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DECARBONIZATION STRATEGY AND GREEN INVESTMENT IN THE REAL ESTATE: TOWARD A NEW SUSTAINABLE PARADIGM

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Abstract. The transformation of the real estate sector towards net-zero emissions is a fundamental transition that requires a need for alignment between the performance of the physical asset and the use of environmental, social, and governance-linked capital. Green investment strategies can be an important solution to ensure the liquidity of assets; however, the existing gap between the practical implementation and the real estate sector decarbonization agenda has been widely observed. The existing studies in the field have often focused on the financial appraisal, technical, and regulatory governance separately, which limits a comprehensive understanding of the whole picture. This study, therefore, aims to narrow down the research-practice gap by methodically investigating the link between green investment and decarbonization by adopting a structured interpretive synthesis approach through a PRISMA-informed review of 74 related articles. The review identified five clusters of drivers (headed by green premium) and eight clusters of structural barriers, starting from the split-incentive problem to green investment. The results confirmed that the sustainable business model is achieved through five major transition pathways: technological adoption, deep retrofit, stakeholder engagement, life-cycle carbon management, and circular economy. In addition, 11 policy initiatives ranging from mandatory performance standards to sustainable public procurement were identified and synthesized to address the long-standing market failures. The findings of this research, when structured in a unified decision-making framework, would assist real estate professionals and policymakers in effectively aligning capital use and physical resilience for long-term value capture in the decarbonized economy.

Keywords: real estate decarbonization, green investment, financial appraisal, regulatory governance, PRISMA, sustainable business model.

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1. Introduction

Anthropogenically driven climate change is one of the greatest challenges that humans face in the 21st century[1]. Carbon dioxide (CO_2) emissions produced by people are the most significant contributor to climate change and to global warming[2]. By early 2025, the property and construction industries will still be significant contributors to global CO_2 emissions because they account for a large portion of the embodied carbon from construction materials (World Green Building Council, 2025). On top of the embodied carbon from construction materials, the construction industry is the most significant contributor to global energy-related CO_2 emissions (GlobalABC, 2025). Projections indicate that the global building stock will double between now and 2060, meaning a failure to eliminate or significantly reduce carbon emissions from the real estate and construction industries will prevent the world from achieving net-zero emissions by 2050 (World Bank, 2024a). Consequently, the real estate and construction industries are essential to transitioning the global economy from a carbon-intensive framework to a low-carbon economic structure (PwC, 2024).

The carbon footprint associated with real estate results from two main sources: operational energy (cooling,

[1] https://www.un.org/en/global-issues/climate-change

[2] https://www.iea.org/reports/global-energy-review-2025/co2-emissions

heating, lighting) and embodied emissions from the construction materials and methods (Kusi et al., 2025). While sustainable real estate technology is progressing, there remain wide gaps in the implementation of these technologies (Akin & Akin, 2025). Behavioral, financial, and regulatory barriers slow the adoption of sustainable technologies across the industry (Schäfer & Hennig, 2026). Some of the challenges faced by developing countries include weak building code enforcement and limited access to green financing (Anjanappa, 2025). Additionally, until recently, financial investors have largely undervalued environmental performance, preferring to invest for immediate financial return rather than long-term sustainability (Nsama, 2025). As a result, there have been growing discrepancies between the environmental goals of the built environment and the behaviour of the marketplace (Organisation for Economic Co-operation and Development [OECD], 2022).

In response, the global community has established frameworks, including the Paris Agreement (UNFCCC, 2016) and the European Green Deal (EU Commission, 2020), to align funding with climate goals. In this context, green investment, including green bonds, sustainability-linked loans (SLLs), and environmental, social, and governance (ESG)-focused portfolios, has been recognized as a critical enabler of the real estate sector's transition (Morri et al., 2024). These financial instruments are designed to redirect investments to energy-efficient buildings and renewable energy projects. However, the adoption of these instruments varies widely across different regions (Akin & Akin, 2025; Al-haimi et al., 2025).

Hence, the transition to a zero-carbon real estate also represents a financial and technological upheaval. The integration of ESG criteria is thus changing the way asset valuation is calculated (Kakinuma, 2025). In parallel, technical solutions, such as smart energy grids or low-carbon materials, are needed to reduce emissions (Yoon & Arshid, 2025). Market information increasingly shows that certified green buildings are associated with a "Green Premium" (increased value), while energy-inefficient assets face a "Brown Discount" (decreased value) (Royal Institution of Chartered Surveyors [RICS], 2024). Despite these trends, uncertainty remains on the scalability of these investments and the guarantee of regulatory consistency[3] (World Economic Forum [WEF], 2024).

Viewed from an academic perspective, the interconnection between real estate decarbonization (RED) strategy and green investment (GI) is still an emerging area. On one hand, research on the topic has often been considered disjointedly by focusing on either financial evaluation models (Jaouhari et al., 2024; Park et al., 2025) or physical building performance (Krishnamurthy & Mahesh, 2024; Walacik & Chmielewska, 2024). While previous studies have attempted to bridge these two approaches, existing frameworks remain mainly conceptual and lack the detailed alignment needed for streamlined implementation (Liu et al., 2025; Tajani et al., 2026). As such, a new sustainable real estate model is needed to bridge environmental performance directly with value creation and its governance (WEF, 2024; OECD, 2025).

Addressing this objective, this paper assesses the convergence between RED and GI by investigating the role of the financial sector in accelerating the low-carbon transition of the property market. Therefore, the study is guided by the following four research questions (RQs):

RQ1: What are the main drivers and barriers for the integration of decarbonization strategies and green investments in the real estate industry?

RQ2: What are the strategic pathways and technological interventions for real estate decarbonization?

RQ3: How do financial instruments and valuation dynamics impact green real estate investment performance?

RQ4: What are the governance structures and policy initiatives needed to steer the sustainable real estate model?

To answer these RQs, the present study provides a systematic literature review (SLR) of peer-reviewed journal articles and grey literature (policy, government, and industry reports). This extensive coverage allows the research to contribute to the state of knowledge by: (a) identifying the mechanisms linking financial innovation to physical decarbonization; (b) establishing a framework that integrates GI with RED strategies; and (c) providing guidance and insights for policymakers and investors to support the net-zero transition.

This study does not seek to develop a definitive or empirically proven model due to the diversity and fragmentation of the evidence. Rather, it creates a structured interpretive synthesis, with an analytical and propositional framework intended to organize current knowledge coherently and direct future empirical validation.

The remainder of the paper is organized as follows. Section 2 reviews the conceptual background. Section 3 outlines the research methodology. Section 4 presents the findings related to the drivers and barriers, strategic pathways and technological mediations, financial instruments and valuation dynamics, and policy measures for the net-zero transition. Section 5 includes an extensive discussion together with the implications for key stakeholders and future research directions. Finally, Section 6 concludes the paper.

2. Theoretical framework

Mitigating and addressing carbon emissions has become a primary focus of academic and regulatory discussion regarding Climate-Neutrality in relation to the Real Estate Environment (RRE)[4]. The RRE has a sizable share of Global Energy and Greenhouse Gas emissions; therefore, it stands as a major target for both Sovereign Abatement Pathways & Corporate Net-Zero Plans (Cheah & Zhi, 2025;

[3] https://www.jll.com/en-au/insights/seizing-the-green-opportunity-amidst-uncertainty

[4] https://www.weforum.org/stories/2025/03/real-estate-economic-case-decarbonization/

GlobalABC, 2025). In the last ten (10) years, research has expanded beyond simply Assets and Asset Efficiency, to also include Strategies, Financial Instruments and Organizational Mechanisms which are necessary to support a Low-Carbon Transition for RRE (Akin & Akin, 2025; OECD, 2025).

2.1. Real estate decarbonization conceptualization

Theoretically, RED can be considered underpinned by three strands of literature: environmental economics, institutional theory, and sustainable finance (Lee & Liang, 2024; Morano et al., 2024). Environmental economics provides a rationale for internalizing the negative externalities of carbon emissions through policy tools like carbon pricing, energy efficiency incentives, and resource optimization (Baeroom et al., 2025; Tan & Zheng, 2022). Institutional theory expounds on how regulatory mandates, professional norms, and market expectations influence the strategic responses of real estate actors to sustainability pressures (Locke et al., 2023; Nyoni et al., 2023). Sustainable finance theory enriches this analysis by linking capital allocation decisions with environmental outcomes, showcasing how investment behavior and risk assessment can accelerate or decelerate the transformation of RED portfolios (E & T, 2025; Ma et al., 2024).

Practical research in this field also highlights the gradual adoption of whole-life carbon assessment, deep retrofit strategies, and net-zero building principles into asset management practices (Agyekum et al., 2025; Ezealigo & Ezealigo, 2025; Zeadat, 2025). Taken together, these practices show that low-carbon performance can be achieved not only through technological innovation but also through the strategic alignment of finance, governance, and stakeholder incentives (GlobalABC, 2025; International Energy Agency [IEA], 2025). However, disparities in organizational capacity and investment maturity continue to limit the overall progress of the real estate climate agenda (Jalil, 2025).

2.2. Green investment as a financing enabler

Simultaneously with the deployment of policy tools, GI has emerged as the financial catalyst (Akin & Akin, 2025). The exponential growth of green bonds, SLLs, and ESG-focused portfolios has created new pathways for directing private capital to low-carbon real estate assets (E & T, 2025; World Bank, 2024b). These instruments embed climate metrics into financial products, allowing investors to align their portfolios with emission reduction targets while hedging against regulatory and transition risks (Kakinuma, 2025).

Recent evidence shows that ESG integration increasingly affects valuation models and asset pricing mechanisms across global real estate markets (Georgiadou et al., 2025). Certified green buildings often exhibit higher risk-adjusted returns, lower vacancy rates, and stronger resilience to policy shocks, suggesting the emergence of a structural "green premium" (Wang et al., 2025). The price or rental advantage of sustainable assets is known as the "green premium," whereas the value loss of non-compliant assets is known as the "brown discount" (Jiao et al., 2025). However, the causal relationship between financial innovation and tangible physical emission reductions is not well theorized. Studies point to a persistent gap between mobilization and actual carbon performance outcomes at the asset level (Biasin et al., 2024; Lee & Liang, 2024).

2.3. Governance, policy, and institutional instruments

The successful orchestration of RED also relies on governance structures that facilitate these financial and technological transitions (Magaletti et al., 2025a). Global initiatives such as the European Green Deal, the European Union (EU) Taxonomy for Sustainable Activities – The EU taxonomy for sustainable activities is used as a specific regulatory framework, while green investment taxonomies (GIT) refers to the broader class of such tools – and the Sustainable Finance Disclosure (SFD) frameworks, including the Sustainable Finance Disclosure Regulation (SFDR) and the Task Force on Climate-related Financial Disclosures (TCFD) have established regulatory frameworks to promote transparency, accountability, and consistency in sustainable real estate investment (OECD, 2025; TCFD, 2021). Supplementary national and local instruments — including building energy codes, mandatory disclosure, mandates, and green public procurement schemes — further anchor sustainable targets in domestic real estate markets (González-Morales et al., 2026; IEA, 2022).

However, despite these advancements, studies reveal that fragmentation still exists between policy design and market uptake. Regulatory diversity, inconsistent enforcement, and non-uniform ESG standards create challenges for benchmarking and deter cross-border capital flows into the sector (Newell et al., 2023). For this reason, it is suggested by researchers to build a comprehensive governance system – green, ecological, and smart – that links fiscal stimuli, reporting requirements, and asset-level carbon tracking to speed up RED (Bienert et al., 2024; Tan et al., 2025).

