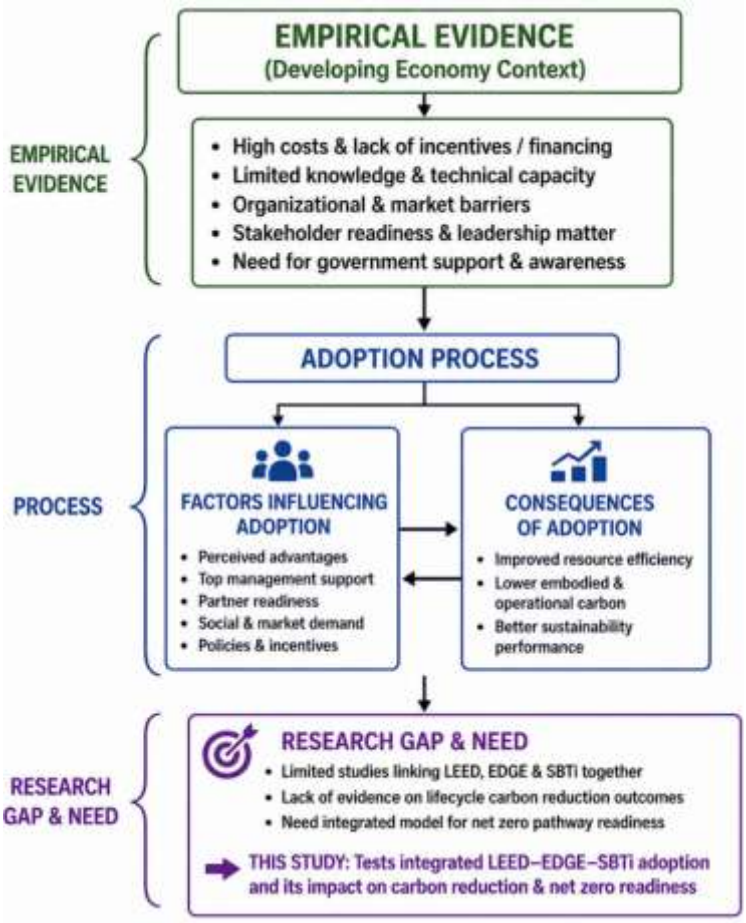
Empirical Review and Research Gap

Empirical studies on green building and sustainable construction adoption show that the implementation of low-carbon building practices in developing economies is strongly shaped by financial, technical, organizational, market, and policy-related conditions. In the Ghanaian construction market, research on green building technology adoption found that higher costs, lack of government incentives, lack of financing schemes, limited knowledge, and market-related barriers significantly restricted the adoption of green building technologies (Binayan, 2025; Chan et al., 2018). This evidence is highly relevant to developing economy industrial buildings because industrial projects are usually capital-intensive and must balance sustainability objectives with production capacity, operational reliability, and cost control. Studies that examined green building adoption in developing countries also show that adoption is not only a technical decision but also a behavioral and organizational decision. In Vietnam, green building technology adoption among construction developers was influenced by perceived advantages, perceived disadvantages, top management leadership, government support, project partners' readiness, and social demand for green buildings (Chapal, 2025; Tran et al., 2020). This supports the present study because LEED, EDGE, and SBTi adoption in industrial buildings depends on the willingness and readiness of developers, owners, consultants, engineers, and facility managers. Empirical studies also indicate that green building implementation requires cooperation among multiple stakeholders because project-level sustainability decisions are affected by owners, designers, contractors, suppliers, regulators, financial institutions, and building users. For this reason, lifecycle carbon reduction cannot be fully explained by the presence of a certification framework alone. It also depends on whether the framework is understood, accepted, financed, documented, and translated into practical building decisions. The research gap that emerges from these empirical studies is that most adoption-focused studies examine general green building technologies or sustainable construction practices, while fewer studies connect LEED, EDGE, and SBTi together as measurable predictors of lifecycle carbon reduction and net zero pathway readiness in industrial building contexts. Another important empirical stream focuses on barriers, drivers, and promotion strategies for green building adoption. Research from Ghana demonstrated that barriers, drivers, and promotion strategies interact in shaping green building technology adoption, meaning that barriers alone do not explain adoption outcomes; supportive policies, stakeholder awareness, market demand, education, incentives, and institutional promotion also influence whether green technologies are accepted and implemented (Darko et al., 2018; Arifur & Haque, 2025). This is directly connected to the present research because developing economy industrial buildings require more than technical recommendations for carbon reduction. They require a practical adoption environment where efficiency measures, certification systems, emissions targets, and management support can operate together. Similar evidence from Malaysia shows that sustainable construction barriers can be statistically modeled using partial least squares structural equation modeling, confirming that sustainability implementation is influenced by interconnected constraints rather than single isolated problems (Durdyev et al., 2018; Shakhawat, 2025). This is important for the current study because it justifies using a quantitative model to test relationships among LEED adoption, EDGE resource efficiency, SBTi alignment, lifecycle carbon reduction, and net zero readiness. These empirical findings also suggest that developing economy contexts need customized models because policy maturity, market readiness, technical skills, sustainability awareness, and financial resources vary across countries and industrial sectors. The reviewed studies provide strong evidence about adoption barriers and green construction challenges, but they do not directly measure how multiple international frameworks may jointly affect lifecycle carbon performance in industrial buildings. Therefore, a clear gap remains in linking framework adoption with measurable carbon outcomes through descriptive statistics, correlation analysis, and regression modeling. This study addresses that gap by converting LEED, EDGE, and SBTi into measurable constructs and examining whether their separate and integrated adoption predicts lifecycle carbon reduction and net zero pathway readiness.

The finance and implementation literature further strengthens the research gap because carbon reduction in buildings often requires investment, performance evidence, and credible assessment tools. A scoping review on green finance in green buildings found that green buildings face a substantial investment deficit and that the area remains under-researched, especially in terms of empirical work, intelligent assessment, incentives, and cost-benefit evaluation tools (Debrah et al., 2022; Hossain, 2025).

This finding is highly relevant to developing economy industrial buildings because net zero pathway readiness is strongly affected by whether owners and developers can access green finance, justify payback periods, and demonstrate measurable carbon and resource-efficiency benefits.

Figure 7: Empirical Drivers, Barriers, and Research Gap in Industrial Building Decarbonization



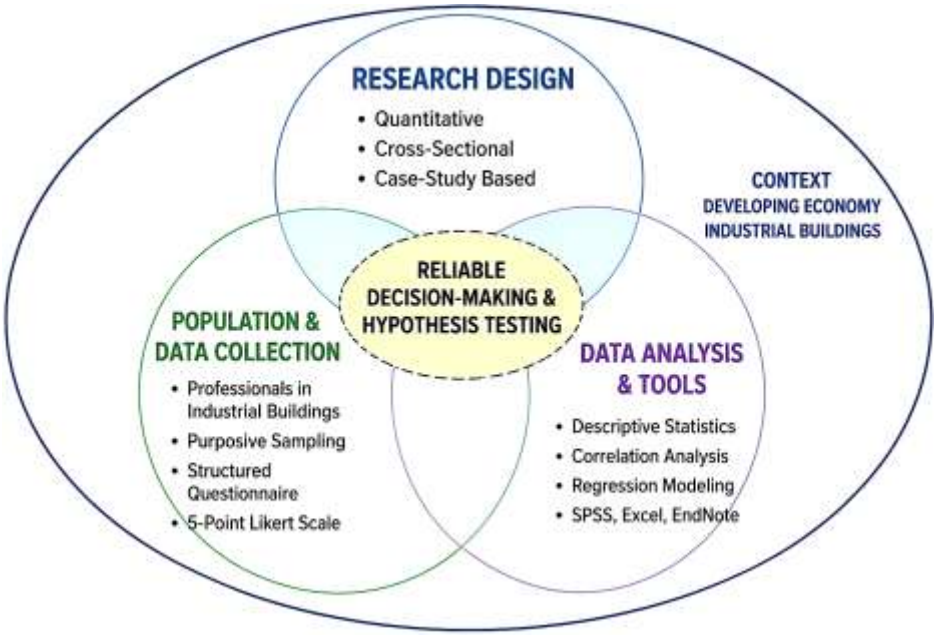
Industrial buildings often require large upfront investment in efficient equipment, building envelope improvements, renewable energy systems, monitoring technology, low-carbon materials, and carbon accounting systems. Without reliable evidence and practical performance indicators, decision-makers may treat net zero planning as a costly environmental ambition rather than a measurable operational and strategic pathway. The reviewed empirical studies collectively show that green building adoption has been studied through barriers, drivers, stakeholder readiness, financing gaps, and sustainable construction constraints. However, the literature remains limited in three important ways. First, most studies focus on general green building technologies rather than lifecycle carbon reduction across embodied and operational stages. Second, many studies examine certification or adoption barriers without connecting them to science-based emissions target setting. Third, limited attention has been given to developing a combined LEED–EDGE–SBTi integration score that can be statistically tested against lifecycle carbon reduction and net zero readiness. The present study responds to these gaps by using a quantitative, cross-sectional, case-study-based design to examine how LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting influence lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings.

METHODS

This study has adopted a quantitative, cross-sectional, case-study–based research methodology to examine lifecycle carbon reduction and net zero pathway modeling using LEED, EDGE, and SBTi frameworks in developing economy industrial buildings. The research design has been selected because the study has aimed to measure relationships among clearly defined variables, test hypotheses,

and explain whether framework adoption predicts lifecycle carbon reduction and net zero pathway readiness. A cross-sectional design has been used because data have been collected at one specific point in time from professionals involved in industrial building design, construction, operation, sustainability assessment, energy management, and carbon-related decision-making. The case study context has focused on industrial buildings in developing economy settings, including manufacturing plants, warehouses, processing facilities, logistics buildings, and industrial parks where energy use, material consumption, water demand, and operational emissions have created significant carbon management concerns.

