

Assessing Sectoral Low-Carbon Transition Impacts

- an assessment approach applied to the embedding of transition debt finance in Swedish commercial real estate

Magnus Berglind

Mälardalen University Press Licentiate Theses
No. 382

ASSESSING SECTORAL LOW-CARBON TRANSITION IMPACTS

**AN ASSESSMENT APPROACH APPLIED TO THE EMBEDDING OF
TRANSITION DEBT FINANCE IN SWEDISH COMMERCIAL REAL ESTATE**

Magnus Berglind

2026



Department of Business and Mathematics

Copyright © Magnus Berglind, 2026
ISBN 978-91-7485-751-1
ISSN 1651-9256
Printed by E-Print AB, Stockholm, Sweden

Abstract

Transition-oriented debt finance has expanded rapidly alongside growing expectations that financial actors will contribute to low-carbon transitions. Yet it remains uncertain whether such financing practices translate into meaningful impacts at the sectoral level. A central difficulty is analytical: when a low-carbon intervention is embedded over time, impacts on sectoral transition cannot be inferred from the scale of embedding, the presence of recognizable change, or compliance with criteria and reporting routines. This licentiate thesis develops and applies an analytically grounded approach for retrospective assessment of sectoral low-carbon transition impacts. It then interprets what the assessments imply about how the embedding of transition debt finance relates to sectoral low-carbon transitions. The approach addresses two analytically distinct types of impact: emission goal alignment of innovation and the acceleration of transformative low-carbon processes. Assessments consider the extent, low-carbon scope, and depth of linked innovation and process change relative to explicit reference points. The approach is applied to the embedding of transition-oriented debt finance in the Swedish commercial real estate sector from 2014 to 2021, an extreme case in which discernible impacts would be comparatively likely. The study adopts a critical realist-inspired research design and conducts a qualitative, retrospective sectoral case study drawing on documents, focus groups and interviews, and structured procedures for analytical linking and assessments. In this case, sectoral low-carbon transition impacts are interpreted as constrained: emission goal alignment is limited in the operations value chain and absent in the construction value chain, while acceleration of transformative low-carbon processes remains limited overall. This shows that extensive embedding of transition debt finance does not guarantee strong sectoral low-carbon transition impacts, even under favorable conditions for discernible impacts. Eligibility and reporting emphasized operations and standardized credentials, while construction and embodied-emission hotspots were less consistently targeted. By developing and applying an assessment approach focused on alignment and acceleration, the thesis advances a sector-level transition impact framing and provides a structured way to assess those impact types against explicit reference points, while treating credentialing as analytically central.

Acknowledgments

To my supervisors Peter Ekman, Cecilia Erixon, Matthias Holmstedt and Jimmie Røndell, my deepest gratitude for your patience, especially when I kept wrestling with loose ends instead of tying them off as you suggested. Thank you for welcoming me as a peer in the larger research project, and for challenging and supporting my ideas and drafts. As discussant, Magnus Frostenson had an important impact on this final version by providing insightful feedback at the final seminar.

I also want to thank the representatives of real estate companies and associations for making this thesis possible. Furthermore, I want to thank the PhD candidates and senior scholars within the Industrial Economics and Organization research specialization at MDU and the Swedish research school of Management and IT for providing a strong learning environment.

Anna and Liv, for inspiring this journey and keeping me going, thank you.

Västerås, February 2026

Magnus

Contents

1. Introduction.....	1
1.1. Background.....	2
1.2. Problematization	7
1.3. Purpose and research questions	9
1.4. Thesis disposition.....	9
2. Theoretical and analytical perspectives	10
2.1. Sectoral low-carbon transitions.....	10
2.2. Finance in low-carbon transitions.....	12
2.3. Accounting and credentialing	16
2.4. Conceptualizing low-carbon transition impacts.....	19
2.5. Analytical logic for assessing low-carbon transition impacts.....	27
2.6. Analytical framework for emission goal alignment.....	32
2.7. Analytical framework for acceleration of transformative low-carbon processes	38
2.8. Summary of analytical development.....	40
3. Research methodology	41
3.1. Critical realism inspiring the research approach.....	41
3.2. Research design	43
3.3. Empirical foundation.....	44
3.4. Analytical procedures.....	51
3.5. Research quality.....	55
3.6. Ethical considerations	55
4. The Swedish CRE sector	57
4.1. The pressure to transition	57
4.2. Sector characteristics.....	59
4.3. Emissions.....	64
4.4. Low-carbon innovations.....	69
5. Embedding of transition debt finance.....	80
5.1. Transition risk considerations.....	80
5.2. Green bonds and loans	84
6. Assessments	94
6.1. Alignment by value chain.....	94

6.2. Solution pathway contributions	97
6.3. Assessed acceleration.....	103
7. Discussion.....	113
7.1. Assessed low-carbon transition impacts.....	113
7.2. Why assessed impacts remain constrained.....	115
7.3. Impact investment and finance in transitions.....	118
7.4. Answering the research questions.....	120
7.5. Analytical contributions to retrospective assessment.....	121
8. Conclusion	123
8.1. Substantive conclusions from the case study.....	123
8.2. Theoretical contributions.....	124
8.3. Policy implications.....	125
8.4. Suggestions for future research.....	127
References	128
Empirical sources.....	135

List of figures and tables

Figure 1. An illustration of the goal–sector–solution space developed by Andersson and Hellsmark (2024, p. 3).....	21
Figure 2. How Andersson and Hellsmark (2024, p. 7) illustrated directionality in the results.	22
Figure 3 Analytical logic for assessing low-carbon transition impacts in relation to transition debt finance.	29
Figure 4 Structuring of innovation patterns by goal orientations, value chains and solution pathways	33
Figure 5 Specification of value chains, solution pathways and goal orientations within the conceptual organization of innovation patterns.	36
Figure 6 Regulatory cap of bought operational energy per sqm (values for the region of Stockholm).....	72
Figure 7 Assessed emission goal alignment of innovation by value chain..	96
Table 1 Summary of low-carbon solution options per generic low-carbon strategy and CRE value chain (and emission category).	27
Table 2 Qualitative analytical scale for joint assessment of extent, low-carbon scope and depth.	31
Table 3 Goals relevant for structuring and interpreting innovation patterns.	34
Table 4 Generic solution pathways for reducing emissions financed and reducing exposure to transition risks.....	35
Table 5 Sectoral value chain categories.....	36
Table 6 Ideal transformative low-carbon processes, (adapted from a typology in Andersen et al., 2023).....	39
Table 7 Framework for acceleration of transformative low-carbon processes	40
Table 8 Description of collected data	49
Table 9 Summary of assessed acceleration of transformative low-carbon processes.	105

Abbreviations

BBR	Boverket building code regulation
CO ₂ e	Carbon dioxide equivalent
CRE	Commercial real estate
GBP	Green Bond Principles
GHG	Greenhouse gas
GO	Guarantee of origin
IPCC	Intergovernmental panel on climate change
MLP	Multi-Level Perspective
R&D	Research and development
sqm	Square meter
TCFD	Task Force on Climate-Related Financial Disclosures

Definitions

Financiers	Actors involved in the provision of debt capital to borrowers. Including lenders, debt investors and intermediaries facilitating larger debt transactions (e.g. underwriters and credit rating agencies in bond issuance). In this thesis, financiers exclude equity investors, as the thesis focuses on debt finance.
Low-carbon transition impacts	In this licentiate thesis, low-carbon transition impacts refer to how an ongoing sectoral transition is affected in relation to its endpoint of effectively addressing climate change. They may materialize both as emission goal alignment of innovation, and as acceleration of transformative low-carbon processes, both assessed against relevant reference points for low-carbon transitions.
Socio-technical system	Encompassing the configurations of actors, institutions and technologies that help coordinate activities to fulfill a specific societal function (such as place and space for service activities).
Transition debt finance	Transition debt finance refers to forms of debt finance that are structured, through practices and criteria, in relation to sectoral low-carbon transitions. This includes conditioning debt finance on low-carbon transition-related criteria, directing capital toward assets and activities expected to align with emission reduction trajectories, and incorporating climate-related transition risks into credit assessment and pricing of debt.
Transition debt finance embedding	Processes through which transition debt finance expands in volume and becomes institutionalized as state of the art and eventually an integral part of debt finance (e.g. in a sector).

1. Introduction

Scientists have a moral obligation to clearly warn humanity of any catastrophic threat and to ‘tell it like it is’. On the basis of this obligation [...] we declare, with more than 11,000 scientist signatories from around the world, clearly and unequivocally that planet Earth is facing a climate emergency. (Ripple et al., 2019, p. 8)

This licentiate thesis explores a topic at the heart of contemporary climate policy and research: how the embedding of low-carbon interventions impacts low-carbon transitions in high-emission sectors. The urgency of this topic is underscored by persistently rising global greenhouse gas (GHG) emissions and by successive assessments by the Intergovernmental Panel on Climate Change (IPCC), which show escalating climate-related risks and damages as global temperatures rise (IPCC, 2014a; IPCC, 2023). These assessments also indicate that effectively addressing climate change requires rapid and deep emission reductions especially in developed economies, in turn requiring rapid and far-reaching transitions in all sectors (IPCC, 2023). Not surprisingly, changed conditions for and redirected flows of finance are a key enabler of low-carbon transitions.

One of the key societal responses emphasized in international climate policy is the redirection of capital flows. In particular, the Paris Agreement highlights the need to make financial flows consistent with pathways toward low greenhouse gas emissions and climate-resilient development. This has contributed to increasing expectations that financial actors, alongside states and firms in the real economy, will play an important role in supporting low-carbon transitions. Finance, including the expanding use of debt-based transition finance, is often described as a critical enabler of climate mitigation, with expectations that financial practices will support the development, diffusion, and scaling of low-carbon solutions while discouraging continued investment in high-emission activities. At the same time, doubts are growing about whether such financing practices translate into meaningful impacts on sectoral low-carbon transitions.

While research increasingly examines relationships between finance and low-carbon change, retrospective assessment of sector-level low-carbon transition impacts remains analytically demanding in contexts where low-carbon interventions, such as transition debt finance, are embedded over time and where impacts on low-carbon transitions cannot be reduced to movement in a single indicator.

In light of these considerations, this licentiate thesis develops an analytically grounded approach for assessing sectoral low-carbon transition impacts, and applies it to the embedding of transition debt finance in the Swedish commercial real estate (CRE) sector.

1.1. Background

The background section introduces climate change and the Paris Agreement, low-carbon transitions, transition debt finance, and the Swedish commercial real estate sector, in order to situate the research topic and motivate the subsequent problematization.

1.1.1. Climate change and the Paris Agreement

Climate change (also referred to as global warming or global heating) was first introduced to the agenda of international politics in 1988. Already in 1990, the United Nations-assembled scientific group, the IPCC, had assessed and summarized the extant body of research related to climate change and called for the establishment of a global treaty. This led to the creation of the United Nations Framework Convention on Climate Change (UNFCCC), which aimed to stabilize the atmospheric concentrations of GHGs at a level considered safe. Despite successive international commitments and decades of negotiations, global GHG emissions have continued to rise.

At the same time, scientific assessments have documented increasing risks of hazardous effects of climate change, including sea-level rise, increased heat stress, water stress, extreme weather events and wildfires (IPCC, 2014a; IPCC, 2023). These physical impacts are associated with degradation of ecosystems and with broader societal consequences such as coastal flooding, food and water shortages, increased poverty and displacement of people, as well as asset damage and supply chain disruptions affecting companies and municipalities (IPCC, 2023). Over time these developments contributed to growing recognition that incremental change is insufficient and that deep reductions in emissions are required within limited time frames.

The Paris Agreement, adopted in 2015, marked a turning point by establishing commitment to temperature goals: to limit global warming to well below 2°C and strive for 1.5°C. The 197 signatory countries committed to providing ambitious societal responses in order to (in their respective home countries) reduce GHG emissions enough to achieve the temperature goals.¹ Under the Paris Agreement's principle of common but differentiated responsibilities, achieving the global temperature goals presupposes deep and rapid sectoral emission reductions in developed countries.

¹ United Nations / Framework Convention on Climate Change (2015-12-12) The Paris Agreement.

In addition to mitigation targets, the Paris Agreement highlights the role of finance. Article 2.1(c) states that financial flows should be made consistent with a pathway toward low greenhouse gas emissions and climate-resilient development. This formulation has contributed to increasing expectations that both public and private finance will play an important role in strengthening societal responses to climate change.

1.1.2. Low-carbon transitions

Research on sustainability transitions has developed to analyze how deeply entrenched systems of production and consumption undergo structural change in response to grand sustainability challenges (Köhler et al., 2019). Within this body of research, low-carbon transitions refer to processes through which socio-technical systems are reoriented in ways that address the problem of climate change (Geels, 2018). This implies that low-carbon transitions involve long-term change from existing, largely fossil fuel-based socio-technical systems toward systems based on low-carbon technologies and including altered markets, user practices, cultural meanings, infrastructures, policies, industry structures, and value chains (Köhler et al., 2019).

In this thesis, low-carbon transition is examined at the sectoral level, where socio-technical systems condition and structure patterns of production and consumption generating GHG emissions. Furthermore, innovation is understood in a broad sense as referring to changes in technologies, practices, business models and infrastructures or institutions in socio-technical systems. Low-carbon innovation refers to such changes when they are oriented toward reducing GHG emissions (or enhancing long-term carbon sinks). This definition specifies the objects of change examined in relation to low-carbon transitions, without presupposing how such changes unfold or with what effects.

Transitions literature often stresses the insufficiency of incremental improvements, efficiency gains, or isolated innovations (Köhler et al., 2019; Markard et al., 2012). At the same time, the relevance of innovative change in this context depends on more than just its disruptiveness or diffusion, but on its contribution to reducing GHG emissions in line with explicit climate goals.

Discussions of directionality and goal orientation have long been present within sustainability transitions research, particularly in debates concerning governance, normative commitments, and the role of policy in shaping transition pathways (Andersson et al., 2021; Smith et al., 2005). However, such discussions typically take a cautious approach, emphasizing open-ended processes, plurality of pathways, and the difficulty of specifying desirable end states in advance. As a result, empirical analyses have tended to focus on examining change dynamics and system reconfiguration without systematically assessing their relation to explicit temperature goals and carbon budgets. For example, Geels (2019) acknowledges that:

transitions scholars tend to say less about sustainability outcomes or impacts. Assuming that ‘green’ innovations are intrinsically positive, they rarely address how much sustainability improvement they offer and if this would be sufficient to address persistent environmental problems at the speed required (p. 189).

Given the time-bound nature of climate targets and the scale of transformation implied by the Paris Agreement, this thesis takes a more explicit stance by examining how observed innovation and change can be understood as low-carbon transition impacts in relation to emission goal alignment and the acceleration of transformative low-carbon processes at the sectoral level.

1.1.3. Transition debt finance

Successive assessment reports by the IPCC have emphasized the role of finance in enabling low-carbon transitions, as deep and rapid emission reductions require large-scale changes in investment patterns and financial flows (IPCC, 2014a, pp. 29-30; IPCC, 2023, p. 111).

Transition debt finance refers to forms of debt finance that are structured, through practices and criteria, in relation to sectoral low-carbon transitions. Such finance encompasses a range of practices, including conditioning debt finance on low-carbon transition-related criteria, directing capital toward assets and activities expected to align with emission reduction trajectories, and incorporating climate-related transition risks into credit assessment and pricing of debt. Examples include practices related to green bonds and loans that since 2014 have expanded rapidly (Flammer, 2021; Maltais & Nykvist, 2020) and started to embed into some sectors characterized by high capital intensity and strong reliance on debt finance.

Access to such finance is typically mediated through formal criteria, reporting requirements, and accounting-based indicators, rather than through the direct specification of technological innovation or changes in sectoral practices.

In financial and policy discourse, transition debt finance is commonly associated with two interrelated goals that have contributed to strong expectations that sectoral embedding of transition debt finance will strengthen low-carbon transitions. First, it is framed as aligning debt finance with credible emission reduction trajectories consistent with the Paris Agreement temperature goals.² Here, alignment involves increasing financing for the development, scaling, and adoption of climate solutions, while also increasing financing for lower-carbon initiatives in high-emitting sectors and phasing out financing for high-emission activities. Second, it is framed as reducing financiers’ exposure to climate transition risks by shifting capital toward activities and companies better positioned in low-carbon transitions. Transition risks refers to financial risks arising from societal responses to climate change, including regulatory change, technological shifts and business model innovation, shifting consumer demand,

² G20 Sustainable Finance Working Group (2022) 2022 G20 Sustainable Finance Report.

and potential reputational or liability issues for laggard corporations.³ Such responses may either incur revenue loss, increased costs or offer business opportunities to assets and corporations which may trigger reassessment of their values and affect their possibilities to attract finance (Campiglio et al., 2023). These corporate transition risks spill over to the financing of these corporations.

Both greenhouse gas emissions and climate-related transition risks were becoming financially material over the decade of 2010-2020, indicated e.g. by higher cost of debt (higher interest rates) for EU companies with higher GHG emissions than their comparable peers and lowered cost of debt for companies improving their climate performance and transparency regarding their climate-related opportunities, risks and performance (Caragnano et al., 2020; Eliwa et al., 2021; Palea & Drogo, 2020).

The emergence of transition debt finance should be understood against this backdrop of evolving goals, expectations, and increasing evidence of financial materiality, rather than as the immediate implementation of a clearly articulated transition finance agenda. Around the time of the Paris Agreement, many debt finance practices that later came to be associated with low-carbon transitions were not explicitly framed in relation to emission reduction trajectories or climate transition risks. Instead, climate-related considerations tended to enter debt markets in more fragmented ways, often through early green finance initiatives, disclosure practices, and risk-related discussions. Around 2020 many debt investors and banks set investment portfolio targets and joined initiatives explicitly linked to climate objectives.⁴

Taken together, these developments contributed to a gradual rearticulation of debt finance practices in relation to low-carbon transitions, rather than a sudden or uniform shift.

At the same time, existing research highlights significant uncertainties and constraints regarding how such finance relates to emission reductions and sectoral transition processes (Akomea-Frimpong et al., 2022; Ante, 2024; Naidoo, 2020; Nykvist & Maltais, 2022; Penna et al., 2023).

Alignment with climate goals is often articulated and assessed through accounting-based representations and certifications, rendering such representations important for how financial actors evaluate, compare, and legitimate transition debt finance. As a result, accounting practices and associated credentials become analytically central to how transition debt finance is embedded in sectors and to how alignment with low-carbon transitions can be assessed.

³ Cicero Shades of Green (2020) Sustainable Edge Sector Brief: Real Estate; Task Force on Climate-related Financial Disclosures (n.d.) About.

⁴ Note: initiatives included the Principles of Responsible Banking, the Net Zero Asset Owners Alliance, the Paris Aligned Asset Owners, and the Net Zero Banking Alliance.

1.1.4. The Swedish CRE sector

The Swedish commercial real estate (CRE) sector constitutes a sectoral socio-technical system in which transition debt finance has been embedded over time. This makes the sector a relevant empirical setting for examining how such finance relates to sectoral low-carbon transitions, without presupposing that financial practices act as direct drivers of change. The CRE sector encompasses interrelated configurations of actors, institutions, technologies, and artefacts that together condition and enable how building space is developed, financed, operated, and used to fulfill its societal function: the provision of place and space for service-sector activities.

Within this sectoral system, high emissions along two key value chains are particularly relevant for understanding the sectoral GHG emissions associated with commercial building space.⁵ These value chains are treated as analytical slices of the wider socio-technical system, tracing distinct but interlinked sequences of production and consumption processes through which emissions arise.

The operations value chain concerns the day-to-day provision of functional and attractive commercial spaces for tenants. This includes processes related to indoor temperature and air quality, lighting, hot water, elevators, security, and other building services. The energy and fuels required for these processes give rise to operational emissions along this value chain.

The construction value chain concerns the longer-term development, maintenance, and adaptation of commercial properties. It includes new construction, extensions, major renovations, repurposing of buildings, repeated maintenance of building elements and systems, and tenant-related space adaptations over contract cycles. Emissions along this value chain arise primarily from the energy and material inputs associated with the extraction, production, transport, and installation of construction materials and building systems, contributing to embodied emissions. Together the operational and embodied emissions render the CRE sector one of the high-emission sectors.

To fulfill its societal function, the CRE sector is highly dependent on large volumes of financial capital for property acquisition, construction, and development. Property values are high relative to annual operating income, resulting in strong reliance on debt finance (Shleifer & Vishny, 2011).⁶

Swedish CRE companies were also early adopters of transition debt finance, including green bonds and green loans. The sector has played a prominent role in the expansion and sectoral embedding of transition debt finance, with targets, criteria, and reporting practices that articulate transition ambition. The combination of high emissions along key value chains, strong dependence on debt

⁵ Note: strictly speaking, each of these are bundles of alternative value chains.

⁶ Sveriges Riksbank (2017) *Fördjupning - Kommersiella fastigheter och finansiell stabilitet*, pp. 35-37; Finansinspektionen (2019) *Den kommersiella fastighetsmarknaden och finansiell stabilitet*, pp. 14-18.

finance, and early and extensive embedding of transition debt finance makes the Swedish CRE sector particularly suitable for retrospective assessment of sectoral low-carbon transition impacts.

1.2. Problematization

Despite strong expectations that finance will contribute to societal responses to climate change, considerable uncertainty remains regarding how such expectations relate to impacts on low-carbon transitions (Naidoo, 2020; Nykvist & Maltais, 2022; Penna et al., 2023; Steffen & Schmidt, 2021). Redirecting capital flows is widely framed as a key enabler of low-carbon transitions (IPCC, 2023),⁷ and transition debt finance has expanded rapidly over the past decade. However, it remains analytically challenging to assess whether, and in what ways, the embedding of transition debt finance can be understood as contributing to low-carbon transition impacts at the sectoral level (Kölbel et al., 2020).

A central difficulty is that ‘impact’ is often invoked without clear separation between different types of change. Sectoral developments may reflect increased activity in climate-related initiatives or improved disclosure and target-setting, without necessarily shifting underlying transition trajectories (Brander et al., 2018; Delmas & Burbano, 2011). This creates an assessment problem in which finance may be associated with ‘greener’ activity, while it remains uncertain whether such developments amount to low-carbon transition impacts at the sectoral level, and if so in what sense.

At the same time, much of the contemporary climate policy landscape is organized around long-term targets, most notably commitments to net-zero emissions, which have become a central reference point for both public and private actors (Hale, 2022). Such targets implicitly rely on assumptions about emission trajectories compatible with the temperature goals of the Paris Agreement. Translating temperature goals into compatible sectoral emission trajectories relies on accounting-based representations, benchmarks and metrics, which introduce specific boundaries around what is counted and assessed. Research has raised concerns that, within such boundary-setting, assumptions may remain implicit. These include reliance on future negative emissions, limited attention to differentiated responsibilities, as well as assumptions embedded in how alignment is accounted for, e.g. through market-based emission accounting approaches (Anderson et al., 2020; Bjørn et al., 2022). These concerns complicate how alignment with long-term targets is understood and assessed in relation to low-carbon transition impacts.