2.4. Review of the state of research and knowledge gaps

The existing RED and GI research has shifted from technology-oriented approaches to multidimensional frameworks integrating financial, policy, and governance lenses (Anjanappa & Singh, 2025; Biasin et al., 2024). Initial studies by the engineering and facilities management communities focused on energy efficiency, on-site renewables, and materials science (Islam et al., 2021; Nwamekwe et al., 2025). Although these contributions demonstrated the technical potential of emissions reduction, they provided limited guidance on the financial and institutional dynamics needed to drive large-scale market transformation. Follow-up research has broadened the analytical scope to

Table 1. Past literature review studies on real estate decarbonization and green investment

Reference	Focus of study	Keywords	Gaps
(Jørgensen & Ma, 2025)	Scoping review of technologies, policies, future directions for energy-efficiency & deep decarbonization in buildings	building energy efficiency; decarbonization strategies; sustainable building technologies	The focus of the article was mainly on energy efficiency and deep decarbonization in buildings
(Akin & Akin, 2025)	Qualitative review of how green investments promote sustainable practices in the United Kingdom real-estate industry	green investment; United Kingdom real estate; regulation; sustainable practices	The only focus was examining how sustainable practices in the UK real estate industry are impacted by green investments
(Rubab et al., 2025)	Critical review of ESG and sustainable investment	environmental, social, governance, sustainable investment, investment decision	The focus of the article was mainly on the effects of environmental, social, and governance (ESG) factors on sustainable investments
(Imtiaz et al., 2025)	Bibliometric analysis of global green-economy research and sustainability	green economy, sustainability, bibliometrics, research collaborations	The focus of the article was mainly on green economy strategies and the United Nations Sustainable Development Goals (SDGs)
(Tetteh & Owusu Kwateng, 2025)	A literature review of green building practices in the construction industry	green building practices, sustainable construction, bibliometric, systematic literature review, r studio software	The only focus was identifying the barriers inhibiting green building practices uptake in the construction industry
(Sesana & Dell'Oro, 2024)	A literature review of sustainability and resilience assessment methods in the construction sector	sustainability; resilience; decarbonization; assessment methods; construction sector	The only focus was on methodological integration of resilience and sustainability assessments in the construction sector
(Kwilinski, 2024)	A comprehensive bibliometric study on green energy and green investment	renewable energy; sustainable development; green energy; investment	The focus of the article was mainly on the interactions between green energy and green investment
This study	A systematic review of decarbonization strategy and green investment in the sustainable real estate system	real estate decarbonization; green investment; regulatory governance; sustainable business model	The focus of the article was mainly on the conceptual integration between RED and GI, without empirical validation

ESG integration, the green bond market, and sustainability certification, arguing that green finance is a performance differentiator and a tool for market stabilization (Loiola et al., 2025; RICS, 2025). More recently, a growing body of literature has advanced a systemic lens that bundles carbon strategies, investment vehicles, and policy instruments, acknowledging that RED is a socio-technical, economic, and institutional transition simultaneously (Jalil, 2025; OECD, 2025; Tajani et al., 2026). Table 1 provides an overview of these literature assessments, characterizing their objectives, coverage, and gaps. Notwithstanding this convergence, the field is still characterized by several challenges. Most existing frameworks lack a comprehensive system thinking perspective that can capture dynamic interactions between finance, technology, and governance. Empirical generalizability is further hampered by inconsistent ESG metrics, fragmented data, and uneven regional evidence (Georgiadou et al., 2025; Newell, 2025). Moreover, the interplay between global climate policy, national regulation, and local implementation strategies is still insufficiently theorized (OECD, 2025). Therefore, a holistic conceptual framework that explicitly links decarbonization strategies, GI, and institutional coordination is needed for further progress, constituting the theoretical basis of this study's comprehensive analysis of the real estate industry's pathway to sustainability.

Although previous research has advocated for integrative frameworks, it is crucial to acknowledge that these frameworks are frequently conceptual constructs generated from diverse evidence bases. In this regard, the current research advances a propositional synthesis in which the classification of drivers, barriers, and different pathways is not a uniquely defined or empirically confirmed taxonomy, but rather an interpretive structure of the literature.

3. Methodology

3.1. Research design and approach

In light of the patchy knowledge base overlapping RED, GI, and sustainable governance, the present study follows a Systematic Literature Review (SLR) method. Following Agrawal and Jain's (2021) guideline, the SLR method was employed to minimize narrative reviews' inclusion bias (Tranfield et al., 2003) and ensure the replicability of the search process (de Oliveira et al., 2018). Such a process is essential for providing a resilient theoretical framework and identifying empirically supported gaps in the emerging field of RED (Wiik, 2025). Although scholarly interest in the real estate sector's net-zero transition has gained momentum in recent years, the literature has been found dispersed in siloed domains, spanning environmental economics, construction management, and corporate finance (Newell & Marzuki, 2022; Petkov et al., 2023; Van Tam et al., 2024). A systematic review is thus necessary to bridge those isolated streams of evidence, assess the efficacy of emerging GI tools, and document the regulatory divergence across jurisdictions. To this end, this study combines early-stage qualitative evidence and develops ESG policy frameworks to explain the drivers and barriers of the industry's low-carbon transition.

The search process was completed in strict compliance with the PRISMA (Preferred Reporting Items for Systematic Review and Meta-Analyses) statement (Page et al., 2021). The protocol followed four phases: (i) database search; (ii) eligibility screening; (iii) thematic data extraction; and (iv) critical synthesis. Figure 1 illustrates the iterative workflow of this research process.

As a result, the methodological approach, which combines qualitative abstraction with systematic review procedures, is consistent with a structured interpretative synthesis. The goal is not statistical generalization, but rather the development of an integrative framework based on recurrent patterns in the literature that is theoretically informed but not validated.

3.2. Information sources and search strategy

Owing to the interdisciplinary nature of this research, the search strategy gave preference to refereed, high-impact journal publications indexed in Scopus and Web of Science (WoS). The two database services were adopted to their comprehensive scope of energy policy, urban economics, and real estate finance (Vergara-Perucich, 2023; Zhang et al., 2020). The grey literature search was then complemented to capture professional innovations in RED and GI, and a broader review of relevant institutional and policy grey literature (Adams et al., 2017). This approach helped to avoid the risk of publication delays, where ESG real estate practices and policy tools have been actively developed in the past few years (Green Street et al., 2022).

The time span of the search was set between 2016 and 2025 to capture the period of increasing regulatory activities post Paris Agreement (Erbach, 2016). The search syntax used Boolean operators ("AND", "OR") to combine two key thematic clusters: Real estate decarbonization and Green Investment. The keyword variants are detailed in Table 2. The preliminary database search retrieved 352 combined records. After the removal of duplicates, a total of 182 unique hits were screened. A "recursive reference tracking" technique (backward citation analysis) was then performed on selected seminal papers, leading to the identification of 13 additional relevant grey literature sources

Table 2. Search string strategy and keyword clustering

Conceptual cluster	Keywords and search terms
Cluster A: Real-estate decarbonization	("Real estate decarbonization" OR "Net-zero building" OR "Building decarbonization" OR "Energy retrofits" OR "Low-carbon transition" OR "Embodied carbon" OR "Sustainable construction" OR "Building energy performance" OR "Sustainable real estate")
Cluster B: Green investment and financial strategy	("Green investment" OR "ESG investing" OR "Sustainable property valuation" OR "Sustainable finance" OR "Green real estate finance" OR "Climate transition risk" OR "Green bonds" OR "Green premium")
Boolean operator	Cluster A & Cluster B

3.3. Study selection and eligibility criteria

The screening process was applied in line with the PRISMA four-level filtration design. At first, titles and abstracts were checked for relevance, eliminating research that focused solely on technical engineering without any mention of sustainable, strategic, and financial aspects. The remaining records were then screened at the full-text level against the following inclusion and exclusion criteria (summarized in Table 3) to ensure quality and topic alignment. The eligibility criteria were set to favour refereed empirical and theoretical contributions that directly link RED strategies to investment or valuation dynamics. After this rigorous filtration, a total of 74 sources (61 refereed articles and 13 grey literature reports) were retained for final review.

Table 3. Inclusion and exclusion criteria

Parameter	Inclusion criteria	Exclusion criteria
Timeframe	2016 – December 2025	Pre-2016 publications
Scope	Concentrating on the intersection of ESG, decarbonization or green finance in the real estate sector	Concentration not related to real estate (i.e. general corporate) or technical engineering studies without any management/ financial perspective
Source type	Peer-reviewed journal articles; reputable grey literature (e.g. OECD, IEA, World Bank)	Conference proceedings, book reviews, editorials, or non-verifiable websites
Language	English	Non-English publications

3.4. Data analysis and thematic coding

Content analysis protocol was followed in order to yield meaningful inferences by discriminating manifest (observed bibliometric data) and latent (inferred theoretical constructs) content (Kleinheksel et al., 2020). For analytical rigour, two analysts coded a random sample of the data set with a Cohen's Kappa value of (κ = 0.86) to ascertain high inter-rater reliability (McHugh, 2012). The codes were further aggregated to the second-order, broader theoretical constructs by inductive aggregation, giving rise to five thematic pillars: (1) Drivers and barriers of RED and GI; (2) Strategic paths for RED; (3) Financial instruments and valuation dynamics; (4) Policy initiatives and governance for sustainable real estate and (5) Future research direction for the new sustainability paradigm.

3.5. Synthesis and reporting

The narrative synthesis method was used in data synthesis. This approach is used to qualitatively explore and explain the complex interplay between regulatory drivers, financial innovations, and asset-level actions. The results are presented based on the identified thematic pillars, thus providing an overarching map of the enablers of the nexus of RED and GI.

As a result, the resulting synthesis should be considered heuristic and configurational, with the identified themes and linkages serving as analytical propositions rather than constructions that have been experimentally tested. Moreover, the synthesis qualitatively shows the relative strength of evidence supporting each pathway to enhance interpretability. Broad descriptions based on the consistency and convergence of findings across the examined studies are used to represent these findings, such as well-established, nascent, or fragmented evidence.

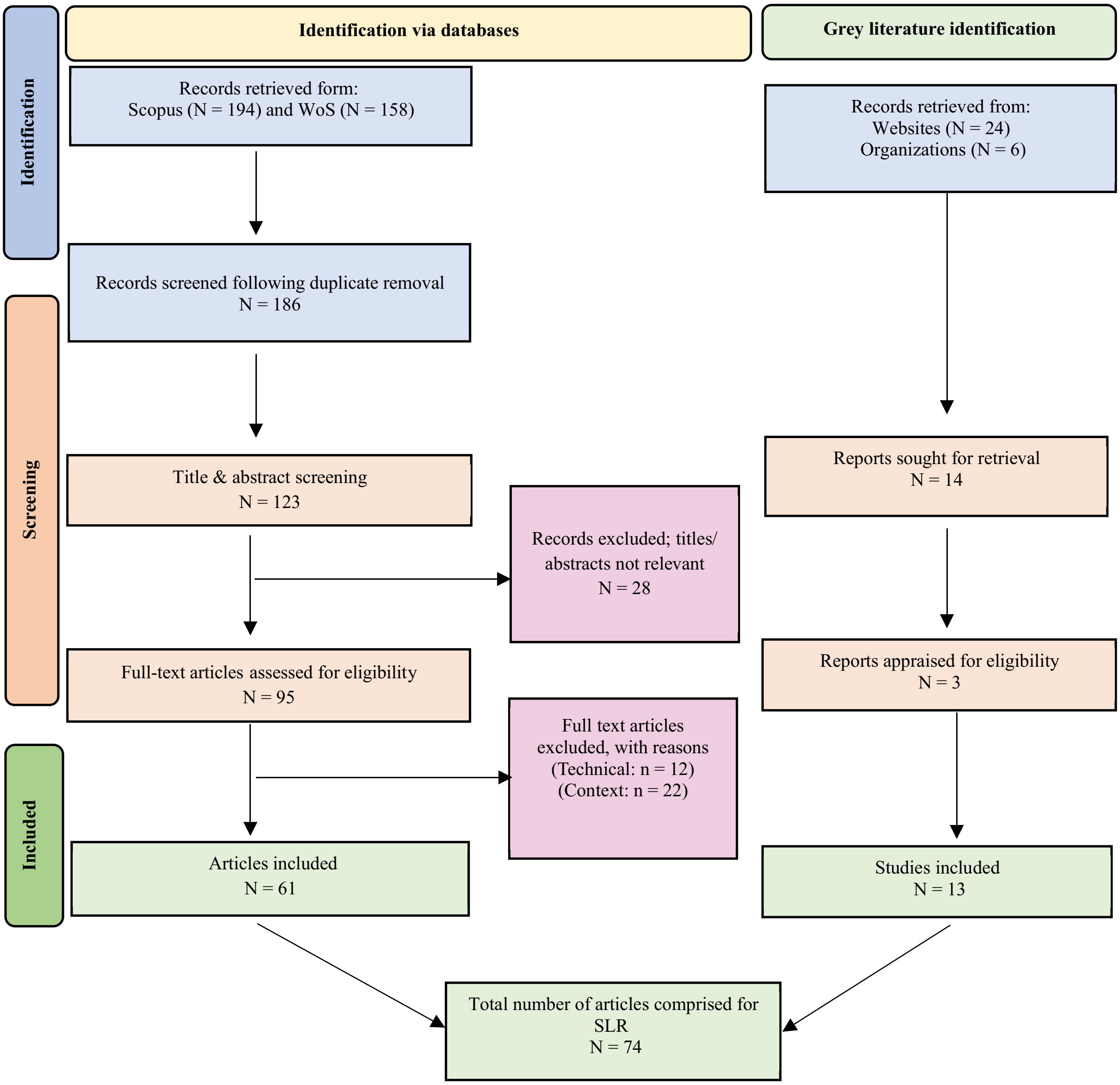


Figure 1. Flow diagram of the study selection process

4. Thematic analysis

A systematic interpretive synthesis of the examined literature is reflected in the results shown in this section. Rather than serving as validated models, figures and tables are meant to be used as analytical tools to arrange complicated and dispersed evidence. Furthermore, this exploratory research utilized a thematic analysis of the existing body of work that explored the relationship between the RED strategies and GI to explain the mechanisms linking financing to environmental sustainability from the viewpoint of the real estate sector. In addition, the thematic analysis provided an organised method of analysing these two core concepts through the identification, classification, and combination of the major themes in the body of literature about RED strategies and GI (Castleberry & Nolen, 2018). As a result of this thematic analysis, there were four main themes scrutinized: (i) the drivers and barriers of achieving a net-zero transformation within property transactions (RQ1); (ii) tactical and technology-based interventions necessary to achieve carbon reduction in assets (RQ2); (iii) the financial value of investing in environments that provide carbon reduction (RQ3); and (iv) the policy initiatives and governance frameworks needed to support the paradigm shift to sustainable real estate (RQ4). By using the structured approach of thematic analysis, this thematic analysis provided a comprehensive view of the current state of sustainable real estate and created the theoretical platforms for a process-based, empirically supported framework for the emerging discipline of sustainable real estate.