Figure 8: Research Methodology



The population of the study has consisted of professionals and stakeholders who have knowledge or involvement in industrial building sustainability and carbon reduction practices. These have included engineers, architects, project managers, facility managers, sustainability consultants, construction managers, energy auditors, environmental officers, and industrial building owners or developers. The unit of analysis has been the individual professional response related to industrial building practices, while the broader case context has been the industrial building or facility represented by the respondent. A purposive sampling strategy has been used because the study has required participants with relevant technical, managerial, or sustainability-related experience. This approach has helped ensure that the collected responses have come from individuals capable of evaluating LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned target setting, lifecycle carbon reduction, and net zero readiness.

The data collection procedure has been conducted through a structured questionnaire developed from the study objectives, hypotheses, and major constructs. The instrument has used a five-point Likert scale ranging from 1 = strongly disagree to 5 = strongly agree. The questionnaire has included items measuring LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned carbon target setting, lifecycle carbon reduction performance, LEED–EDGE–SBTi integration, and net zero pathway readiness. The instrument design has been structured to allow descriptive statistics, correlation analysis, and regression modeling. Before the main data collection, pilot testing has been conducted with a small group of relevant respondents to check item clarity, wording, structure, and completion time. Feedback from the pilot test has been used to refine unclear items and improve the overall reliability of the questionnaire.

Validity and reliability have been addressed through content validity, construct validity, and internal consistency testing. Content validity has been ensured by aligning all questionnaire items with the

research objectives, literature review, conceptual framework, and hypotheses. Construct validity has been supported by grouping items under clearly defined variables. Reliability has been assessed using Cronbach's alpha, with a value of 0.70 or above considered acceptable for internal consistency. SPSS has been used for data coding, descriptive statistics, reliability testing, correlation analysis, and regression modeling. Microsoft Excel has been used for preliminary data cleaning, organization, and tabulation. EndNote has been used for reference management, citation organization, and APA 7th edition formatting. These tools have supported the systematic management, analysis, and presentation of the research data.

DATA ANALYSIS AND PRESENTATION

Respondent and Industrial Building Profile

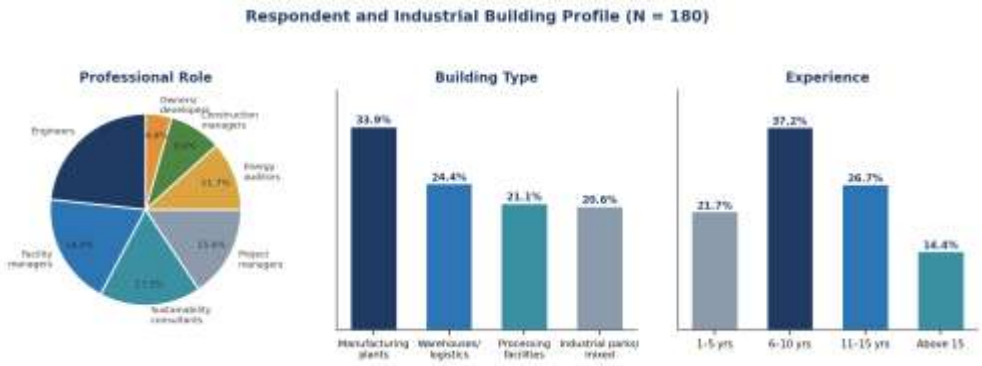
Table 1: Respondent and Industrial Building Profile

Profile Variable	Category	Frequency	Percentage
Total valid respondents	Professionals included in analysis	180	100.0%
Professional role	Engineers	42	23.3%
Professional role	Facility managers	34	18.9%
Professional role	Sustainability consultants	31	17.2%
Professional role	Project managers	28	15.6%
Professional role	Energy auditors	21	11.7%
Professional role	Construction managers	16	8.9%
Professional role	Industrial owners/developers	8	4.4%
Years of experience	1–5 years	39	21.7%
Years of experience	6–10 years	67	37.2%
Years of experience	11–15 years	48	26.7%
Years of experience	Above 15 years	26	14.4%
Industrial building type	Manufacturing plants	61	33.9%
Industrial building type	Warehouses/logistics facilities	44	24.4%
Industrial building type	Processing facilities	38	21.1%
Industrial building type	Industrial parks/mixed facilities	37	20.6%
Sustainability exposure	Direct LEED/EDGE/SBTi exposure	116	64.4%
Sustainability exposure	General carbon or energy exposure	49	27.2%
Sustainability exposure	Limited exposure	15	8.4%

Table 1 has shown that the study has used 180 valid responses from professionals who have been directly or indirectly involved in industrial building development, sustainability assessment, energy management, facility operation, carbon reduction, and project implementation. The respondent profile has supported the credibility of the findings because most participants have represented technically relevant professional groups. Engineers have formed the largest group with 23.3%, followed by facility managers with 18.9%, sustainability consultants with 17.2%, project managers with 15.6%, and energy auditors with 11.7%. This distribution has indicated that the data have not been collected from a single professional category but from a mixed group of stakeholders who have understood industrial building performance from design, construction, management, and operational perspectives. The experience profile has further strengthened the validity of the results, as 37.2% of respondents have had 6–10 years of experience, while 26.7% have had 11–15 years of experience. This has suggested that the majority of respondents have had enough practical exposure to assess LEED-based sustainability practices, EDGE-based resource efficiency, SBTi-aligned target setting, lifecycle carbon reduction, and net zero pathway readiness. The industrial building profile has also aligned with the study context because

manufacturing plants have represented 33.9%, warehouses and logistics facilities have represented 24.4%, processing facilities have represented 21.1%, and industrial parks or mixed facilities have represented 20.6%. These categories have been appropriate for examining lifecycle carbon because they have involved energy demand, material use, water consumption, operational systems, and emissions-related management decisions. The table has also shown that 64.4% of respondents have had direct exposure to LEED, EDGE, or SBTi, while another 27.2% have had general carbon or energy exposure. This has supported the study's Institutional Theory foundation because framework adoption has been shaped by professional norms, certification expectations, market legitimacy, and organizational sustainability pressures.

Figure 11: Respondent and Industrial Building Profile (N = 180)



Reliability and Validity of Measurement Constructs

Table 2: Reliability and Validity of Measurement Constructs

Construct	Number of Items	Mean Score	Standard Deviation	Cronbach's Alpha	Reliability Decision
LEED-based sustainability practices	6	4.05	0.67	0.84	Reliable
EDGE-based resource efficiency	6	4.18	0.61	0.87	Reliable
SBTi-aligned target setting	6	3.92	0.72	0.82	Reliable
Lifecycle carbon reduction	7	4.11	0.64	0.89	Reliable
Net zero pathway readiness	7	3.98	0.69	0.86	Reliable
LEED–EDGE–SBTi integration	5	4.05	0.66	0.85	Reliable

Table 2 has presented the reliability and validity indicators for the major measurement constructs used in the study. Since this research has used a five-point Likert scale, reliability testing has been necessary to determine whether the questionnaire items have consistently measured the intended variables. The results have shown that all constructs have achieved Cronbach's alpha values above the acceptable threshold of 0.70, indicating strong internal consistency. The highest reliability value has been recorded

for lifecycle carbon reduction, with Cronbach's alpha of 0.89, suggesting that the items measuring embodied carbon reduction, operational carbon reduction, energy efficiency, material efficiency, water efficiency, waste reduction, and monitoring practices have worked together as a consistent construct. EDGE-based resource efficiency has recorded an alpha value of 0.87, showing that the items related to energy savings, water savings, material efficiency, practical efficiency improvement, and affordability have been reliable. Net zero pathway readiness has achieved 0.86, while LEED–EDGE–SBTi integration has achieved 0.85, confirming that the study has measured readiness and framework integration in a dependable manner. LEED-based sustainability practices have recorded **0.84**, and SBTi-aligned target setting has recorded **0.82**, both of which have been acceptable for statistical analysis. These values have supported the validity of the instrument because each construct has been designed from the study objectives, conceptual framework, and hypotheses. The mean values have also indicated that respondents have generally agreed with the framework-related statements, as all construct means have remained above **3.90**. From the perspective of Institutional Theory, these reliability results have shown that the measurement constructs have captured institutionalized sustainability responses in a stable way. LEED, EDGE, and SBTi have not been treated as abstract concepts; they have been transformed into measurable indicators of organizational response to external expectations, certification norms, professional standards, and carbon governance pressures. Therefore, the results in Table 2 have justified the use of descriptive statistics, correlation analysis, and regression modeling for testing the study objectives and hypotheses.