Similar tensions are evident in the literature on climate/green/transition finance and impact investing. An expanding empirical evidence base links

⁷ United Nations / Framework Convention on Climate Change (2015-12-12) The Paris Agreement, article 2.1c.

financial instruments and financing conditions to climate-relevant outcomes and performance metrics. However, this evidence does not resolve the assessment problem at the center of this thesis: how sectoral embedding of transition debt finance can be retrospectively assessed as low-carbon transition impacts over time, under explicit criteria.

The challenge is an absence of assessment logics and analytical frameworks that make explicit what counts as impact, and relative to what (see e.g., Schlütter et al., 2024). Such an approach should also enable interpretation of sectoral change without reducing low-carbon transition impact to a single indicator or single dimension of change. In this context, two analytically distinct questions become salient: whether changes to innovation patterns are aligned with emission goals, and whether process-related changes indicate an acceleration of transformative low-carbon processes rather than symbolic alignment or incremental adjustments. These distinctions motivate the development of an analytically grounded approach that separates emission goal alignment from process acceleration when assessing sectoral low-carbon transition impacts.

Although the empirical focus here is transition debt finance, the analytical challenge is broader and concerns how embedded low-carbon interventions in sectoral contexts can be retrospectively assessed in relation to low-carbon transition impacts.⁸ Sustainability transitions research has long discussed goal orientation and directionality, including how to accelerate low-carbon transitions (Andersen et al., 2023) and how to characterize the low-carbon directionality of policy-related innovation patterns (Andersson & Hellsmark, 2024). At the same time, the literature has been cautious about translating accounts of system change into systematic assessments of outcomes and impacts. Geels (2019) notes that transitions scholars tend to say less about the magnitude of sustainability improvement and whether such improvements are sufficient to address climate change “at the speed required” (p. 189). This creates a persistent assessment gap: how to judge the emissions-goal alignment of innovation and whether observed change reflects an acceleration of transformative low-carbon processes, rather than incremental low-carbon adjustment or the acceleration of transformative processes that are not low-carbon.

The Swedish CRE sector is used as an analytically strategic case in this thesis. As described in section 1.1.4, the sector is emission-intensive and debt-dependent, with unusually deep and early embedding of transition debt finance. Taken together, these features make Swedish CRE an extreme and information-rich setting for examining how transition debt finance relates to sectoral low-carbon transition impacts, under relatively favorable conditions for such impacts. Accordingly, the case provides strong leverage for assessing and interpreting this relationship, and for stress-testing the assessment approach developed in this thesis.

⁸ Note: in this thesis, low-carbon interventions encompass policy and policy-like interventions, including transition debt finance.

1.3. Purpose and research questions

Based on the analytical challenge identified above, the purpose of this licentiate thesis is to develop and apply an adaptable, analytically grounded approach for retrospectively assessing low-carbon transition impacts in a sectoral case where a low-carbon intervention has been embedded over time. The purpose is also to interpret what the assessments imply about the relationship between such embedding and sectoral low-carbon transitions more generally.

Accordingly, the thesis addresses two research questions:

RQ1. How can low-carbon transition impacts be retrospectively assessed, with separate attention to the emission goal alignment of innovation and the acceleration of transformative low-carbon processes?

RQ2. How is the embedding of transition debt finance related to sectoral low-carbon transition impacts in the Swedish CRE sector?

The thesis contributes to research and policy discussions on assessing sectoral low-carbon transitions by clarifying how sectoral low-carbon transition impacts can be assessed and interpreted when low-carbon interventions are embedded over time, with separate attention to emission goal alignment of innovation and the acceleration of transformative low-carbon processes.

Empirically, the approach is applied to the Swedish commercial real estate sector, where transition debt finance has been extensively embedded, to evaluate the approach's applicability and analytical leverage and to provide an empirically grounded basis for interpreting how such embedding relates to sectoral low-carbon transition impacts.

1.4. Thesis disposition

The licentiate thesis is structured as a monograph with eight chapters. Following this introduction, chapter 2 presents the theoretical and analytical perspectives and develops the analytical frameworks used to assess low-carbon transition impacts. Chapter 3 outlines the methodological premise, research design, empirical foundation and analytical procedures used and discusses research quality and ethical considerations. Chapter 4, the Swedish CRE sector, provides context to the study. Chapter 5 covers the embedding of transition debt finance and related innovation patterns and processual changes. Chapter 6 presents the assessed emission goal alignment of innovation, and the assessed acceleration of transformative low-carbon processes. Chapter 7 discusses the findings. Chapter 8 concludes the thesis and outlines implications and suggestions for future research.

2. Theoretical and analytical perspectives

This chapter focuses on theoretical perspectives relevant given the purpose and research questions, and develops analytical logic and frameworks for assessment of low-carbon transition impacts.

2.1. Sectoral low-carbon transitions

Sustainability transitions research offers perspectives for analyzing transitional change, where the Multi-Level Perspective (MLP) on sustainability transitions (Geels 2002; Geels 2004; Geels, 2011, Köhler et al., 2019) is a middle-range theory that conceptualizes overall dynamic patterns in socio-technical transitions. In this thesis, the MLP is used as a generic analytical heuristic, while the retrospective impact assessment is developed through a separate analytical approach with explicit criteria and reference points. While the MLP foregrounds niche–regime–landscape interactions, this thesis uses the embedding of low-carbon interventions as the analytical anchor for retrospective assessment, where low-carbon interventions are not treated as niches.

2.1.1. MLP and socio-technical transitions

The MLP was created to help analyze system innovation (transition) at the level of socio-technical systems (Rip and Kemp, 1998; Geels, 2002; Geels, 2011). It combines concepts from evolutionary economics (trajectories, regimes, niches, path dependence, routines), science and technology studies (sense making, social networks, innovation as a social process shaped by broader societal contexts), structuration theory, and neo-institutional theory (rules and institutions as ‘deep structures’ on which knowledgeable actors draw in their actions, duality of structure, ‘rules of the game’) (Geels, 2011; Köhler et al., 2019).

With the MLP, socio-technical transitions are conceptualized as coming about through dynamic interactions within and between three analytical levels: niche, regime, and landscape.⁹ One way of justifying them as ‘levels’ is their increasing degree of institutionalization and structuration of practices (Geels, 2011; Fünfschilling and Truffer, 2014).

⁹ Note: they are analytical, not ontological levels.

The regime level represents an incumbent socio-technical system, often conceptualized as a deep structure or semi-coherent set of rules that orient and coordinate the activities of the social groups that reproduce the various elements of socio-technical systems (Geels, 2004; Geels, 2011). Transitions are often defined as structural shifts from one regime to another.

The niche level represents innovative alternatives to the regime (Rip and Kemp, 1998). Analytically, the MLP sees the niche level as derived from the regime level, defined in relation to the regime and analyzed along the same dimensions (Geels, 2011). For example, a niche may deviate on technical rules and market rules but stay close to existing rules with regard to usage and behavior. Sustainable niches comprise networks of real-world initiatives or practices that embody a novel and weakly institutionalized socio-technical configuration likely to lead to substantial sustainability gains (Berkhout et al., 2010; Smith et al., 2010). As niches are normally not able to compete against the selection environments in each dimension of a system regime, a niche space depends on multiple processes shielding, nurturing and empowering it, involving e.g. incubators, programs, subsidies, mobilization of actors, policies, etcetera (Kemp et al., 1998; Smith & Raven, 2012).

The landscape level is an external economic, political and cultural context beyond the influence of system actors, where the MLP is mainly interested in those exogenous factors conducive to stabilizing the regime and those landscape developments (e.g. crises) that put pressure on the regime to change, which in turn can open a window of opportunity for niches (Geels, 2002; Geels, 2011).

Emerging problems within a system can also open up windows of opportunity for niches (Turnheim & Geels, 2012). For example, emerging problems with technology, changing user preferences, or government regulations may generate misalignments, realignments, and incremental responses in a regime, which open up windows of opportunity for niches to compete for attention and influence.

The MLP, with its conceptualization of regime as institutionalized rule sets (Geels, 2002) or as an institutional logic (Fünfschilling & Truffer, 2014) has been criticized for tending to steer the analyst toward underplaying both agency and materiality (Sorrell, 2018; Svensson & Nikoleris, 2018). Where Sorrell (2018) argues for adopting a critical realist conception of structure (Archer, 1995), which would imply that it is the structured system elements of the socio-technical system that guide action, not only regime rules or institutions. This critique informs how sectoral systems are treated in this thesis (but without shifting to mechanism-based explanation).

2.1.2. Low-carbon interventions as analytical anchor

Low-carbon interventions are distinct from how niches are conceptualized in sustainability transitions research. Niches typically refer to emerging socio-technical configurations and protective spaces that enable novel technologies or practices to develop and challenge the incumbent regime. By contrast, low-

carbon interventions are purposeful policy or policy-like arrangements, such as transition debt finance, that broadly target incumbent actors and become embedded into sectoral practice over time and shape innovation patterns and transition processes. In the Swedish CRE case, transition debt finance is therefore not treated as a niche competing with incumbent regime; it is treated as a low-carbon intervention embedded through financial practice (e.g., eligibility logics, risk analysis, documentation, and reporting conventions) that conditions innovation and process change within the sector. This motivates an assessment approach that focuses on changes analytically linked to embedded interventions rather than on niche–regime dynamics.

2.2. Finance in low-carbon transitions

Köhler et al. (2019) identify the role of financial capital in restricting and promoting direction of change as an important research direction for sustainability transitions research. Geddes and Schmidt (2020) propose strengthening the role of finance in the MLP by conceptualizing it as a separate socio-technical regime: a selection environment involving financiers and financial markets, strongly interacting (and slightly overlapping) with all other socio-technical regimes and interacting with niches of other socio-technical systems. In their view, technological innovations and financial regime need to align in order for (enough) finance to flow to niches to facilitate their breakthrough (Geddes & Schmidt, 2020).

Steffen & Schmidt (2021) argue that the financial system may not operate like other socio-technical systems and that finance-related transition dynamics may therefore need to be represented differently. Transition scholarship has distinguished pathways that differ in how far incumbent regimes are reworked. For the purposes of this thesis, the relevance of this distinction is limited to one implication: finance has incentives to favor transition dynamics (transformation or reconfiguration) that preserve incumbent viability and limit stranded-asset risk, rather than disruptive substitution (Geels & Schot, 2007; van der Ploeg & Rezai, 2020). These considerations align with framing transition debt finance as a low-carbon intervention that targets incumbent sectoral actors and conditions change processes and innovation patterns, rather than as a niche or regime.

Limits to finance as driver or accelerator of transitions

Nykvist & Maltais (2022) studied Swedish financial actors' engagement with sustainable finance in 2017-2018 and, based on the results and extant research, discussed whether the finance sector can act as a driver or accelerator of sustainability transitions. These authors identified that financiers' mandates to maximize risk-adjusted return rates constitute an important barrier to acting as drivers in sustainability transitions (including low-carbon transitions). Such mandates make financial actors hesitant to finance less proven sustainability

solutions (where risks are difficult to assess due to elements of uncertainty) and slower to withdraw finance from unsustainable solutions. The authors concluded that financial actors are unlikely to act as drivers in sustainability transitions (including low-carbon transitions) and pointed out the need for public policy mixes to tip the balance by further improving the conditions and competitiveness of novel sustainability solutions relative to existing unsustainable solutions (Nykqvist & Maltais, 2022).

Other studies (Naidoo, 2020; Penna et al., 2023) discuss what changes in the financial system are required in order to support sustainability transitions. For example, they argue that responses of the financial system to the Paris Agreement need to be adapted to the contextual needs of transitions (Naidoo, 2020).

2.2.1. The problem of demonstrating impact

Penna et al. (2023) argue that the core rule of sustainable investing should be to invest in impact, such that “focus of investment should be on supporting activities, projects, and companies that contribute to system change (instead of investing in individual projects and companies that contribute to system optimization)” (p. 4). They propose operationalizing this investment focus on system change impact by assessing the contributions of investments to core sustainability transitions processes.

In recent years, following the establishment of the SDGs and the Paris Agreement on climate change, streams within the literature on sustainable finance have increasingly discussed ‘impact investment’ and ‘investment impact’ and may be described as sustainable finance 3.0, a third step or stage of sustainable finance toward contributing to sustainable development (Shoenmaker & Schramade, 2019). Sustainable finance 3.0 is characterized by financing only companies and projects that either meet specific sustainability criteria or are deemed to have the potential to generate significant positive social and environmental impacts. While ensuring a ‘fair financial return’, which often means at par with or close to a normal or comparable market-rate return. As the starting point for investment at this third stage concerns identifying opportunities for actual social and environmental impact through investment and lending, it is often referred to as impact investing (Shoenmaker & Schramade, 2019). A systematic review of impact investing research finds that the literature rarely scrutinizes impact above and beyond organizational-level outputs (Schlütter et al., 2024).

Often, financiers and equity investors claiming to use an impact investment strategy (or to be impact investors) actually apply an investment strategy more closely aligned with sustainable finance 2.0, as they do not prioritize actual sustainability solutions over financial return and use the term ‘impact’ to attract sustainability-oriented savers (Busch et al., 2021).

Kölbel et al. (2020) and Marti et al. (2024) reviewed existing literature on ways investor activities can trigger change in companies’ environmental and social

impact and found that there is strong empirical support for impact through shareholder engagement and partial support for impact through capital allocation.

Capital allocation strategies that apply sustainability screening approaches may incentivize companies to improve the environmental or social quality of activities in order to fulfill investor inclusion criteria. To be an effective incentive, enough equity investors or financiers need to apply similar screening criteria that affect corporate share prices (Rohleder et al., 2022) and cost of debt. Capital allocation strategies that create more favorable financial conditions, for example a lower cost of debt and improved access to debt capital, for companies with a positive impact may also allow them to grow faster than unsustainable competitors (Kölbel et al., 2020).

Kölbel et al. (2020) highlight a knowledge gap regarding impact of capital allocation: “studies that not only relate [Sustainable investment] to asset prices but also investigate the response of affected companies in terms of management and investment decisions would advance understanding of investor impact decisively” (p. 569).

A third impact strategy is field building, which fosters corporate sustainability by influencing companies’ institutional context (Marti et al., 2024). Financiers may indirectly trigger change in companies’ environmental and social impact by stigmatizing specific business activities, establishing sustainability disclosure standards or voicing support for regulatory change.

Busch et al. (2021) suggest differentiating between two categories of impact-related investments: ‘impact-aligned’ and ‘impact-generating’. Impact-aligned investments are undertaken based on already achieved impact, for example finance conditioned on a sustainability performance indicator meeting a benchmark. Whereas impact-generating investments are undertaken based on expectations of further impact through the investment. For example, finance may be conditioned on corporations having set science-based climate targets and a credible transition plan, complemented with criteria for post-investment evaluation (Busch et al., 2021). They also argue that there are three ways for financiers to actively contribute to impact generation:

- (i) provide additional capital that allows companies or projects to generate a social and/or environmental impact;
- (ii) focus on companies that establish forward-looking targets toward impact generation;
- (iii) prompt companies to change by effectively utilizing the two post-investment decision approaches: voting and engagement regarding social and environmental issues, using clear milestones (Busch et al., 2021).

This literature on impact investing highlights the analytical difficulty of identifying and assessing real-economy transition impacts of finance.

2.2.2. Transition debt finance through capital allocation

Finance via green bonds and loans is a manifestation of capital allocation strategy that saw consistent strong growth from around the time of the Paris Agreement (Flammer, 2021). This growth was fueled by strong debt investor demand, with higher oversubscription of green bonds than of regular bonds, thus offering issuers lower interest rates and more reliable access to capital compared to regular bonds (Löffler et al., 2021; MacAskill et al., 2021). Also in Sweden, common reasons for corporate bond issuers to issue green bonds include access to a broader investor base, a lower cost of debt, and meeting investor demand (Maltais & Nykvist, 2020).

Another manifestation of capital allocation strategy concerns debt pricing and constraints on access to debt capital based on exposure to transition risks (Semieniuk et al., 2021). Because exposure to corporate transition risks aggregates in debt (and equity) portfolios, high-emitting companies may face lower valuations and increased finance costs if financiers and equity investors systematically embed climate-related transition risks into their credit and portfolio risk assessments (Campiglio et al., 2023).

Financiers face several challenges in effectively considering transition risks:

- (i) Transition risks are partly expected to materialize beyond the traditional horizons of most finance (and business) actors (Schoenmaker & Schramade, 2019); notably including credit rating agencies whose assessments typically do not cover more than the next five years.
- (ii) Financiers tend to downplay future financial implications of transition risks by strongly discounting them via required rates of return. For example, even when attempts are made to internalize sustainability impacts in investment decisions, the principle of time value of money reflected in required return rates tends to favor short-term profitability (even with negative long-term sustainability impacts) and disfavor sustainable investments (when positive sustainability impacts materialize long-term) (Baur & Lagoarde-Segot, 2016).
- (iii) Added uncertainty stems from the fact that transition risks are partly generated and reinforced by financial activities,¹⁰ given that transition risk exposure depends on the actualization of low-carbon innovation and enablers (including redirections of finance), and that actualization in turn depends on how societal actors (including financiers and financial supervisors) perceive the financial risks of pursuing those innovations and enablers (IPCC, 2022, p. 1583). As long as climate policies are not stringent and strong enough to send credible signals regarding how the transition will be pursued, it is extra challenging for financiers to assess and manage transition risks and identify a rational pace of portfolio reallocation toward low-carbon investments (Battiston et al., 2017).

¹⁰ Note: unlike other financial risks assumed to originate from outside the financial system.

These constraints further complicate the assessment of whether and how financial embedding contributes to low-carbon transition impacts.

2.3. Accounting and credentialing

Accounting practices and certification credentials are treated as mediating devices through which alignment with climate goals is articulated, assessed and operationalized in transition-related finance, rather than as neutral representations of biophysical emissions.

2.3.1. Climate accounting perspectives

GHG accounting may be conducted by creating an inventory of emissions associated with a product (through attributional life-cycle analysis), a corporation (according to scopes 1-3 in the GHG Protocol) or a sector (e.g. via input-output analysis), within specified boundaries (e.g. delimiting away parts of a value chain or activities outside a geographic area or country).

Attributional methods are suitable for tracking an entity's GHG emissions over time, for example to assess a sector's progress toward an emissions target relative to a base year (Brander, 2022). Attributional methods create an inventory of emissions associated with a corporate or sectoral value chain. Due to complexity and data availability, such inventories cannot account for all activities within the value chain or for the full range of variations in locations, inputs, and processes used. Normative choices regarding inventory boundaries and data sources therefore affect the inventory results.

Consequential methods on the other hand, may be used retrospectively to estimate the result of an intervention by comparing resulting GHG emissions to a counter-factual baseline. Such analyses allow inclusion of consequences outside of inventory boundaries (which would delimit an analysis based on an attributional method) but introduce uncertainties through counterfactual assumptions regarding baseline scenarios (Brander, 2022).

Accordingly, climate accounting should not be taken at face value, and both the delimitations inherent in attributional accounting and the counterfactual assumptions embedded in consequential accounting merit scrutiny.

2.3.2. Market-based energy accounting and credentialing

Environmental accounting has been pointed out as an effective countermeasure against greenwashing, but there are also climate accounting rules that have been criticized for allowing greenwashing. Environmental accounting literature has criticized the corporate use of market-based accounting method to calculate GHG emissions from the production of energy purchased (Brander et al., 2018; Bjørn et al., 2022).

Relevant e.g. for CRE companies where GHG emissions from generation of purchased electricity and heat, mainly accounted for in scope 2 but also partly in scope 3, represent an important part of total company emissions.

The dominant GHG accounting standard, the GHG Protocol, has since 2015 allowed companies to disclose two values in parallel for GHG emissions from purchased energy (scope 2): location-based (using grid or network average emission factors) and market-based. Companies can then choose which of these two emission values to include in their total emissions aggregation.¹¹ The GHG Protocol also allows companies to use market-based energy emission calculations for setting company-level emission targets and for consequential or intervention accounting, such as calculating and reporting GHG emission impact from green finance.

Market-based accounting allows companies that purchase energy with a renewable origin guaranteed by the energy vendor to report the GHG emissions from its production (often zero), rather than the production emissions associated with the actual energy mix delivered to the company through electricity grids and district heating networks. At the start of the period studied, the EU countries already had regulated a designated market instrument called guarantees of origin (GOs)¹².

While companies paying a small price premium for purchased ‘renewable’ energy are entitled to use the associated low or zero emission factors, other companies purchasing standard electricity or heat offerings (without a guaranteed origin) instead must calculate the market-based energy emissions (in scope 2) using ‘residual mix’ emission factors.¹³

The GHG emission factor for the ‘residual mix’ is typically very high, as it represents the residual electricity or heat mix after deducting all contracted renewable electricity or heat with a guaranteed origin. Nevertheless, the electricity and district heating delivered through grids and networks to companies remain unchanged, still depending on the mix of energy inputs to grids and networks depending on where the company is located, and thus continue to produce the same actual GHG emissions to the atmosphere. Several studies suggest that, collectively, GOs and other variants of renewable energy certificates or energy product labels do not substantially contribute to a shift from fossil to renewable energy production (Hamburger & Harangozó, 2018; Mulder & Zomer, 2016), and that the market-based method to account for energy GHG emissions provides misleading information to stakeholders about companies’ GHG emissions and progress toward emission targets (Brander et al., 2018).

The use of contractual renewable energy products combined with market-based energy emission accounting is also indicated to help companies

¹¹ GHG Protocol (2015) GHG Protocol Scope 2 Guidance, p. 8.

¹² Note: based on the EU Renewable Energy Directive.

¹³ GHG Protocol (2015) GHG Protocol Scope 2 Guidance.

demonstrate progress toward their science-based emission targets without any biophysical emission reductions (Bjørn et al., 2022).

Building certification schemes can similarly function as credentials that enhance perceived climate responsiveness and are susceptible to symbolic compliance with limited biophysical emission reductions (Greer et al., 2019; Nygaard, 2023).

Thus, the use of such accounting practices and credentials, for example in eligibility criteria, performance indicators, or benchmarks, deserves analytical attention when assessing the sectoral embedding of transition debt finance and related low-carbon transition impacts.

2.3.3. The relevance of embodied emissions

Traditionally, top-down categorization of economic activities into sectors has typically separated building operations from building construction into different economic sectors.¹⁴ In line with this separation, much of the literature on buildings and energy has focused on optimizing the ‘operational’ energy use and associated GHG emissions (Röck et al., 2020). Case studies from the late 1990s and the 2000s on building life-cycle energy also indicated that operational energy was four to nine times that of embodied energy, supporting a focus in low-carbon innovation and public policy on the operational energy (Ramesh et al., 2010).

Furthermore, emission disclosure standards and literature on climate mitigation and low-carbon innovation initially focused on emissions that were relatively easy to account for and address: scope 1 and 2 emissions.¹⁵ These scopes cover the point-of-generation emissions for operational energy. With increasing interest in both the (un)sustainability of business models and the corporate exposure to transition risks (which often stem from value chains), attention has slowly turned toward accounting for and mitigating scope 3 emissions produced along the value chain (Blanco, 2021), which include embodied emissions generated in the CRE construction value chain.