4.1. Drivers and enablers of real estate decarbonization and green investment (RQ1)

The shift toward a carbon-neutral property landscape represents a major structural change driven by market pressures rather than exclusively moral mandates (Vimpari, 2020). A systematic content analysis of the 74 curated peer-reviewed literature and ancillary grey literature segregates the crucial determinants accelerating this transformation. Divergent from prior epochs of discretionary corporate social responsibility (CSR), the contemporary assimilation of GI tactics is grounded in the conservation of asset solvency and the alleviation of valuation depreciation (Kumar, 2025). The following section classifies these drivers by their operational and financial relevance. Table 4 reflects a synthesis-based classification and aggregates these drivers, delineating the correlation between specific decarbonization interventions and their investment implications. Given the scope and coherence of findings in the literature, Table 4 also shows variations in the strength of evidence across the drivers' pathways.

4.1.1. Sustainability drivers

The main environmental driver in real estate is the mitigation of transition risk, particularly the risk of asset obsolescence resulting from misalignment with decarbonization paths such as the Carbon Risk Real Estate Monitor (CRREM) (Spanner & Wein, 2020). Empirical evidence suggests that as climatic pathways constrict, assets failing to satisfy energy intensity benchmarks confront hastened redundancy (Tavano & Salvo, 2025). Hence, carbon abatement is progressively instrumentalized as a protective tactic to safeguard terminal valuation (Spanner & Wein, 2020). Moreover, the circular economy has materialized as a pivotal sub-driver, reorienting attention from operational energy toward the curtailment of embodied carbon via adaptive reuse (Ploeger et al., 2019). This harmonization with institutional imperatives functions as a precondition for enticing capital pledged to the Principles for Responsible Investment (PRI) (Hoepner et al., 2021).

4.1.2. Organizational and regulatory drivers

Regulatory pressure has shifted from voluntary guidance toward binding legal requirements, significantly influencing real estate investment and management practices (Mattila & Heinilä, 2022). Mandatory disclosure regimes—such as the EU's SFDR and emerging climate-related reporting rules from the U.S. Securities and Exchange Commission (SEC)—require investors to measure and report portfolio emissions with a high degree of accuracy and transparency (Castro & Kell, 2023; Cremasco & Boni, 2024). At the organizational level, green leases have become an important governance tool to address the principal–agent, or split-incentive, problem by formalizing data sharing and cost allocation for energy upgrades (Collins et al., 2018). At the same time, growing demand from corporate tenants seeking to reduce their own Scope 3 emissions has contributed to a segmented rental market, where non-compliant buildings increasingly face elevated vacancy risks (Wiegelmann & Schwab, 2025).

4.1.3. Technological drivers

Advances in property technology (PropTech) have significantly improved the practical feasibility of decarbonization efforts (Xu et al., 2025). Beyond basic digitalization, tools such as digital twins and AI-enabled building management systems allow for detailed, real-time monitoring of energy use, supporting the level of data granularity required for investment-grade ESG reporting (Magaletti et al., 2025b; Meslec et al., 2025). Technological progress also includes physical innovations, notably electrification through heat pumps and the integration of on-site renewable energy, which can directly lower operating expenses (OpEx) (Padovani et al., 2021). The scalability of these solutions enables large institutional investors, including Real Estate Investment Trusts (REITs), to roll out standardized retrofit programs that reduce marginal abatement costs across portfolios (Liu & Chen, 2025).

4.1.4. Competency drivers

The successful implementation of GI strategies requires not only a traditional approach to property management but also other skill sets beyond what is typically required for property management (Onuoha et al., 2018). One

Table 4. Key drivers and factors of decarbonization and green investment in real estate

Key category	Sub-category	Operational mechanism	References
Sustainability drivers	Transition risk mitigation	Preventing regulatory obsolescence risk and asset stranding against decarbonization pathways (e.g. CRREM)	(Spanner & Wein, 2020)
	Physical climate resilience	Increasing asset resilience against acute (e.g. flood risk) and chronic (e.g. heat stress) climate risks	(Urban Land Institute & Heitman, 2020)
	Embodied carbon reduction	Lowering upfront carbon emissions through adaptive reuse, circularity and low-carbon material selection	(Spanner & Wein, 2020)
	Energy efficiency optimization	Lowering operational energy intensity (kWh/m^2) to align with net zero operating target	(An & Pivo, 2020)
	Biodiversity & ecosystems	Integration of nature-positive impacts (Taskforce on Nature-related Financial Disclosures (TNFD)) and urban greening infrastructure	(Parris et al., 2018)
Organizational & regulatory drivers	Mandatory compliance	Mandatory compliance fulfils mandatory legislation (SFDR, Minimum Energy Efficiency Standards (MEES)- MEES are a specific type of mandatory performance standards (MPS)-for market access	(Schütze & Stede, 2024)
	Voluntary reporting standards	Alignment with voluntary institutional frameworks (Global Real Estate Sustainability Benchmark (GRESB), TCFD, Science-Based Targets Initiative (SBTI)) for investor reporting expectations	(Eccles & Krzus, 2019)
	Green leases	Legal agreements that overcome the split-incentive problem of data sharing and retrofit CapEx	(Collins et al., 2018)
	Corporate tenant demand	Corporate tenant demand Pressure on the part of global occupiers for net-zero certified space to meet Scope 3 targets	(Robinson et al., 2017)
	Internal carbon pricing	Internal carbon price Setting of a shadow carbon price as a test case in investment models for future asset performance stress testing	(Bento & Gianfrate, 2020)
Technological drivers	Proptech & digital twins	Use of AI-powered digital twins' platforms for real-time monitoring, predictive maintenance and operational auditing	(Xu et al., 2025)
	Building information modeling (BIM) for lifecycle assessment	Use of BIM in design phases to model and quantify Whole Life Carbon (WLC)	(Soust-Verdaguer et al., 2017)
	Electrification technologies	Replacement of on-site gas and oil boilers with high-efficiency heat pumps	(Padovani et al., 2021)
	Smart grid facilitation	Enabling buildings to be flexible energy nodes (demand response) to better optimize interaction with the energy grid	(Almihat et al., 2025)
	Blockchain & smart contracts	Tracing supply chain provenance and traceability and verifying Renewable Energy Certificates (RECs)	(Liu & Chen, 2025)
Competency drivers	Green certification	Technical know-how and management required for gaining and maintaining third-party accreditations (LEED, BREEAM, German Sustainable Building Council (DGNB)) as proxies for quality	(Wang et al., 2025)
	ESG data governance	Ability to collect, verify and manage the quality of investment grade non-financial data for regulatory disclosures	(Mariani et al., 2025)
	Climate risk assessement	Literacy in quantifying Climate Value-at-Risk (CVaR) and value at risk from climate scenario analysis	(Anjanappa & Singh, 2025)
	Supply chain engagement	Managing the complexities of Scope 3 emissions across the building construction and fit-out/facilities management supply chain	(WEF, 2021)
	Cross-functional capabilities	Overshooting the gap between sustainability operations and investment decision-making silos	(Taghizadeh-Hesary & Yoshino, 2019)
Economic drivers	The "green premium"	Increasing rental and capital uplifts on high performance, certified sustainable buildings	(Wang et al., 2025)
	Brown discount	Avoiding a premium cost of capital (liquidity/tenure discount) and a reduced collateral value on energy-inefficient buildings	(Jiao et al., 2025)
	Cost of capital advantage	Availing lower interest rates on Green Bonds and Sustainable loans or SLLs	(Flammer, 2021)
	Opex & yield improvement	Increasing NOI through reduced energy consumption/utility bills and lower maintenance	(An & Pivo, 2020)
	Fiscal incentives	Availability of government-backed tax credits, accelerated depreciation or grants to offset green retrofit costs	(Yuan et al., 2023)

competency area includes the ability to navigate through the many complex sustainability certification systems (e.g., Leadership in Energy and Environmental Design (LEED), Building Research Establishment Environmental Assessment Method (BREEAM), WELL building standard, etc.), which have become increasingly recognized by investors as indicators of the quality and performance of an asset in the marketplace (Butt, 2025). Additionally, Organizational Agility is emerging as the defining characteristic of leading organizations and describes the organization's ability to anticipate regulatory changes as well as to proactively reallocate capital (Mariani et al., 2025). The literature has repeatedly emphasized the need for finance professionals and technical experts to work closely together to recast retrofit measures into relatable financial evaluations and underwriting decisions (Andaloro et al., 2022).

4.1.5. Economic drivers

Economic factors continue to be the most powerful driver of RED (Bogdanov et al., 2021). A significant theme in the literature is the presence of a "green premium," where certified sustainable assets command higher rents and capital values than traditional buildings (Wang et al., 2025). Conversely, energy-inefficient properties face a "brown discount", eroding net asset value (NAV) and incentivizing timely capital expenditure (CapEx) on retrofits (French, 2020). On the financing side, the growing green debt markets have introduced measurable cost-of-capital advantages, with green bonds and sustainability-linked loans offering more favorable borrowing terms for eligible projects (Mishra et al., 2023). Finally, assets with lower carbon intensity tend to have more stable operating costs, less affected by fossil fuel price fluctuations, which, over time, bolsters the reliability of net operating income (NOI) (An & Pivo, 2020).

4.2. Barriers and challenges toward decarbonization and green investments in real estate (RQ1)

The Real Estate sector exhibits a significant gap between regulatory and investor expectations concerning asset-level decarbonization. While there are many drivers for increased momentum for green investments, regulatory, investor, or tenant pressures alone do not explain the observed disparity between actual and expected progress on decarbonizing properties (Spanner & Wein, 2020). In this section, we will focus on the constraints that maintain this inertia and why market actors do not act upon GI opportunities even though it is economically rational to do so. Drawing from the 74 studies included in this review and using supporting evidence from respected grey literature, we will identify a complex network of interrelated barriers that limit the ability to reach net-zero outcomes. We have categorized the barriers into eight categories for analytical purposes: organizational, regulatory, process-related, social/cultural, financial, technical, strategic, and technological. Figure 2 illustrates an interpretive representation derived from the literature synthesis of how the barriers are interconnected, and Table 5 provides detailed characteristics for each barrier category. The barriers classification is a synthesis-based classification designed to improve analytical clarity. Furthermore, there is a range of evidence supporting the barrier pathways shown in Figure 2 and Table 5, from established associations to more recent or exploratory connections.