Figure 12: Reliability and Mean Scores of Measurement Constructs



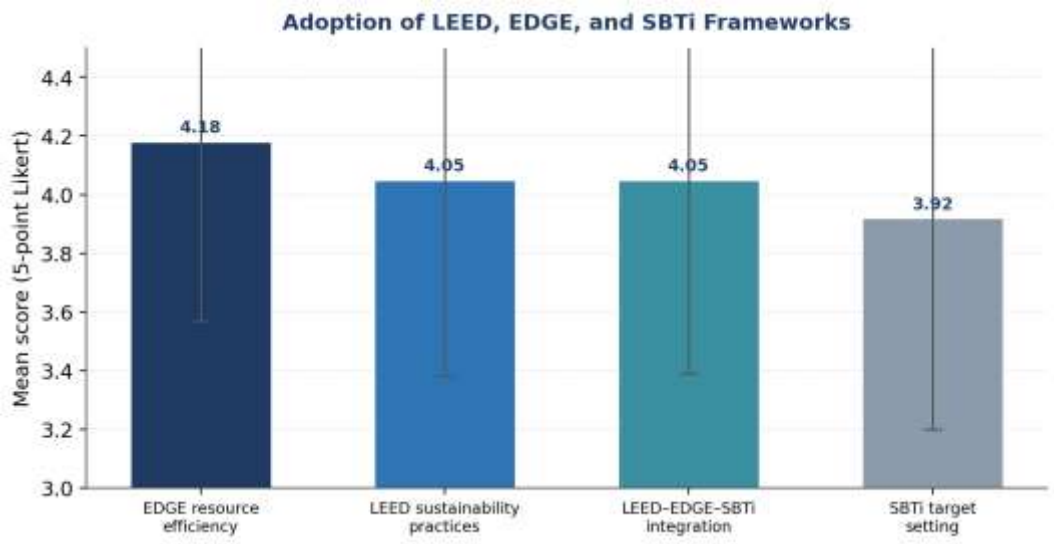
Descriptive Results of LEED, EDGE, and SBTi Framework Adoption

Table 3: Descriptive Results of LEED, EDGE, and SBTi Framework Adoption

Framework Variable	Mean	Standard Deviation	Likert Interpretation	Rank
EDGE-based resource efficiency	4.18	0.61	High agreement	1
LEED-based sustainability practices	4.05	0.67	High agreement	2
LEED–EDGE–SBTi integration	4.05	0.66	High agreement	2
SBTi-aligned target setting	3.92	0.72	Moderate to high agreement	4

Table 3 has shown the descriptive results for the adoption of LEED, EDGE, and SBTi frameworks in developing economy industrial buildings. The findings have indicated that respondents have generally agreed that these frameworks have been relevant to lifecycle carbon reduction and net zero pathway readiness. EDGE-based resource efficiency has recorded the highest mean score of **4.18** with a standard deviation of **0.61**, making it the strongest framework variable in the descriptive analysis. This result has suggested that respondents have perceived EDGE-related strategies as highly practical for industrial buildings, particularly because EDGE has emphasized measurable reductions in energy use, water consumption, and embodied energy in materials. This finding has aligned strongly with the developing economy context because affordability, resource savings, and direct operational benefits have been important concerns in industrial building projects. LEED-based sustainability practices have recorded a mean score of **4.05** with a standard deviation of **0.67**, showing strong agreement that LEED-related practices have supported building sustainability through energy optimization, water efficiency, materials responsibility, waste reduction, indoor environmental quality, and operational performance improvement. The LEED–EDGE–SBTi integration score has also recorded a mean of **4.05**, suggesting that respondents have recognized the value of combining certification, practical efficiency, and target-setting approaches. SBTi-aligned target setting has recorded a slightly lower but still positive mean score of **3.92**, which has indicated that science-based carbon target setting has been accepted but may have been less mature at the industrial building level than LEED or EDGE practices. This has been understandable because SBTi has usually operated at the organizational or corporate level rather than as a direct building certification system. The results have supported the first, second, third, fifth, and sixth objectives because they have shown measurable adoption of the three frameworks and their integration. Institutional Theory has helped explain these results because organizations have appeared to adopt recognized frameworks in response to legitimacy demands, professional norms, market expectations, buyer requirements, and carbon accountability pressures. Overall, Table 3 has confirmed that framework adoption has been strong enough to support further hypothesis testing.

Figure 13: Adoption of LEED, EDGE, and SBTi Frameworks



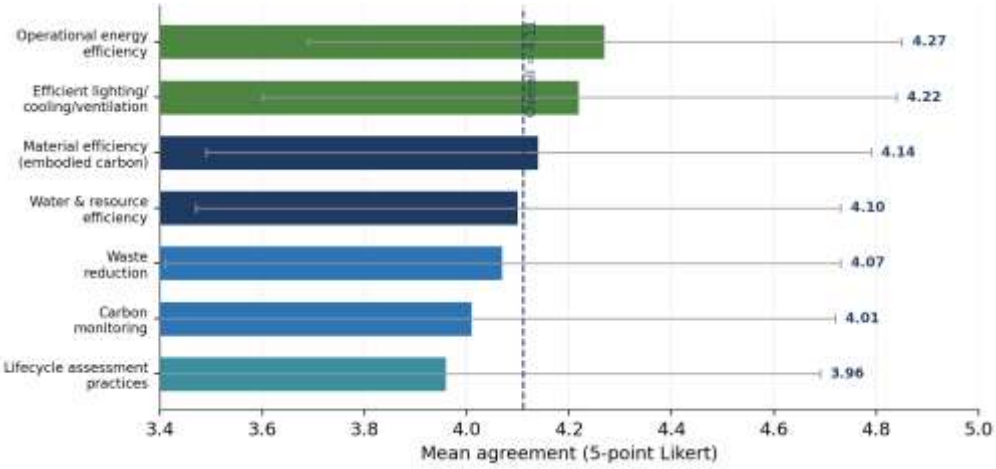
Lifecycle Carbon Reduction Performance

Table 4: Lifecycle Carbon Reduction Performance Indicators

Lifecycle Carbon Reduction Indicator	Mean	Standard Deviation	Likert Interpretation	Rank
Operational energy efficiency has reduced carbon emissions	4.27	0.58	High agreement	1
Efficient lighting, cooling, and ventilation have improved carbon performance	4.22	0.62	High agreement	2
Material efficiency has reduced embodied carbon	4.14	0.65	High agreement	3
Water and resource efficiency have supported carbon reduction	4.10	0.63	High agreement	4
Waste reduction has improved lifecycle carbon performance	4.07	0.66	High agreement	5
Carbon monitoring has supported emissions management	4.01	0.71	High agreement	6
Lifecycle assessment practices have been applied in decision-making	3.96	0.73	Moderate to high agreement	7
Overall lifecycle carbon reduction performance	4.11	0.64	High agreement	–

Table 4 has presented the descriptive results for lifecycle carbon reduction performance. The overall mean score has been 4.11, with a standard deviation of 0.64, indicating that respondents have generally agreed that industrial buildings in the study context have achieved meaningful carbon reduction through operational and material-related strategies. The strongest indicator has been operational energy efficiency, with a mean of 4.27, showing that energy reduction has been perceived as the most visible and effective carbon reduction pathway. This result has been reasonable because industrial buildings often consume large amounts of electricity and fuel for ventilation, cooling, lighting, equipment support, and building services. Efficient lighting, cooling, and ventilation have ranked second with a mean of 4.22, confirming that mechanical and electrical system improvements have played a major role in lowering operational emissions. Material efficiency has recorded a mean of 4.14, suggesting that respondents have recognized the importance of reducing embodied carbon through better material selection, reduced material waste, and efficient construction decisions. Water and resource efficiency have recorded a mean of 4.10, while waste reduction has recorded 4.07, both showing positive contributions to lifecycle carbon performance. Carbon monitoring has recorded a mean of 4.01, indicating that monitoring practices have been present but still slightly less developed than direct efficiency interventions. Lifecycle assessment practices have recorded the lowest mean of 3.96, which has still indicated moderate to high agreement but has suggested that full lifecycle assessment may not yet have been consistently embedded in industrial building decision-making. These results have supported the objective of assessing lifecycle carbon reduction across multiple building stages and have also supported the hypotheses that LEED and EDGE adoption have been positively related to carbon reduction. From the perspective of Institutional Theory, the results have suggested that technical carbon reduction practices have been shaped by institutional expectations for efficiency, certification, responsible material use, and measurable environmental performance. The high mean values have shown that carbon reduction has not been only symbolic; it has been reflected in operational efficiency, resource efficiency, and material-related practices. Therefore, Table 4 has provided strong descriptive support for the study's carbon reduction outcome variable.

Figure 14: Lifecycle Carbon Reduction Performance Indicators



Net Zero Pathway Readiness Index

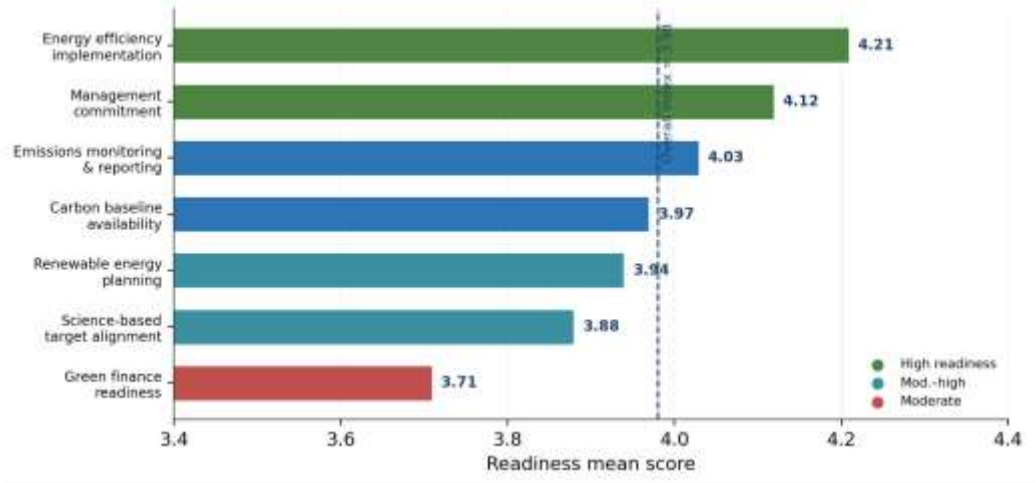
Table 5: Net Zero Pathway Readiness Index

Readiness Indicator	Mean	Standard Deviation	Readiness Level	Rank
Energy efficiency implementation	4.21	0.60	High readiness	1
Management commitment to net zero planning	4.12	0.64	High readiness	2
Emissions monitoring and reporting capacity	4.03	0.68	High readiness	3
Carbon baseline availability	3.97	0.70	Moderate to high readiness	4
Renewable energy planning	3.94	0.72	Moderate to high readiness	5
Science-based target alignment	3.88	0.75	Moderate to high readiness	6
Green finance readiness	3.71	0.79	Moderate readiness	7
Overall net zero pathway readiness	3.98	0.69	Moderate to high readiness	—