Recommendations to focus on operational building emissions simultaneously diverted attention away from ‘embodied’ building emissions related to new construction, maintenance, adaptations for tenants, renovations, and demolition. For example, building code regulations applicable to new construction and major renovations in many countries, including Sweden, required the measurement and limitation of operational energy (and thus operational GHG emissions), whereas the energy related to construction materials and construction work was excluded from building code regulation (Birgisdottir et al., 2017).

However, most of the early case studies validating the rule of thumb that operational energy and associated emissions are much higher than embodied energy and emissions were conducted in geographical contexts where operational

¹⁴ Examples include the primary/secondary/tertiary sector classification and the IEA classification of energy-use sectors as buildings/industry/transport.

¹⁵ GHG Protocol. (n.d.)

energy was derived from fossil fuels and the buildings were not, by modern standards, constructed to be energy efficient (see, e.g., Ramesh et al., 2010).

As shown by Röck et al. (2020, p.258), modern buildings subject to strict energy performance requirements have a higher share of embodied emissions than buildings constructed in earlier periods or under less rigorous requirements. This shift is further pronounced in regions where operational electricity and heating rely on energy mixes with lower GHG emission factors and construction still rely mainly on high-emission energy sources derived from fossil fuels (e.g., coal for cement and steel production), where embodied emissions may exceed operational energy emissions over the building life-cycle (Birgisdottir et al., 2017; Röck et al., 2020).

These accounting boundaries are analytically important for assessing low-carbon transition impacts, because they shape which value chains are made more or less visible.

2.4. Conceptualizing low-carbon transition impacts

In assessing low-carbon transition impacts, it is important to distinguish between innovation patterns and processual change. Innovation patterns refer to the orientation, composition, and prioritization of changes in technologies, practices, business models, frame conditions through regulation and policy, and/or changing user preferences and practices that are relevant for GHG emissions. Processual change, by contrast, refer to how such changes unfold over time through the reorientation of actors, institutions, and technologies within sectoral socio-technical systems.¹⁶

Despite long-standing discussions of directionality and goal orientation within sustainability transitions research, the field has primarily focused on explaining patterns and dynamics of socio-technical change rather than on assessing how such changes relate to explicit climate goals, and questions of sustainability impacts have often remained implicit or assumed (Geels, 2019).

However, given the biophysical urgency of climate change and the time-bound nature of climate targets, particularly in relation to the role of policy and policy-like interventions in shaping transition pathways, a more explicit engagement with low-carbon transition impacts becomes necessary. This shift in analytical attention creates a need for analytically grounded approaches that enable retrospective assessment of how observed innovation and change can be understood in relation to low-carbon transitions.

Building on literature strands that emphasize different aspects and characteristics of innovation and transition processes, low-carbon transition

¹⁶ Note: in the emission goal alignment assessment developed below, innovation patterns are operationalized in a solution-oriented manner, which is why some forms of low-carbon innovation are assessed as transformative low-carbon processes.

impacts are here conceptualized along two analytically distinct but interrelated types, impacts related to:

- (i) emission goal alignment of innovation;
- (ii) transformative low-carbon processes.

These two types are elaborated in the following subsections, drawing on existing literature to situate and justify the conceptual choices made, while analytical specification is provided in subsequent sections.

2.4.1. Emission goal alignment of innovation

Building on existing literature on climate targets and directionality of innovation, this thesis conceptualizes a first type of low-carbon transition impact in terms of emission goal alignment of innovation.

In the context of climate change, such goals are typically articulated through temperature targets, most prominently those established under the Paris Agreement, and associated CO₂ and GHG emission reduction trajectories reviewed by the IPCC as being compatible with these goals. These provide prominent global benchmarks for low-carbon transitions (Hale et al., 2020). From this perspective, low-carbon transitions are beyond diffusion of radical innovation also about whether the direction of innovation is compatible with such benchmarks (Geels, 2019; Geels & Turnheim, 2022).

Within transitions research, this orientation has historically been treated with caution. While directionality has long been discussed in relation to governance and policy steering, empirical analyses have often avoided explicit assessment of how innovation patterns relate to temperature goals. This reluctance reflects concerns about normativity, uncertainty, and the difficulty of translating global targets into sectoral benchmarks. As a result, many studies document innovation trajectories, diffusion patterns, or regime shifts without systematically assessing whether such developments can be understood as aligning with emission reduction goals.

However, assessing low-carbon transitions without reference to emission goals risks conflating change with progress. In this thesis, emission goal alignment provides a normative reference point for assessing whether innovation patterns are oriented toward addressing climate change, but not for assessing aggregated emission outcomes as such.

2.4.2. Directionality of innovation

Closely related to emission goal alignment are discussions of the directionality of innovation in transitions research. Directionality concerns not whether innovation occurs, but what kinds of innovation are promoted, stabilized, or marginalized over time. In the context of low-carbon transitions, this involves questions of

whether innovation trajectories reinforce continued reliance on high-emission solutions or imply a reorientation toward low-carbon technologies and practices.

Innovation in established systems is over time typically characterized by path dependency, proceeding along existing innovation pathways, due to higher plausibility and increasing returns to adoption (Arthur, 1989). That is, even before a low-carbon transition, innovation in socio-technical systems has directions. Innovation pathways that are preferable in relation to sustainability goals may be termed to exhibit normative directionality (Andersson et al., 2021).

Directionality therefore provides an analytical lens for assessing whether innovation patterns align with available low-carbon solution pathways, emission-relevant value chains, or emission goals. The notion of directionality of innovation implies a vectoral perspective on innovation, in turn raising the question in which n-dimensional space the vector exists (Andersson et al., 2021). Andersson and Hellsmark (2024) propose a three-dimensional solution space with the dimensions: sectoral coverage, solution pathways, and transition goals. Their goal-sector-solution space with the dimensions populated for their study, is illustrated in Figure 1 below:

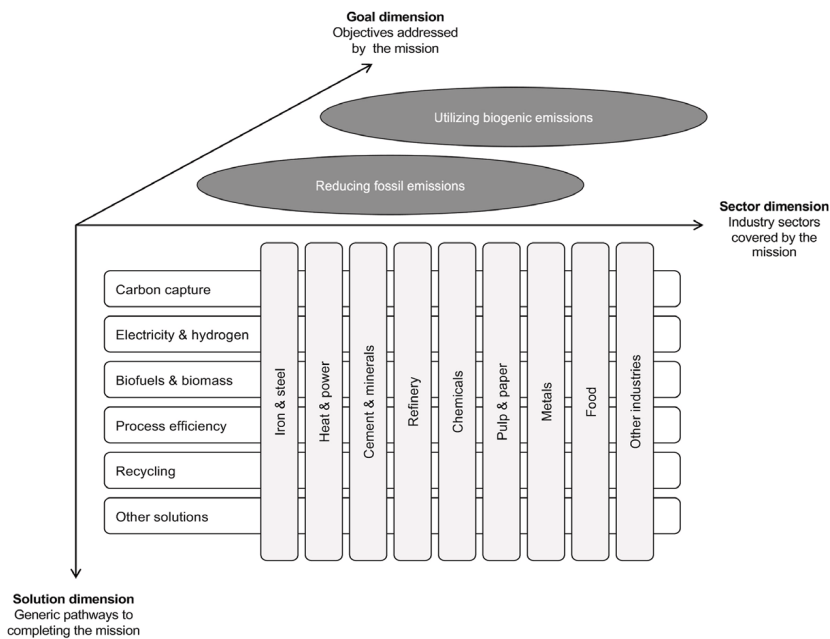


Figure 1. An illustration of the goal–sector–solution space developed by Andersson and Hellsmark (2024, p. 3).

In their study, Andersson and Hellsmark (2024) used the goal–sector–solution space to assess the directionality of mission-driven innovation activities. The dimensions enabled mapping the where, what, and goal of the amounts invested in mission-driven innovation activities, assigning to each investment amount a

mission-relevant combination of sector, socio-technical solution pathway and goal. Directionality then referred to the pattern of investment prioritization among sectors, solution pathways, and mission goals for the mission-driven innovation activities. The resulting directionality could then be illustrated graphically and numerically, see Figure 2 below.

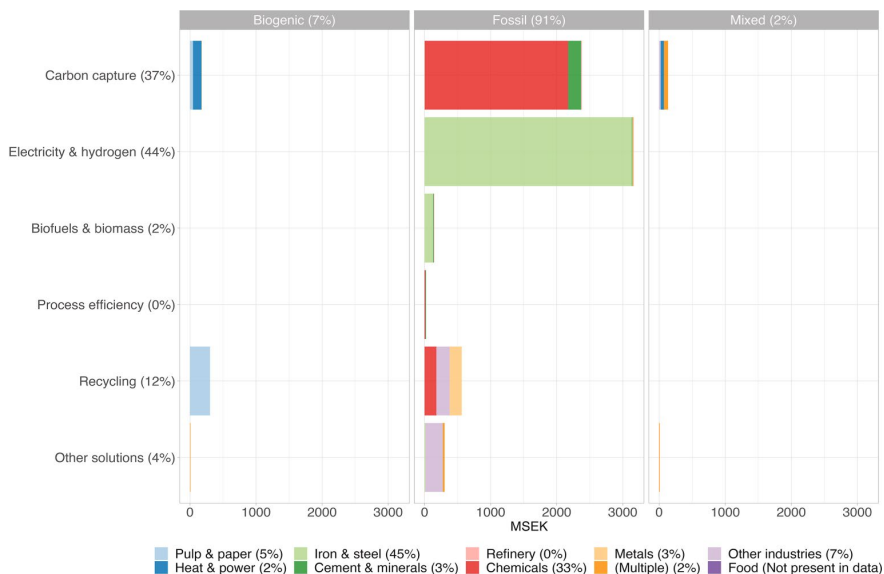


Figure 2. How Andersson and Hellsmark (2024, p. 7) illustrated directionality in the results.

Thus, the framework offered Andersson and Hellsmark (2024) a way to highlight the degree to which each sector, generic solution, and goal were targeted via the transformative policy mission. The framework also offered a way to highlight the degree to which different sector-solution-goal combinations were addressed.

In this thesis, directionality is treated as an analytical lens that supports the assessment of emission goal alignment, while remaining conceptually distinct from questions of the extent of change. Directionality thus helps clarify how innovation trajectories relate to low-carbon goals, without presupposing that innovation automatically translates into emission reductions.

2.4.3. Transformative low-carbon processes

A second type of low-carbon transition impacts, as conceptualized in this thesis, concerns the acceleration of transformative low-carbon processes. This understanding draws on literature emphasizing key ways to accelerate low-carbon transitions (Köhler et al., 2019). In particular, the literature stream on accelerating low-carbon transitions has focused on identifying the processes and process characteristics that may be key to accelerating low-carbon transitions.

Andersen et al. (2023) frame a typology of nine ways to accelerate low-carbon transitions.¹⁷ The typology groups the nine ways by the principal socio-technical system dimension affected (institutional, actor, or technology) and is summarized below.

The institutional dimension may be affected via stronger policy support (Axsen et al., 2020; Kivimaa & Kern, 2016), changing social norms that influence consumer preferences in the direction of low-carbon technologies or social practices (Bowles, 1998), the development and strengthening of visions for a net-zero society, including new technologies and social practices (Bergek et al., 2008; Schot & Geels, 2008).

The actor dimension may be affected via the reorientation of business actors leading to increased belief and investments in low-carbon technologies and business models (Stalmokaitė & Hassler, 2020), increased adoption of low-carbon technologies or social practices by users as solutions become better and cheaper and as social norms change (Rogers, 2003), and the formation of actor coalitions around low-carbon innovations, which lobby and exert pressure for policy change (Meckling et al., 2015; Roberts & Geels, 2019).

The technology dimension may be affected via performance improvements of low-carbon technologies resulting from research and development or learning processes (Malhotra & Schmidt, 2020), cost reductions arising from economies of scale and learning-by-doing (Arthur, 1989), and the availability of supporting assets such as skills, materials, and finance, as well as complementary technologies and infrastructure (Rosenberg, 1976).

A literature search addressing these and related processes did not identify additional ways to accelerate low-carbon transitions, but pointed to complementary or clearer conceptualizations (David, 2017; Späth & Rohracher, 2010; Teece, 1986).

To some extent, Andersen et al. (2023) and other sources also have highlighted how these processes may interact, ideally to form positive feedback loops (Geels & Ayoub, 2023). For example, the strategic reorientation of business actors toward low-carbon innovations may spur, and be spurred by, the formation of actor coalitions and strengthened policy support for low-carbon innovations (Schot & Geels, 2008). Another potential feedback loop is that increased adoption of low-carbon technologies or social practices by users may both help scale production, resulting in cost reductions, and enable learning processes that yield performance improvements, both in turn stimulating further adoption (Arthur, 1989).

¹⁷ Note: Andersen et al. (2023) talks about ‘mechanisms’ but I have chosen to denote them ‘ways’ as they are not consistent with a critical realist generative causality view of mechanisms (Danermark et al., 2002).

An adapted process typology

Drawing on Andersen et al. (2023) and complementary sources (David, 2017; Späth & Rohracher, 2010; Teece, 1986), I have adapted the typology of Andersen et al. (2023) to clarify the how and the low-carbon character where warranted. The adapted typology functions as an ideal-typical analytical reference, describing ideal processes for accelerating low-carbon transitions.

Institutional:

- (i) adding multi-dimensional policy support for low-carbon niche innovations and removing policy support for institutionalized high-emission practices and technologies (Kivimaa & Kern, 2016), helping to destabilize the system by reducing the value of existing high-emission practices and technologies and incentivizing incumbent actors to engage in the transition (Kivimaa & Kern, 2016), or even exnovate high-emission technologies deemed obsolete (David, 2017);
- (ii) changes to practices and societal discourse, in turn changing social norms that influence user preferences toward low-carbon technologies and social practices (Bowles, 1998);
- (iii) developing and institutionalizing guiding visions of low-carbon systems or societies and low-carbon pathways, which help mobilize corporate agency (Schot & Geels, 2008; Späth & Rohracher, 2010).

Actor:

- (iv) strategic reorientation of business actors (changes in direction of innovation experimented with and adopted), which helps mobilize belief in and investment in new technologies and business models (Stalmokaitė & Hassler, 2020);
- (v) increased adoption of low-carbon technologies or social practices by users as solutions become better and cheaper, as they gain attention, and as social norms change (Arthur, 1989; Rogers, 2003);
- (vi) formation of actor coalitions around low-carbon innovations and their lobbying for policy change in support of the innovations (Roberts & Geels, 2019).

Technology:

- (vii) R&D or learning processes resulting in performance improvements of low-carbon innovations (Malhotra & Schmidt, 2020);
- (viii) scaling production and learning-by-doing, helping to make low-carbon technologies competitive on cost (Arthur, 1989);
- (ix) making available complementary assets, technologies and infrastructure supporting low-carbon technologies (Teece, 1986).

Assessment of actual processes vs ideal processes

As conceptualized in the typology, these processes accomplish technological, institutional, and actor low-carbon reorientations and the strengthening of low-carbon pathways. It may seem straightforward to simply assess the manifestation of ideal processes as low-carbon transition impacts. However, it is important to recall that these are ideal processes, and actual processes cannot be expected to manifest ideally. Instead, actualizations may vary with regard to persistence over time, the range of actors, technologies, or institutions involved, their low-carbon orientation, and their potential to disrupt or transform the system. This makes it necessary to assess their focus on system transformation and low-carbon directionality. A transformative focus implies displaying the potential to achieve disruptive or deep change in elements within a socio-technical system dimension (Geels & Turnheim, 2022; Johnstone & Kivimaa, 2018). Examples of such disruptive or deep changes (within the actor dimension) include shifts in actors' power positions (Johnstone & Kivimaa, 2018), and shifts in strategies and technical capabilities of incumbent actor groups (Geels & Turnheim, 2022).

Process-related low-carbon transition impacts may thus be more or less low-carbon oriented and more or less ambitious in their low-carbon orientation (Geels, 2018).¹⁸

Furthermore, the acceleration across the nine ideal low-carbon transition processes provides an indication of the breadth (Geels & Turnheim, 2022) of low-carbon transition impacts.

2.4.4. Relating the types of impacts

While analytically distinct, emission goal alignment of innovation and the acceleration of transformative low-carbon processes are closely interrelated. Emission goal alignment of innovation without supportive transition processes risks being confined to accounting-based representations or a passing trend, while accelerated transformative processes without emission goal alignment of innovation may reinforce pathways that are incompatible with climate goals.

Assessing low-carbon transition impacts therefore requires analytical approaches capable of engaging with both types simultaneously, without collapsing one into the other.

After the next subsection, the following three sections build on this framing by specifying the analytical logic and structure as well as the two analytical frameworks used in this thesis to assess emission goal alignment of innovation and the acceleration of transformative low-carbon processes in a consistent and transparent manner.

¹⁸ Note: in a strictly mathematical vectoral perspective, orientation would not indicate in which end to put the arrowhead of the vector (that would be its sense), but here orientation also implies sense of direction.

2.4.5. Sector-specific low-carbon solution pathways

This subsection introduces low-carbon solution pathways relevant to the CRE sector. These pathways provide substantive reference points for interpreting the directionality of innovation patterns toward the emission-reduction goal in the empirical analysis.

Traditionally, much of the research on climate mitigation and low-carbon solutions has focused on supply-side mitigation through technological low-carbon solutions (Creutzig et al., 2018), for example categorized as generic low-carbon strategies: reduce input fuel and energy emission intensity, increase production and resource efficiency, increase end-use technology efficiency, and improve system efficiency (IPCC, 2014b, p. 68). Examples of low-carbon solutions for these strategies in the CRE sector include rooftop solar panels, low-carbon building materials, high-performance heat pumps, and zero energy buildings. Circular economy principles are also recognized as contributing to climate change mitigation and add demand-side strategies and prioritization. For example emphasizing that reducing demand is preferable to reuse, which in turn is preferable to repair, and repair to recycle (Reike et al., 2018).

In the context of low-carbon transitions in end-use sectors such as CRE, where emissions arise from both production and use, it is relevant to consider not only supply-side but also demand-side low-carbon solutions. The latter add two key low-carbon strategies: reduce service demand and increase service efficiency (Creutzig et al., 2018; IPCC, 2014b, p. 676). Examples of these two strategies in the CRE include: reduce the scope of space adaptations for tenants and reduce total space needs through shared spaces. Extensive lists of contextually relevant low-carbon solution options are available e.g. in IPCC (2014b, p. 676; IPCC 2022, pp. 901-902, 977-985) reports and Ürge-Vorsatz et al. (2020) and they are summarized in Table 1 below per generic low-carbon strategy and relevance to CRE value chain and category of emissions.

Please note that solutions addressing a potential third CRE emission category (Tenant use emissions) are excluded from the table. Low-carbon solution options within the strategies ‘Service efficiency’ and ‘Service demand reduction’ relate to use but are in the table assigned to the emission categories operational and embodied. While many low-carbon solutions that could be classified as addressing tenant use emissions fall outside of the system boundaries and are therefore not in focus in this study. This follows from the sectoral delimitation, which excludes activities related to tenants’ service provision. An example is tenant commuting and associated low-carbon solutions, such as providing locker rooms and secure bicycle parking, which are excluded from both Table 1 and the study.

Table 1 Summary of low-carbon solution options per generic low-carbon strategy and CRE value chain (and emission category).

Low-carbon strategy	Construction value chain, embodied emissions	Operations value chain, operational emissions
Lower-emission energy and fuel	Shift to electricity/bioenergy in building material production. Shift to electricity/bioenergy in building construction.	On-site renewables. Grid electricity decarbonization. District heating decarbonization. Low-carbon refrigerants. Electric service cars.
Production and resource efficiency	Substitute for low-carbon construction materials. Shift in construction methods. Lightweight building design. Design for disassembly and adaptability.	
End-use technology efficiency		Efficient heating. Efficient ventilation. Efficient appliances and lighting.
System efficiency	Circular Business models and markets for building materials. Carbon storage via biobased building materials. Repurpose unused buildings.	Mandating zero-energy new construction. CHP District heating networks. Advanced building control.
Service efficiency	Space sharing.	Space sharing.
Service demand reduction	Reduce the scope of space adaptations for tenants.	Smart metering.

2.5. Analytical logic for assessing low-carbon transition impacts

The analytical logic developed and applied for assessing low-carbon transition impacts in this study is grounded in theoretical perspectives on low-carbon transitions and related conceptualizations of impacts, outlined earlier in this chapter. In particular, it draws on literature examining ways to accelerate low-carbon transitions (e.g. Andersen et al., 2023), the directionality of innovation (e.g., Andersson & Hellsmark, 2024), and recurring concerns in transition research regarding the depth, scope, and extent of innovation-related and processual change (e.g. Geels, 2002; Geels & Turnheim, 2022). These perspectives inform how low-carbon transition impacts are framed and assessed in this study.

The purpose of the analytical logic is to support two qualitative, retrospective assessments of sectoral low-carbon transition impacts over time. Rather than assessing performance against fixed indicators or attributing outcomes to single causal factors, the analysis focuses on when and how changes related to processes and innovation patterns can be analytically assessed as impacts on low-carbon transitions.

Building on the preceding theoretical discussion, the analytical logic treats two analytically distinct but complementary types of low-carbon transition impacts. The first concerns emission goal alignment of innovation, focusing on how changes in innovation patterns relate to the alignment of sectoral developments with long-term GHG emission goals. The second type concerns acceleration of transformative low-carbon processes, focusing on how process-related changes relate to ideal processes for accelerating low-carbon transitions. Together, these two perspectives enable complementary assessments of impacts on low-carbon transitions.

To operationalize the analytical logic developed in this study, a shared set of analytical principles and two corresponding analytical frameworks are constructed, one for each type of low-carbon transition impact. While the two assessments differ in their empirical focus, objects of assessment, and explicitly specified reference points, they rely on a shared analytical logic adapted to the respective objects of assessment. Together, the analytical logic and the two frameworks constitute a theoretically informed approach to the retrospective assessment of sectoral low-carbon transition impacts.

This approach is particularly suited to contexts where low-carbon interventions have been embedded over time, such as low-carbon-oriented policies or transition debt finance, which is part of the empirical focus in this study. The low-carbon intervention is the analytical anchor for linking analytically relevant changes in innovation patterns and processes, which are the objects of assessment.

The analytical logic does not treat all observed changes in a retrospective study as direct inputs to assessment. While retrospective analyses may span prolonged periods and capture a wide range of innovation- and process-related changes, only some are analytically relevant from a low-carbon transition perspective, and only a subset can be analytically linked to, in this study, the sectoral embedding of transition debt finance. Accordingly, only analytically relevant changes are subjected to assessment. Changes are treated as analytically relevant when they can be plausibly linked, in part or conditionally, to the embedding of transition debt finance (methodologically elaborated for this study in section 3.4). This linking does not presuppose full causal attribution, nor does it assume that transition debt finance is a necessary condition for the changes to occur.

Figure 3 below summarizes the analytical logic developed in this study by providing an overview of how analytically relevant changes are conceptually linked to the two types of assessed low-carbon transition impacts. The figure clarifies the scope and orientation of the analytical logic, while detailed

specifications of analytical dimensions, reference points, qualitative scale, and assessment structure are provided in the subsection that follow.