4.2.1. Organizational barriers

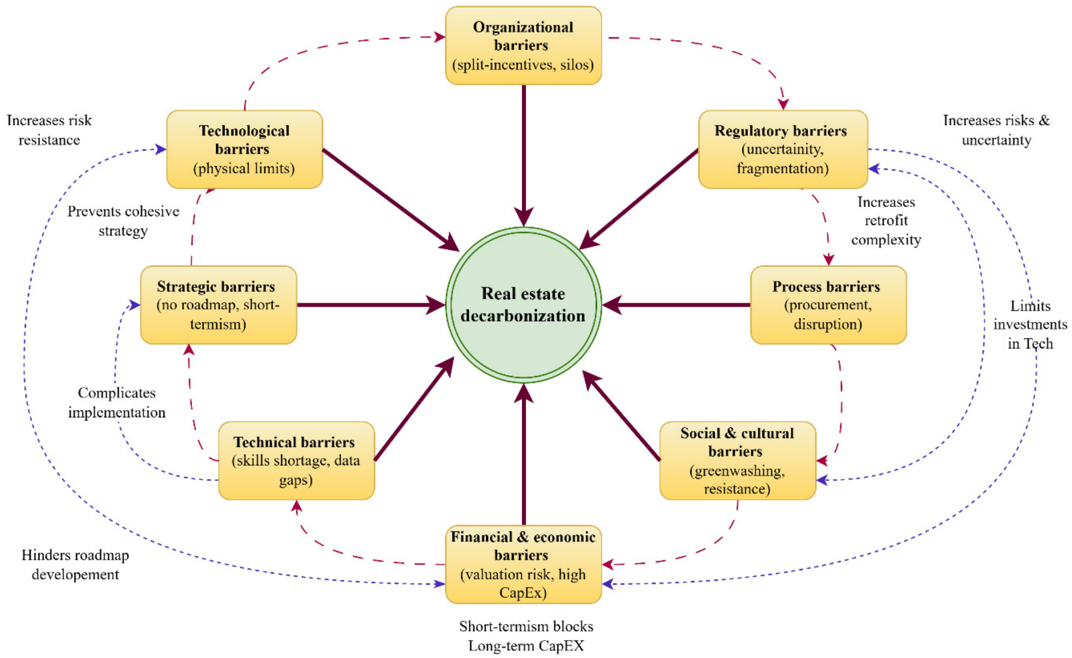
The decarbonisation pathway from passive ownership to actively managed low-carbon stock is coupled with the requirement for a restructure of the internal governance mechanisms (Siegfried et al., 2023). A key organisational barrier that compounds the split-incentive is the principal–agent problem. Property owners are liable to bear the capital cost of retrofits while the tenant is in occupancy to reap the rewards of the lower energy bills (Singhal et al., 2025). The split-incentive problem is particularly severe when coupled with a triple-net (NNN) lease (Huerta-Sanchez et al., 2025). The organisational challenge is underpinned by a siloed decision-making structure within real estate entities. Investment committees may not have the technical knowledge to interpret ESG risk drivers, while in sustainability teams may not have the budgetary powers to sanction large capital outlays (Jackson & Orr, 2021). SMEs in particular can struggle with the knowledge and capacity internally to assess options and plan and implement retrofits. In organisations without a dedicated

Table 5. Barriers and challenges to decarbonization and green investment in real estate

Key category	Sub-category	Operational mechanism	References
Organizational barriers	Principal-agent problem	Misaligned incentives, e.g., between investors paying retrofit CapEx and tenants capturing OpEx savings	(Liao et al., 2023)
	Siloed governance	Mismatch between investment committees (yields) and sustainability teams (ESG)	(Christensen et al., 2018)
	Operational inertia	Institutional resistance to shift from passive holding to active, hands-on green management	(Sing et al., 2019)
	Change management deficit	Lack of internal frameworks for coordinating the required stakeholder engagement for net-zero transformations	(Panakaduwa et al., 2025)

End of Table 5

Key category	Sub-category	Operational mechanism	References
Regulatory barriers	Policy heterogeneity	Fragmentation between global frameworks (CRREM, GRESB) and local building codes, leading to greater compliance costs	(Bakar et al., 2024)
	Regulatory uncertainty	Unpredictable changes in the carbon price and building efficiency regulations (MEES) complicate long-term capital allocation decisions	(Aphecetche, 2025)
	Enforcement asymmetry	Lack of monitoring and penalties for underperforming buildings leaves low-hanging fruit	(Wagner, 2025)
	Data privacy conflict	Tight tenant data privacy regulations (e.g., GDPR) hamper the sharing of energy use data needed for Scope 3 reporting	(Wallace et al., 2026)
Process barriers	Lease cycle rigidity	Inability to perform deep retrofits without vacant possession risks delaying action until the end of the lease	(Gong et al., 2025)
	Procurement friction	Transaction costs related to identifying and sourcing low-carbon materials and vetting contractors	(European Investment Bank, 2025)
	The "performance gap"	Bias in the post-occupancy performance of the building, systematically higher than modeled energy design performance	(Chiang et al., 2025)
	Operational disruption	Constraints preventing major interventions (e.g., HVAC replacement) due to the risk of tenant displacement	(Streicher et al., 2021)
Social & cultural barriers	Information asymmetry	Ongoing skepticism around green claims by stakeholders based on a legacy of "greenwashing" in the industry	(Eckberg et al., 2025)
	Behavioral rebound	Disconnect between highly engineered, energy-efficient buildings and occupant behavior (e.g., the Jevons Paradox)	(Aydin et al., 2017)
	Risk perception bias	Industry overestimates the risk of green technology options (new untested systems) relative to the known performance of existing systems	(Zhang et al., 2025)
Economic & financial barriers	Capital rationing	Increased CapEx burden with relatively long payback periods (7–20 years) for major interventions creates liquidity constraints	(Zheng & Lee, 2026)
	Valuation uncertainty	Nability to capture the "Green Premium" in a formal appraisal due to a lack of comparables from a low transaction volume	(CBRE, 2023)
	ROI volatility	Uncertainty in projecting future financial returns (OpEx) due to volatile energy prices, and evolving carbon taxes	(Jose Valdez Echeverria et al., 2023)
	Financing constraints	Limited market access to sustainable or green debt products for smaller assets, or those not held by institutions	(OECD, 2025)
Technical barriers (Data/skills)	Human capital deficit	Lack of qualified skilled labor (ESG analysts, retrofit project managers) to take on the complex projects	(Panakaduwa et al., 2025)
	Legacy data silos	Data locked in siloed systems that are not designed to work together and can't provide a holistic picture across a portfolio	(Berlato et al., 2025)
	Measurement risks	Lack of standard methodologies and assumptions in calculating hard metrics like "Embodied Carbon" of a building	(Hirsch et al., 2019)
Strategic barriers	Temporal mismatch	Mismatch between short investment cycles of real estate funds (3–5 years) and the time horizon for seeing returns on decarbonization projects (10+ years)	(Marcato & Nanda, 2022)
	Roadmap deficit	A lack of a defined asset-specific pathway and interim decarbonization targets (CRREM analysis) in an owner's wider business strategy, leading to ad-hoc project selection	(Ruggeri et al., 2020)
	Joint-venture (JV) misalignment	Strategic misalignment between JV partners on the need for (a) sustainability to preserve the asset value vs (b) cash flow (show me the money)	(Prat et al., 2020)
	Selection paralysis	Hesitancy to select for capital deployment until industry standards have settled on which technology (HVAC, BIPV, etc.) is the "best"	(Royapoor et al., 2023)
Technological barriers (Physical)	Asset obsolescence	Fixed physical constraints on older stock (low ceiling heights) that cannot accommodate modern systems	(Carroll et al., 2020)
	Infrastructure limits	Inability of the local electricity network to accept new load growth from building electrification and EV charging	(Priyadarshan et al., 2025)
	Technology immaturity	Lack of cost-competitive and/or commercially available solutions for hard-to-abate sectors (carbon negative concrete)	(Wouda & Opdenakker, 2019)
	Supply chain volatility	Vulnerability to disruptions and price fluctuations in the supply of key low-carbon materials/components	(Bolomope et al., 2024)



Note: Arrows indicate reinforcing feedback loops and causal links among barriers.

Figure 2. Structural interdependencies of RED barriers

sustainability team, the only activities available to other employees may be those that require low budgets or fall under business-as-usual operations, rather than full-scale retrofits (Khosravi et al., 2024).

4.2.2. Regulatory barriers

As well as supporting, fragmented policy and regulatory environments can present additional hurdles to decarbonisation. Ambiguity and misalignment between various carbon accounting frameworks (CRREM vs EU taxonomy for sustainable activities vs national building regulation) create compliance costs for developers and increase risks for international investors (Tettamanzi et al., 2024). Frequent updates or changes to emissions thresholds or reporting requirements create uncertainty for investors and businesses, adding to the regulatory transition risk (Sautner et al., 2023). In addition, the enforcement of these voluntary standards is often weak (Bingler et al., 2022). These factors are more prominent in emerging markets where the regulatory environment may be underdeveloped or voluntary green building standards may be unsupportive of decarbonisation. Without clear government-backed codes of practice for green buildings or financial incentives to offset the cost, retrofitting or low-carbon development is at a competitive disadvantage for those actors that choose to internalise the cost of carbon before it is mandated (Mohamed et al., 2023). The implementation of new technology is also subject to legal barriers around data privacy and protection, with privacy legislation (GDPR) a challenge to sourcing tenant-level energy data for Scope 3 calculation, for example (Bakar et al., 2024).

4.2.3. Process barriers

Process barriers also stifle the decarbonization of commercial real estate stock. Deep retrofit solutions are often highly intrusive and disruptive, with the level of work on the building envelope or Heating, Ventilation, and Air Conditioning (HVAC) system requiring the temporary relocation of tenants. These vacancy periods are coupled with the costs of lost income for property owners, causing some to delay making efficiency improvements until the end of leases (Tetteh & Owusu Kwateng, 2026). As such, the market-level retrofitting of existing stock lags behind, making this a time-sensitive issue (Wilkinson & Sayce, 2020). The procurement process is non-standardised, and low-carbon solutions come at a cost premium. This is further affected by a fragmented construction value chain between architects, engineers, contractors, and facility managers. This has been shown to create a performance gap, where the energy savings that could be expected from a certain retrofit solution are not fully realised due to problems with installation, commissioning, or measurement (Liang et al., 2019).

4.2.4. Social and cultural barriers

Social and cultural barriers to RED are not always technocratic. Behavioural challenges are important, as increasing energy efficiency can paradoxically make the occupants use more energy (the rebound effect, also known as the Jevons Paradox) than predicted (Özsoy, 2024). In some cases, it is necessary to face some cultural resistance, especially if the deployment of RES is concerned. For example, there are often regulations protecting the conservation of historical sites or districts, and solar panels or heat pumps may be limited or prohibited by residents' associations or "not in my backyard" (NIMBY) sentiments (Shi & Dou, 2025). An organizational-level issue is a lack of "deeply rooted" sustainability culture, which allows for greenwashing (manufacturing a sustainable image, for example, through public relations, marketing, or corporate social responsibility without a corresponding performance) (Raghunandan & Rajgopal, 2022). Tenant apathy is another barrier to overcome; even the best building management system will be limited by the absence of users' engagement (Ebuy et al., 2023).

4.2.5. Economic and financial barriers

Economic and financial barriers are one of the most commonly reported constraints. The most prominent source of uncertainty relates to the interplay between the expected "green premium" and the nascent "brown discount" (Jiao et al., 2025). Although the cost of green finance has come down, the significant upfront capital requirement of deep retrofits tends to lead to payback periods that often exceed typical 5–7-year investment timeframes (Bertoldi et al., 2021). This discourages private equity and value-add investors from engaging in long-term decarbonization strategies (Jackson & Orr, 2021). Meanwhile, the failure of traditional valuation methods to capture climate risk and energy performance effectively perpetuates a view that GI could lead to value destruction (Sayce et al., 2022). Smaller asset owners may also face liquidity constraints in accessing green bonds or sustainability-linked loans, causing delays in upgrades (Bertoldi et al., 2021). Fluctuating energy prices add another level of uncertainty to return on investments (ROIs) on renewable energy systems (Leskinen et al., 2020a).

4.2.6. Technical barriers

Technical barriers are those associated with poor-quality data and skills gaps (Mahpour, 2018). The main constraint is the lack of credible, investment-grade data, especially in areas like Scope 3 tenant emissions and embodied carbon impacts (Bakar et al., 2024). For mature building stock, the lack of smart metering infrastructure often means that data is estimated rather than measured, reducing the credibility of ESG disclosures (Ntafalias et al., 2024). At the same time, there is a shortage of skilled professionals such as retrofit coordinators, heat pump specialists, and ESG data analysts (Panakaduwa et al., 2025). These skills gaps drive up execution risk and lengthen project delivery timelines. Finally, interoperability challenges between old building management systems and new PropTech tools create isolated data silos that inhibit portfolio-level analysis (Berlato et al., 2025).