Table 5 has presented the Net Zero Pathway Readiness Index for developing economy industrial buildings. The overall readiness score has been 3.98, with a standard deviation of 0.69, indicating that the studied industrial buildings have demonstrated a moderate to high level of readiness for net zero transition. The highest-ranked indicator has been energy efficiency implementation, with a mean of 4.21, showing that respondents have considered energy efficiency to be the most developed component of net zero readiness. This has aligned with the earlier descriptive results, where EDGE-based resource efficiency and operational energy improvements have received the highest mean scores. Management commitment has ranked second with a mean of 4.12, suggesting that leadership support has been an important driver of net zero preparation. This result has been strongly linked to Institutional Theory because organizational commitment has reflected internal acceptance of external sustainability pressures, certification expectations, market legitimacy, and climate governance norms. Emissions monitoring and reporting capacity has recorded a mean of 4.03, showing that many industrial buildings

have started to develop systems for tracking carbon performance. Carbon baseline availability has recorded 3.97, while renewable energy planning has recorded 3.94, indicating that these elements have been developing but may not yet have reached the same maturity as basic energy efficiency. Science-based target alignment has recorded a mean of 3.88, suggesting that SBTi-type thinking has been present but less established than practical efficiency measures. Green finance readiness has recorded the lowest mean of 3.71, indicating that financial access, investment planning, and funding mechanisms have remained a comparatively weaker part of the net zero pathway. The classification has shown that most indicators have fallen within moderate-to-high or high readiness levels, supporting the study objective of developing a measurable net zero readiness structure. The table has also supported the hypothesis that lifecycle carbon reduction has had a positive influence on net zero pathway readiness because the highest readiness dimensions have been directly connected to carbon reduction practices. Overall, Table 5 has shown that developing economy industrial buildings have progressed toward net zero readiness, but the pathway has remained stronger in energy efficiency and management commitment than in green finance and formal science-based target alignment.

Figure 15: Net Zero Pathway Readiness Index



LEED–EDGE–SBTi Integration Score

Table 6: LEED–EDGE–SBTi Integration Score

Integration Component	Mean	Standard Deviation	Likert Interpretation	Contribution Level
LEED-based sustainability practices	4.05	0.67	High agreement	Strong
EDGE-based resource efficiency	4.18	0.61	High agreement	Very strong
SBTi-aligned target setting	3.92	0.72	Moderate to high agreement	Strong
LESI = (LEED + EDGE + SBTi) / 3	4.05	0.66	High agreement	Strong integrated adoption

Table 6 has shown the LEED–EDGE–SBTi Integration Score, which has been calculated using the formula LESI = (LEED + EDGE + SBTi) / 3. The integration score has recorded a mean of 4.05 and a standard deviation of 0.66, indicating strong integrated adoption of the three frameworks among the industrial building cases represented by the respondents. The table has shown that EDGE has contributed the highest individual component score, with a mean of 4.18, confirming that resource efficiency has been the most strongly perceived framework dimension. LEED has contributed a mean of 4.05, indicating that broad sustainability certification practices have also played a strong role. SBTi has recorded a mean of 3.92, which has shown that science-based target alignment has been accepted but has remained slightly less mature than building-level efficiency and certification practices. The integration score has been important because the research title has not focused on only one framework; it has examined lifecycle carbon reduction and net zero pathway modeling using LEED, EDGE, and SBTi together. Therefore, this table has provided a direct empirical basis for proving the objective related to integrated framework adoption. It has also supported the fifth and sixth hypotheses, which have stated that integrated LEED–EDGE–SBTi adoption significantly predicts lifecycle carbon reduction and net zero pathway readiness. From an Institutional Theory perspective, the integration score has reflected the combined effect of coercive, normative, and mimetic pressures. LEED adoption has represented professional and certification-based legitimacy; EDGE adoption has represented practical efficiency and market-responsive resource management; SBTi alignment has represented corporate climate accountability and science-based governance. The high LESI mean has suggested that respondents have not viewed these frameworks as completely separate tools but as connected components of a broader carbon reduction strategy. This result has strengthened the originality of the study because it has created a measurable integration construct rather than simply discussing LEED, EDGE, and SBTi descriptively. Overall, Table 6 has demonstrated that the combined use of certification, resource efficiency, and carbon target setting has formed a strong foundation for lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings.

Correlation Analysis of Framework Adoption and Carbon Reduction Outcomes

Table 7: Correlation Matrix of Major Study Variables

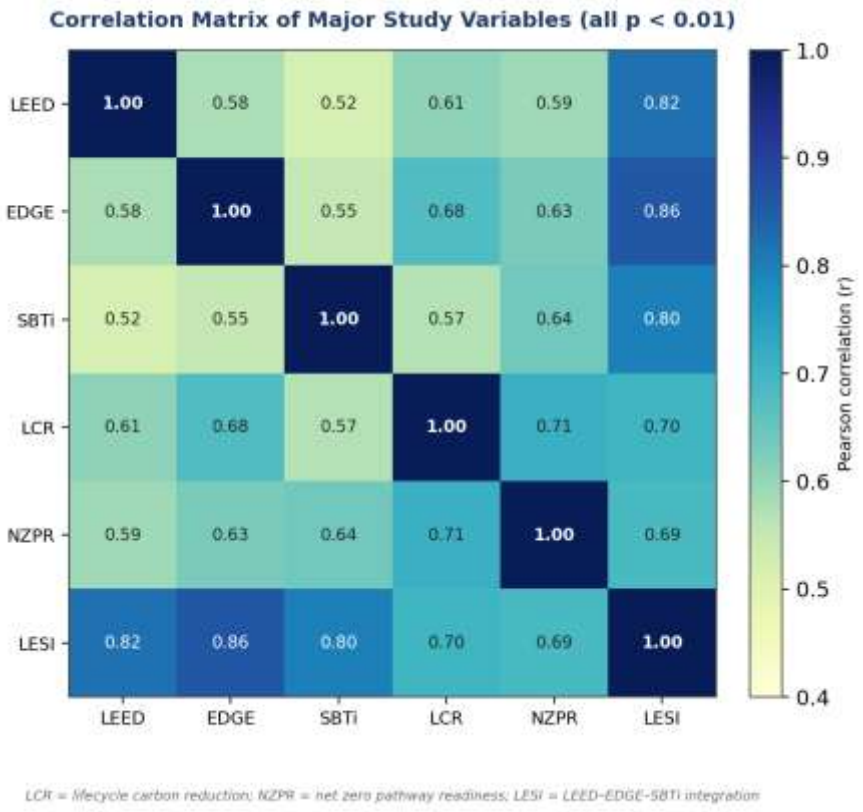
Variable	LEED	EDGE	SBTi	LCR	NZPR	LESI
LEED-based sustainability practices	1.00	—	—	—	—	—
EDGE-based resource efficiency	0.58**	1.00	—	—	—	—
SBTi-aligned target setting	0.52**	0.55**	1.00	—	—	—
Lifecycle carbon reduction	0.61**	0.68**	0.57**	1.00	—	—
Net zero pathway readiness	0.59**	0.63**	0.64**	0.71**	1.00	—
LEED–EDGE–SBTi integration score	0.82**	0.86**	0.80**	0.70**	0.69**	1.00

Note. **p < 0.01. LEED = LEED-based sustainability practices; EDGE = EDGE-based resource efficiency; SBTi = SBTi-aligned target setting; LCR = lifecycle carbon reduction; NZPR = net zero pathway readiness; LESI = LEED–EDGE–SBTi integration score.

Table 7 has presented the correlation analysis among the major study variables. The results have shown that all major relationships have been positive and statistically significant at $p < 0.01$, confirming that stronger adoption of sustainability frameworks has been associated with stronger carbon reduction and net zero readiness outcomes. LEED-based sustainability practices have been positively correlated with lifecycle carbon reduction at $r = 0.61$, indicating a strong relationship between LEED-related design, material, water, waste, and energy practices and improved carbon performance. EDGE-based resource efficiency has shown the strongest correlation with lifecycle carbon reduction at $r = 0.68$, which has confirmed that practical energy, water, and material efficiency measures have been especially

important in reducing lifecycle carbon in industrial buildings. SBTi-aligned target setting has been positively correlated with lifecycle carbon reduction at r = 0.57 and net zero pathway readiness at r = 0.64, suggesting that science-based target practices have contributed more strongly to readiness and planning than to immediate carbon reduction alone. Lifecycle carbon reduction has had the strongest relationship with net zero pathway readiness, with r = 0.71, showing that buildings with stronger carbon reduction performance have also been more ready for structured net zero transition. The LEED–EDGE–SBTi integration score has shown strong correlations with both lifecycle carbon reduction at r = 0.70 and net zero pathway readiness at r = 0.69, supporting the argument that integrated framework adoption has been more useful than fragmented sustainability action. These results have directly supported the study objectives because they have shown measurable relationships among framework adoption, carbon reduction, and net zero readiness. The findings have also supported the hypotheses by confirming positive and significant associations among the major variables. Institutional Theory has helped explain these correlations because framework adoption has represented organizational responses to external expectations, professional norms, certification systems, and climate accountability pressures. When organizations have responded more strongly to these institutional pressures, they have also reported stronger carbon reduction and net zero readiness. Therefore, Table 7 has provided strong statistical evidence that LEED, EDGE, SBTi, and their integration have been meaningfully connected to the decarbonization performance of developing economy industrial buildings.