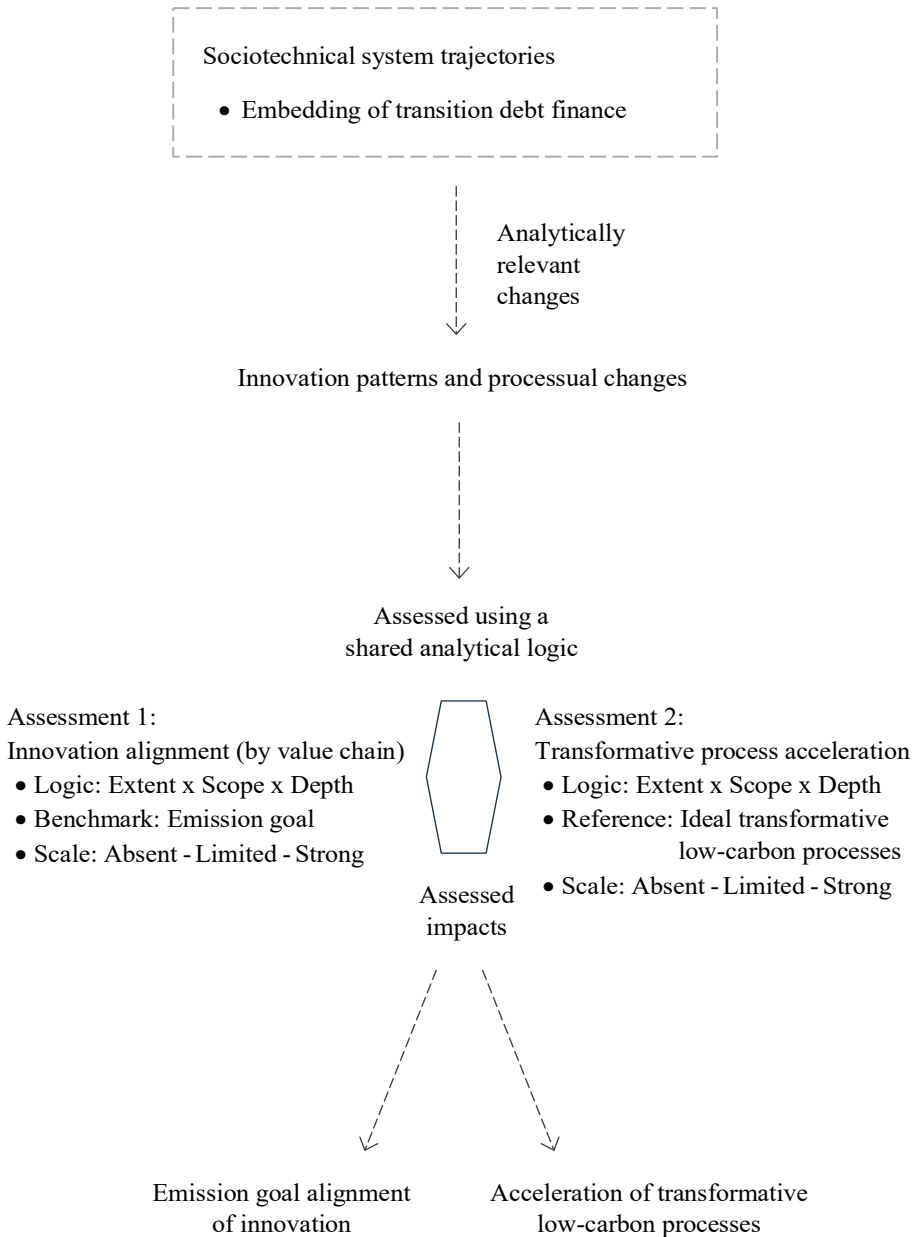


Figure 3 Analytical logic for assessing low-carbon transition impacts in relation to transition debt finance.

2.5.1. Analytical logic and structure of assessment

This subsection specifies how the analytical logic, introduced at an overarching level and summarized in Figure 3, is structured for application to analytically relevant process changes and changes in innovation patterns.

The analytical structure reflects the distinction between innovation-related and processual types of low-carbon transition impacts, motivating the separation into two analytically distinct but complementary assessments: emission goal alignment of innovation and the acceleration of transformative low-carbon processes. The analytical structure allows these assessments to be conducted in parallel, using a shared analytical logic adapted to the respective objects of assessment.

Analytically linked innovation-related and process-related changes are both examined using a shared set of three analytical dimensions: extent, low-carbon scope, and depth. However, these dimensions are operationalized differently to capture the specific characteristics of changes in innovation patterns and transition processes.

For the assessment of emission goal alignment of innovation:

- (i) extent refers to the observed breadth of adoption and experimentation across relevant actors/assets;
- (ii) low-carbon scope refers to the degree to which innovation patterns cover the main emission sources;
- (iii) depth refers to the emission mitigation strength implied by the innovation patterns for the emission sources they target, irrespective of limitations in extent and scope.

For the assessment of acceleration of transformative low-carbon processes:

- (iv) extent refers to the range and persistence of actors, institutions, or technologies involved;
- (v) low-carbon scope refers to the relevance of the process for low-carbon orientation of technologies, institutions or actors;
- (vi) depth refers to the degree of transformative or disruptive focus of the process.

In addition to the analytical dimensions, both types of assessments apply specific reference points. The emission reduction goal benchmark and the ideal low-carbon transition processes reference point support qualitative assessment of the degree of alignment or acceleration, rather than imposing fixed or quantitative performance criteria.

Finally, the assessments apply a shared qualitative analytical scale consisting of the categories absent, limited, and strong. The scale is threshold-based and specifies minimum thresholds for limited and strong assessments, while absent denotes failure to meet the minimum threshold for limited. Threshold configurations (e.g. moderate–moderate–weak or moderate–strong–strong) are

used as qualitative reference points to guide joint assessment across the analytical dimensions.¹⁹ The qualitative analytical scale is applied consistently across all assessments and is specified in Table 2 below.

Table 2 Qualitative analytical scale for joint assessment of extent, low-carbon scope and depth.

Qualitative assessment	Minimum threshold (joint qualitative assessment of extent, low-carbon scope and depth)
Absent	Does not meet the minimum threshold for Limited.
Limited	The joint assessment of extent, low-carbon scope and depth meets a minimum threshold corresponding to a moderate–moderate–weak configuration.
Strong	The joint assessment of extent, low-carbon scope and depth meets a minimum threshold corresponding to a moderate–strong–strong configuration.

The assessment of emission goal alignment of innovation is structured around the categorization of analytically relevant changes in innovation patterns by value chains and solution pathways. Reflecting the fact that emission reduction goals and benchmarks are defined at the value-chain level, the assessment of emission goal alignment is first conducted by evaluating overall change in innovation patterns against an emission goal benchmark, by value chain. This allows for an assessment of how analytically relevant changes in innovation patterns align with the sectoral emission goal. Subsequently, changes in innovation patterns are structured by solution pathway. This second step supports a qualitative judgment of which solution pathways account for the assessed value chain alignment, how pathway contributions are constrained by extent, low-carbon scope, or depth, and when pathway-related innovation is decoupled from alignment.

For the assessment of the acceleration of transformative low-carbon processes, analytically relevant process-related changes are structured according to ideal processes, previously outlined in section 2.4.3 and adapted from the typology proposed by Andersen et al. (2023). These ideal processes function as analytically informed reference points against which analytically relevant observed processual changes are assessed using the analytical dimensions. Each process is first assessed individually. Thereafter, the overall acceleration is assessed based on the assessment pattern across all individual processes, allowing attention to both variation across processes, their combined breadth across socio-technical system dimensions, and their combined contribution to the acceleration of transformative low-carbon processes.

The analytical logic and the two assessment frameworks are designed to be transferable in qualitative sector studies where low-carbon interventions have been embedded over time.

¹⁹ Note: ‘moderate’ is not in the scale but used when defining minimum thresholds, where it denotes a clear but constrained manifestation of a given analytical dimension.

2.6. Analytical framework for emission goal alignment

This section develops an analytical framework for assessing emission goal alignment of innovation. In this framework, innovation takes a solution-oriented meaning, which is why, for example, changes in policy or actor strategies are covered in the processual assessment in section 2.7. The framework takes Andersson and Hellsmark (2024) as a point of departure and is informed by their way of organizing innovation patterns, while reconfiguring the framework's analytical function to enable retrospective assessment and interpretation of low-carbon transition impacts. The framework is therefore not merely adapted for this study; it is further developed and operationalized to enable a qualitative assessment of emission goal alignment in line with the analytical logic set out in Section 2.5.

This implies that the framework should enable analytically relevant changes in innovation patterns to be structured by categorized value chains and solution pathways. It should also support representation of emission goal alignment assessed at the value-chain level against an emission goal benchmark, indicating which solution pathways account for the assessed alignment and which analytical dimensions constrain their contributions.

2.6.1. Framework reconfiguration

The present framework uses the Andersson and Hellsmark (2024) goal-sector-solution space, previously illustrated in Figure 1, as a starting point to organize innovation patterns. That organization is respecified for an intra-sectoral setting by distinguishing value chain categories and specifying solution pathways relevant to the study context. Furthermore, as this framework focuses on assessing emission goal alignment of innovation, it respecifies goal orientation conceptually by distinguishing assessed goal from contextual goal/s. The framework thereby recognizes that innovation patterns may also be oriented toward other goals, and retaining them analytically (without assessment) may help to contextualize patterns of alignment and misalignment with the emission reduction goal. The framework structures innovation patterns by goal orientation, value chain category and solution pathway (Figure 4 below). This structuring supports categorization of analytically relevant changes and the representation of assessed emission goal alignment using the analytical dimensions introduced in section 2.5.

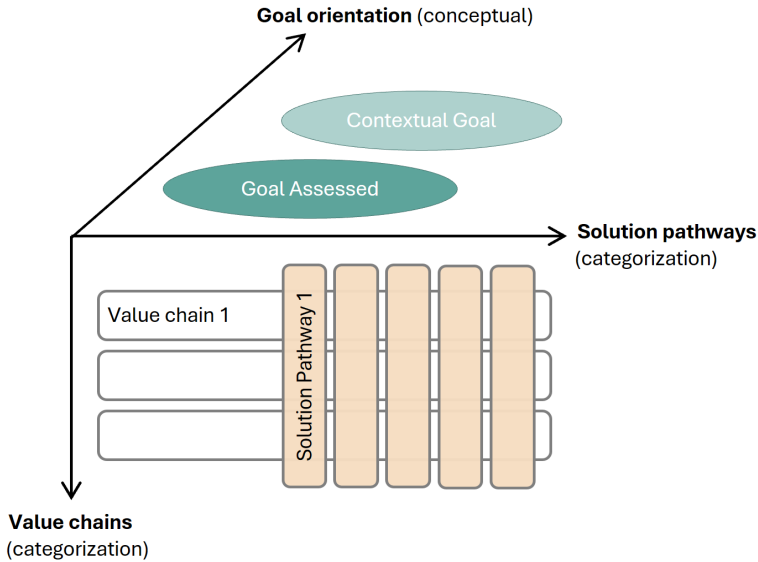


Figure 4 Structuring of innovation patterns by goal orientations, value chains and solution pathways, (building on Andersson & Hellsmark, 2024).

A further substantive development is the move away from the Andersson & Hellsmark (2024) amount-based representation of directionality. Instead, the present framework supports a qualitative, threshold-based representation of emission goal alignment of innovation by value chain. It also represents how solution pathways contribute to the assessed alignment and what constrains those contributions (as shown in Figure 7 in chapter 6).

2.6.2. Specifying goals, solution pathways and value chains

To complete a useful conceptual organization of innovation patterns, the categorization of goals, value chains, and solution pathways must be specified.

Starting with goals, when applying the framework in this study, the two goals of transition debt finance, introduced in subsection 1.1.3, are taken as a starting point for an assessed and a contextual goal. A salient and relevant benchmark for the goal of reducing emissions from financed value chains, is a reduction rate consistent with what climate science deems necessary to meet the temperature goals of the Paris Agreement.²⁰ This goal can therefore be formulated as reducing sectoral emissions at a rate consistent with Paris-aligned trajectories toward net-zero emissions. The second goal of transition debt finance is to reduce exposure to transition risks associated with financed sectoral assets and business activities.

Note that while both goals are analytically relevant, only the first emission reduction goal is assessed using the analytical dimensions and qualitative scale

²⁰ G20 Sustainable Finance Working Group (2022) 2022 G20 Sustainable Finance Report.

introduced in section 2.5 and a benchmark defined further below. The goals are specified in analytical terms in Table 3 below.

Table 3 Goals relevant for structuring and interpreting innovation patterns.

Goal category	Goal description	Analytical role
Emission reduction (assessed goal)	Sectoral emission reduction consistent with a Paris-aligned net-zero trajectory.	Used to assess emission goal alignment of innovation as low-carbon transition impact, based on extent, low-carbon scope and depth, and an emission goal benchmark.
Transition risk reduction (contextual goal)	Reduction of exposure to regulatory, market, technological or reputational risks associated with low-carbon transitions.	Contextual (not assessed). Included to interpret innovation patterns that display limited or absent emission goal alignment.

Related to emission reduction, the transition debt finance is open to a broad flora of solutions (making financial flows consistent with a pathway toward low GHG emissions) which taken together may support an orderly economy-wide transition. A central interest in this study, and an intended use of the framework, is to structure analytically relevant low-carbon innovation patterns for value chain assessment of emission goal alignment and to support interpretation of how solution pathways contribute. Accordingly, categorization of solutions is guided primarily by the emission reduction goal and is based on solutions identified in the literature as having substantial emission reduction potential (rather than based on current total contribution). Consequently, this study adopts the categorization of supply-side and demand-side low-carbon solutions proposed by Creutzig et al. (2018). While that study refers to generic mitigation strategies, the categories are used here as generic solution pathways for structuring innovation patterns.

Please note that an innovative solution that primarily contributes to lowering the exposure to transition risks, while not aligning with the emission reduction goal, does not substantively support low-carbon transitions. Nevertheless, retaining the goal of reducing exposure to transition risks as a contextual goal is relevant, given the potential for goal conflicts when selecting solutions, and it can aid in interpreting innovation patterns not contributing to emission goal alignment. To enable such interpretations, one generic solution pathway is introduced in the framework. This pathway encompasses solutions that primarily fulfill the function of signaling credible responsiveness to market actors (Spence, 1974), thereby oriented toward the goal of reducing transition risk exposure. Notable examples include the purchase of carbon offsetting, environmental product certifications, and renewable energy guarantees of origin (GOs) coupled with market-based emission accounting (Brander et al., 2018; Greer et al., 2019; Hamburger & Harangozó, 2018; Nygaard, 2023). This solution pathway is labeled Credentialing, drawing on the notion of credentials as evidence of one's

right to credit for something, and credentialing as activities undertaken to produce such evidence.

A brief description of the categories used to distinguish solution pathways is provided in Table 4 below.

Table 4 Generic solution pathways for reducing emissions financed and reducing exposure to transition risks.

Solution pathway	Description
Lower-emission energy and fuel	Reduce emission intensity of input energy and fuels and substituting for renewable energy technologies.
Production and resource efficiency	Increase the energy and materials efficiency of production, e.g. via reused or renewable construction materials and building products. Design for durability, adaptability and disassembly.
End-use technology efficiency	Adoption of more energy efficient technological solutions. Optimizing the energy efficiency of systems in use.
System efficiency	Systematize circularity in material flows. Improve infrastructures and collaboration. Carbon storage.
Service efficiency	More intensive use of assets/products, by means of e.g. sharing or repurposing.
Service demand reduction	Changes to use patterns and practices (incl switch to alternative modes), that reduce the demand for energy and materials. Regulations (e.g. taxes) that encourage sufficiency.
Credentialing	Solutions that mainly fulfill the function of signaling credible responsiveness to market actors.

Even though some solutions could be categorized under more than one pathway, each solution is classified into a single primary pathway for analytical consistency when interpreting how different pathways contribute to the assessed value-chain alignment.²¹

The intra-sectoral categorization of innovation patterns is conducted based on emission-relevant categories of value chains. The CRE sector can be decomposed into several value chain categories, but based on the sectoral boundaries defined in this study, and on the reviewed literature regarding emission sources relevant to buildings and the CRE sector, two value chain categories account for the dominant share of sectoral emissions. Innovative low-carbon solutions typically target activities within one of these two value chain categories, also making them relevant to target for transition debt finance.²²

²¹ Note: for example, although heat pump solutions to some extent also relate to input energy emission intensity, they are mainly highly energy-efficient and classified as End-use technology efficiency.

²² Note: a value chain category includes the different variants of a value chain.

Accordingly, emission goal alignment is distinguished across two categories of value chains: Operations and Construction, specified in Table 5 below.

Table 5 Sectoral value chain categories

Value chain	Description
Operations	Ventilating, heating, cooling, and operating building systems (e.g. elevators and communal lighting). Including related upstream activities that are material for emissions (such as generation of the energy/fuel used).
Construction	New construction, renovation, retrofit, maintenance and demolition of buildings, space adaptations for tenants. Including upstream activities that are relevant for emissions, such as generation of energy/fuel, extraction of raw materials and the manufacture and transport of building materials and components.

A summary of the conceptual specification of goals, solution pathways and value chains for the CRE sector is illustrated in Figure 5 below:

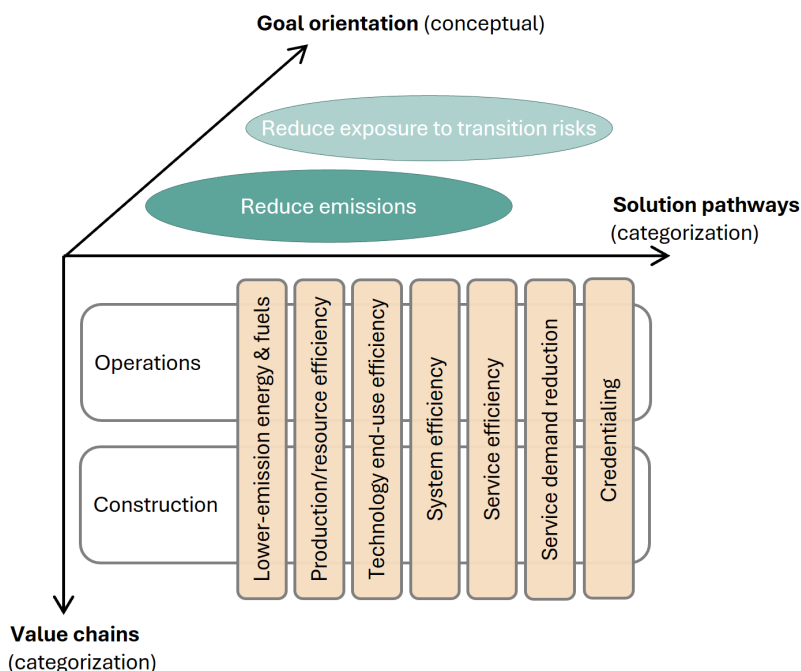


Figure 5 Specification of value chains, solution pathways and goal orientations within the conceptual organization of innovation patterns.

2.6.3. Operationalizing dimensions and benchmark

Building on the conceptualization of emission-related transition impacts in section 2.4 and the analytical dimensions introduced in section 2.5, this framework specifies how extent, low-carbon scope, and depth are interpreted for

the assessment of emission goal alignment of innovation. The assessment is conducted in two analytical passes. First, emission goal alignment is assessed by value chain. Second, the analysis qualitatively examines how solution pathways contribute to the assessed alignments at the value-chain level, including which analytical dimensions constrain pathway contributions and when pathway-related innovation is decoupled from emission goal alignment. While the analytical dimensions retain the same conceptual meaning, they are applied at different levels: first to assess emission goal alignment at the value-chain level, and then to interpret how solution pathways contribute to alignment within each value chain.

Extent captures how widely solutions are adopted or experimented with across actors and their assets. Low-carbon scope captures how far innovation patterns reach across the value chain's main emission sources, rather than remaining confined to a narrow subset. Depth captures the mitigation strength implied by the innovation pattern for the emission sources it targets, evaluated where the innovation is applied (e.g., in a building or project). At the value-chain level, emission goal alignment is qualitatively assessed across analytically linked innovation patterns, taking into account each pattern's mitigation strength where applied (depth) alongside its extent and low-carbon scope.

To enable assessment of alignment with the goal of reducing sectoral emissions in a manner consistent with a Paris-aligned net-zero trajectory, an operationalized benchmark is introduced. As an indicative benchmark, this study draws on the Science Based Targets initiative (SBTi), which proposes a linear absolute reduction of sectoral emissions of 4.2% per year to achieve Paris-aligned net-zero goal consistency.²³ It is acknowledged that this reduction rate has been questioned, for example by Anderson et al. (2020), who argue that substantially higher reduction rates may be warranted in specific national and sectoral contexts, such as the Swedish CRE sector. While the 4.2% annual reduction does not constitute a definitive standard for determining consistency with the emission reduction goal, it serves as a relevant indicative minimum benchmark for assessing strong alignment with the goal of reducing sectoral emissions in line with a Paris-aligned net-zero trajectory.

The benchmark is applied analytically to support qualitative assessment of emission goal alignment at value-chain level, rather than to quantify achieved emission reductions. Alignment is assessed by examining whether analytically relevant changes in innovation patterns display an extent, emission scope, and mitigation strength that plausibly correspond to the level of emission reduction implied by the benchmark. The benchmark thus functions as a threshold for distinguishing strong alignment from more limited or absent alignment within the qualitative analytical scale defined in section 2.5.

²³ The Science Based Target initiative (2020) Science-based Target Setting Manual. Version 4.1, pp. 19, 24.

The results produced using the framework can indicate innovation-related low-carbon transition impacts, as well as promote reflexivity regarding how low-carbon interventions could relate to them.

The framework is presented as an adaptable analytical tool that can be applied together with the analytical logic across empirical settings with limited context-specific tailoring (for example, in the categorization of value chains and specification of any contextual goal).

2.7. Analytical framework for acceleration of transformative low-carbon processes

Building on the Andersen et al. (2023) typology as adapted in section 2.4.3, and also drawing on Johnstone and Kivimaa (2018) and Geels and Turnheim (2022), this section develops an analytical framework for assessing the acceleration of transformative low-carbon processes, based on analytically relevant process changes. In line with the analytical logic previously presented, the framework uses ideal processes as reference points and applies the analytical dimensions to assess acceleration at both the process level and overall.

2.7.1. From adapted typology to assessment framework.

The framework treats ideal processes as analytically informed reference points for retrospective assessment of acceleration of transformative low-carbon processes, as a type of low-carbon transition impact.

Actual process-related changes cannot be expected to materialize in accordance with ideal processes. In order to assess actual process-related changes as transformative low-carbon processes, beyond using ideal processes as reference points, the qualitative analytical dimensions introduced in section 2.5 must be operationalized. Accordingly, acceleration is assessed in two analytical passes: each process is assessed first, followed by an overall assessment based on the pattern across processes (and socio-technical dimensions).

Analytically relevant process-related changes are structured in relation to ideal transformative low-carbon processes, restated in Table 6 below.