4.2.7. Strategic barriers

The fourth category of strategic barriers mainly relates to the need to align long-term sustainability goals with short-term commercial incentives (AlJaber et al., 2023). There is evidence that many real estate companies are somewhat strategically myopic, with a bias towards delivering immediate yields to investors rather than building long-term asset resilience through GI (Cao et al., 2024). As a result, many firms lack a well-articulated portfolio-level decarbonization roadmap and tend to tackle individual interventions in an ad hoc fashion rather than in a coordinated manner (Ruggeri et al., 2020). Joint venture partnerships can also create strategic tensions when ESG aspirations are not fully aligned with short-term cash flow imperatives (Christensen et al., 2018). Strategic decision-making can also be paralyzed by uncertainty about future technology pathways, including a lack of clarity about the relative role of hydrogen vs full electrification in hard-to-abate sectors (Royapoor et al., 2023).

4.2.8. Technological barriers

The last type of constraint, technological barriers, is primarily linked to the physical nature of existing assets and their underlying infrastructure (Aktan et al., 2019). Many existing buildings, particularly those with heritage protection, have structural limitations that make it difficult to install modern insulation or heat pump technologies (Nair et al., 2022). Local electricity grid constraints are another major bottleneck, with many networks struggling to absorb the impact of full electrification and increased EV charging (Meunier et al., 2021). In addition, certain solutions for hard-to-abate emissions, such as carbon-negative construction materials, are still in their infancy and are therefore not widely applicable in the near-term (Habert et al., 2020). Global supply chains for some low-carbon technologies like batteries and semiconductors are also still volatile, which further complicates planning (Bolomope et al., 2024).

4.3. Transition pathways and technological enablers for the decarbonization of real estate portfolios (RQ2)

Transitioning real estate portfolios away from carbon-intensive assets and towards assets aligned with net-zero targets depends on an orchestrated interplay of technology adoption and managerial decision-making (Tan & Miller, 2023). Market drivers signal economic incentives, barriers constitute the constraints, and strategic pathways offer the mechanism to convert ambition into action. In this section, we propose key interventions for closing the implementation gap by grouping enablers around five interrelated axes: deep retrofitting and electrification (DRE), digitalization and smart asset operations (DSAO), lifecycle carbon management (LCM), stakeholder integration and green governance (SIGG), and circularity and resilience integration (CRI). Based on the breadth and consistency of findings in the literature, Table 6 presents an overview of the identified strategic paths and technology solutions along with their features, highlighting variations in the quality of evidence across pathways. These pathways also address many of the structural barriers identified in Section 4.2. For instance, DSAO mitigates information asymmetries by producing verifiable data on asset perfor-

Table 6. Strategic pathways and technological interventions matrix for real estate decarbonization

Strategic pathway	Technological intervention	Working principle & strategic enabler	References
Deep retrofitting & electrification (DRE)	High-efficiency heat pumps	Working principle: Swapping fossil fuel combustion for thermal load electrification Strategic enabler: Break from fossil fuel price volatility and carbon intensity exposure	(Carroll et al., 2020)
	Thermal envelope optimization	Working principle: Installation of triple-glazing windows and high R-value insulation Strategic enabler: Substantial lowering of building baseline energy needs	(Nair et al., 2022)
	Building-integrated PV	Working principle: Generation of solar energy from rooftop and façade integration Strategic enabler: Reduced grid demand and scope 2 emissions footprint	(Ibrahimi et al., 2025)
	Intelligent LED lighting	Working principle: Embedding of motion/daylight harvesting sensors Strategic enabler: Reduction of the electricity baseload	(Ntafalias et al., 2024)
	Waste heat recovery	Working principle: Extraction of residual heat from ventilation air or IT racks Strategic enabler: Recirculation of thermal energy to the asset and reduction of primary heating load	(Royapoor et al., 2023)
Digitalization & smart asset operations (DSAO)	IoT sensor network	Working principle: Fine-grained sensing of occupancy, IAQ, temperature, and more Strategic enabler: Immediate tuning of systems to meet actual demand	(Al-haimi et al., 2025)
	Digital twins	Working principle: Digital twin of the physical asset for operational performance Strategic enabler: What-if scenario testing to optimize CapEx of retrofit interventions	(Mousavi et al., 2024)
	Smart sub-metering	Working principle: Installation of zone-wise or sub-metering points for building equipment Strategic enabler: Detection of irregular energy flows and accurate tenant billing	(Tan & Miller, 2023)
	Predictive maintenance AI	Working principle: Artificial intelligence that can detect anomaly patterns of systems and equipment Strategic enabler: Prevention of non-planned efficiency decay and equipment failure	(Aktan et al., 2019)
	Blockchain ledgers	Working principle: Blockchain recording of all energy, load, and carbon performance data Strategic enabler: Granular ESG performance tracking and verification for internal or external auditing purposes	(Wouda & Opdenakker, 2019)
Lifecycle carbon management (LCM)	Bio-based materials	Working principle: Timber, bamboo, or hempcrete specification. Strategic enabler: Carbon sequestration in building stock (negative emissions)	(Siegfried et al., 2023)
	Material passports	Working principle: Digitally embedded passports in all components containing relevant material composition details Strategic enabler: Identification of material composition in the building stock for recovery in the future	(Oliveira et al., 2024)
	Low-carbon concrete	Working principle: Use of industrial by-products (fly ash or slag) in place of cement Strategic enabler: Reduction of high-embodied intensity in concrete structure	(Habert et al., 2020)
	Recycled steel	Working principle: Specification of electric arc furnace (EAF) scrap metal instead of iron ore Strategic enabler: Reduction of supply-chain based extraction emissions	(Bacheva et al., 2025)
	Additive manufacturing (3D)	Working principle: Layer-by-layer fabrication of components using 3D printing. Strategic enabler: Optimization of on-site material consumption and less wastage	(Jørgensen & Ma, 2025)
Stakeholder integration and green governance (SIGG)	Green leases	Working principle: Digitally embedded clauses to include energy/data sharing and cost-recovery mandates Strategic enabler: Assuring that landlord and tenant are aligned for shared financial interest in savings	(Collins et al., 2018)
	Tenant engagement apps	Working principle: Apps to allow tenants to control and report their environment in the building Strategic enabler: Behavior modification to improve tenant well-being and environmental awareness	(Day et al., 2020)
	Gamification platforms	Working principle: Tools to allow energy consumption to be benchmarked against peers in the building Strategic enabler: Behavior change through incentivization and awareness building among tenants	(Ebuy et al., 2023)
	P2P energy trading	Working principle: P2P energy trading platforms for localized and community energy markets Strategic enabler: Building-block creation of micro-grid communities and engagement with end-users	(Almihat et al., 2025)

End of Table 6

Strategic pathway	Technological intervention	Working principle & strategic enabler	References
Circularity and resilience integration (CRI)	Adaptive reuse	Working principle: Adaptive reuse of building's shell and partial or full interior renovation Strategic enabler: Zero demolition emissions and retaining embodied carbon of structure	(Liao et al., 2023)
	Modular construction	Working principle: Prefabrication of sub-units in an off-site location and module assembly on-site Strategic enabler: Minimized on-site construction waste and accelerated building delivery	(Pierzchlewicz et al., 2025)
	Design for disassembly	Working principle: Specifying mechanical (bolts) over permanent (glue) connections for all sub-units and systems Strategic enabler: Transformation of the asset into a future material bank	(Munonye & Ajonye, 2025)
	Green roofs and walls	Working principle: Integration of plants and water retention reservoirs Strategic enabler: Urban heat island reduction and storm water runoff abatement	(Parris et al., 2018)
	Rainwater harvesting	Working principle: Integration of surface catchment and filtration systems for rainwater harvesting Strategic enabler: Decoupling of building water consumption from municipal grid and drought resiliency	(Sesana & Dell'Oro, 2024)

mance that is amenable to audit and reporting (Baptista et al., 2023), whereas SIGG addresses the principal–agent problem by establishing contractual incentives and sanctioning mechanisms that better align landlords' and tenants' incentives (Collins et al., 2018). The framework thus coalesces around a number of recurring themes from the literature. Spanner and Wein (2020) frame electrification as the enabler by which the operation of buildings can be decoupled from carbon intensity, whereas Mahpour (2018) frames circularity as a hallmark of more mature approaches to embodied emissions. Empirical validation of these pathways as a means of CRREM-aligned decarbonization of real estate portfolios is also ubiquitous (McArthur & Jofeh, 2016; Brounen et al., 2020; Spanner & Wein, 2020).

4.3.1. Deep retrofit and electrification (DRE)

The bulk of most RED action plans centres around the deep retrofit of the existing building stock (Streicher et al., 2021). DRE pathways are characterised by the planned phase-out of on-site fossil fuel systems (e.g., gas boilers) and the decarbonisation of the thermal energy system through both the enhancement of the building envelope's thermal performance and a shift to high-efficiency heat pumps (Lingard, 2021). This is accompanied by on-site renewable generation, often in the form of building-integrated photovoltaics (BIPV) (Ibrahimi et al., 2025), in order to align with net-zero transition pathways. Lowering the overall energy use intensity (EUI) through deep retrofit also mitigates the asset stranding risk associated with tightening MEES (Curtin et al., 2019). However, deep retrofit can be operationally disruptive, necessitating a staged retrofit pathway that is closely aligned with lease expires in order to limit vacancy periods and lost income (Ruggieri et al., 2023).

4.3.2. Digitalization and smart asset operations (DSAO)

Achieving the operational performance required for net-zero necessitates the shift from "set-and-forget" building management towards continuous data-driven control (Royapoor et al., 2023). DSAO, the second of our RED pathways, focuses on using PropTech to generate a dynamic digital asset performance register, typically using building management systems (BMS) and IoT devices to enable real-time energy monitoring and control (Tan & Miller, 2023). The deployment of digital twins in this pathway allows for scenario analysis and the predictive optimization of HVAC systems to minimize wasted energy and operating costs (Hosamo et al., 2023). Critically, DSAO also provides the data required for reporting under ESG investment frameworks with green standards such as TCFD and GRESB (Tan & Miller, 2023). However, DSAO is reliant on the integration of building data across different systems, meaning that data silos and cybersecurity are key risks (Mousavi et al., 2024).

4.3.3. Lifecycle carbon management (LCM)

LCM complements DRE and DSAO to account for a broader perspective of asset decarbonization (Bacheva et al., 2025). In particular, it focuses on whole-life carbon (WLC) management from a life cycle assessment (LCA) perspective, through stages of design, refurbishment, and redevelopment (Chen et al., 2023). The approach prioritizes low-carbon construction materials and techniques, such as CLT and green steel, as well as the preservation of existing building fabric (Priore et al., 2026). LCM also allows for buildings to be aligned with the EU taxonomy for sustainable activities by fulfilling its technical criteria for "substantial contribution to climate change mitigation" (World Green Building Council, 2025). However, one of the key challenges to LCM is currently the data required to make whole-life carbon assessments. The availability of carbon data is often a barrier to accurate measurement (Olanrewaju et al., 2024).

4.3.4. Stakeholder integration and green governance (SIGG)

Decarbonization technology must be accompanied by the operational and cultural changes needed to adapt to a new climate-resilient order (Day et al., 2020). SIGG pathways to RED refer to the need to integrate ESG objectives with landlord–tenant relationships, which are often structured as a zero-sum, adversarial engagement. This is often achieved through the use of green leases that stipulate shared access to energy consumption data and cost apportionment arrangements for energy efficiency improvements (Collins et al., 2018). This contractual engagement is usually associated with a broader paradigm of asset governance based on shared value rather than the classic landlord-tenant model (Valero, 2024). SIGG therefore extends beyond legal agreements to include the tenants' active demand-side engagement rather than passive consumption of space. This is crucial for measuring and addressing Scope 3 emissions, which can make up the bulk of tenant-related carbon impacts. However, the main impediment to SIGG is overcoming existing split-incentive models and finding mechanisms to incentivize transparency (Collins et al., 2018).

4.3.5. Circularity and resilience integration (CRI)

Our fifth pathway, CRI, addresses the need for RED to be paired with climate resilience and circular economy considerations (AlJaber et al., 2023). The former involves building-level adaptation strategies that enable climate resilience of the building fabric to physical climate risks like heat stress and flooding, ensuring that decarbonization measures do not detract from usability and comfort (Munonye & Ajonye, 2025). The latter focuses on the design-for-disassembly of new-build to facilitate asset recycling and the adaptive reuse of existing, low-performing, or obsolete stock to prevent shortening of building lifecycles (Pierzchlewicz et al., 2025). It also frames existing buildings as material banks in order to optimize for long-term value retention (Oliveira et al., 2024). Key barriers to this pathway include a regulatory environment that favours demolition over refurbishment and the embedded nature of linear construction industry business models (AlJaber et al., 2023).