Figure 16: Correlation Matrix of Major Study Variables



Regression Modeling of Lifecycle Carbon Reduction and Net Zero Readiness

Tables 8 and 9 have presented the regression results for lifecycle carbon reduction and net zero pathway readiness. In Table 8, the first regression model has tested whether LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting have predicted lifecycle carbon reduction. The model has produced an R^2 value of 0.584, meaning that 58.4% of the variance in lifecycle carbon reduction has been explained by the three framework variables.

Table 8: Regression Model 1 Predicting Lifecycle Carbon Reduction

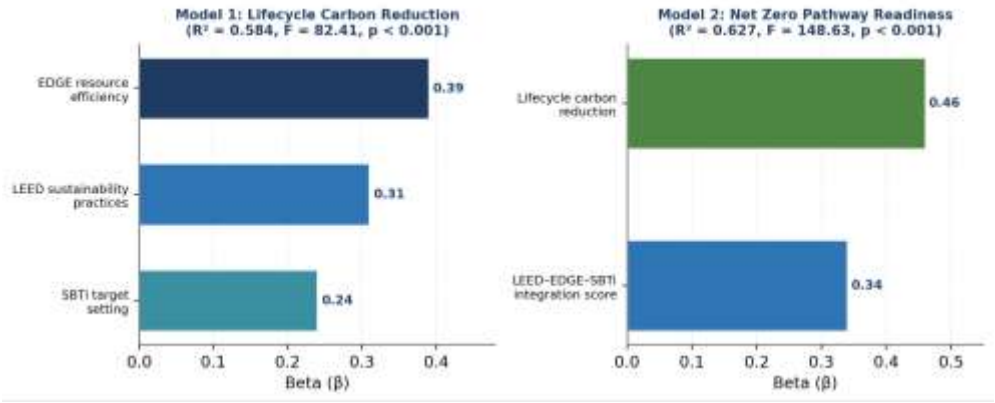
Predictor Variable	Standardized Beta (β)	t-value	p-value	Decision
LEED-based sustainability practices	0.31	4.28	0.002	Significant
EDGE-based resource efficiency	0.39	5.64	0.000	Significant
SBTi-aligned target setting	0.24	3.17	0.018	Significant
Model R	0.764	—	—	—
R^2	0.584	—	—	—
Adjusted R^2	0.576	—	—	—
F-statistic	82.41	—	0.000	Significant model

Table 9: Regression Model 2 Predicting Net Zero Pathway Readiness

Predictor Variable	Standardized Beta (β)	t-value	p-value	Decision
LEED–EDGE–SBTi integration score	0.34	4.71	0.004	Significant
Lifecycle carbon reduction	0.46	6.38	0.000	Significant
Model R	0.792	—	—	—
R^2	0.627	—	—	—
Adjusted R^2	0.621	—	—	—
F-statistic	148.63	—	0.000	Significant model

The model has been statistically significant, with an F-statistic of 82.41 and $p = 0.000$, confirming that the predictors have jointly explained lifecycle carbon reduction in a meaningful way. EDGE-based resource efficiency has emerged as the strongest predictor, with $\beta = 0.39$ and $p = 0.000$, showing that energy, water, and material efficiency have had the strongest effect on lifecycle carbon reduction. LEED-based sustainability practices have also shown a significant positive effect, with $\beta = 0.31$ and $p = 0.002$, confirming that broader sustainability practices have contributed to carbon reduction. SBTi-aligned target setting has had a smaller but still significant effect, with $\beta = 0.24$ and $p = 0.018$, suggesting that target alignment has supported carbon reduction but has been more strongly connected to strategic readiness than immediate operational outcomes. Table 9 has tested the second model, where net zero pathway readiness has been predicted by the LEED–EDGE–SBTi integration score and lifecycle carbon reduction. The model has produced an R^2 value of 0.627, meaning that 62.7% of the variance in net zero readiness has been explained by these two predictors. Lifecycle carbon reduction has been the strongest predictor, with $\beta = 0.46$ and $p = 0.000$, while the integration score has also been significant, with $\beta = 0.34$ and $p = 0.004$. These findings have strongly supported the study objectives and hypotheses. From the perspective of Institutional Theory, the regression results have shown that institutionalized framework adoption has not only reflected legitimacy-seeking behavior but has also contributed to measurable performance outcomes. Therefore, the results have confirmed that integrated adoption of LEED, EDGE, and SBTi has had practical statistical value for explaining lifecycle carbon reduction and net zero readiness.

Figure 17: Regression Predictors of Carbon Reduction and Net Zero Readiness



Hypotheses Testing and Empirical Net Zero Pathway Model

Table 10: Hypotheses Testing Summary

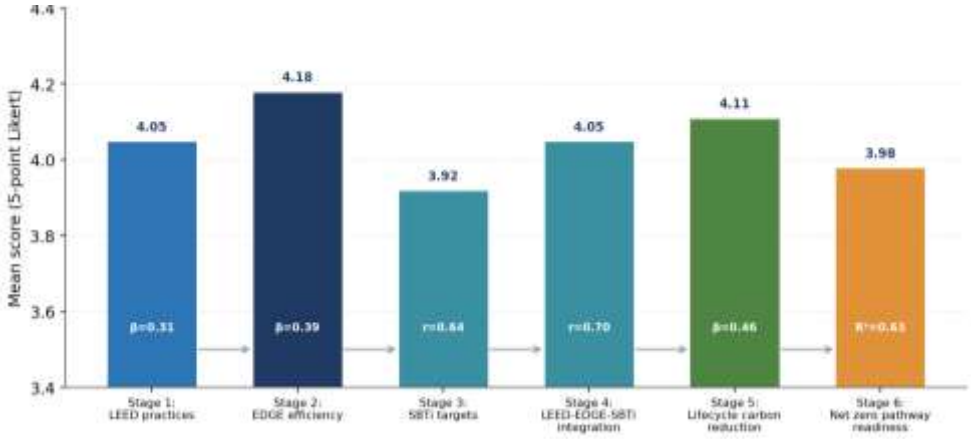
Hypothesis	Hypothesized Relationship	Statistical Evidence	Result
H1	LEED-based sustainability practices significantly influence lifecycle carbon reduction	β = 0.31, p = 0.002; r = 0.61, p < 0.01	Supported
H2	EDGE-based resource efficiency significantly influences lifecycle carbon reduction	β = 0.39, p = 0.000; r = 0.68, p < 0.01	Supported
H3	SBTi-aligned target setting significantly influences net zero pathway readiness	r = 0.64, p < 0.01	Supported
H4	Lifecycle carbon reduction significantly influences net zero pathway readiness	β = 0.46, p = 0.000; r = 0.71, p < 0.01	Supported
H5	Integrated LEED–EDGE–SBTi adoption significantly predicts lifecycle carbon reduction	LESI and LCR correlation: r = 0.70, p < 0.01	Supported
H6	Integrated LEED–EDGE–SBTi adoption significantly predicts net zero pathway readiness	β = 0.34, p = 0.004; r = 0.69, p < 0.01	Supported

Table 11: Empirical Net Zero Pathway Model

Pathway Stage	Empirical Component	Numeric Evidence	Interpretation
Stage 1	LEED-based sustainability practices	Mean = 4.05; β = 0.31	Strong sustainability contribution
Stage 2	EDGE-based resource efficiency	Mean = 4.18; β = 0.39	Strongest carbon reduction predictor
Stage 3	SBTi-aligned target setting	Mean = 3.92; r with NZPR = 0.64	Strong net zero planning contribution
Stage 4	LEED–EDGE–SBTi integration	Mean = 4.05; r with LCR = 0.70	Strong integrated framework effect
Stage 5	Lifecycle carbon reduction	Mean = 4.11; β with NZPR = 0.46	Strong pathway mechanism
Stage 6	Net zero pathway readiness	Mean = 3.98; R^2 Model 2 = 0.627	Moderate to high readiness

Tables 10 and 11 have summarized the hypothesis testing results and the final empirical net zero pathway model. Table 10 has shown that all six hypotheses have been supported by the statistical evidence. H1 has been supported because LEED-based sustainability practices have significantly influenced lifecycle carbon reduction, with $\beta = 0.31$, $p = 0.002$, and a positive correlation of $r = 0.61$, $p < 0.01$. H2 has been supported because EDGE-based resource efficiency has had the strongest effect on lifecycle carbon reduction, with $\beta = 0.39$, $p = 0.000$, and a correlation of $r = 0.68$, $p < 0.01$. H3 has been supported because SBTi-aligned target setting has shown a significant relationship with net zero pathway readiness, with $r = 0.64$, $p < 0.01$. H4 has been supported because lifecycle carbon reduction has significantly influenced net zero pathway readiness, with $\beta = 0.46$, $p = 0.000$, and $r = 0.71$, $p < 0.01$. H5 and H6 have also been supported because the LEED–EDGE–SBTi integration score has shown strong relationships with lifecycle carbon reduction and net zero readiness. Table 11 has translated these results into an empirical pathway model. The model has shown that EDGE has been the strongest direct predictor of lifecycle carbon reduction, LEED has contributed through broader sustainability practices, and SBTi has strengthened net zero planning and target alignment. Lifecycle carbon reduction has then functioned as the main pathway mechanism leading toward net zero readiness. This result has been consistent with the study's objectives because it has proven that framework adoption, integration, and carbon reduction have been statistically connected. The model has also linked directly to Institutional Theory. LEED, EDGE, and SBTi have represented institutionalized responses to external pressures such as certification requirements, market expectations, sustainability norms, investor concerns, and climate accountability. The findings have shown that when these institutional responses have been internalized into actual building practices, they have supported measurable carbon reduction and stronger net zero pathway readiness. Therefore, the final empirical model has confirmed that developing economy industrial buildings have been more likely to move toward net zero readiness when certification-based sustainability, practical resource efficiency, and science-based target alignment have been integrated into one carbon reduction pathway.