Table 6 Ideal transformative low-carbon processes, (adapted from a typology in Andersen et al., 2023).

Socio-technical dimension	Ideal transformative low-carbon processes	References
Institutional	Adding policy support for low-carbon niche innovations and removing policy support for institutionalized high-emission practices and technologies, helping to destabilize the system and incentivize incumbent actors to engage in the transition, or even exnovate high-emission technologies.	David, 2017; Kivimaa & Kern, 2016
	Changing social norms that influence user preferences in the direction of low-carbon technologies and social practices.	Bowles, 1998
	Developing and institutionalizing guiding visions of low-carbon system or society and transition paths, which helps mobilize corporate agency.	Schot & Geels, 2008; Späth & Rohracher, 2010
Actor	Strategic reorientation of business actors (change in direction of innovation experimented with and adopted), which helps mobilize belief and investments in low-carbon technologies and business models.	Stalmokaitė & Hassler, 2020
	Increased adoption of low-carbon technologies or social practices by users as solutions become better and cheaper, as they gain attention, and as social norms change.	Arthur, 1989; Rogers, 2003
	Forming actor coalitions around low-carbon innovations and lobbying for policy change in support of low-carbon innovation.	Roberts & Geels, 2019
Technology	R&D or learning processes which improve performance of low-carbon technologies.	Malhotra & Schmidt, 2020
	Scaling production and learning-by-doing, helping to make low-carbon technologies competitive on cost.	Arthur, 1989
	Making available complementary assets, technologies and infrastructure supporting low-carbon technologies.	Teece, 1986

2.7.2. Operationalized dimensions and analytical reference points

The ideal processes function as analytically informed reference points against which analytically relevant processual changes are assessed. The assessment framework is summarized in Table 7.

Building on the analytical dimensions introduced in section 2.5, this framework specifies how extent, low-carbon scope, and depth are interpreted when assessing the acceleration of transition processes. The assessment is conducted in two analytical passes: first, each individual process is assessed; thereafter, overall acceleration is assessed based on the pattern of assessments across all individual processes. Overall acceleration is here understood as the combined strengthening of multiple transformative low-carbon transition

processes, in terms of their extent, low-carbon scope, and depth. Structuring the framework by socio-technical dimension and letting it qualify each analytical dimension for the ideal processes, allows transparency regarding both acceleration and the dimensions limiting the acceleration.

Extent refers to the range and persistence of actors, institutions, or technologies involved in the process. Low-carbon scope refers to the relevance of the process for the low-carbon orientation of technologies, institutions, or actors. Depth refers to the degree of transformative or disruptive focus of the process. Within this framework, higher assessed levels of extent, low-carbon scope, and depth indicate stronger acceleration of the respective process. Assessed acceleration reflects a qualitative judgment based on the joint consideration of extent, low-carbon scope and depth.

Table 7 Framework for acceleration of transformative low-carbon processes (own framework drawing on Andersen et al., 2023; Johnstone & Kivimaa, 2018; Geels & Turnheim, 2022).

Socio-technical dimension	Ideal transformative low-carbon processes	Extent	Low-carbon scope	Depth	Assessed acceleration (Absent = white, Limited = light gray, Strong = dark gray)
----------------------------------	--------------------------------------------------	---------------	-------------------------	--------------	--------------------------------------------------------------------------------------------------

The ideal processes are applied as analytically informed reference points to support qualitative assessment of acceleration, within the qualitative analytical scale defined in section 2.5.

Beyond its use for assessment, the framework can also offer an analytical and policy-oriented tool that maps plausible processes and related qualitative characteristics relevant to how policy-like interventions such as transition debt finance may accelerate transformative low-carbon processes.

2.8. Summary of analytical development

The preceding sections have presented the analytical logic and the two assessment frameworks developed and used in the thesis. By specifying how retrospective assessment of sectoral low-carbon transition impacts can be conducted, they provide the constructive part of the answer to the first research question (RQ1). The answer is completed in chapters 6–7. Chapter 6 presents the results of the application of the approach. In chapter 7, section 7.5 discusses what the approach adds and how its limitations became visible when confronted with the case evidence, while section 7.4 provides a summarized answer to RQ1.

3. Research methodology

The first section elaborates on the guiding methodological premise. Then the research design applied is presented along with the empirical foundation. Followed by analytical methods and analytical frameworks used. Finally, the research quality and ethical considerations are discussed.

3.1. Critical realism inspiring the research approach

From my 18 years in business working with process and business development projects, I have learned that projects often hurt due to unrecognized logics or issues. I bring an epistemological inclination to also focus (querying, following leads and reflecting) on context that may be unrecognized (by informants and me) but causally relevant. This aligns well with the epistemological implications of critical realism's ontological distinction between the empirical, actual and real domains (Bhaskar, 1998). One example from the thesis study is the - among Swedish CRE actors - latent issue of embodied emissions. I use the social scientific philosophy of critical realism (Archer, 1995; Bhaskar, 1998; Danermark et al., 2002; Sayer, 2000) as a premise guiding the methodological approach.

A central assumption in critical realism is that reality, including the social, exists independently of how/whether humans know or perceive it, and extends beyond both what is observable and actual events to also include underlying structures and mechanisms causally involved in producing the events (Danermark et al., 2002). As our knowledge of reality involves subjective interpretation and sharing through language, it is theory-dependent, incomplete and fallible (Bhaskar, 1998). This, in combination with a revelatory research objective of 'understanding why things are as they are' which may differ from shared meanings (Sayer, 2000, pp. 18-19), urges the analyst to be skeptical about both own and others' explanations while dedicated to developing them. While critical realism encourages the identification of generative mechanisms (Danermark et al., 2002), this study does not offer an articulated mechanism-based explanation. Instead, it clarifies structural conditions with plausible causal relevance to the phenomena studied.

Critical realism holds that the real objects that we investigate in a specific context, are constituted by their structure: a set of necessary relations that

provides the entity with its properties and its abilities to causally influence and be influenced. For example, to be a landlord the relation to tenant is necessary. Such necessary relations may be between an object and other objects, or between components of an object. The landlord–tenant relation can, for instance, be part of the structure of a market or sector.

Critical realism emphasizes the temporal interplay between social structures and agency (Archer, 1995): structure analytically precedes action and action precedes reproduction or transformation of social structures. Structures are then the context in which action and social interaction occur, and structures may causally enable or restrict action and social interaction.

Social structures are here understood as objective relations between social positions and between social positions and resources, rules and other social objects (Porpora, 1998). For example, the landlord-tenant relation exists regardless of which agents inhabit these positions (regardless of how they view the relation), and positions can be associated with different interests, resources, rules and powers, shaping differing possibilities and interests for actor collectives (Buch-Hansen & Nielsen, 2020). Agents are here understood as collectives with common relations to a set of structural resources.

In other words, agency is associated with a structural position. Collectives may organize to articulate interests and coordinate action toward explicit aims, (corporate agency), or act without organized coordination toward any explicit aim, as primary agents (Archer, 1995). Thus, heterogeneous groups partly act on shared goal/s and partly on own agency (Danermark et al., 2002).

The above ontological and epistemological assumptions have four implications for the research approach and methodology applied in this thesis:

- (i) A reality independent of our knowledge (Bhaskar, 1998) justifies an attempt to investigate the Swedish CRE sector and the embedding of transition debt finance as phenomena with objective features, while recognizing that certainty is not achievable (Maxwell, 2012). For example, what changes to innovation patterns are causally linked to the embedding of transition debt finance is not just a matter of opinion – there is a factual answer (even if accurately knowing it is challenging).
- (ii) Acknowledging that all knowledge is theory-dependent but improvable implies that theoretical perspectives are necessary to understand research objects, while also warranting skepticism toward existing theoretical knowledge (Sayer, 2000). This justifies abduction as a strategy for scientific reasoning, using theoretical frameworks as mediators for deriving understanding, while continuously checking interpretations against empirical evidence to avoid only seeing what theory filters us to see (Danermark et al., 2002).

- (iii) The temporal interplay between structure and agency (Archer, 1995) helps avoid both a deterministic view (of actors as puppets of structure) and a voluntarist view (of structures not mattering). This perspective implies that data collection and analysis should pay attention also to the context and motivations of events. This justifies retroduction as a strategy for scientific reasoning to clarify plausibly necessary contextual conditions (Danermark et al., 2002).
- (iv) The ‘to interpret what the assessments imply about’ part of the research purpose requires a focus on deeper understanding of the ‘how’ in RQ2, beyond documenting and interpreting sequences of events or informant perceptions. This justifies a case study approach using multiple data sources to enable in-depth contextual analyses.

3.2. Research design

The research was designed in line with the above four implications from critical realism (Archer, 1995; Bhaskar, 1998; Danermark et al., 2002; Maxwell, 2012; Sayer, 2000). The thesis employs a critical realist, abductive-retroductive, longitudinal and retrospective, case study design. It combines focus groups, interviews and document analysis. The design enables tracing plausible causal relations and contextual interactions over time, linking the embedding of transition debt finance to changes in innovation patterns and transition-related processes and interpreting low-carbon transition impacts.

Case study is “a research strategy that examines, through the use of a variety of data sources, a phenomenon in its naturalistic context, with the purpose of ‘confronting’ theory with the empirical world” (Piekkari et al., 2009, p. 569). To achieve this ‘confronting’, abductive and retroductive reasoning are used as strategies for scientific reasoning in the study.

3.2.1. The case

The specific case selected is the embedding of transition debt finance and its low-carbon transition impacts, in the Swedish commercial real estate (CRE) sector. The case is delimited timewise from the approximate start of Swedish CRE green bond financing (2014) until the approximate end of a long period with low interest rates (2021). I followed the case longitudinally during 2019-2021 and studied 2014-2018 in retrospect. This choice allowed a detailed understanding of how the phenomena relate over time in the study setting, including agency dynamics. This also minimized the risk of overemphasizing the relevance of short-term bursts of enthusiasm or trends.

To further clarify boundaries and delimitations of the case:

- (i) The CRE sector as defined in this thesis, excludes provision of place and space for housing, industrial production, utilities or transportation.

- (ii) Provision of space and place is primarily considered within CRE building properties while excluding tenant furniture and equipment.
- (iii) The service sector activities performed by tenants (consider for example a retailer selling shoes in a store) do not pertain to the CRE sector and are outside the case.
- (iv) To capture the production of greenhouse gas (GHG) emissions related to CRE sector activities, the construction and building operation value chains are examined also upstream/downstream, beyond traditional sector borders.

While the main unit of analysis is the sectoral level, lower-level analysis is used where relevant as components of the sectoral picture (not separate cases).

The larger research project I was initially part of engaged a set of CRE actors and served as a catalyst for identifying the case. The casing involved selections based on theoretical interest, and the empirical base was initially characterized as an extreme case (Flyvbjerg, 2006), given that:

- (i) Both the country and sector selected and the country-sector combination studied stood out as frontrunners in embedding transition debt.
- (ii) CRE informants highlighted causal meaning to transition debt finance (specifically green finance via bonds and loans).
- (iii) Historical national energy and climate policy and energy production displayed low-carbon transition ambitions and tendencies providing the case subject with a particular starting point including availability of low-carbon grid electricity, mid/low-carbon district heating and a national commitment²⁴ toward non-fossil energy use in industry and transport sectors.

In addition, the core of the unit of observation comprised frontrunner CRE actors related to sustainability and transition debt finance, where evident low-carbon transition impacts from transition debt finance were more likely to manifest than elsewhere. However, initial analysis indicated that such impacts may be limited, suggesting that the case could also be categorized as a critical case (Flyvbjerg, 2006), with potential to expose inherent weaknesses in transition debt finance and counteracting contextual conditions (Danermark et al., 2002, p. 184).

3.3. Empirical foundation

To understand the case and examine what was required to answer the second research question, multiple data collection methods were used: focus group interviews, semi-structured interviews, document analysis and (to a limited

²⁴ Note: complemented by legislation (the Swedish climate act).

extent) direct observations. Using several data sources enabled a more comprehensive picture and allowed triangulation (Maxwell, 2012).

My initial involvement in the larger research project enabled my early data collection through interviews combined with company visits and focus group interviews, drawing on informants recruited through that project. These informants included sustainability managers from CRE companies that were sustainability frontrunners and frontrunners in the use of transition debt finance, as well as energy and environmental specialists from some of the same companies and industry experts.

Empirical material collected early in that project setting served as a catalyst for defining the case, purpose and research questions, and informed continued data collection. As CRE companies own, develop, manage and operate properties both financially and technically, they provided a central vantage point in the case. Data collection was iteratively expanded over time to deepen the empirical focus and broaden the empirical base, including additional data sources and a wider range of actor voices. This included publicly available documentation for retrospective coverage and cross-checking of claims, as well as observations and informal conversations at five CRE industry events/trainings on sustainable properties, building certification schemes and green finance.

I followed the case longitudinally during 2019–2021, while data collection continued into 2023, as some relevant information regarding 2021 was not available earlier and because information regarding 2022 was collected and used as temporal context. More details on the three main data collection methods are presented below, followed by a description of all collected data in Table 8.

3.3.1. Focus group interviews

The focus group interviews provided a window into sectoral discourse and sensemaking on targeted questions and important context, capturing nuance as well as areas of consensus and contention that individual interviews may not provide (Morgan, 1997). Six focus group interviews were conducted from autumn 2019 to spring 2022 within the larger research project. I moderated two sessions and co-moderated three, with varying influence on topics across sessions.

Sessions included 4–10 CRE informants; several participated in most sessions, while others participated based on topical expertise. Informants included sustainability managers from CRE companies that were sustainability frontrunners and frontrunner users of transition debt finance, as well as energy and environmental specialists from some of the same companies and industry experts. The sessions were semi-structured and organized around a few broad questions. During sessions, the moderator facilitated balanced participation and additional researchers occasionally asked follow-up questions or requested clarification.

All focus groups were audio recorded and transcribed verbatim. Most sessions served to capture relevant context and indicate where to dig deeper. One session conducted at the end of the period studied provided key input for assessing perceived financier expectations, requirements and incentives, and whether such pressures had materially accelerated innovation and transformative low-carbon processes over 2011–2021; informants also discussed how financiers could further accelerate sustainability in CRE.

3.3.2. Interviews

Eleven interviews (typically around 90 minutes) were conducted in 2019–2022 with representatives of organizations involved in the larger research project I was initially part of. Informants were recruited via the project and snowball referrals. They included five sustainability managers, an energy specialist, a business developer from CRE companies, and two real estate industry experts; most also participated in focus group interviews. Two informants were interviewed twice to capture developments over time. Interviews were conducted in person when possible (six in total) and otherwise online via video. I was often accompanied by one or two peers, and all but one interview were audio recorded and transcribed verbatim. The informants provided essential subject matter expertise, as many of the informants had in-depth understanding about the phenomena in focus in this study (the embedding of transition debt finance in CRE and its low-carbon and other consequences on company and sector level).

The interviews served to probe the embedding of transition debt finance in CRE and its low-carbon and other consequences on company and sector levels, and to follow up themes raised in the focus groups. Topics included Swedish CRE sustainability and low-carbon innovations, green finance, and the perceived financial materiality of climate transition risks, including relevance, adoption, activities, plans, challenges and opportunities. While focusing on current issues and developments (at the time of the interview), the interviews also queried about previous developments in the first half of the period studied.

The semi-structured interviews were designed to allow domain experts to describe practices and developments in their own terms, while enabling systematic follow-up probing consistent with a critical realist logic. In practice, this meant repeatedly asking for concrete examples, clarifying sequences ('what happened before/after'), and testing counterfactual reasoning ('what if it had not been for...') in order to strengthen the plausibility of analytical linking and to reduce reliance on post-hoc rationalizations (Danermark et al., 2002; Sayer, 2000).

A twelfth interview with a sustainability expert at a commercial bank focused on debt climate risk assessment and green loans. Interviews were complemented by informal conversations, and three informants showed internal documents, commercial spaces and/or technical installations to provide concrete examples.

3.3.3. Documents

To supplement and triangulate accounts from focus groups and interviews, extensive document search and analysis was conducted. Documents offered both factual information, including historical, detailed and aggregated mater, as well as additional perspectives from actor groups not interviewed. The documents covered characteristics, trends, considerations, and accounting of green finance and transition risks, as well as building, company and value chain characteristics, trends, climate performance and low-carbon innovations (see Table 8 and the list of empirical sources at the end of the thesis).

When documents aligned with interview statements the documents still typically complemented and added context. Documents sometimes contradicted interviews in revealing ways. For example, the conservatism of green building certification schemes became evident when the most widely used scheme (Miljöbyggnad), for several years retained a loophole to claim energy performance 20% better than regulatory requirements.²⁵

Documents were traced from publicly available sources (primarily text, but also videos), across key actor categories in Swedish CRE and its value chains. The document base included CRE companies, municipalities, regions, green finance aggregators, credit rating agencies, external reviewers of green finance frameworks, sustainability assessors, commercial banks, pension companies, investment banks, architects, construction companies; producers in relevant supply chains (of steel, cement, other construction materials, HVAC, electricity, district heating), tenant companies, waste management companies, authorities²⁶, industry analysts, standardization boards, advisory bodies, and publishers of professional magazines. In most actor categories, documents from 4-5 actors were used, selected mainly based on relevance (including mentions in collected empirics and keyword searches), but also to introduce contrast relative to previous selections. For CRE companies, 44 companies were studied to cover different sizes, ownership, property focus (types, sizes, geographies and values), and approaches to sustainability and finance.²⁷ Sources included actor websites, annual and sustainability reports, green finance frameworks and impact reports, second party opinions from external reviewers, industry analyst publications, advisory body reports, national statistics, energy performance certificates filed to Boverket, and relevant news and magazine articles.²⁸

Overall, information for the years 2014-2022 was collected from documents regarding:

²⁵ Note: in 2017, the building code replaced kWh-based energy performance with a formula-based metric and adjusted regulatory thresholds accordingly. The Swedish Green Building council nevertheless left certification energy criteria unchanged, still in 2021 relying on kWh summation.

²⁶ Note: including the EU, UNEP, Boverket, Swedish energy agency, A fossil free Sweden.

²⁷ Note: Most were large or medium-sized and some were smaller, with main operations in Sweden. A few operating in other parts of the world were selected to provide context.

²⁸ Many, but far from all, documents used in the analysis are referenced and listed under the heading Empirical sources.

- (i) CRE company and value chain characteristics/trends, including ownership, finance, business model, projects, low-carbon initiatives, energy performance and climate accounting.
- (ii) Energy and GHG accounting and statistics for buildings.
- (iii) Green finance and climate risk characteristics, trends, considerations, and accounting, including 'rules' applied, CRE projects financed and impact accounted, actors' implementation, and aggregated green finance information applicable to Swedish CRE.
- (iv) Climate risk exposure of CRE sector globally and in Norway and USA, including risk characteristics and transition risk exposure level compared to other (global) sectors (only covering 2020-21).
- (v) Low-carbon innovations applicable to CRE value chains, including past and ongoing experiments, regulatory and voluntary standards, adoption rates and implementation scopes, and (potential, reported or biophysical) effects on GHG emissions.
- (vi) Characteristics and environmental performance of new building design and construction (covering building completion years 2015-22) in Swedish CRE, focusing building materials chosen, energy solutions and performance, green building certifications and sustainability efforts, (construction material and GHG emission inventories²⁹).

²⁹ Note: in parenthesis as they were only rarely available.

Table 8 Description of collected data

Data Source	Topics covered³⁰
<p>6 focus group interviews with subject matter experts, carried out 2019-22. 1 designed topics and moderated discussions in 2 of the focus group interviews, and in another 3 I had influence on topics and co-moderated discussions.</p>	<p>Characteristics, relations and discourse regarding Swedish CRE³¹ sustainability and low-carbon innovations, green finance and financial materiality of climate transition risks. Covering 2014-21 with emphasis on 2019-21. Categories and examples of sustainability innovation experimentation/adoption in Swedish CRE that were or were not materially accelerated via green finance and financial materiality of climate risks. Covering 2011-21.</p>
<p>11 interviews carried out with subject matter experts 2019-22.</p>	<p>Characteristics, relations and discourse regarding Swedish CRE sustainability and low-carbon innovations, green finance and financial materiality of climate transition risks: including business and emission reduction relevance, adoption, activities, plans, challenges and opportunities. Covering 2014-21 with emphasis on 2019-21.</p>
<p>Observations at 5 industry conferences/trainings (2019-22) on topics relevant to this study. Enabled informal conversations with 11 industry insiders.</p>	<p>Characteristics of and discourse regarding sustainable properties, building certification schemes and green finance in CRE: including business and emission reduction relevance, adoption, activities, challenges and opportunities.</p>
<p>Documentation collected 2020-23 regarding 15 Swedish CRE and Construction companies, 6 Swedish Municipalities and Regions, 2 Swedish green finance Aggregators, 3 Swedish Commercial Banks and 3 public Investment Banks, from company green finance frameworks, impact reports, annual and sustainability reports, plus second party opinions from external reviewers.</p>	<p>Green finance and climate risk characteristics, trends, considerations, and accounting: including 'rules' applied, CRE projects financed and climate impact accounted, actors' implementation, aggregated green finance information applicable to Swedish CRE. Covering 2013-22.</p>
<p>Documentation collected 2020-23 regarding global and Swedish CRE green finance market trends, from NGOs and commercial analyst yearly reports.</p>	

³⁰ Filtered to topics with relevance for this study.

³¹ refers here to the Swedish CRE sector as well as specific actors in this sector.

<p>Documentation collected during 2020-23 regarding ‘global’ and 2 national CRE sectors, and regarding 2 credit rating agencies, from reports and web pages of corporate climate risk assessment institutes.</p> <p>Documentation collected 2020-23 regarding 53 Swedish CRE companies, credit institutes and pension companies, from financial and sustainability reports, company websites, industry publications.</p>	<p>Climate risk exposure of CRE sector globally and in Norway and USA, including risk characteristics and transition risk exposure level compared to other (global) sectors. Covering mainly 2020-21.</p> <p>Company and value chain characteristics/trends: including ownership, finance, business model, projects, low-carbon initiatives, energy performance and climate accounting. Covering 2014-22.³²</p>
<p>Documentation collected during 2019-23 regarding 39 low-carbon innovations, from company sustainability reports and websites, industry analyst publications and advisory body reports.</p>	<p>Low-carbon innovations applicable to CRE value chains, including past and ongoing experiments, regulatory and voluntary standards, adoption rates and implementation scopes, (potential, reported or biophysical) effects on GHG emissions. Covering 2014-22.³³</p>
<p>Documentation collected during 2020-23 regarding 46 newly constructed CRE buildings, from company sustainability reports and websites, industry publications and energy performance certificates filed to Boverket.</p>	<p>Characteristics and environmental performance of new building design and construction (covering building completion years 2015-22) in Swedish CRE, focusing building materials chosen, energy solutions and performance, green building certifications and sustainability efforts, (construction material and GHG inventories).</p>

³² Note: company characteristics from 2022 were used as temporal context to the period studied (2014-2021) in focus.

³³ Note: information regarding 2022 on low-carbon innovations were used as temporal context to the period studied (2014-2021) in focus.