4.4. Financial mechanisms and valuation dynamics of green real estate investment (RQ3)

The ultimate driver of RED is the movement of capital through property markets (Biasin et al., 2024). The levers outlined in Section 4.3 facilitate this physical abatement, but financial mechanisms can offer liquidity and incentives to scale up action (Taghizadeh-Hesary & Yoshino, 2019). In this section, we chart the development of green real estate investment's emerging valuation logic. In contrast to traditional investment models driven by location, there is a clear trend toward pricing in asset quality, environmental performance, and climate resilience (Taghizadeh-Hesary & Yoshino, 2019). An interpretive illustration derived from the literature synthesis has established five financial dimensions, which are listed and visualized in Figure 3: sustainable capital mobilization (SCM), operational yield optimization (OYO), climate risk pricing (CRP), stranded asset mitigation (SAM), and green premium (GP).

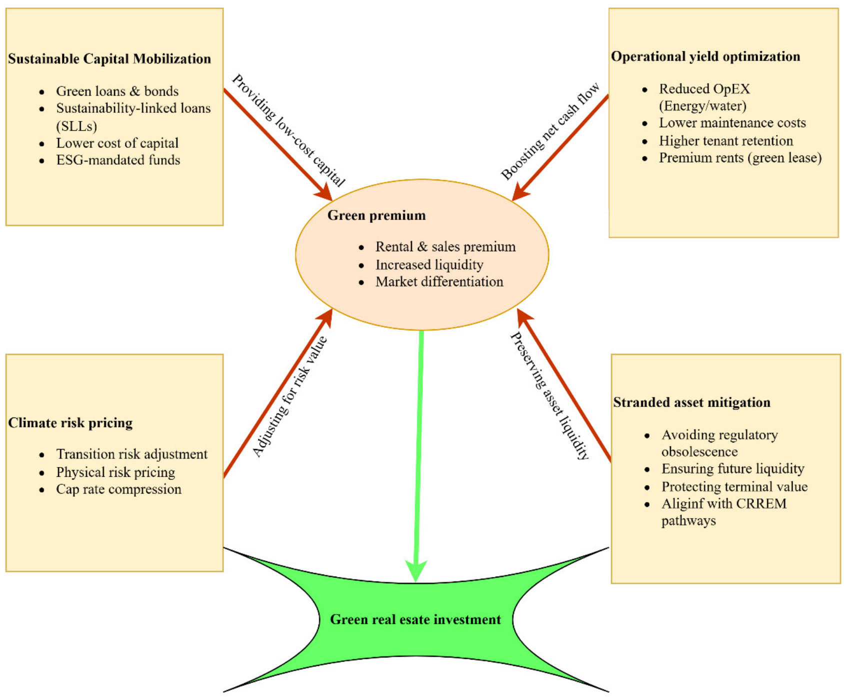


Figure 3. Financial mechanisms and valuation dynamics of green real estate investment

Taken together, these five dimensions have been shown to drive a reinforcing investment dynamic of mutual gains in which financial returns and decarbonization feed into each other. This virtuous cycle is illustrated in Figure 3. A growing empirical base informs this mapping. Brounen et al. (2020) demonstrate that certified sustainable buildings can realize a quantifiable rental premium, in large part explained by the lower total cost of occupancy. In contrast, Jiao et al. (2025) describe the appearance of a brown discount where transition risk is being priced into capitalization rates. On balance, these findings are consistent with the view that such mechanisms are driving the disconnection of low-carbon assets' financial performance from the market average.

4.4.1. Sustainable capital mobilization (SCM)

Deep decarbonization is highly dependent on the availability of cost-effective financing (An & Pivo, 2020). SCM is achieved through dedicated debt and equity channels, primarily green bonds and sustainability-linked loans (SLLs), to finance retrofits and low-carbon developments (Mishra et al., 2023). SLLs have distinct margin-adjustment mechanisms, meaning the interest rate spread is reduced (typically 2.5 to 10 basis points) if the borrower meets pre-agreed sustainability key performance indicators (KPIs), such as a GRESB score or emission reduction target (Cheah & Zhi, 2025). By lowering WACC, this structure can increase project IRR and improve financial feasibility (Flammer, 2021). However, the scalability of SCM is often limited by the lack of a viable pipeline and the transaction cost associated with satisfying taxonomy and disclosure requirements, such as the EU taxonomy for sustainable activities alignment (Aphecetche, 2025).

4.4.2. Operational yield optimization (OYO)

RED has direct and often immediate effects on operating performance (Morano et al., 2024). OYO has the capacity to increase net operating income (NOI) through the permanent reduction in non-recoverable operating costs (Islam et al., 2021). As high-performance buildings use less energy and require less maintenance, these factors directly translate into profitability improvements (Liao et al., 2023). Assets with lower cost footprints typically also enjoy higher-quality income with reduced vacancy risk and tenant churn. Tenant demand for net-zero–aligned space from corporates seeking to meet their own Scope 3 emission reductions is a key driver of this trend (CBRE, 2023). The greater NOI stability contributes to lower risk premiums, enabling yield compression even in static or falling rent markets (Robinson et al., 2017).

4.4.3. Climate risk pricing (CRP)

With higher efficiency and transparency, environmental externalities become increasingly reflected in asset values (Bento & Gianfrate, 2020). CRP is the quantification of the discount and capitalization rate adjustments for physical climate risks and transition risks (Hirsch et al., 2019). This may include a higher risk premium applied to "brown" properties on the basis of retrofit costs, regulation, and potential carbon pricing (Spanner & Wein, 2020). Energy-inefficient buildings may be subject to a brown discount, leading to permanent structural devaluation versus the market (Tavano & Salvo, 2025). Assets with a strong climate resilience profile have been shown to have the opposite effect, with their risk premia compressing as they are viewed as safer, more defensive investments (Newell et al., 2023). However, there remains a lack of standardized, long-term data linking specific climate risks to value erosion on an asset-level basis (Sayce et al., 2022).

4.4.4. Stranded asset mitigation (SAM)

On a defensive basis, there is a view that the primary role of GI is to protect end-of-life asset value (Hirsch et al., 2019). SAM strategies aim to manage the liquidity and obsolescence risks to assets that do not meet existing or expected minimum energy performance criteria, such as EPC grades by 2030 (Sayce et al., 2022). With the acceleration of decarbonization pathways such as CRREM, it is likely that non-compliant assets will become stranded, that is, almost impossible to lease, finance, or, in the case of mortgages, refinance (Hirsch et al., 2019). In this scenario, GI can be a way of hedging against obsolescence from regulatory changes and market forces, thereby ensuring continued access to institutional capital and finance (Newell et al., 2023). Research has found that, in times of market uncertainty, liquidity differentials between green and brown assets can grow by an order of magnitude as green investments become "safe havens" (Hau et al., 2023; Intonti et al., 2023).

4.4.5. Green premium (GP)

Taken together, the interaction of these levers can be measured as a GP: a statistically significant increase in rent and capital values for assets that meet green credentials (Leskinen et al., 2020b). The evidence from recent studies supports this as a structural rather than a speculative effect. For example, Addae-Dapaah and Wilkinson (2020) identify a 22% increase in sales price premiums for high-performing BREEAM-rated assets. This represents the capitalization of the NOI gains and the avoided costs of obsolescence and transition risk. Therefore, the economic rationale for decarbonization can be shown empirically, but there is also evidence that the green premium will evolve with regulatory uplift and sustainable benchmarks becoming table stakes (Sayce et al., 2022).

4.5. Policy initiatives and governance mechanisms for the net-zero transition

In addition to the maturity of technologies or access to financing, the rate and success of RED also depend on the stability and design of the policy and institutional environment in which these processes unfold (Nyoni et al., 2023). The content analysis reveals that while market forces are gaining momentum, they are not yet powerful enough to deliver the deep decarbonization required at the necessary scale and pace. Persistent market failures, in particular incentive misalignment stemming from principal–agent problems, as well as the longer-term under-pricing of climate risk, continue to create structural frictions that impede faster progress. This is gradually leading to a changing role of the state, from setting the rules of the game to becoming a more active "market shaper" with a view to establishing a polycentric governance regime to address some of these underlying inefficiencies.

A key component of this new governance approach is the transition from signaling mechanisms to MPS. Voluntary schemes such as the LEED certification have important visibility effects but are not binding, while regulations – especially MEES – have a direct impact on the marketability of an asset by limiting or banning its leasing or sale if below a certain performance threshold (Sayce et al., 2022). This type of constraint is being further strengthened under SFDR regimes (Cremasco & Boni, 2024). To this end, standardized reporting of portfolio-level carbon intensity in line with disclosure frameworks such as the EU taxonomy for sustainable activities and reporting standards creates fewer information asymmetries for regulators and facilitates the channelling of institutional capital towards assets above a certain sustainability benchmark (Tettamanzi et al., 2024).

At the same time, regulation risks accelerating asset stranding if there are no economic pathways to compliance (Sayce et al., 2022). For this reason, an effective combination of policy mixes also features carbon pricing mechanisms (CPM) and more targeted fiscal support (Yuan et al., 2023). Carbon taxes or emissions trading systems (ETS) schemes serve to internalize the social cost of carbon into building operating cost profiles and improve the financial case for deep retrofitting by shortening the payback period for RD projects (Petkov et al., 2023). At the same time, supply-side measures such as incentive-based urban planning (IBUP), including density bonuses for net-zero developments, allow developers to capture sustainability-related benefits into the value of a project and to address viability gaps (Onuoha et al., 2018).

In addition to formal regulation and pricing tools, the results of the research suggest that sector governance needs to also address the institutional and operational capacity of the sector. Public authorities are important as demand-side actors through green public procurement (GPP), imposing net-zero performance for publicly owned buildings and de-risking supply for private contractors and investors (European Investment Bank, 2025). To deal with the continued fragmentation of data in the built environment over the entire asset lifecycle, digital building logbooks (DBL) are starting to play a central role as information that is securely stored and made available over a number of ownerships and protects information on previous renovations and material composition (Berlato et al., 2025). In addition, training and skills requirements can be built into public procurement requirements to help address the current skills gap and shortages of retrofit professionals, reducing risks of cost inflation and delivery delays (Panakaduwa et al., 2025).

Last but not least, it is important to recognize that the new governance framework also needs to address challenges at the level of districts and urban areas that go beyond the building envelope. District-level solutions, such as decentralised heating or cooling systems, need institutional arrangements that can combine public risk-sharing with private investment and capital (Royapoor et al., 2023). Eight primary categories—Regulatory, Informational, Market, Fiscal, Planning, Organizational, Procurement, and Labor/Education—are used to group the various instruments and policy initiatives (Table 7). This classification is based on a synthesis-driven classification intended to improve analytical clarity while also reflecting variations in the strength of evidence across policy initiative pathways, based on the scope and consistency of findings in the literature, and the overall proposed decision-making framework, with its different elements, is shown in Figure 4.