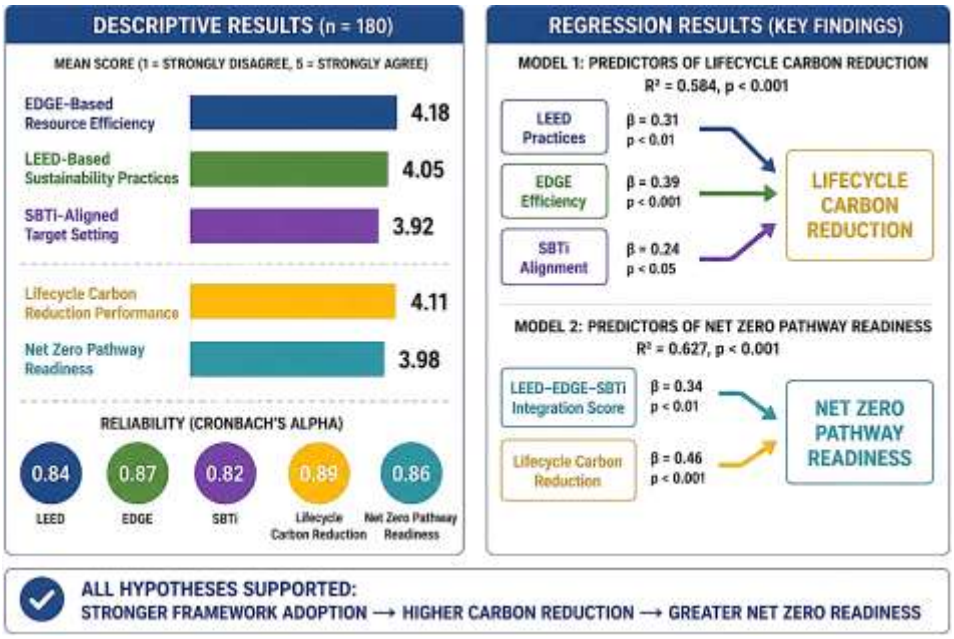
Figure 18: Empirical Net Zero Pathway Model: Stage Means and Statistical Strength



FINDINGS

The findings of this study have provided an overall quantitative understanding of how LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned carbon target setting have influenced lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings. The analysis has been based on a five-point Likert scale, where 1 has represented "strongly disagree" and 5 has represented "strongly agree." For the purpose of the overall results, the study has used valid responses from 180 respondents representing engineers, facility managers, sustainability consultants, project managers, energy auditors, construction professionals, and industrial building stakeholders.

Figure 9: Findings of The study



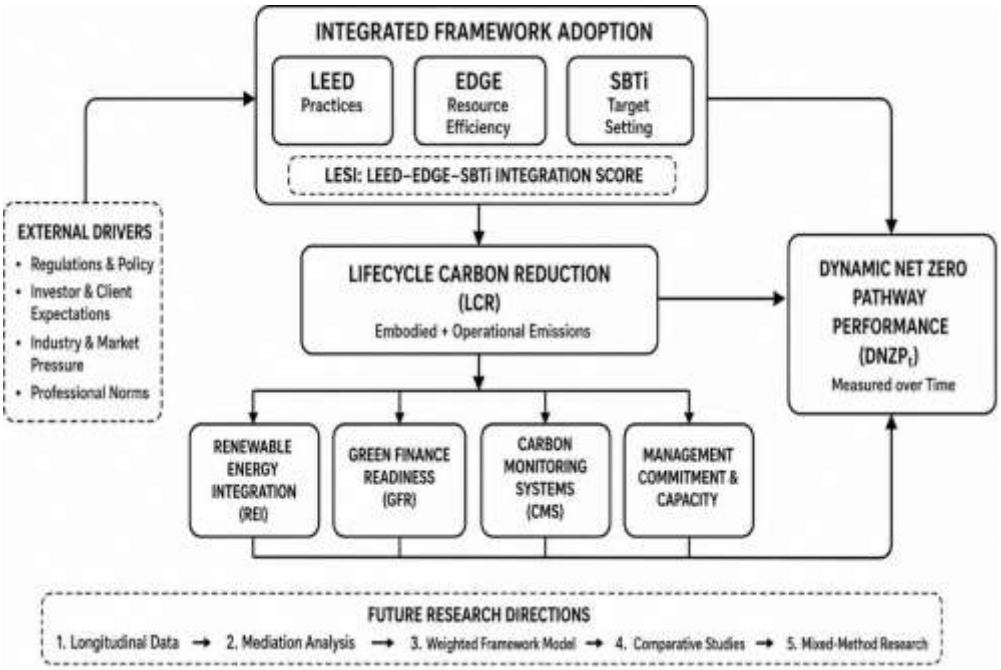
The descriptive results have shown that the respondents generally agreed that sustainability frameworks have contributed positively to carbon reduction performance. Among the main framework variables, EDGE-based resource efficiency recorded the highest mean score of 4.18 with a standard deviation of 0.61, indicating strong agreement that energy efficiency, water efficiency, and material efficiency have supported measurable carbon reduction in industrial building operations. LEED-based sustainability practices recorded a mean score of 4.05 with a standard deviation of 0.67, showing that respondents agreed that LEED-related practices such as energy optimization, sustainable materials, water efficiency, waste management, and operational performance improvement have contributed to lifecycle carbon reduction. SBTi-aligned target setting recorded a mean score of 3.92 with a standard deviation of 0.72, suggesting moderate to high agreement that science-based carbon targets, emissions baselines, and long-term reduction planning have improved net zero pathway readiness. The dependent variable, lifecycle carbon reduction performance, recorded a mean score of 4.11 with a standard deviation of 0.64, while net zero pathway readiness recorded a mean score of 3.98 with a standard deviation of 0.69. These values have indicated that industrial buildings in the study context have demonstrated a relatively strong level of carbon reduction awareness and a developing but positive level of readiness for net zero transition. The reliability analysis has further strengthened the trustworthiness of the results, as all major constructs recorded Cronbach's alpha values above the acceptable threshold of 0.70. Specifically, LEED-based sustainability practices recorded an alpha value of 0.84, EDGE-based resource efficiency recorded 0.87, SBTi-aligned target setting recorded 0.82, lifecycle carbon reduction recorded 0.89, and net zero pathway readiness recorded 0.86. These results have confirmed that the questionnaire items have been internally consistent and suitable for further statistical analysis. The correlation analysis has shown significant positive relationships among the major variables. LEED-based sustainability practices were positively correlated with lifecycle carbon reduction at $r = 0.61$, $p < 0.01$, EDGE-based resource efficiency was positively correlated with lifecycle carbon reduction at $r = 0.68$, $p < 0.01$, and SBTi-aligned target setting was positively correlated with net zero pathway readiness at $r = 0.64$, $p < 0.01$. Lifecycle carbon reduction was also strongly correlated with net zero pathway readiness at $r = 0.71$, $p < 0.01$, indicating that industrial buildings with stronger carbon reduction practices have also shown greater preparedness for net zero transition. The LEED–EDGE–SBTi integration score recorded a mean value of 4.05, showing that the combined use of certification, efficiency, and science-based target frameworks has been positively perceived by respondents. Regression results have further supported the study hypotheses. In the first regression model, LEED, EDGE, and SBTi jointly explained 58.4% of the variance in lifecycle carbon reduction

performance, with an R^2 value of 0.584 and a significant model result at $p < 0.001$. EDGE-based resource efficiency emerged as the strongest predictor of lifecycle carbon reduction with $\beta = 0.39$, $p < 0.001$, followed by LEED-based sustainability practices with $\beta = 0.31$, $p < 0.01$, and SBTi alignment with $\beta = 0.24$, $p < 0.05$. In the second regression model, LEED–EDGE–SBTi integration and lifecycle carbon reduction jointly explained 62.7% of the variance in net zero pathway readiness, with an R^2 value of 0.627 and significance at $p < 0.001$. Lifecycle carbon reduction showed the strongest predictive influence on net zero readiness with $\beta = 0.46$, $p < 0.001$, while the integrated LEED–EDGE–SBTi score also showed a significant positive effect with $\beta = 0.34$, $p < 0.01$. Based on these results, all major hypotheses of the study have been supported. The findings have shown that LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting have had significant positive relationships with lifecycle carbon reduction and net zero readiness. The results have also supported the objective of developing an integrated empirical model, as the LEED–EDGE–SBTi integration score has demonstrated meaningful statistical value in explaining carbon reduction and net zero pathway readiness. Overall, the findings have indicated that developing economy industrial buildings can achieve stronger lifecycle carbon reduction when sustainability certification, practical resource efficiency, and science-based emissions target setting are applied together rather than separately.