3.4. Analytical procedures

First it is important to point out the emergent character of the research process, where analyses started during early data collection with the purpose of scoping the study, by finding and defining the case and the research questions. The analyses developed and restarted over time with successively more empirical data and improved conceptual preconceptions.

Multiple case readings using alternate templates (Langley, 1999) helped maintain a self-critical approach and an abductive research process (Maxwell, 2012). In single case study analyses it is key to holistically capture the complexity of a case (Langley, 1999), warranting analytical procedures that retain context while analyzing empirical material. Thus, while the analytical frameworks involve categorization, I relied heavily on connecting strategies to identify substantive factual relations and to trace connections in time and place that tie the empirics into narratives or sequences (Danermark et al., 2002; Maxwell & Miller, 2008).

Analytical procedures should go beyond documenting sequences of events or patterns in informant perceptions to gain a deeper understanding of the 'how' in the research questions (Bhaskar, 1998). This involved abductively using theoretical frameworks as mediators for deriving understanding, while continuously checking emerging interpretations against empirical evidence. For example, abduction involved recontextualizing low-carbon transition impacts as emission goal alignment of innovation and acceleration of transformative low-carbon processes, including the two analytical frameworks developed in this study. Retroductive reasoning including counterfactual thinking was used to clarify plausible transfactual structural conditions (Danermark et al., 2002), direct analytical attention to absences, and support the development of the analytical frameworks, analytical linking, and interpretations of the assessment results as low-carbon transition impacts.

Please note that retroductive reasoning in this study was used to clarify plausible contextual conditions and constraints, not to develop or test a mechanism-based explanation, which is beyond the scope of the licentiate thesis. To further secure the validity of the results (Danermark, 2002; Maxwell, 2012) they were produced with two different analytical frameworks and structured separately, allowing corroboration through non-contradictory results.

3.4.1. Analytical process

The analytical process was not linear but explorative, with iterative moves between theory, empirical material, analytical frames and the case, which

evolved interdependently and prompted mutual revisions. For example, the case was abductively reinterpreted using different theoretical perspectives to confront the empirical material (Danermark, 2002), which could call for replacing theory, developing the analytical framework, or complementing the empirical material.

Reflexivity was maintained throughout the process, recognizing that theoretical ideas and analytical frameworks inevitably shape interpretation. Retroductive reasoning was used as a strategy to remain skeptically open to alternative theoretical perspectives and interpretations. It also aided the development of the analytical frameworks, the analytical linking of changes to innovation patterns and processes, and interpretation of assessment results as low-carbon transition impacts (Danermark et al., 2002). Retroductive reasoning in this study involved asking questions like: What made persistently limited low-carbon transition impacts possible? What properties must transition debt finance have to produce sectoral low-carbon transition impacts? Which contextual conditions are necessary for transition debt finance to produce sectoral low-carbon transition impacts?

The analytical process also drew on domain knowledge, which supported connecting moves and triangulation. Domain knowledge was built through literature reviews of published research and gray literature as well as through extended empirical tracing.

Connecting strategies involved tracing factual threads across interview transcripts and documents, triangulating and developing memos of tentative substantive factual relations (Danermark et al., 2002) regarding for example relations conditioning the eligibility for green finance of buildings. Tentative connections, once identified, inspired digging deeper by guiding follow-up interview questions and additional search for, and review of, documentation. Categorizing strategies were used when developing the analytical frameworks and mapping observed innovative practices and processual changes into framework categories (Maxwell & Miller, 2008).

An early step in the analytical process was to delineate the object of analysis as low-carbon innovation patterns and transition-related processes supported by transition debt finance within the Swedish CRE sector over the period studied. The empirical material was first structured according to whether it described the embedding of transition debt finance, innovation-related changes or process-related changes, in line with the analytical distinction developed in the theory chapter.

Analytical linking of empirical material

An analytical linking step was used to determine which innovation- and process-related changes were analytically relevant for subsequent assessments. This step was necessary because a retrospective case study over a prolonged period captures a wide range of developments, whereas only a subset is relevant from a low-carbon transition perspective and only a subset

can be plausibly linked, in part or conditionally, to the sectoral embedding of transition debt finance. Analytical linking was conducted through connecting strategies (Maxwell & Miller, 2008), tracing factual threads across interview transcripts, focus group discussions and documents, and iteratively testing tentative connections. Counterfactual reasoning about how innovation patterns and low-carbon processes would plausibly have evolved in the absence of transition debt finance, supplemented by selective triangulation with settings where it was not embedded, was used qualitatively to inform the linking step and discipline decisions about analytical relevance.

A change was treated as analytically linked when it: (i) pertained to innovation patterns or processes with direct relevance, or strong indirect relevance, to sectoral emissions, and (ii) could be plausibly linked, in part or conditionally, to the embedding of transition debt finance. Such links did not require transition debt finance to be a necessary condition for the change to occur. Instead, linking is used to justify which changes are brought into assessment.

In operational terms, a change was treated as plausibly linked when several considerations supported the link. Supporting indications include independent sources and documentation that, taken together, corroborate that eligibility criteria or other features of transition debt finance incentivized, required, or otherwise shaped the change.³⁴

The analytically relevant changes were then categorized using the analytical frameworks (Sections 2.6 and 2.7). The categories of value chains and solution pathways were developed and defined well into the study based on domain knowledge and iterative categorization work, including the addition of a credentialing solution pathway.

Retrospective assessments of emission goal alignment of innovation patterns and acceleration of transformative low-carbon processes among CRE companies and their properties involved in the embedding of transition debt finance provided a basis for interpreting how transition debt finance could plausibly contribute to sectoral low-carbon transition impacts.

Assessing goal alignment

To assess emission goal alignment of innovation at the value-chain level, analytically relevant changes in innovation patterns were examined at the company and property levels against the benchmark set out in section 2.6.3, scaled to a five-year horizon. The assessment examined the degree to which changes in innovation patterns were consistent with emission reduction trajectories of at least 21% reduction in five years, by value chain. Alignment was classified as strong, limited, or absent based on combined appraisal of extent, low-carbon scope and depth. In practice, strong alignment is indicated when innovation patterns display mitigation strength consistent with the 21%

³⁴ Note: also include consideration of temporal alignment.

benchmark (depth), broad adoption/experimentation (extent), and substantive coverage of value chain's main emission sources (low-carbon scope).

A five-year assessment horizon was selected because, in the empirical material, transition debt finance tended to structure related innovation into approximate five-year cycles.³⁵ A five-year horizon also provided a practical basis for appraising meaningful changes in innovation patterns at the company and property levels. At company level, the five-year assessment period typically began in the year preceding a company's first green bond framework issuance. At property level, the five-year window typically covered the years leading up to eligibility for green debt; for properties made eligible early in the period studied, the window instead covered subsequent years.³⁶

In a second analytical pass, the analysis identified how solution pathways accounted for each assessed value chain goal alignment (i.e. relative contribution rather than alignment). Solution pathways were classified as main contributors or other contributors, depending on whether they accounted for the largest contribution to the assessed value-chain alignment. The primary limiting analytical dimension (extent, low-carbon scope, or depth) was also identified, for example that a contribution was primarily constrained by narrow adoption/experimentation. Pathways with substantial innovation activity but not substantively supporting emission goal alignment were classified as decoupled from alignment.³⁷

Assessing process acceleration

Structuring analytically relevant process-related changes by ideal transformative low-carbon processes and using these as reference points, the assessment first examined for each process whether extent, low-carbon scope and depth were absent, limited or strong. Based on this, the qualitative analytical scale defined in Table 2 was used to classify acceleration of each process as absent, limited, or strong.

In practice, strong acceleration is indicated when a process involves a broad and persistent set of institutions, actors, or technologies (extent), has strong relevance for low-carbon reorientation of institutions, actors, or technologies (low-carbon scope), and is characterized by a transformative or disruptive focus (depth). By contrast, limited acceleration is indicated when process-related changes are evident but remain constrained or uneven, for example, when a process involves some institutions, actors or technologies (extent), yet shows moderate relevance to low-carbon reorientation (low-carbon scope) and weak transformative or disruptive focus (depth).

³⁵ Note: when companies after four to five years had shifted to green debt, early green bonds and loans approached maturity and tightened eligibility criteria tended to initiate a subsequent cycle of similar duration of low-carbon measures linked to refinancing green.

³⁶ Note: as the Covid pandemic made 2020 an atypical year, it was not used as a window end-year.

³⁷ Note: results of the assessments in both analytical passes are summarized in Figure 7.

In a second analytical pass, overall acceleration was assessed based on the pattern of acceleration assessments across individual processes. Overall acceleration is understood as the combined strengthening of multiple transformative low-carbon processes categorized across the socio-technical dimensions. For example, if strong acceleration had been assessed for many of the processes, the overall acceleration would also have been assessed as strong.³⁸

3.5. Research quality

Ensuring research quality in critical realist case studies requires addressing both empirical adequacy and theoretical soundness (Danermark et al., 2002; Maxwell, 2012). Empirical adequacy includes descriptive adequacy (avoiding factual errors and misquoting informants) and interpretive adequacy (securing domain and contextual knowledge to avoid misunderstanding the meaning of empirical statements) (Maxwell, 2012).

Validity is here understood in a critical realist sense as fidelity to underlying reality rather than to surface regularities (Sayer, 2000). Two key measures were applied to secure validity: triangulation across data sources and methods to counter validity threats such as factual errors, self-reporting bias, or misinterpretations (Maxwell, 2012), and repeatedly testing interpretations by asking how results and conclusions were fallible (Maxwell, 2013).

Choosing a case with characteristics of both an extreme and critical case (Flyvbjerg, 2006) improved chances of revealing additional information and gaining a deeper understanding (Danermark et al., 2002). Triangulation was used consistently, supported by connecting strategies, tracing substantive factual relations across data types and over time, and iteratively refining connections through comparison with contrasting data and theoretical reasoning (Maxwell & Miller, 2008). At the same time, my interpretations of meaning and causal relations remain fallible (Bhaskar, 1998).

3.6. Ethical considerations

Confidentiality and informed consent were central for gaining access and collecting relevant data. Good research practice³⁹ prescribes informed consent, i.e. that informants should be informed in advance about the research and its purpose and provide consent to participate.

The larger research project used a written declaration stating the overall aim of the research project, how collected information would be used, and that

³⁸ Note: results of both analytical passes are summarized in Table 9.

³⁹ Vetenskapsrådet (2024) God forskningssed 2024, pp. 62-65.

participation was voluntary. When it became clear to me and the research project manager that my focus partly aligned but also partly deviated from the overall project purpose, I indicated to informants that my focus was low-carbon innovation and the role of green finance, and that I would mainly focus on sector-level dynamics (including and beyond their companies). I did not explicitly discuss my theoretical perspectives with informants to limit guidance to their answers; for example, the Multi-Level Perspective (MLP) on sustainability transitions was only briefly introduced in one of the latter focus group interviews and did not structure the topics or discussions.

An additional ethical consideration concerned the research ambition to contribute to society through criticizing inaccurate representations of reality (ideas) and those actively spreading such ideas (Buch-Hansen & Nielsen, 2020). I therefore reflected and discussed with peers how to ensure that critique remains knowledge-based, respectful and fair to informants (regardless of their confidentiality), who were never treated as targets.

The study did not require collection of formally sensitive personal information such as political views.⁴⁰ However, doing an in-depth field study involves access to information that informants may *consider* sensitive for themselves or their organization to reveal. I therefore promised informants that measures would be taken to protect the integrity and confidentiality of studied organizations and informants. Confidentiality is a more general obligation not to communicate information given in confidence and entails protection against unauthorized persons partaking of the information. (Swedish Research council, 2017).

To ensure confidentiality company and person names were replaced with code keys in interview transcriptions and idiosyncratic details were removed from presentations and publications. Pseudonymization and intent limitation of personal data collection were also used to minimize risks of harm when conducting observations in public events where it was not feasible to inform and obtain consent beforehand. As a consequence, the Empirical foundation section and subsequent chapters use codes (e.g. informant 52A) instead of informant names and workplaces.

⁴⁰ Integritetsskyddsmyndigheten (n.d.) Känsliga personuppgifter.

4. The Swedish CRE sector

This chapter provides context relevant to the embedding of transition debt finance by introducing the Swedish commercial real estate (CRE) sector and its dependence on debt finance, and by highlighting information that matters for the assessments, such as where emissions are concentrated in sectoral value chains and which low-carbon innovations were present (and thus plausible for transition debt finance to strengthen).

4.1. The pressure to transition

This section summarizes pressure exerted on the Swedish CRE sector to effectively help address climate change via sectoral low-carbon transition.

4.1.1. Policy responses

As a response to the Paris Agreement, the Swedish Parliament adopted a climate policy framework with a climate act in 2017. It included ‘shall’-goals to radically reduce domestic transport emissions until 2030 and reach net-zero territorial greenhouse gas (GHG) emissions by 2045 and required the government to base national climate policy on the shall-goals and to produce a climate policy action plan and a yearly climate report.⁴¹

The EU Emission Trading System provided a limited emission reduction pressure on electricity and heat generation, and the production of steel, cement and glass⁴². The pressure increased toward the end of the period studied, as prices of traded carbon emission allowances soared and the EU as part of its ‘European Green Deal’ announced a gradual radical tightening of the Emission Trading System emission caps, followed by a climate act with a new emission reduction target for 2030 and proposals of regulatory measures (‘Fit for 55’) to support the more ambitious target.⁴³

Already prior to the Paris Agreement, a few months into the period studied (in 2014), the Swedish Government defined an ambition that Sweden would transition to ‘fossil-free’ by 2045. The goal was set both to address climate

⁴¹ Regeringskansliet (2017-06-17) Det klimatpolitiska ramverket.

⁴² Note: as the total EU Emission Trading System cap of emission allowances decreased by 1,74% yearly.

⁴³ European Commission Climate Action (n.d) Increasing the ambition of EU emission trading.

change and to secure competitive advantages and future welfare. To build collective trust and action, the Government then set up a policy initiative (Fossil Free Sweden) engaging companies, municipalities, regions and NGOs.

Business sector/industry focused work groups (mainly during 2018) defined 22 roadmaps covering opportunities to become fossil fuel free and related public policy requests. Five of the 22 Fossil free Sweden industry roadmaps relate to the two main CRE value chains generating GHG emissions. The roadmaps for the electricity and heating sectors address the supply of operational energy for CRE.⁴⁴ While the roadmaps for the concrete and steel industries address two high-emitting construction materials central to CRE construction projects. The roadmap for the construction and civil engineering sector directly targets activities in the CRE construction value chain.⁴⁵

Jointly, the policy responses contributed to increasing expectations on high emission sectors, including CRE.

4.1.2. Climate change discourse

Over the period studied, Swedish climate discourse shifted from viewing climate change as a distant concern to framing it as a near-term issue requiring more active responses. The shift happened mainly in the second half of the period studied, reinforced by reporting and discussions related to for example the extreme and extended summer heatwave with drought and extensive forest wildfires in the summer of 2018. A mobilization for treating the climate issue as a crisis emerged in the study setting from the autumn of 2018 with Greta Thunberg's Friday school strikes and climate strike youth movements rapidly growing there and internationally.⁴⁶

These developments helped legitimize and pressured business actors, politicians and academia in Sweden to put low-carbon innovation and emission reduction on the agenda. At the same time, low-carbon transition in the sense of radical system changes remained peripheral and met resistance as most Swedes continued to believe in and support slightly tweaking the business-as-usual with insignificant personal lifestyle changes and relying on future technological advances such as carbon capture. One example is that despite that Sweden belonged to the more unsustainably resource consuming countries, rather than focusing on drastically lowering total resource and energy consumption, the roadmaps for a Fossil free Sweden taken together

⁴⁴ Fossilfritt Sverige (n.d.) Electricity sector; Note: CRE persistently had access to a low-carbon electricity grid mix but several of roadmaps outlined massive electrification likely affecting supply of operational energy after the period studied.

⁴⁵ Fossilfritt Sverige (2018-12-28) Färdplan för fossilfri konkurrenskraft: Bygg- och anläggningssektorn; Note: includes the whole built environment including housing and infrastructure.

⁴⁶ Notably Fridays For Future and the Sunrise movement.

estimated a need to increase the use of biomass for bioenergy by roughly 30% between 2019 and 2030.⁴⁷

Incumbent CRE sector faced only mild tension because cultural discourse framed climate change primarily as a problem of fossil fuels, solvable mainly through a switch to bio-based and renewable fuels and energy. This framing downplayed the high embodied energy and emissions in construction materials and processes and, to some extent, the latent potential for energy efficiency improvements in CRE operations.

4.2. Sector characteristics

This section strives to offer a condensed contextual understanding of the CRE sector, complementing the definition and brief introduction in section 1.1.4.

4.2.1. Ownership and leases

Commercial properties are the central artifacts of the CRE sector and are typically controlled with regards to ownership, development, maintenance and building operation by a CRE company. While one or multiple tenant organizations lease, manage and use CRE space to conduct service activities.

The landlord-tenant relationship is structured through lease contracts, norms associated with landlord and tenant positions, and regulation such as the rental law.⁴⁸ Extra customization of the space, known as space adaptations for tenants, may be agreed in the lease in exchange for higher lease payments. Because both relocation and tenant space adaptations are costly, leases are typically 3-5 years for offices and retail and longer for specialized spaces such as a concert hall.⁴⁹ In Sweden, the agreements typically provide economic incentives to the landlord to provide energy-efficient ventilation and heating and provide economic incentives to the tenant organization to ensure efficient usage of electricity and effective waste sorting.⁵⁰

Commercial property ownership in Sweden is relatively dispersed. Toward the end of the period studied, about half of the Swedish CRE building floorspace was owned by a multitude of medium-sized (in terms of turnover and headcount) CRE companies that mainly own and operate CRE properties within Sweden. However, in terms of asset values (often 10-20 times higher than the turnover) many of these companies match large companies. About a quarter of the Swedish CRE building floorspace was owned by a large number

⁴⁷ Naturvårdsverket (n.d) Konsumtionsbaserade utsläpp per person; World Bank Group (n.d.) Total greenhouse gas emissions excluding LULUCF per capita; Fossilfritt Sverige (2021) Strategi för fossilfri konkurrenskraft – Bioenergi och Bioråvara i industrins omställning, pp. 20, 23.

⁴⁸ Handledning till Fastighetsägarna Sveriges hyreskontrakt för lokal Formulär nr 12b.2; Jordabalk (1970:994) 12 kap. Hyra.

⁴⁹ Business Sweden (2021) Commercial leases and rents.

⁵⁰ Boverket (2013) Analys av delade incitament för energieffektivisering, p. 9.

of municipalities and regions. The remaining quarter was dispersed across other Swedish and international owners.

4.2.2. The importance of debt finance

In the CRE sector, commercial properties constitute real assets whose acquisition, construction, development and ownership require considerable investments of financial capital. Corporations rely on external finance by issuing additional equity, or by raising debt through loan subscription or bond issuance. In the latter case an underwriter helps with the bond issuance and the corporation typically has previously engaged a credit rating agency for creditworthiness evaluation.

Corporate equity does not have a maturity date, typically instead a portion of yearly profit pays a dividend (or an equity buy-back). Whereas corporate debt typically has an end-date at which the corporation, if still in need of the money, has to refinance the maturing debt amount.

This means corporations relying on debt regularly demand attractively priced debt financing. To mitigate refinancing risk, which is the risk that a company faces significant cost increases due to temporary difficulties in renewing or refinancing maturing debt, highly leveraged CRE companies tend to spread their debt maturities over several years (Choi et al., 2018). Debt is the primary external capital source for non-financial corporations across both the EU and the Swedish CRE sector.⁵¹

CRE property is characterized by high capital-intensity and comparably low annual net operating income generated.⁵² In the period studied, estimated property values typically amounted to around 20-25 times the net operating income they generated, a. k. a. net yield of 4-5%. Even though some Swedish CRE companies entered stock markets through issuing equity during the period studied, low net yields that may not meet shareholders' required rate of return make it less attractive to mainly finance CRE investments via equity issuance. Sourcing debt finance at interest rates lower than the yield was preferred as a highly leveraged capital structure can boost the return on equity.

The CRE sector has a strong debt financing capacity due to CRE companies' long-term leases with inflation-hedged rents, combined with valuable long-lived property collateral, contributing to high creditworthiness. Aligning with bank preferences for collateralized loans and institutional investor mandates to invest in corporate bonds with high credit ratings. Thereby enabling CRE companies to raise exceptional amounts of debt at

⁵¹ European Investment Bank (2018.04.11) Proof of Europe's crazy aversion to equity.

⁵² Finansinspektionen (2019) Den kommersiella fastighetsmarknaden och finansiell stabilitet, p. 14.

comparably low interest rates, rendering CRE companies with highly leveraged capital structure, including, for larger companies, corporate bonds.⁵³

The high capital intensity along with a strong reliance on debt makes CRE companies (as borrowers) highly sensitive to the cost of debt, constituted by interest payments to banks for loans and to investors in bonds issued by CRE companies.⁵⁴ Because high interest rates may make debt costs exceed net operating income, the debt financing capacity may be weakened in times of turbulence where interest rates tend to soar. Following the 2008 financial crisis, banks became slightly more restrictive in lending to CRE companies and regulators imposed stricter capital requirements upon the banks at the start of the period studied (2014), but the debt financing capacity was upheld as corporate bond issuance emerged as a complement to bank loans.

Corporate bond issuance, where companies issue bonds with a bank acting as underwriter (helping the issuer to sell the bonds), grew rapidly as a debt financing source among large and medium-sized CRE companies, from zero in 2008 to significant at the start of the period studied and important toward the end of the period studied. Loans from commercial banks to CRE companies also grew over the period studied, although at a slow pace, and small CRE companies continued to rely on bank loans rather than combining them with bond issuance. At the end of the period studied, loans from commercial banks still constituted the main debt financing source for the Swedish CRE sector.⁵⁵

Low inflation persisted before and throughout the period studied, despite the Swedish central bank lowering and eventually setting negative policy rates. Combined with other developments reducing required rates of return among financiers,⁵⁶ nominal and real interest rates for CRE debt were initially relatively low and became extremely low over the second half of the period studied. Meanwhile, the access to debt capital improved and CRE companies were active in taking on additional low-cost debt enabling them to both construct and buy additional commercial buildings.⁵⁷

A boosted demand for CRE property drove up transaction prices as well as market values of CRE buildings in the vicinity of those traded. As large and medium-sized CRE companies typically account for building assets at estimated market value (a. k. a. fair value in investment property accounting), these companies reported high profits and over time added equity (retained earnings) which made CRE companies look more solid and provided them the power to take on additional (low-cost) debt to use for purchasing additional

⁵³ Finansinspektionen (2019) Den kommersiella fastighetsmarknaden och finansiell stabilitet, pp. 8, 15; IMF Global Financial Stability Report, April 2021, p. 54.

⁵⁴ Finansinspektionen (2019) Den kommersiella fastighetsmarknaden och finansiell stabilitet, p. 18.

⁵⁵ Alfelt et al. (2022) Financial stability risks following reduced demand for offices, p. 4.

⁵⁶ Draghi, M. (2016) Addressing the causes of low interest rates [speech transcript].