Table 7. Policy initiatives and governance mechanisms for the decarbonization of real estate markets

No.	Policy initiative (PI)	Operational scope	Strategic function & economic rationale	Category	References
PI1	Mandatory performance standards (MPS)	Establishment of minimum energy ratings (e.g., EPC 'B' rating) required for the legal rental or sale of assets	Liquidity constraint: De-risking CapEx by creating an existential threat to the asset's ability to trade	Regulatory	(Sayce et al., 2022)
PI2	Sustainable finance disclosure (SFD)	Compulsory reporting of portfolio carbon intensity and climate risk exposure (e.g., SFDR, TCFD)	Market transparency: Eliminating information asymmetry to allow capital to flow more efficiently to best-in-class performers	Informational	(Cremasco & Boni, 2024)
PI3	Carbon pricing mechanisms (CPM)	Imposing either a carbon tax or an Emissions Trading System (ETS) on the commercial real estate sector	Cost internalization: Correcting for an unpriced externality and internalizing its associated cost of inaction (fossil fuel usage) into the ROI decision-making process	Fiscal/Market	(Petkov et al., 2023)
PI4	Green fiscal incentives (GFI)	Tax abatements, tax depreciation or cash grants offered to building owners to offset the cost of energy-efficiency retrofits	Viability Gap Funding: Softening the blow of the very high upfront capital requirements for deep retrofit projects	Fiscal	(Liu et al., 2025)

End of Table 7

No.	Policy initiative (PI)	Operational scope	Strategic function & economic rationale	Category	References
PI5	Green investment taxonomies (GIT)	Definitions which set minimum, science-based, performance requirements for "sustainable investment" to avoid "greenwashing" (EU taxonomy for sustainable activities, etc.)	Standardization: Solving information asymmetry for investors and standardizing which projects and issuers are eligible to raise funds via "green bonds"	Regulatory	(Tettamanzi et al., 2024)
PI6	Incentive-based urban planning (IBUP)	Density bonuses or other planning fast-track advantages offered to developers of net-zero carbon buildings	Supply-Side Motivation: Bidding up developer margins to better absorb the incremental cost premiums of green building	Planning	(Onuoha et al., 2018)
PI7	Public-Private Partnerships (PPPs)	Multi-stakeholder co-investment partnerships to share the financial risk and rewards of district energy or social housing retrofit projects	Risk Sharing: Using public sector credit guarantees to de-risk private investment, especially in low-yield property subsectors	Organizational	(Taghizadeh-Hesary & Yoshino, 2019)
PI8	Circular economy mandates (CEM)	Pre-demolition audit requirements, and new-build use of "Material Passports" and other circular economy principles	Embodied Carbon Control: Generating positive incentives to prevent demolition and incentivize asset reuse, while reducing the amount of waste generated by new construction	Regulatory	(Oliveira et al., 2024)
PI9	Green public procurement (GPP)	A requirement for all government-leased, owned, or operated real estate to be net-zero	Market Creation: Guaranteeing demand in the market for green buildings, allowing scale-economies to develop in the supply chain	Procurement	(European Investment Bank, 2025)
PI10	Digital building logbooks (DBL)	A "central register" of asset data which tracks renovation history, and energy performance over time	Data Continuity: Eliminating a common leakage point of "green value" loss when an asset changes hand	Informational	(Berlato et al., 2025)
PI11	Workforce skills mandates (WSM)	A requirement for all contractors bidding on public construction projects to include "green skills" training as part of their bid	Capacity Building: Proactively solving a predicted skills-shortage to avoid bottlenecks in retrofit projects	Labor/Education	(Panakaduwa et al., 2025)

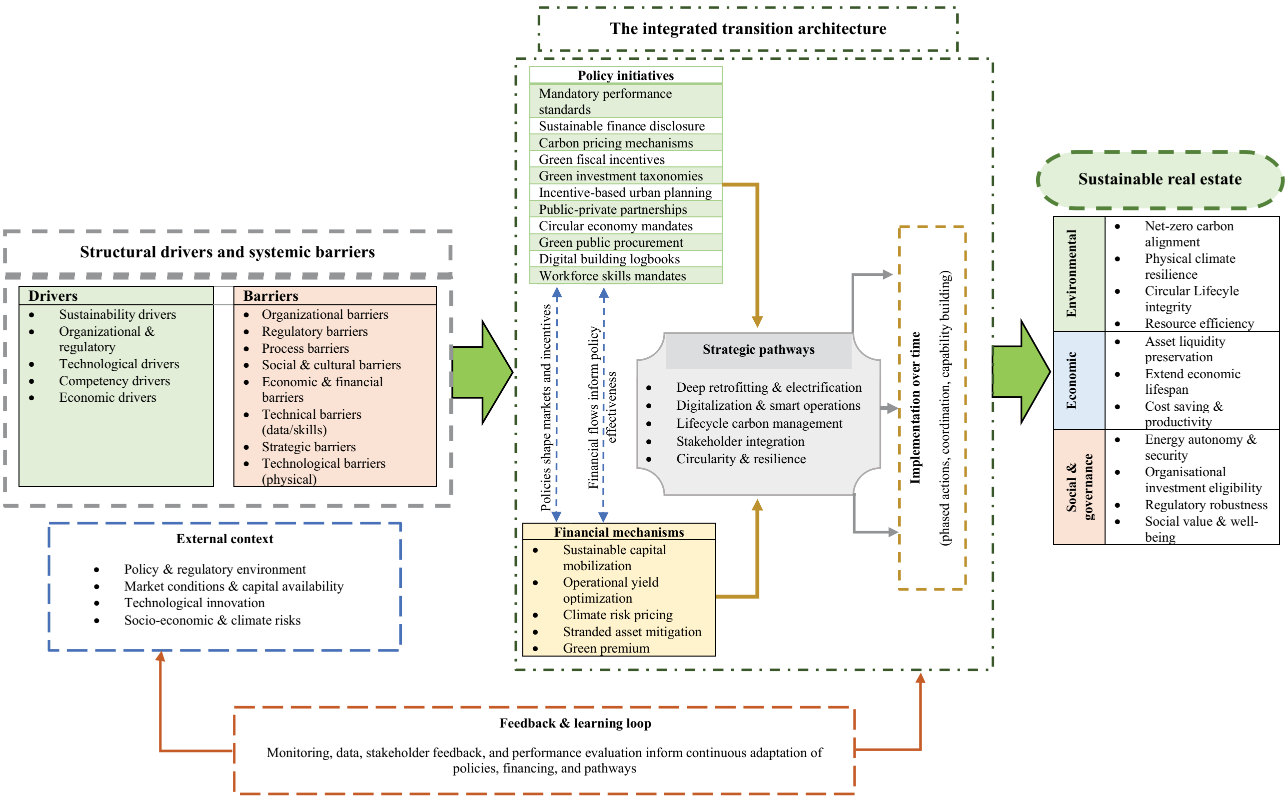


Figure 4. A multi-dimensional decision model for sustainable real estate paradigm

The practical implementation of this type of governance architecture will be context-specific, with mature economies with a large and older building stock facing a different set of constraints than developing and emerging markets, which implies the need for a differentiated but ultimately coordinated policy sequencing. However, the literature on governance is clear in that policy predictability, in particular in the form of ratcheting mechanisms that see regulation tightening in a clear and foreseeable manner, is one of the main drivers influencing long-term investor and capital allocation decisions (Sayce et al., 2022; Nyoni et al., 2023).

5. Discussion

The momentum building around the global real estate sector's sustainability transition has already reached a stage that far exceeds mere compliance. It is now actively disrupting and reconfiguring the core determinants of capital retention, asset liquidity, and long-term value creation (Newell & Marzuki, 2022). The primary contributions of this paper include: 1) extending the state of knowledge by developing a consolidated, interpretive, and integrated decision framework (Figure 4) to enable dynamic linkages between valuation, decarbonization strategy, and sustainability governance; 2) building on and bringing together the existing conceptual research and emerging case studies that address and support market transformation at the system, corporate, and asset levels; 3) highlighting a need for concurrent evolution of financial underwriting and technical retrofitting practices that have thus far remained largely isolated, yet are rapidly converging into a powerful self-reinforcing loop that can either drive a sustainable transition or act as a formidable structural barrier to it; and 4) showing how strategic responses (RQ2) can create access to finance mechanisms (RQ3), which in turn help break the logjam imposed by legacy system constraints (RQ1), but only when supported by additional policy interventions (RQ4).

A significant portion of the existing body of literature has been built around value effects measured through one or another of two distinct paradigms: engineering-driven studies on building energy performance and econometric analyses of market valuation (Leskinen et al., 2020b; Ruggeri et al., 2020; Nyoni et al., 2023). Although the seminal work by Jiao et al. (2025) helped quantify the phenomenon of energy efficiency capitalization in terms of green premium, the overall picture presented in the current paper points to a broader shift in investment rationale. Incentives to pursue the upside appear to be gradually losing out to motives of downside risk aversion, which are becoming the primary driver of market behavior (Sayce et al., 2022; Jiao et al., 2025). Empirical evidence suggests that both physical and transition risk pricing have now emerged as the dominant forces of real estate valuation, with the effects of brown discount outweighing the green premium in a number of markets (Sayce et al., 2022; Tavano & Salvo, 2025). This is in line with Cremasco and Boni (2024), who also noted that SFDR requirements are now effectively becoming gatekeeping mechanisms for access to capital. In addition, favorable financing terms, including those available via sustainability-linked loans, are increasingly tied to alignment with forward-looking, science-based decarbonization pathways, such as CRREM, rather than reliance on backward-looking certification labels (Hirsch et al., 2019; Mishra et al., 2023).

The persistent existence of an implementation gap, despite the now-evident clarity of the economic incentives at the asset level, points to a corresponding need for active policy intervention. The second key contribution of this research is, therefore, the identification of specific, targeted policy instruments to help address these well-documented market failures. As the analysis in this paper has shown, a central organizational challenge is posed by the so-called split-incentive problem, which causes landlords to forgo capital investment because efficiency gains benefit tenants (Singhal et al., 2025). This situation is clearly not sustainable and is unlikely to be corrected by market forces. Instead, green leases and MEES appear to be necessary to align the economic interests of owners and occupiers. Meanwhile, digital building logbooks (PI10) help overcome informational barriers by providing continuous data integrity across changes in ownership, thus allowing the valuation benefits to be more fully realized at the point of sale. Skills mandates (PI11) on the supply side are also an important component, enabling appropriate technical competence and avoiding inflationary pressure in retrofit labor markets as the financing mechanisms (PI4) scale. Finally, measures to promote a circular economy (PI8) are also important in this context, to shift attention away from operational energy use and towards whole-life carbon impacts, thus addressing embodied emissions from new development.

Building management systems are not new, but the deeper transition to more advanced digitalization and smart asset operations provides a clear strategic edge for the new sustainable paradigm (Tan & Miller, 2023). In contrast to their predecessors, which focused mainly on passive monitoring, AI-powered digital twins can actively optimize operational yields by continuously fine-tuning energy consumption in response to real-time conditions, including grid and occupancy signals (Hosamo et al., 2023). This helps to close the energy performance gap between design intent and actual operation. Meanwhile, the combination of deep retrofit and electrification also helps to decouple from fossil fuel price volatility (Royapoor et al., 2023). By using on-site renewable generation and high-efficiency heat pumps, assets can achieve a higher degree of energy independence, which would, in turn, support more stable net operating income by reducing exposure to external shocks (Petkov et al., 2023). In this sense, DRE and DSAO constitute a mutually reinforcing and complementary strategy that both bolsters technical resilience to physical climate risks and increases financial resilience to transition risk (Petkov et al., 2023; Tan & Miller, 2023).

Taken as a whole, the results of this research both confirm and build on the findings of previous studies. A long-established theme in the academic literature on energy efficiency and sustainability in real estate is the need for policy intervention to address market failures (Taghizadeh-Hesary & Yoshino, 2019; Singhal et al., 2025). This paper agrees with that position but goes further in its argument. Voluntary adoption mechanisms have largely reached their saturation point. The strongest possible incentives, namely mandatory performance standards (PI1), appear to be the most effective drivers of capital flows within the existing stock. This can be seen as a kind of validation of the barriers identified through the SLR, which are particularly resonant in terms of the well-known misalignment between investment time horizons and climate benefits, as well as valuation gaps more generally. It is thus clear that any attempts to reconcile the longer-term objectives with the short-term financial cycles will face significant challenges (Taghizadeh-Hesary & Yoshino, 2019). This study adds to the literature by: 1) proposing an interpretive and integrated decision framework that shows linkages between specific inputs and desired outputs (Figure 4); 2) positioning stranded asset mitigation as the critical interface between technical interventions and corporate strategy; and 3) specifically identifying key policy tools, such as green public procurement, as market catalysts beyond traditional regulation.

5.1. Implications for theory, practice, and policy

In general, the key findings of the study have important implications for theory development, managerial practice, and public policy, challenging conventional wisdom in real estate economics. By synthesizing the key drivers, barriers, and strategic responses, it shows that the transition to sustainable real estate is not just a technical upgrade, but a fundamental shift in the conceptualization of value and value creation within the property market.

5.1.1. Theoretical implications

The theoretical contribution of this study has important implications for the conceptualization of risk and return in real estate investment. For much of its history, previous research has framed sustainability in terms of value enhancement, with the green premium serving as a source of competitive advantage and differentiation (Leskinen et al., 2020b). In contrast, the findings of this paper suggest a shift towards value protection as the dominant paradigm. The evidence suggests that the key pricing dynamics are shifting away from a reward-based system toward penalty-driven mechanisms, which lends support to transition risk theory as the main conceptual lens for understanding asset depreciation arising from carbon obsolescence (Semieniuk et al., 2021).