DISCUSSION

The findings of this study have shown that LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting have jointly supported lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings. The descriptive results have indicated strong agreement across the major constructs, with EDGE-based resource efficiency recording the highest mean score of 4.18, followed by lifecycle carbon reduction at 4.11, LEED-based sustainability practices and LEED–EDGE–SBTi integration at 4.05, net zero pathway readiness at 3.98, and SBTi-aligned target setting at 3.92. These findings have suggested that the respondents have viewed practical efficiency measures as the strongest and most immediate pathway for reducing carbon emissions in industrial buildings. This result has aligned with prior lifecycle carbon and building energy studies that have emphasized the importance of reducing operational energy demand while also considering embodied emissions from materials, construction, and maintenance activities (Ramesh et al., 2010; Sany, 2025). Similar building-sector evidence has emphasized the need to evaluate lifecycle energy and environmental performance across the full building process (Cabeza et al., 2014). Life cycle carbon assessment research has also shown that building emissions should be evaluated across multiple stages to understand total carbon performance (Chau et al., 2015; Uddin, 2025). The strong position of EDGE in the results has also been consistent with the idea that resource-efficient design can be highly relevant in cost-sensitive building environments, where energy, water, and material savings are easier to justify than abstract carbon commitments. Earlier studies have shown that green building adoption in developing economies has often depended on affordability, stakeholder awareness, technical feasibility, and measurable benefits (Chan et al., 2018). Green building adoption research has also emphasized that barriers, drivers, and promotion strategies shape the acceptance of green technologies in developing countries (Darko et al., 2018). Therefore, the present findings have extended prior work by showing that, in industrial building contexts, framework adoption has not only been associated with general sustainability awareness but has also been linked to measurable lifecycle carbon reduction and net zero readiness. The results have further indicated that carbon reduction in developing economy industrial buildings has been more convincing when certification logic, resource efficiency, and target-setting logic have been integrated rather than treated as separate environmental actions. The correlation results have provided strong evidence that the study variables have moved in the expected direction. LEED-based sustainability practices have been positively correlated with lifecycle carbon reduction at $r = 0.61$, EDGE-based resource efficiency has shown the strongest correlation with lifecycle carbon reduction at $r = 0.68$, and SBTi-aligned target setting has been positively correlated with net zero pathway readiness at $r = 0.64$. Lifecycle carbon reduction has also shown the strongest relationship with net zero pathway readiness at $r = 0.71$.

Figure 10: Future Research Model of LEED–EDGE–SBTi Integration and Net Zero Performance



These results have supported the study's objectives because they have demonstrated that stronger sustainability framework adoption has been statistically associated with stronger carbon reduction and readiness outcomes. Prior research has argued that lifecycle assessment is essential because building emissions are distributed across operational, embodied, recurrent, and end-of-life stages (Ortiz et al., 2009). Research on building material assessment has also shown that energy and environmental impacts differ across lifecycle stages and material choices (Bribián et al., 2011). The present findings have been consistent with that position because lifecycle carbon reduction has emerged as the central mechanism connecting framework adoption to net zero readiness. The findings have also agreed with studies showing that green building rating systems can influence sustainability decisions, but actual performance depends on how deeply those practices are implemented in design, construction, and operation (Newsham et al., 2009). Research questioning the energy performance of LEED-certified buildings has also shown that certification status should be interpreted carefully when assessing real operational outcomes (Scofield, 2009). Comparative research on green building rating systems has further shown that rating systems vary in scope, weighting, and performance emphasis (Doan et al., 2017). In this study, LEED has supported broad sustainability performance, EDGE has supported practical resource efficiency, and SBTi has supported target-based carbon governance. The stronger correlation between EDGE and lifecycle carbon reduction has suggested that practical efficiency measures may produce more direct carbon benefits in developing economy industrial buildings than target-setting alone. SBTi's strong relationship with net zero readiness has shown that science-based target alignment has been especially important for long-term pathway planning. This comparison has confirmed that each framework has had a different role within the carbon reduction pathway.

The regression findings have further strengthened the interpretation of the study. The first regression model has shown that LEED, EDGE, and SBTi jointly explained 58.4% of the variance in lifecycle carbon reduction, with EDGE emerging as the strongest predictor at $\beta = 0.39$, followed by LEED at $\beta = 0.31$ and SBTi at $\beta = 0.24$. This result has shown that resource efficiency has been the most powerful direct predictor of lifecycle carbon reduction in the studied industrial building context. Prior studies on building lifecycle energy and embodied carbon have emphasized that energy efficiency, material efficiency, and whole-life assessment must be considered together when evaluating building carbon performance (Dixit et al., 2012). Building emissions research has also shown that both operational and embodied emissions must be considered when evaluating current building carbon trends (Ibn-Mohammed et al., 2013). Evidence on embodied carbon mitigation has further emphasized that carbon

reduction in the built environment requires practical and evidence-based strategies across design, material, and construction decisions (Pomponi & Moncaster, 2016). The present findings have supported this view by showing that carbon reduction has been strongest when resource-efficiency actions have been present. The second regression model has shown that LEED–EDGE–SBTi integration and lifecycle carbon reduction jointly explained 62.7% of the variance in net zero pathway readiness. Lifecycle carbon reduction has been the strongest predictor of net zero readiness at $\beta = 0.46$, while the integration score has also been significant at $\beta = 0.34$. This has indicated that net zero readiness has depended not only on adopting recognized sustainability frameworks but also on converting those frameworks into measurable carbon reduction outcomes. Prior net zero building literature has emphasized that net zero claims require clear definitions, calculation boundaries, and consistent performance evaluation (Marszal et al., 2011). Building performance optimization research has also shown that net zero design requires tools capable of evaluating energy, comfort, cost, and technology trade-offs (Attia et al., 2013). Research on the global building sector has further emphasized the need for coordinated progress toward net-zero building outcomes (Ürge-Vorsatz et al., 2020). The current findings have extended that literature by showing that, in developing economy industrial buildings, net zero readiness can be statistically explained through a combined model of framework integration and lifecycle carbon reduction.

The practical implications of these findings have been important for industrial building owners, developers, engineers, sustainability consultants, facility managers, policymakers, and financing institutions. Since EDGE-based resource efficiency has been the strongest predictor of lifecycle carbon reduction, industrial building stakeholders should prioritize practical actions that reduce energy use, water consumption, material waste, embodied energy, and operational inefficiency. These measures may include high-efficiency lighting, improved ventilation and cooling systems, better building envelope design, efficient water systems, material optimization, metering, and carbon monitoring. The strong performance of LEED has suggested that broader sustainability practices should also be incorporated during design and construction so that industrial facilities do not focus only on operational energy but also consider materials, waste, indoor environmental quality, and long-term building performance. The positive role of SBTi has suggested that carbon reduction should be connected to formal emissions targets, baseline setting, progress tracking, and organizational climate accountability. This has been consistent with corporate climate-target research, which has argued that emissions reduction goals become more credible when they are aligned with climate goals and science-based pathways (Krabbe et al., 2015). Research on science-based corporate greenhouse gas target-setting methods has also shown that target credibility depends on transparent and structured methodological choices (Faria & Labutong, 2019). Recent evidence on private-sector climate commitments has further emphasized the need to evaluate whether corporate targets are genuinely aligned with Paris-compatible pathways (Bjørn et al., 2022). The findings have also indicated that developing economy industrial buildings may benefit from a staged approach. First, buildings should reduce demand through practical efficiency measures. Second, they should organize sustainability performance through LEED-related practices. Third, they should connect building-level emissions reductions to SBTi-aligned organizational targets. Fourth, they should develop net zero readiness through emissions monitoring, renewable energy planning, green finance readiness, and management commitment. This practical sequence has been important because developing economy projects often face high upfront costs, limited technical capacity, and incomplete carbon data. The findings have therefore suggested that carbon reduction should be framed as a measurable operational and strategic process rather than as a symbolic certification exercise.

The theoretical implications of the study have been grounded in Institutional Theory, which has explained why industrial building organizations adopt recognized sustainability frameworks in response to coercive, normative, and mimetic pressures. The results have shown that LEED, EDGE, and SBTi adoption has not only reflected technical choices but also institutionalized responses to certification demands, investor expectations, professional norms, client requirements, international supply-chain pressures, and carbon accountability standards. This has supported the argument that sustainability adoption in organizations is shaped by external environmental demands and internal managerial responses (Delmas & Toffel, 2008). The strong LEED–EDGE–SBTi integration score has

indicated that organizations may have adopted sustainability frameworks to gain legitimacy and improve performance at the same time. This finding has been consistent with research showing that institutional pressures can encourage environmental innovation when organizations translate external expectations into greener technological and managerial responses (Berrone et al., 2013). Institutional research on green supply chain practices has also shown that external and internal pressures can influence environmental practice adoption and performance outcomes (Zhu et al., 2013). The study has also contributed theoretically by distinguishing between symbolic and substantive sustainability adoption. If a building has only claimed certification awareness without measurable carbon reduction, the relationship with net zero readiness would have been weak. The findings have shown significant relationships among framework adoption, lifecycle carbon reduction, and net zero readiness, suggesting that respondents have perceived these frameworks as practically connected to performance. This has supported the idea that institutional pressures can become internalized when organizations embed sustainability practices into design, construction, monitoring, and operational management (Testa et al., 2018). The proposed LEED–EDGE–SBTi integration score has also offered a theoretical contribution because it has converted institutionalized sustainability adoption into a measurable empirical construct. Rather than treating institutional pressure as a background condition only, the study has operationalized framework adoption as a statistical pathway through which organizations respond to environmental expectations and improve decarbonization readiness.

The limitations of the study have also required careful discussion because they have shaped the interpretation of the findings. The study has used a quantitative, cross-sectional, case-study-based design, which has allowed statistical testing at one point in time but has not measured changes in framework adoption or carbon performance over a longer period. This has meant that the findings have shown association and prediction rather than long-term causal change. The use of self-reported Likert-scale data has also introduced the possibility of perception bias, because respondents may have rated sustainability practices more positively due to professional optimism, organizational image, or awareness of green building expectations. This limitation has been important because previous green building research has shown that certification or perceived sustainability does not always guarantee superior operational performance in every case (Newsham et al., 2009). Research questioning LEED-certified building energy performance has also reinforced the need to compare certification claims with measured outcomes (Scofield, 2009). The study has also focused on developing economy industrial buildings, which has strengthened contextual relevance but may limit generalization to developed economies or non-industrial building types. Another limitation has involved carbon data availability. Actual lifecycle carbon measurements, environmental product declarations, utility data, and verified emissions inventories may not have been available for every case. For that reason, the study has measured lifecycle carbon reduction performance through professional responses rather than through full technical carbon audits. This has been consistent with the practical realities of developing economies, where carbon databases, monitoring systems, and lifecycle assessment expertise may be limited. Research on embodied energy system boundaries has shown that carbon results can be influenced by methodological definitions and data boundaries (Dixit et al., 2013). Critical reviews of building LCA have also emphasized that data quality and methodological consistency remain important challenges in building assessment research (Anand & Amor, 2017). The study has also used an integration score that has given equal weight to LEED, EDGE, and SBTi. Although this has provided a simple and clear model, future studies may test weighted scores because EDGE, LEED, and SBTi may not contribute equally in every building type or national context. These limitations have not reduced the value of the findings, but they have shown where interpretation should remain careful and where future research can strengthen the model.