⁵⁷ Lokalnytt (2016, June 2) Hur lågt kan det bli?

CRE property at high transaction prices, in turn contributing to raised market values, more profits and equity... This self-reinforcing cycle was actualized throughout the period studied and even toward the end with the Covid pandemic, the low cost of debt combined with generous access to capital was upheld as central banks in Sweden, the EU and elsewhere quickly injected additional capital by means of both generous lending buying bonds (already issued) on secondary markets.⁵⁸

At the same time, the CRE companies growing with the help of additional debt also became increasingly dependent on and sensitive to, future access to and cost of capital, as regularly expiring debt instruments prompt refinancing. If interest rates go up (as observed after the period studied) it may become difficult to pay debt costs and to refinance expiring loans or bonds for highly leveraged CRE companies.⁵⁹ And in scenarios with more constrained access to debt capital, CRE assets and companies considered more risky (not only due to high leverage) may run into difficulties to refinance debt⁶⁰.

While CRE assets and companies with ability to (also) attract transition debt finance instead may have a comparably lower refinancing risk. Thus, CRE companies relying heavily on debt finance had an additional reason to focus on limiting their climate transition risks.

In the empirical setting debt finance played a particularly dynamic and prominent role during the period studied.

Both institutional investors and commercial banks are relatively risk-averse in their debt financing, meaning that they are primarily interested in financing corporate activities and projects involving mature technologies and low project risks, while hesitant to finance immature innovations (e.g. a project involving high degree of experimentation or an initial market introduction of a new technology), given the limited nominal return rates on debts. On the other hand, given the magnitude of these financial flows, debt finance may stimulate mainstream adoption of innovations as well as allow some additional outlays for innovative experimentation.

4.2.3. Time cycles and actor groups

The CRE sector can be said to function according to four different time cycles:

- (i) project for new construction or development (e.g. extension, major renovation or repurpose from e.g. industrial to office) relying also on municipal plans and permits, integration with physical infrastructure such as water, district heating, electricity, sewage and transport;

⁵⁸ Wollert (2020) Svenska företagsobligationer under coronapandemin; Sveriges Riksbank (n.d.) Åtgärder under Coronapandemin; SVT Nyheter (2023-05-29) Riksbanken kan ha bidragit till fastighetsbubblan.

⁵⁹ Finansinspektionen (2019) Den kommersiella fastighetsmarknaden och finansiell stabilitet, pp. 18-19.

⁶⁰ *ibid.*

- (ii) building service life with repeated maintenance and renovations of building elements and systems;
- (iii) contract cycle with negotiations between landlord and tenant, space adaptations for tenants, and moves in/out;
- (iv) daily operation and use, including operation of building systems and use by tenants and their visitors implying commuting, production of waste, consumption of electricity (operation of building systems and tenant use), heat, water and repairs.

The building service life (time) cycle is often very long, e.g. only about 25-30% of total CRE space in use in Sweden was newly constructed in the last 30 years, whereas about 40-45% was originally constructed more than 50 years ago.⁶¹ The dispersed construction years makes artifactual heterogeneity inherent in the building stock. Despite the relatively slowly changing building materials, construction technologies, heating and ventilation technologies, infrastructures, and preferences/fashion in building design and use, and despite that building elements and technical systems have partly been updated in older buildings. There is also some heterogeneity among new CRE properties as new construction projects in CRE are commissioned and designed individually (as opposed to in batches) due to varying spatial constraints, availability of infrastructure (e.g. district heating) and tenant demand. This implies substantial variation in renovation and retrofit needs and feasibility across properties.

The time cycles involve a range of different actor groups, some directly while others provide resources or regulate activities. The only actor group central in all four time cycles is the actor group owning properties and inhabiting the landlord position. For example in time cycle (i) above, a CRE company takes an investment decision regarding a new construction project and is then responsible to arrange: finance for the project, a designated plot, a building permit from the municipality, specified project requirements in order to fulfill customer and regulatory requirements, and to some extent also fulfill societal norms e.g. related to sustainability. To do all this, the CRE company involves architect and technical consultants regarding building design, negotiates with a building contractor that then takes responsibility for sourcing the resources required and for the actual construction works. Via the building contractor, multiple suppliers of construction and installation expertise are involved, as well as wholesalers and producers of construction materials, and (often municipal) suppliers providing connections to local infrastructure such as district heating, electricity grid, water and sewage.

CRE companies inhabiting both the owner and landlord positions are often the final arbiter for activities and resource flows that significantly contribute

⁶¹ Boverket (2020-10-16) Energistatistik för lokaler 2019, table 2.7

to sectoral GHG emissions, making them key in reproducing and changing the CRE system and its emissions.

4.2.4. Value chains producing emissions

The CRE sector is high-emitting because its operations and construction value chains depend on massive flows of materials—most notably concrete and steel—and energy. Large volumes of materials are extracted and processed using substantial (often fossil) fuels and then used in construction and renovation, while buildings also rely on large amounts of fuels and electricity for space heating, ventilation, and other building services.

To study sectoral GHG emissions, and changes and innovations affecting them, the focal scope is extended to cover the value chains heavily involved in lifecycle emissions of buildings. Upstream activities linked to construction and operations become relevant, as do downstream activities linked to space demand and scoping of space adaptations for tenants.

4.3. Emissions

This section covers sectoral emissions by value chain.

4.3.1. Operations and operational emissions

The CRE operations value chain contributes heavily to operational GHG emissions, mainly from the energy and fuels required to keep commercial buildings with a comfortable indoor temperature and air quality, hot tap water, and electricity for lights, elevators, security and appliances, and repairs.

Over the study period, discourses on GHG emissions from buildings and the CRE sector, along with building regulations, green building certifications (Amiri et al., 2021), and CRE sustainability reports, tended to focus mainly on the energy used and emissions produced in the operations value chain.⁶²

Structures conditioning operational emissions

Operational energy use and operational emissions of the CRE sector are conditioned by several structural relations. The existing buildings' structural components and building-interior systems, regulation and tenant contracts stipulating indoor temperatures, and cold and dark winter combine to condition CRE operational energy consumption.⁶³ Energy consumption was

⁶² BPIE (2020-08-24) A guidebook to European Building Policy; World Economic Forum (2021-11-01) Why building greener is crucial to meeting Paris climate targets; Propmodo (2022-09-13) Embodied Carbon is a Pesky Real Estate Decarbonization Challenge; SVT Nyheter (2021-05-30) Byggnader stora klimatbovar – energieffektivisering en del av lösningen.

⁶³ Note: about 80% of CRE space is located in the southernmost third of Sweden, where average winter temperatures of urban areas are colder than other EU countries except Finland, Estonia and Lithuania.

also conditioned by institutionalized expectations that Swedish electricity and district heating price levels will remain low, in combination with extensive established infrastructure for district heating, and structures relating to heat pumps. Cleaner energy production was commonly seen as the main pathway to low-carbon operational emissions (more important than energy efficiency).

The building locations relate to available electricity and heat production through electricity grids and, in Sweden widely available, district heating networks. The Swedish electricity grid provided mainly renewable hydro and wind plus nuclear power produced within Sweden and did not import fossil-based electricity, with consistently low (around 30 gCO₂e/kwh) average lifecycle GHG emissions per kwh consumed.⁶⁴

Regarding heating, over the period studied about three quarters of total CRE space was fully or mainly heated via district heating⁶⁵. The district heating networks were mainly delivering heat from combustion of residual waste and bioenergy, which meant that district heating on average had rather low and slowly decreasing lifecycle GHG emissions per kwh consumed, from around 70 to below 60 gCO₂e/kwh (even before Covid).⁶⁶ In the remaining quarter of total CRE space, about half was using the low-emission grid electricity in local heat pumps to extract space heat from e.g. the air or the ground. Within-building heating systems powered by fossil fuels had largely been phased out already at the start of the period studied (2014).

Taken together, this meant that already before the start of the period studied, key parts of the operations value chain of the Swedish CRE sector had been transitioning toward low operational GHG emissions.

Some highly energy efficient CRE properties in Sweden already at the start of the period studied had low-carbon operational GHG emissions. Energy-performance certificates filed to Boverket during or before the period studied suggest a substantial efficiency gap: for example, around 70% of the office buildings performed at least 40% worse than the required energy performance for new office buildings in 2021, and even higher gaps in categories such as schools and retail.⁶⁷

Operational use

Given the sectoral boundaries defined in the study, the GHG emissions generated via tenant operations are out of scope. Left in scope is the extent of tenant space use. Thus, here primarily structural relations conditioning and trends in tenant space demand are discussed.

⁶⁴ European Commission – Joint Research Centre (2024) GHG Emission Factors for Electricity Consumption, table 3.

⁶⁵ Boverket (2020-10-16) Energistatistik för lokaler 2019, table 'Underlag_F2'.

⁶⁶ Energiföretagen (2024-08-20) Miljövärdering av fjärrvärme, table 'Genomsnittliga miljövärden för Sverige 2010-2023'.

⁶⁷ CIT Energy management (2022-12-14) Topp 15 och 30 procent av de bästa byggnaderna, p. 12; Boverket (2020-07-01) BFS 2020:4, BBR29, p. 6.

Office space was predominantly constituted of the open-plan type (Rolfö, 2018) which translates into relatively high employee to space ratio (compared to traditional offices), although office spaces were still rarely used in evenings and weekends. Retail space had relatively small storage spaces and relatively long opening hours which translates into relatively efficient space use. Rising rents combined with a rapid increase in online shopping, led many small retail spaces to be vacated and often repurposed (e.g. as cafés or beauty salons).

4.3.2. Construction and embodied emissions

As previously highlighted in the subsection 4.2.4, the CRE construction value chain contributes heavily to embodied emissions which derive mainly from the energy and fuels required to extract, produce and transport building elements and systems, and in construction processes.

Sector overlooks embodied emissions

Embodied emissions in the CRE construction value chain have typically been overlooked (Birgisdottir et al., 2017; Röck et al., 2020), which was also evident in the study. For example, Swedish building code regulation (BBR) required measurement and limitation of operational energy (and thus also operations emissions) for new construction and major renovations, whereas excluding the energy (and emissions) embodied in materials and construction work.⁶⁸ This persisted until after the period studied, when a new requirement introduced retrospective reporting of GHG emissions from new buildings to authorities, however without any upper limits or performance rating.⁶⁹

CRE companies traditionally have focused on operational energy efficiency given its substantial cost-saving potential, aligning reduced operational GHG emissions with a profitability focus. GHG emission accounting and data availability was more challenging for embodied than operational emissions. Addressing embodied emissions was also deemed more difficult, as a CRE company sustainability manager expanded on:

We are very dependent on Swedish mining and production industries like steel, concrete, wood and their processes, because the climate footprint of the materials we need to construct and maintain buildings, is the largest source of emissions today.⁷⁰

Here the one-off project nature of construction works adds relevant context, positioning CRE developers as tiny customers at a distance from the big companies in the upstream construction material industries.

Sectoral emissions from the construction value chain were higher than from the operations value chain. For example, among Swedish CRE companies

⁶⁸ Boverket (2020-07-01) BFS 2020:4, BBR29.

⁶⁹ Lag (2021:787) om klimatdeklaration för byggnader.

⁷⁰ Informant 12B (2022-02-18)

actively investing in turnover growth and energy efficiency, embodied emissions constituted a majority of the annual corporate emissions (i. e., scope 1-3) and were two-four times greater than (location-based) operational energy emissions.⁷¹ Still, CRE discourse and accounting related to climate change and low-carbon innovation kept focusing mainly on energy and tended to overlook or downplay the role of emissions embodied in the construction value chain.

Structures conditioning embodied emissions

Construction and embodied GHG emissions of the CRE sector are conditioned by several structural relations. Firstly, CRE company and tenant company have an intentional relationship: the CRE company aims to adapt both the building's structural components (during construction or major renovation) and building spaces (at each contractual cycle) to meet common and specific tenant requirements, depending on tenants' willingness to pay through higher rent. Efforts to increase reuse of interiors in adaptations conflicted with norms that interiors should be 'new and fresh'.

Secondly, relations within building material supply chains, where institutionalized construction techniques and building materials help architect, contractor and CRE company to collaborate on minimizing project risks. The building materials and construction techniques were still mainly relying on high emission energy derived from fossil fuels (e.g. coal for cement and steel production and diesel powering construction sites). Thirdly, the low salience of embodied emissions within governance and market practices, where norms as well as regulation underplay the significance of embodied GHG emissions compared to operational emissions.

The above pervasive structures remained intact throughout the period studied. To be transparent in sustainability reports regarding weight and proportions of materials used in the construction of new buildings remained an exception, even among the largest Swedish construction companies. Limited reporting available indicated, for example, that a newly constructed mid-rise building used around one ton of building materials (primarily virgin concrete) per sqm of gross floor area.⁷²

By the end of the period studied, CRE construction based on business-as-usual techniques with GHG-intense materials remained legitimate.

New construction, renovations and retrofits

New construction is not only driven by existing buildings being considered obsolete but also by demand of additional or specialized commercial space in specific locations. Construction relied on virgin structural materials with high emissions, particularly cement-based concrete reinforced with steel in foundation and load-bearing structures. Non-standardized building design,

⁷¹ Own analysis of 2021 sustainability reports from five large CRE companies.

⁷² Plant (2018-08-26) Materialrapport Hubben.

due to ad-hoc land and building permits and architectural creativity, makes optimization of material usage and construction processes hard. An example: New office building (5 floors, 17000 sqm heated and 12500 sqm leasable) built in 2017 with the most ambitious green building certification level (LEED Platinum). Materials used in the construction embodied about 6 tons of CO₂e emissions per tenant employee workspace.

Stringent qualitative demands for construction and cultural expectations both mandate new construction for longevity. Design and construction prioritized durability, but not adaptability (future renovations and repurposing) or deconstruction and reuse (instead of demolition/recycling). No regulatory caps or other regulations were effectively limiting GHG emissions from new construction of commercial buildings.⁷³ In addition, construction machinery and transport were largely powered with fossil energy.

Long building life cycles and shorter lifetimes of installations and interiors make renovations and retrofits relevant. They are both generating upfront emissions but may also help reduce future emissions through increased energy efficiency and/or extended building lifetime.

Construction and demolition waste was often recycled while about a third of the construction waste went to energy recovery at the start of the period studied. By its end, the high waste amounts had not been effectively addressed, as standard practice was still to quickly demolish interiors and whole buildings, preventing reuse of building materials and products.

Space adaptations for tenants

Contract negotiations typically include the extent of adaptations for tenants. The landlord is often willing to perform some customizations of the building space to make the tenant consider signing a contract, and additional space adaptations if the tenant agrees to a higher contracted rent or longer contract period. Further adaptations of office space were driven by a shifting office culture, accelerated by the Covid pandemic, replacing own offices and modules with activity-based workplaces (Lund et al., 2021).

Tenants often require adaptations involving the demolition or replacement of otherwise functional interiors, as they perceive leased space as critical for branding and profiling toward customers and employees. Therefore, space adaptations for tenants often implied extensive replacement of interior components (such as fixtures, doors, floors) before the expiration of their economic and technical lifespans. Installed interior building components were typically not designed to facilitate partial replacement to accommodate change of appearance without shortening the lifespan of the component.

⁷³ Note: only after the period studied a law was passed requiring developers of new CRE buildings to submit a climate declaration upon completing the construction, but caps on GHG emissions per sqm are not due until 2027.

Landlords and tenants typically agreed on space adaptations for tenants without considering GHG emissions implied by furthering the customization. Even toward the end of the period studied, while a few frontrunner CRE companies had begun to calculate the GHG emission footprint from adaptations for tenants they were using calculations for retrospective/annual GHG emission reporting. But not even these CRE companies had yet engaged the sales reps to start discussing upfront with tenants requiring improvements regarding the GHG emission footprint and options to reduce it. As illustrated in this frustrated quote:

An extreme ignorance has persisted regarding the environmental impact of building materials.[...] This goes also for existing commercial buildings where we [CRE companies] consume materials irrepressibly and make adaptations for tenants and then tear it all out again after three years.⁷⁴

The CRE companies that started to measure and account (in scope 3) for the GHG emissions of space adaptations for tenants typically found that those emissions constituted a significant part of their total GHG emissions.

4.4. Low-carbon innovations

This section covers low-carbon innovation in the CRE operations and construction value chains, and outlines key developments regarding the innovation patterns linked to solution pathways, including developments not linked to transition debt finance. The credentialing solution pathway is covered in a third subsection, due to partly spanning both value chains.

4.4.1. Low-carbon innovation in operations

Lower-emission energy and fuel

Lower-emission energy and fuel concerns decarbonization of fuels, heat and electricity used in CRE operations. Energy production in Sweden over the period studied was shutting down some of the remaining fossil electricity production and expanding renewable electricity from primarily wind, while the imported electricity remained dominated by renewable hydro from Norway. This contributed to declining location-based (scope 2) GHG emissions per kwh electricity consumed in Swedish CRE.⁷⁵

Heavy investments were made in low/lower-carbon district heating production before and throughout the period studied, also contributing to the relatively (e.g. compared with other countries) low emissions from operational

⁷⁴ Informant 14A (2021-10-20)

⁷⁵ Note: for example, the European Commission Joint Research Centre provides historical activity-based GHG emission factors for national electricity consumption.

energy in the CRE sector over the period studied. Some pre-studies and pilots regarding district heating with negative emissions - carbon capture and storage (BioCCS) - were conducted in the second half of the period studied, while no major investments in these areas were initiated.⁷⁶

Rooftop solar panels, combined with heat pumps, became common in new CRE buildings in the second half of the period studied. However, large solar panel installations carried higher tax, rules inhibited sharing of locally produced electricity between neighboring buildings, and selling generated electricity to the grid was considered unprofitable. Therefore, rooftop solar panel installations were typically modestly sized, so that peak output roughly matched summer-day electricity demand under low building use. Toward the end of the period studied, most large and medium-sized CRE companies invested in adding rooftop solar panels on existing buildings.

End-use technology efficiency

End-use technology efficiency concerns optimization and innovation regarding efficiency in heating, ventilation and building systems. Before the period studied, low-carbon innovations broadly diffused in the Swedish CRE sector were mainly focusing operational energy efficiency (in addition to waste recycling).⁷⁷ Over the period studied large and medium-sized Swedish CRE companies continued to focus on energy efficiency improvements in existing buildings both through optimization of ventilation and heating and through investments (mainly) in efficient ventilation and heating systems. Such as ventilation system with high heat recovery and heat pumps.

Although optimizing ventilation and heating can reduce operational energy usage and efficiency investments are often considered profitable, a portion of CRE companies did not work systematically with energy efficiency across their portfolios. As exemplified when CRE companies with ambitious energy efficiency targets have purchased existing buildings from other CRE owners:

We have halved the energy [usage in] the properties purchased recently. Despite being large buildings operated by a professional property manager, there has been so much to fix in them. [...] just with small measures, a good organization, you tune up the building quick as hell.⁷⁸

There is so much left to do regarding energy efficiency. I think we can all testify to that. Our company has more than halved the energy use in our portfolio over ten years. And a bit cocky we often say that we can purchase any building with the knowledge that in principle we are able to halve its energy consumption. We'll need to invest a little, but in measures that are highly profitable. With payoff usually within two years.⁷⁹

⁷⁶ Stockholm Exergi (2022-03) Års- och hållbarhetsredovisning 2021, p. 35-36.

⁷⁷ Based on statements in interviews and workshops by informants 10A, 12B, 13B, 14A, 15A, 51A, 52A as well as analysis of documents such as early sustainability reports.

⁷⁸ Informant 13A (2019-10-18).

⁷⁹ Informant 14A (2019-10-18).

In the second half of 2021, higher electricity prices in Sweden helped make energy efficiency a priority also for laggard medium-sized CRE companies, although much of the resulting energy efficiency optimizations and investments were done after the period studied.

Toward the end of the period studied (2020-2021), low-carbon innovations with broad adoption in the Swedish CRE sector (in addition to waste recycling) were focusing operational energy efficiency and self-produced energy,⁸⁰ which jointly contributed to substantial emission reductions in the CRE operations value chain during the period studied.

System efficiency

This subsection clarifies how building energy regulation, carbon storage and building infrastructure have contributed to system efficiency of Swedish CRE. Non-commercial actors such as citizens, NGOs and politicians potentially may play important roles in low-carbon innovation, e.g. to pressure and incentivize commercial actors' innovation e.g. by changing taxes, subsidies, regulations or standards. Over the period studied, the main regulatory changes directly targeting low-carbon innovation in the CRE sector were the raised energy performance requirements through the Boverket building code regulations (BBR).

Since 1980, Swedish building regulations have included requirements intended to secure reasonable energy performance in new buildings, and since 2013 also in major renovations. Since 2008, CRE property owners have been required to commission an energy performance certificate, publicly display its summary including A-G building energy rating, and renew it every decade. In 2010, the EU adopted an Energy Performance of Buildings directive which prompted Swedish authorities to gradually tighten the energy performance requirements for new commercial buildings and for buildings undergoing major renovation, toward 'near-zero energy'.

As a first step, from 2013 with Boverket Building Regulations (BBR) version 19 the maximum allowed (as per design) yearly purchased building operational electricity and heating energy per sqm was lowered about 20% (while unchanged for electrically heated buildings).⁸¹ Then over the period studied, allowed levels of purchased energy for new and majorly renovated buildings were further reduced by about 10% in 2015 with BBR version 22 and then from 2020 further reduced about 20% with BBR version 29, as illustrated in Figure 6 below.⁸²

⁸⁰ Informant 51A (2020-01-10).

⁸¹ Note: electricity used for operating building systems such as ventilation and elevators, but excluding any tenant electricity (e.g. used to power tenant IT servers and equipment).

⁸² Boverket (2020-07-01) BFS 2020:4, BBR29.

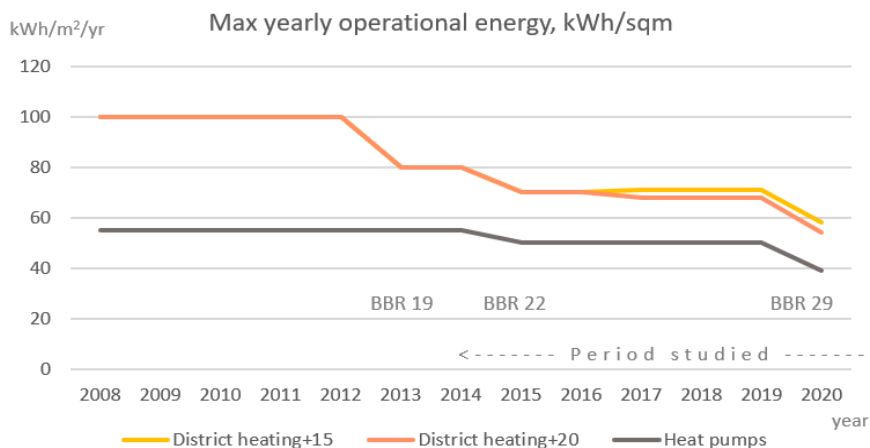


Figure 6 Regulatory cap of bought operational energy per sqm (values for the region of Stockholm). For years 2017-2020 two different values are shown for new buildings fully heated by district heating, based on 15 and 20 kWh/sqm of operational electricity.