The paper also contributes to agency theory by reframing the split-incentive problem. Whereas the previous literature has treated this as a contractual inefficiency, it now emerges as a broader market failure that prevents the efficient deployment of capital. Solving this issue therefore requires an evolution in both property rights and governance structures, especially green leases and stakeholder-oriented governance, which would redefine the responsibilities of owners and occupiers.

5.1.2. Managerial implications

Asset managers and institutional investors should heed the practical implications of the results and reevaluate their investment mandates accordingly. As the mechanism of stranded asset mitigation is now recognized as a key financial enabler, all capital expenditure related to decarbonization should be considered a defensive investment in order to protect liquidity, rather than as part of optional maintenance. Going beyond static ESG checklists, managers need to explicitly account for climate value-at-risk in DCF valuation models. This could be done by using internal carbon pricing as a basis for portfolio stress-testing against future regulatory and market scenarios, including CRREM-aligned pathways.

Operationally, the prominence of data-related barriers among the constraints in the model suggests a clear sequencing logic. Firms would be well advised to prioritize digitalization and smart asset operations ahead of any major physical retrofitting. The lack of appropriate data infrastructure (e.g., digital twins, advanced metering) would otherwise mean the asset is unlikely to meet the reporting requirements for sustainable capital access. Therefore, overcoming organizational silos is also crucial, with the most successful transition paths depending on effective cooperation between engineering, sustainability, and finance functions within unified governance structures.

5.1.3. Policy implications

For public policymakers, the implications of the analysis are that voluntary-only approaches are no longer sufficient to unlock decarbonization at the scale needed to meet global climate targets. A persistent implementation gap suggests the need for a dual policy mix that combines regulatory stick with targeted financial carrots. MPS should be used to phase out the most inefficient assets while fiscal de-risking instruments provide the needed investment stimulus and supply chain strength.

The findings also point to policy fragmentation as a significant structural barrier in its own right, thus highlighting the value of harmonization efforts to align local building regulations with global taxonomies, such as the EU taxonomy for sustainable activities. Divergent standards increase the compliance burden and serve as a major deterrent to cross-border investment. Finally, governments are also encouraged to take a more active role as market-makers through green public procurement, which would help create long-term, stable demand signals that can help accelerate the adoption of new technologies while also supporting the maturation of sustainable real estate markets.

5.2. Research gaps and future research pathways

The analysis shows that although certain paths are backed by solid evidence, others are still in the early stages of development or have scant evidence, indicating crucial areas for further study. Furthermore, several important research gaps are identified in the areas of RED and GI, and priority questions at the intersection of finance, decarbonization strategy, and sustainability governance are mapped. Table 8 highlights a structured research agenda as one of the main deliverables of this systematic review.

First, there remain major gaps in both valuation and governance. While there are now widely studied and consistent findings around the existence of green premiums, the processes through which brown discounts and stranding risks are now incorporated into formal appraisal methods are much less well understood. It is also not clear how circular economy principles might interact with financial instruments and how operational energy efficiency needs to be balanced with embodied carbon impacts from deep retrofits and new development. Second, from a methodological point of view, there is an obvious need for a more diverse approach. A large body of existing empirical research has relied on hedonic pricing models to develop its findings, but this leaves out potentially significant behavioral and organizational dynamics. More use of qualitative and longitudinal research could help to show how spreads in valuations between green and brown assets change over time and through different market cycles. Experimental designs might also be useful to see how investors and tenants perceive and price resilience and sustainability attributes. Finally, mixed-method research could help to understand the role of organizational factors, such as the differences between REITs, private equity firms, and others. The strategic choice to develop in-house capabilities or

Table 8. Decarbonization strategy and green investment in real estate: future research agenda

Thematic pillar	Critical research gaps	Propositions	Future research questions (FRQs)
Theme 1: Financial valuation & risk integration	Existing valuation methods are static and unable to properly value the long-tail "stranding" risks. There is no market consensus on how to adjust the discount rate for brown vs. green assets	Proposition 1: A quantifiable brown discount and green premium are produced by the rising capitalization of transition and physical climate concerns into real estate valuation parameters (discount rates, cap rates)	FRQ 1.1: To what extent do transitional risk indicators affect capitalization and discount rates in different asset classes? FRQ 1.2: What differences exist in the cost of physical climate risks between various real estate markets?
Theme 2: Organizational dynamics & governance	The "black box" of board level decision making is relatively unstudied. Past research has not explained the agency cost and inertia that explain why well capitalized firms are unable to execute	Proposition 2: Decarbonization initiatives are more aligned with companies that have more robust ESG governance systems and board-level competences	FRQ 2.1: How do ESG capabilities at the board level affect real estate companies' acceptance of science-based goals? FRQ 2.2: Which governance frameworks make it easier for investment committees to incorporate sustainability?
Theme 3: Policy efficacy & regulatory interaction	High level frameworks (i.e., SFDR) are developed in Brussels/DC, yet are ill-fitted for local market conditions. "Implementation gap" of how policy filters down to asset compliance is undocumented	Proposition 3: Capital allocation to green real estate assets is heavily influenced by regulatory frameworks and required transparency methods	FRQ 3.1: What is the impact of required ESG disclosure on capital flows into investments in sustainable real estate? FRQ 3.2: To what extent does the financial viability gap for retrofit projects get closed by fiscal incentives?
Theme 4: Technological transformation & data	PropTech is rapidly expanding, but data is still siloed and does not allow for holistic ESG management. Validation is lacking for how digital tools improve reporting vs carbon reduction	Proposition 4: PropTech and digital infrastructure usage improves operational carbon efficiency and ESG data transparency	FRQ 4.1: What role do digital twins play in real-time building energy performance optimization? FRQ 4.2: What effect does digitization have on carbon accounting and ESG reporting accuracy?
Theme 5: Circular economy & embodied carbon	The majority of research is focused on operational energy and GHG emissions. The embodied carbon data gap is growing, and impact of circular business models (Space-as-a-Service) is unproven	Proposition 5: Capital allocation is shifted toward adaptive reuse and low-carbon materials when whole-life carbon considerations are incorporated into investment decisions	FRQ 5.1: How can early-stage investment appraisals operationalize whole-life carbon assessments? FRQ 5.2: What are the financial trade-offs between techniques for adaptive reuse and demolition?
Theme 6: Social equity & the just transition	The "S" in ESG is marginalized in real estate. The link between aggressive decarbonization and the displacement of vulnerable tenants/ increasing inequality has not been explored	Proposition 6: Real estate decarbonization measures could exacerbate socioeconomic inequality in the absence of inclusive governance structures	FRQ 6.1: How can decarbonization policies be developed to prevent social exclusion and tenant displacement? FRQ 6.2: Which funding sources enable fair retrofitting of affordable housing?

End of Table 8

Thematic pillar	Critical research gaps	Propositions	Future research questions (FRQs)
Theme 7: Physical resilience & adaptation strategy	The real estate literature is heavily weighted towards "mitigation". Adaptation is not explored, and the underlying question of "how" is left for individual investors. No systematic investor-friendly methods/tools exist to value resilience as a tangible asset class	Proposition 7: Physical climate risks should be incorporated into investment and portfolio strategies since they are becoming more significant to asset performance	FRQ 7.1: How can real estate valuation models routinely incorporate physical climate risks? FRQ 7.2: How do the dynamics of the insurance market affect investment choices in high-risk sectors?
Theme 8: Supply chain & scope 3 management	Scope 3 emissions (supply chain) are a massive data black hole in the industry. The question of how developers/landlords can govern their multi-tier construction supply chains is not well understood	Proposition 8: Scope 3 emissions is A crucial but little-measured aspect of real estate decarbonization plans	FRQ 8.1: How can developers accurately measure and report Scope 3 emissions across construction supply chains? FRQ 8.2: Which procurement techniques make it possible to obtain low-carbon materials on a large scale?

outsource innovation to energy service companies (ESCOs) is also under-explored and would require an interdisciplinary, multi-disciplinary research effort to examine how it modulates decarbonization performance.

6. Conclusions and limitations

The international decarbonization targets are shifting the basis of economic viability for the real estate sector. For this reason, the asset management logic is no longer the point of reference in terms of value appraisals, shifting to a risk–reward framework for climate adaptation and carbon performance. This study fills this gap in the literature by contributing to a better understanding of the changing nexus between RED and GI through a systematic synthesis of the transition. The data extraction covered 74 articles and reports to articulate the taxonomy of valuation levers, governance models, and technological interventions underlying the shift towards realignment of built assets with net-zero pathways. The derived findings and their visual illustration in this work provide a valuable guide for real estate decision-makers and researchers for repositioning stranded property portfolios towards being a new asset class of climate-transition investments.

The key insights from addressing RQ1 and RQ2 shed light on the underlying architecture of the nascent real estate paradigm based on sustainability criteria. In response to RQ1, the article synthesizes the five key groups of transition levers (sustainability–related, organizational, technological, competency-based, and economic) and the important barriers (split incentive, physical, and technical obsolescence) most frequently discussed in the reviewed literature. Regarding RQ2, the five main pathways (DRE, DSAO, LCM, SIGG, and CRI) that facilitate the operationalization of decarbonization for real estate assets have been identified. In the aggregate, the findings related to the first two research questions presented here suggest the transition toward a mandatory realignment of real estate investments with the impending carbon regulations to avoid obsolescence and a diminishing business case.

Concerning RQ3, there is an apparent change in the appraisal logic of real estate assets. While the green premium appeared to be the primary consideration for embedding sustainability in commercial and residential buildings, the persistent value proposition of built assets has more to do with the effective convergence of regulation adherence, tech-readiness, and physical hardening. As for RQ4, this work concludes with an articulation of a multi-step decision-making architecture representing the endogenous response of real estate companies to the exogenous forces (regulatory, ESG risks) in the form of a generic but data-driven visualization framework. This approach explains how asset liquidity, under certain conditions, is no longer a function of location or expected yield but is increasingly dependent on the firm's GI practices to internalize the embodied carbon circularity and social implications in the transition process. In this way, this work transcends the knowledge silos between sustainable finance and property management literature, conceptualizing decarbonization pathways for real estate portfolios as a risk-avoidance response to potential asset stranding in the form of superior operational outcomes. Furthermore, the pathways reported in this study have different empirical foundations, and some of them need additional verification to ensure their applicability in various scenarios.

The review also surfaces significant gaps in the existing body of literature, which forms the backbone for a future research agenda (Table 8). The outcomes of this study are therefore expected to impact subsequent real estate research directions by prompting a shift from traditional to more climate-responsive valuation logic. It also applies to researchers exploring the practical challenges associated with the integration of ESG criteria in investment and capital market decision-making in an era of heightened and accelerating climate risk.

Limitations

While this work offers a unique conceptual basis for appraising the nexus between RED and GI in the broader context of sustainable real estate investment, it is subject to several notable limitations. First, this is primarily an integrative study, which, by triangulating the primary literature, produces a conceptual model but does not validate it using empirical evidence from primary data. In this regard, rather than testing causal relationships or quantifying effect sizes, this study is primarily descriptive and interpretive, aiming to organize and synthesize current knowledge. As a result, its practical implications may have lower external validity in a different investment context or set of boundary conditions. Second, while it was necessary to include grey literature sources to account for applied industry practice and public policy, the search of academic sources was limited only to Scopus and Web of Science. Although this search strategy reflects the highest bibliometric standard and consistency, some studies that are exclusively cited in specialized grey sources or published in regionally specific journals were left out. As a result, the most current debate on some underdeveloped areas of GI or innovative RED interventions that are underrepresented in these indices may have been lost. Third, the current study was limited to the intersection of real estate investment and long-term strategy decision-making. The corpus was limited to strictly property management or engineering perspectives if and only if their implications for valuation or real estate decision-making were clear. Purely technical or engineering-specific design principles and solutions are thus relevant to building performance as they concern physical interventions, but were out of the scope of this work. Finally, this review has identified that, while multiple cross-sectional studies in the existing literature have provided proof of concept for each of the RED and GI interventions of practical interest, no rigorous longitudinal data is available in the context of real estate. The preponderance of cross-sectional data in this emerging field limits the possibility of making robust causal inferences between some of the key decarbonization initiatives (e.g., circular retrofit strategies) and long-term financial value creation. The proposed framework and its several components would therefore benefit from being tested against longitudinal data from the portfolios that have already been identified with net-zero ambition and aligned with the relevant roadmaps in the holding periods going beyond five years to generate conclusions with stronger external validity.

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