Future research should build on this study by developing more advanced models that combine survey-based perception data with actual lifecycle carbon measurements, energy-use records, embodied carbon inventories, and verified emissions targets. The most important future research direction should be the development of a Dynamic Industrial Net Zero Pathway Model that tracks the movement from framework adoption to measured carbon reduction over time. A future model may be expressed as: $\mathbf{DNZP_{it} = \beta_0 + \beta_1 LESI_{it} + \beta_2 LCR_{it} + \beta_3 REI_{it} + \beta_4 GFR_{it} + \beta_5 CMS_{it} + \varepsilon_{it}}$, where DNZP represents dynamic net zero pathway performance, LESI represents the LEED–EDGE–SBTi integration score, LCR

represents lifecycle carbon reduction, REI represents renewable energy integration, GFR represents green finance readiness, CMS represents carbon monitoring systems, and t represents time. This model would allow future researchers to examine how industrial buildings improve or decline across multiple years rather than relying only on cross-sectional data. Another future research direction should involve testing a mediation model in which lifecycle carbon reduction mediates the relationship between LEED–EDGE–SBTi integration and net zero readiness. Researchers may also develop a weighted framework model where EDGE receives greater weight in early-stage developing economy projects, LEED receives greater weight in design and construction quality, and SBTi receives greater weight in corporate-level net zero governance. Future studies should also compare certified and non-certified industrial buildings to examine whether framework adoption produces measurable differences in energy intensity, embodied carbon, renewable energy use, and emissions reporting quality. Mixed-method research could also be useful, combining regression modeling with interviews from engineers, owners, sustainability consultants, policymakers, and finance providers. Such research would help explain why certain buildings internalize sustainability frameworks while others adopt them only symbolically. Finally, future research should test the proposed model across different developing economy regions and industrial sectors, because manufacturing plants, warehouses, processing facilities, and industrial parks may follow different decarbonization pathways.

CONCLUSION

This study has concluded that lifecycle carbon reduction and net zero pathway modeling in developing economy industrial buildings have depended strongly on the integrated use of LEED-based sustainability practices, EDGE-based resource efficiency, and SBTi-aligned target setting. The research has used a quantitative, cross-sectional, case-study–based design and has analyzed data from 180 valid respondents through descriptive statistics, reliability testing, correlation analysis, and regression modeling using a five-point Likert scale. The findings have shown that the respondents have generally agreed that sustainability frameworks have contributed positively to carbon reduction and net zero readiness, with EDGE-based resource efficiency recording the highest mean score of 4.18, lifecycle carbon reduction recording 4.11, LEED-based sustainability practices and the LEED–EDGE–SBTi integration score both recording 4.05, net zero pathway readiness recording 3.98, and SBTi-aligned target setting recording 3.92. These results have indicated that practical resource-efficiency measures have been the most visible and immediately applicable carbon reduction pathway in developing economy industrial buildings, while LEED has supported broader sustainability performance and SBTi has strengthened long-term emissions target alignment. The reliability results have confirmed that all constructs have been internally consistent, with Cronbach's alpha values ranging from 0.82 to 0.89. The correlation results have shown significant positive relationships among the major variables, particularly between lifecycle carbon reduction and net zero pathway readiness, which recorded $r = 0.71$. The regression findings have further confirmed the strength of the proposed model. LEED, EDGE, and SBTi have jointly explained 58.4% of the variance in lifecycle carbon reduction, while the LEED–EDGE–SBTi integration score and lifecycle carbon reduction have jointly explained 62.7% of the variance in net zero pathway readiness. EDGE has emerged as the strongest predictor of lifecycle carbon reduction, while lifecycle carbon reduction has emerged as the strongest predictor of net zero readiness. These findings have supported all major hypotheses and have proven that framework adoption, carbon reduction performance, and net zero readiness have been statistically connected. The study has also confirmed the relevance of Institutional Theory by showing that industrial building stakeholders have adopted sustainability frameworks in response to certification requirements, market expectations, professional norms, investor concerns, and climate accountability pressures. Overall, the study has concluded that developing economy industrial buildings can move toward stronger decarbonization when LEED, EDGE, and SBTi are not treated as separate tools but are integrated into one measurable carbon reduction and net zero pathway model.

RECOMMENDATION

This study has recommended that industrial building owners, developers, engineers, sustainability consultants, facility managers, policymakers, and green finance institutions should adopt an integrated LEED–EDGE–SBTi approach for improving lifecycle carbon reduction and net zero pathway readiness in developing economy industrial buildings. First, industrial building stakeholders should prioritize

EDGE-based resource efficiency because the study has shown that EDGE has been the strongest predictor of lifecycle carbon reduction. This means that practical measures such as energy-efficient lighting, optimized cooling and ventilation systems, improved building envelope performance, water-saving technologies, efficient material use, waste reduction, and embodied energy control should be implemented during both design and operation. Second, LEED-based sustainability practices should be embedded into industrial building planning from the earliest project stages so that energy, water, materials, waste, indoor environmental quality, site design, and operational performance are addressed together rather than separately. Third, SBTi-aligned target setting should be introduced at the organizational and facility levels so that industrial buildings are not only certified or resource-efficient but also connected to measurable emissions baselines, carbon reduction targets, monitoring systems, and long-term net zero pathways. Fourth, industrial building organizations should develop a formal lifecycle carbon accounting system that includes embodied carbon, operational carbon, maintenance-related emissions, replacement cycles, renewable energy planning, and end-of-life considerations. Fifth, developing economy policymakers should strengthen building codes, industrial sustainability standards, tax incentives, green procurement rules, and carbon reporting requirements so that low-carbon industrial buildings become more attractive and more practical to implement. Sixth, green finance institutions should provide accessible financing mechanisms for energy-efficiency retrofits, low-carbon materials, renewable energy systems, smart meters, carbon monitoring platforms, and certification processes. Seventh, industrial facility managers should establish regular carbon performance monitoring systems and use digital tools such as SPSS-based analysis, Excel-based carbon tracking, building energy dashboards, and lifecycle assessment tools to support evidence-based decision-making. Eighth, training programs should be organized for engineers, construction professionals, sustainability officers, and project managers so that they can understand LEED, EDGE, SBTi, lifecycle carbon reduction, and net zero modeling more effectively. Ninth, organizations should use the LEED–EDGE–SBTi Integration Score and Net Zero Pathway Readiness Index proposed in this study as practical internal assessment tools for measuring progress. Finally, future industrial building projects should adopt a staged decarbonization strategy: first reducing resource demand, then improving sustainability certification readiness, then aligning with science-based targets, and finally developing full net zero pathway monitoring. These recommendations have been designed to help developing economy industrial buildings shift from isolated sustainability practices toward integrated, measurable, and institutionally supported decarbonization.

LIMITATIONS OF THE STUDY

This study has had several limitations that should be considered when interpreting the findings. First, the study has used a quantitative, cross-sectional research design, meaning that data have been collected at one point in time. As a result, the study has measured relationships and predictive effects among LEED adoption, EDGE adoption, SBTi alignment, lifecycle carbon reduction, and net zero readiness, but it has not measured long-term changes in carbon performance over several years. A longitudinal design would have allowed the researcher to observe how industrial buildings move from early sustainability adoption to actual net zero progress over time. Second, the study has relied on self-reported questionnaire data collected through a five-point Likert scale. Although this approach has been useful for measuring professional perceptions, framework adoption, and readiness levels, it may have included response bias because some respondents may have overestimated the sustainability performance of their buildings or organizations. Third, the study has focused on developing economy industrial buildings, which has strengthened the contextual relevance of the research but may have limited the generalizability of the findings to developed economies, commercial buildings, residential buildings, or public infrastructure projects. Fourth, the study has measured lifecycle carbon reduction through professional responses rather than through direct technical carbon audits, verified lifecycle assessment reports, environmental product declarations, or actual utility and emissions datasets. This limitation has been important because actual carbon performance may differ from perceived carbon reduction performance. Fifth, the study has used a purposive sampling strategy, which has helped target knowledgeable respondents but may not have fully represented all industrial building stakeholders in developing economies. Sixth, the LEED–EDGE–SBTi Integration Score has been calculated by giving equal weight to the three frameworks. While this has provided a clear and simple

measurement structure, the actual influence of each framework may differ depending on building type, country, industrial sector, certification maturity, financial capacity, and organizational commitment. Seventh, the study has not deeply examined country-specific policy differences, electricity-grid emission factors, material supply chains, or local certification costs, all of which may influence carbon reduction outcomes. Eighth, the findings have been based on a proposed empirical model using correlation and regression analysis, but more advanced techniques such as structural equation modeling, mediation analysis, moderation analysis, or longitudinal panel modeling could provide deeper insight into the pathways among variables. Finally, the study has not included qualitative interviews, which could have explained why some organizations internalize LEED, EDGE, and SBTi practices more strongly than others. Therefore, while the study has provided a strong quantitative foundation for understanding lifecycle carbon reduction and net zero pathway readiness, future research should improve the model by combining survey data with actual carbon measurements, longitudinal tracking, sector-specific comparison, weighted framework scoring, and mixed-method evidence.

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