The progressively stricter energy performance requirements have not really led to ‘near zero’ purchased operational energy in newly constructed CRE buildings,⁸³ as a main aim has been to limit energy performance requirement ambitions to what can be *profitably achieved* using best available technology.⁸⁴ But the tightened energy performance requirements have provided a driving force to design new buildings for energy efficiency and stimulate demand for innovative and state of the art construction solutions and building systems. For example, toward the end of the period studied ventilation with heat recovery (FTX) had become a de facto standard in new commercial buildings. Whereas buildings designed before the study period could meet requirements without heat recovery. Because compliance and energy ratings are measured against purchased energy only, stricter requirements also created an added incentive to invest in self-produced electricity in new CRE buildings, such as rooftop solar panels.

However, unlike countries like Australia or the UK, over the period studied the energy performance regulation in Sweden did not require any improvements in existing buildings unless they were subject to a major renovation. Furthermore, no national policies were introduced to stimulate or enforce rooftop electricity production in existing CRE properties, and there were no major public incentives targeting improvements in existing

⁸³ Note: even in 2021, a new office building in Stockholm relying on district heating could be designed to purchase over 1000 kWh of heat plus electricity per employee annually, excluding tenant electricity.

⁸⁴ Boverket (2023) Kontrollstation av reglerna för byggnaders energiprestanda, p. 8.

commercial buildings with poor energy performance.⁸⁵ Which limited the regulatory relevance for system efficiency in Swedish CRE operations.

Service efficiency and demand reduction

Service efficiency and demand reduction focuses on usage innovations that help lower CRE energy usage. Reduced space demand via activity-based offices with more remote work also translated into slightly lowered operational energy and GHG emissions in Swedish CRE.⁸⁶ Pure co-working space offerings appeared in the second half of the period studied and captured a very small niche market with difficulties to scale. Educational institutions pursued efficiency through larger classes and preschool groups, but reducing educational space demand was challenging in the Swedish setting where all pupils may choose between public and independent schools.⁸⁷

4.4.2. Low-carbon innovation in construction

Lower-emission energy and fuel

This subsection covers innovations and developments related to shifts to electricity/bioenergy in building material production and construction processes. Cement and steel producers in Sweden and neighboring countries initiated pilots and committed to investments in scaled net-zero steel production (targeting 2026/2030/2033). These investments could reduce emissions from steel and concrete, but only after the period studied.

However, when it comes to reinforcement steel (corrosion sensitive low-alloy steel used to reinforce concrete), several Nordic producers already at the start of the period studied used electric arc furnaces powered by (nearly) low-carbon grid electricity to melt scrap iron/steel, thus offering (nearly) low-carbon reinforcement steel for CRE construction in Sweden.

The concrete industry developed and, over the second half of the period studied, launched climate-improved concrete that partially replace emission-intense cement as binder with fly ash or slag. It typically allowed 10% reduction of concrete emissions (excluding reinforcement) and, near the end of the period studied, the Swedish concrete standard was updated to allow higher portions of cement to be replaced with the low-carbon binder materials upping the emission reduction potential of climate-improved concrete to about 20% (excluding reinforcement).⁸⁸

Construction sites continued to rely mainly on fossil fuels for vehicles and machines and for heating site barracks. Major construction companies participated in decarbonization experiments, but by the end of the period

⁸⁵ Boverket (2022) Implementation of the EPBD in Sweden, pp. 7-11.

⁸⁶ Note: minor, because offices make up just one-third of all CRE space and some of the savings were offset in other types of CRE space.

⁸⁷ Riksrevisionen (2022) Skolpengen – effektivitet och konsekvenser.

⁸⁸ Svensk betong (2022) Vägledning Klimatförbättrad betong – utgåva 2, p. 14.

studied they had not begun to scale fuel switching in fleets or to decarbonize barracks through electrification and efficiency.⁸⁹

Production and resource efficiency

In construction, innovation related to production and resource efficiency concerns substitution for low-carbon construction materials, shifts to lightweight design, design for disassembly and adaptability, and application of more efficient construction methods. In the Construction and Civil Engineering industry roadmap for a Fossil free Sweden adopted in 2018, the initial period through 2022 focused on emission inventories (e.g. EPDs and value-chain mapping) and preparation for transition. Preparation included improving standards, proposing and lobbying for regulatory changes, and carrying out pilot projects related to materials, logistics and construction. In 2022 a follow-up of the roadmap for Construction and Civil Engineering sector reported⁹⁰ that a majority of the signatory organizations had mapped their emissions, identified mitigation areas and set emission reduction targets, and reported progress mainly as a number of ongoing/completed pilot projects (e.g. an electrified crane tested in piling a pre-school constructed with low-carbon foundation and wood structure)⁹¹ and that production and use of ‘climate-improved’ concrete is growing (from a low level).

Given that the value chains of the CRE sector are associated with high GHG emissions, one way for actors active in or contributing to the CRE sector to secure legitimacy among stakeholders may be to try to position themselves as ‘participants in the transition’ to fossil free or net-zero emissions. Some of them engaged in the roadmap for Construction and Civil Engineering sector. Some of these engagements subsequently involved them in collaborative low-carbon experimentation projects in 2019-2021.

Given the high emissions of incumbent fossil-based construction materials, the use of renewable organic building materials offers potential low-carbon alternatives. Due to Sweden’s prominent wood resources, there is a long tradition of constructing houses dominated by wood materials. However, until 1994 the Swedish building code did not allow the construction of midrise (and high-rise) wood-framed buildings,⁹² and before the period studied design and construction of multi-story wood-framed buildings mainly focused and reached some success with apartment buildings (housing instead of CRE), encouraged e.g. via a Swedish government program launched in 2004.

At the start of the period studied there were only a small number of (still mainly 1-2 story) CRE buildings constructed with wood-frame. Over the

⁸⁹ Based on analysis of the annual and sustainability reports from 2020-2023 of 3 major construction companies (and triangulation with empirics from some of the interviews conducted).

⁹⁰ Fossilfritt Sverige (2022) Färdplaner för fossilfri konkurrenskraft – uppföljning 2022, p. 18.

⁹¹ Strand Nyhlin, M. (2022-01-19) Extremt koldioxid snål förskola ger framtidshopp.

⁹² Note: technically only the vertical frames could not be made of wood, but this made it less attractive to design the horizontal frames or the roof with wood.

period studied, showcase and flagships projects experimented with mid-rise and high-rise wood-framed construction involving some CRE companies.

In Sweden, the manufacturing capacity of structural wood, especially cross laminated, multiplied toward the end of the period studied. While slowly maturing technically and attracting certain tenants, wood-framed construction in CRE remained a relatively immature niche.

Another key to production and resource efficiency is to increase reuse of building materials and products. During the first half of the period studied (2014-2017) sectoral actors seemed relatively content with that an increasing portion of the construction and demolition waste was recycled while much of it still went to incineration or landfill. Relatively scarce attention was paid to achieving remanufacture, refurbish or even reuse of ‘old’ building materials (wood, concrete, tile and brick) and products (e.g. windows) by means of deconstructing/disassembling instead of demolishing whole buildings or building spaces.⁹³

A Swedish research project initiated in 2015 resulted in a niche arena called CCBUILD, aiming to increase circularity (primarily reuse) in construction.⁹⁴ Toward the end of the period studied (2020-2021) this niche was rapidly gathering actors, examples of success projects, and inventory in its second-hand marketplace for building elements (windows, panels, etcetera). Furthermore, some CRE companies started to explore, measure and focus on reuse of building materials and products in upcoming building projects. However, the reuse principle was still absent in discussions on adaptations for tenants.⁹⁵

The empirical material does not indicate that developers altered their choices based on GHG emissions of building products. Throughout the period studied large and medium-sized CRE companies referred to that they ensure ‘environmentally sound’ building products, with the help of a software (called Byggvarubedomningen). However, even though that software rated both chemical content and lifecycle aspects, it was mainly used for negative screening to avoid hazardous products. Toward the end of the period studied, planning software used in space adaptations were extended with EPD data and a module for calculating the GHG emissions of selected materials. This could have supported discussions with tenants about reducing GHG emissions from space adaptations. In practice, CRE companies still rarely raised the climate footprint in discussions with tenants about space adaptations.⁹⁶

⁹³ Based on analysis of annual and sustainability reports from 2016-2017 (and compared against more recent) of frontrunner CRE and Construction companies, and of Swedish official waste statistics and reports.

⁹⁴ Centrum för Cirkulärt Byggnade, lead by IVL Svenska Miljöinstitutet, is a national arena collaborating with several local arenas.

⁹⁵ Informants 10A, 10C, 11D, 14A, 51B and 52A (2021-10-20); Informant 12B (2022-02-18).

⁹⁶ Ibid.

Compared with sectors with standardized production and supply chains, CRE construction is more heterogeneous and project-based, with geographic fragmentation (e.g., differing building codes and infrastructures). This makes it difficult for CRE actors to induce low-carbon innovation in construction supply chains and difficult for suppliers to standardize and scale innovative solutions. One consequence is slow progress in designing buildings for functional adaptability.

Throughout the period studied new construction in CRE continued to rely on virginal and cement-based reinforced concrete and steel in foundation and load-bearing structures. No national policies were introduced to stimulate reuse or low-carbon material selection in construction and renovation. Even developers with a strong environmental image reported that unless they specifically asked architect and contractor to prioritize reused and low-emission (virginal) building products, solutions relying on traditional low-cost building products were typically proposed and often implemented, associated with high embodied emissions.⁹⁷

System efficiency

System efficiency here refers to innovations and developments related to systems for circularity, carbon storage and repurpose of unused buildings. Before the period studied, low-carbon innovations related to circularity broadly diffused in the Swedish CRE sector were focusing waste recycling. During most of the period studied it was not mandatory to separate demolition waste at the building site, something that encouraged demolition rather than deconstruction and only limited volumes of building materials and products followed circularity principles with significant potential reduction of emissions, such as remanufacture, refurbish or reuse. In the final 16 months of the period studied, a new regulation (2020:614) mandated separation of demolition waste materials at the building site when technically feasible. It also prohibited sending separated materials to incineration.⁹⁸

Over the period studied, a couple of the 350 municipalities actively organized collection and resell of leftover materials from construction and demolition between construction companies.⁹⁹

However, at the end of the period studied, resell and reuse of building materials remained relatively immature niche practices in CRE with very limited material volumes and still considered to add complexity and costs making CRE companies and construction companies hesitant to scale up.

⁹⁷ Informant 12B (2022-02-18).

⁹⁸ Naturvårdsverket (n.d) Vägledning Bygg- och rivningsavfall

⁹⁹ IVL Svenska Miljöinstitutet (2020) Återanvändning av bygg- och rivningsmaterial och produkter i kommuner.

Service efficiency and demand reduction

This subsection covers usage innovations and developments affecting service efficiency and demand and their consequent impact on CRE scope of construction. Office work in Sweden was already highly digitalized at the beginning of the period studied, and office workers had broadband at home and many of them also some experience of working from home. During 2018-2021, many office tenants shifted toward activity-based flexible offices and expanded remote work, which reduced demand for office space and therefore the need for new office construction. Some of the GHG savings were offset by rebound effects, including added demand and construction for other spaces used for remote work (e.g., cafés, hotels, padel courts, or extra room at home).

4.4.3. Credentialing

Credentialing manifested through combining a climate accounting innovation and renewable energy contracting, as well as through green building certifications.

Climate accounting innovation and energy contracting

Accounting-wise, market-based accounting of corporate GHG emissions from energy combined with contracting renewable energy origin often produced large emission reductions for CRE companies, but without affecting actual GHG emissions to the atmosphere (Brander et al., 2018; Hamburger & Harangozó, 2018).

In Sweden a system for electricity guarantees of origin (GOs) was established before the period studied and used extensively throughout it.¹⁰⁰ Swedish authorities published and referred companies to a residual-mix emission factor for the Nordic (rather than the Swedish) electricity grid. The GOs enabled electricity suppliers to offer ‘renewable’ electricity (e.g. wind or hydro power) alongside residual-mix electricity, allowing Swedish CRE companies to report very different market-based energy emissions from purchased electricity depending on the electricity contract chosen. The market-based scope 2 emission factors for residual mix electricity were between 250-372 gCO_{2e} per kWh over the period studied.¹⁰¹

Electricity with a guaranteed renewable origin grew popular among first large and then also medium-sized CRE companies over the period studied as it merely involved paying a small fraction extra for purchased energy.

More and more suppliers of district heating also started to offer CRE companies district heating with a specified renewable allocation or environmental label, as an add-on service with lower associated emission

¹⁰⁰ Note: is different from the Swedish-Norwegian Electricity Certificate Market, through which all CRE actors paid a premium on electricity purchases to boost renewable supply.

¹⁰¹ Energimarknadsinspektionen (n.d.) Residualmix; Energimarknadsinspektionen (n.d.) Residualmixen för tidigare år.

factors. Despite that these district heating offerings were not backed by GOs they were also usable for CRE companies in their market-based climate accounting to demonstrate low heating emissions. When buying heat from a district heating supplier that only offers ‘standard heat’, CRE companies would use the supplier’s average/location-based emission factor also when calculating market-based heat emissions. Also district heating labeled as renewable or environmental grew popular among CRE companies, albeit slightly later and slower.

At the end of the period studied, some CRE companies had reached 100% contracted renewable electricity while it was still rare to reach 100% contracted renewable/environmental heating, whereas many smaller and some medium-sized CRE companies were not paying extra for renewable electricity/heat.

Along with the institutionalization of market-based accounting of GHG emissions from purchased energy (scope 2) early in the study period, even backed by the Science-based targets initiative,¹⁰² large and medium-sized CRE companies increasingly put focus on their ‘market-based’ emissions from purchased electricity and district heating in their corporate climate disclosures. In doing so, they typically highlighted these values over location-based values, using them in summation of total corporate emissions and in targets and trends for energy GHG emissions. Also, the CRE frontrunners setting company-level science-based targets around the end of the period studied used market-based GHG emissions from purchased energy (scope 2).

The arguments that collectively GOs are *not* substantially contributing to a shift from fossil to renewable energy production and that the market-based method to account for energy GHG emissions provides misleading information to stakeholders were supported by trends in the European GO market throughout the period studied. There was low demand of renewable GOs compared to the supply and wholesale GO prices were low compared to electricity prices¹⁰³ and a significant portion of renewable energy production was sold without a GO.¹⁰⁴ In addition, an assessment of existing Swedish district heating offerings with a specified renewable allocation or environmental label in 2022, reported that neither the analysts nor the district heating providers considered that these offerings lead to any environmental benefits.¹⁰⁵

¹⁰² Science Based Target initiative (n.d.) What role do market-based accounting approaches play in target-setting with the SBTi?

¹⁰³ RE-Source (2021) Guarantees of origin and corporate procurement options, pp. 11-12.

¹⁰⁴ Energimarknadsinspektionen (n.d.) Residualmixen för tidigare år; Note: 13% renewable energy in the residual mix of electricity (without GOs) supplied in Nordic countries 2021.

¹⁰⁵ Westerberg et al. (2023) Miljöprodukter för fjärrvärme i ett systemperspektiv, p. 8.

Green building certifications

Green building certifications often span both the operations and construction value chains. Certification schemes can motivate the adoption of specific measures to reach a targeted certification level, including measures that have no or indirect relevance for emission reductions (for example, amenities to support bicycling). Some certification schemes (e.g., Miljöbyggnad) also include specific operational energy performance requirements. However, the schemes are similar to point-based checklists and allow CRE companies to choose among criteria and earn points by documenting compliance when certifying a building. For example, one scheme that also covers the construction value chain allocates 12.5% of total points to building materials, primarily for avoiding materials containing hazardous chemicals and for documenting what materials are used.

Consequently, in the Swedish CRE sector during the period studied, certifications primarily functioned as standardized documentation and signaling practices. Certifications are therefore treated as credentialing in this thesis, and any associated measures with substantive low-carbon relevance are captured under other solution pathways (e.g. energy efficiency). This distinction becomes important in the subsequent assessment of emission goal alignment. Large newly constructed buildings were often certified green already at the start of the period studied. Over time, certifications increasingly extended to existing buildings, and toward the end of the period some CRE companies moved toward portfolio-wide certification.

5. Embedding of transition debt finance

This chapter covers the actual embedding of transition debt finance in the Swedish CRE sector and to some extent also analytically linked changes in innovation patterns and processes.

Over the period studied (2014-2021), Swedish CRE companies began to use green bonds and green loans as financing instruments and were increasingly exposed to, and responding to, expectations and pressure from financiers incorporating climate impact and transition risks into their financing decisions.

In the empirical material, green bonds and green loans were virtually always explicitly or implicitly focused on addressing climate change and are therefore treated here as part of transition debt finance.¹⁰⁶ Green bonds issued by, and green loans offered to, Swedish CRE companies were typically conditioned on operational energy efficiency of the property financed via ‘use of proceeds’ criteria. The use of proceeds criteria in green finance frameworks were in second party opinions explicitly assessed on climate risks and alignment with low-carbon future. For example, Cicero who most Swedish CRE green bond issuers contracted for an external review (a.k.a. Second Opinion) of their green bond framework, described their assessment methodology as a: “climate-science based rating method, focusing on avoiding lock in of greenhouse gas emissions over the asset’s lifetime”.¹⁰⁷ Furthermore, the environmental impact of allocated green finance proceeds was measured and reported in tons of reduced GHG emissions or MWh:s of energy savings.

5.1. Transition risk considerations

Over the period studied, finance rules and practices were introduced focused at incorporating corporate exposure to transition risks (including opportunities) into decisions qualifying, quantifying and pricing debt

¹⁰⁶ Based on analysis of company green finance frameworks, impact reports, annual and sustainability reports, plus second party opinions from external reviewers regarding green finance characteristics, trends, considerations and accounting of 15 Swedish CRE and construction companies, 6 Swedish Municipalities and Regions, 2 Swedish green finance Aggregators, 3 Swedish Commercial Banks and 3 public Investment Banks.

¹⁰⁷ Cicero (2018) Cicero milestones 2018, p. 3.

financing of CRE assets and activities. We focus here on rules and activities that were not an explicit part of green bond and loan adoption. Key developments included the Financial Stability Board's establishment of the Task Force on Climate-related Financial Disclosures (TCFD), which developed and released recommendations for corporate climate-related financial disclosure in 2017.¹⁰⁸

In the second half of the period studied (2018-2021), credit rating agencies, financiers and industry analysts increasingly framed commercial buildings as exposed to transition risks.¹⁰⁹ In 2020, the credit rating agency Moody's assessed the commercial property sector as facing a 'moderate' level of transition risks, citing exposure to carbon taxes and increasing sensitivity among financiers, equity investors and tenants to climate attributes of building assets and leased spaces. Moody's also identified producers of two key materials used in CRE construction, steel and cement, as facing high transition risks.¹¹⁰ Regarding framing of transition opportunities relevant for the CRE sector, a TCFD Banking Program report for example pointed out that highly energy efficient buildings may benefit from higher appeal to commercial tenants and (relatively) lower costs in ambitious transition scenarios.¹¹¹

Financiers (and equity investors) over the period studied encouraged large CRE companies to expand disclosures on GHG emissions, adopt emission targets, and to self-report on climate performance to ESG rating agencies. Such disclosures were occasionally used by financiers as indicators of company-specific exposure to transition risks (including opportunities).

In 2014, a handful of large CRE companies were already disclosing on scope 1 and 2 carbon (not yet GHG) emissions in their annual reports, while most large and medium-sized CRE companies still only disclosed their energy performance.

Companies have been able to choose whether and what to publicly disclose regarding corporate GHG emissions and climate risks, even when in 2017 the EU with the directive NFRD¹¹² made it mandatory for large and some medium-sized CRE companies to issue yearly sustainability reports. In addition, some CRE companies voluntarily followed suit then and in the following years. As encouraged and pressured by financiers, corporations

¹⁰⁸ FSB (2015-11-09) FSB to establish Task Force on Climate-related Financial Disclosures; Task Force on Climate-related Financial Disclosures (n.d) About us.

¹⁰⁹ MCSI (2020-07-08) Measuring Climate Risk in Real Estate Portfolios; UNEP FI (2020) Beyond the Horizon: New Tools and Frameworks for transition risk assessments from UNEP FI's TCFD Banking Program.

¹¹⁰ Moody's investor service (2020-12-14) Moody's Environmental Credit Risk - Sector in-depth, pp. 18, 21, 45.

¹¹¹ UNEP FI (2020) Beyond the Horizon: New Tools and Frameworks for transition risk assessments from UNEP FI's TCFD Banking Program

¹¹² EUR-Lex (2014-10-22) Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups.

often relied on the GHG protocol, an accounting standard for climate emissions, in combination with directions from GRI standards on climate-related disclosures.¹¹³ The yearly sustainability reports allowed financiers to benchmark large CRE companies and make stronger requests for extended and improved climate-related disclosures from CRE companies.

Financiers have also encouraged CRE companies to self-report on climate performance to specialized ESG rating bodies in order to receive an ESG score or even a carbon disclosure score¹¹⁴ that financiers could use as a proxy for judging company-level exposure to transition risks. Some CRE companies signed up to environmental transparency initiatives focused on improving corporate climate disclosures (e.g. the Climate Disclosure Standards Board) and making them available and comparable for financiers (e.g. the Carbon Disclosure Project).

Throughout the period studied, financiers (and equity investors) of large CRE companies requested them to improve disclosures on GHG emissions, initially to accurately disclose scope 1 and 2 emissions. From 2018 onward, more financiers put increasing expectations on large CRE companies to fully report also the scope 3 emissions, to set ambitious emissions targets - soon followed by requests to set Science-based targets or net-zero emissions targets, and to reveal transition plan (how to reach set targets).

Over the second half of the period studied, financiers also started to query large and medium-sized CRE companies about their exposure to transition risks and encouraged the them to assess and report on climate risks according to the TCFD recommendations. From about 2020 requests mounted on CRE companies to follow in the footsteps of the largest public companies by reporting on climate risks according to TCFD recommendations.¹¹⁵ In response, some CRE companies started to report on their company-specific climate-related risks, opportunities, governance and strategies with reference to the TCFD recommendations.¹¹⁶

Over time, particularly toward the end of the period studied, financier encouragement and requests toward large and medium-sized CRE companies for extended and improved climate disclosures and climate action turned into higher expectations and mild requirements (stronger pressures).¹¹⁷

In response, over the second half of the period the studied frontrunner CRE companies:

¹¹³ GHG protocol (n.d) About us; Global reporting initiative (n.d.) About GRI.

¹¹⁴ CDP (2022-03-14) More than 680 financial institutions with US\$130+ trillion in assets call on nearly 10,400 companies to disclose environmental data through CDP; CDP (n.d.) What we do.

¹¹⁵ Informant 13B (2020-05-04); Sigblad, A. (2020-04-22) Det innebär TCFD-ramverket.

¹¹⁶ Task Force on Climate-related Financial Disclosures (2022-10) 2022 TCFD Status report.

¹¹⁷ Informants 10A, 10C, 11D, 14A, 51B and 52A (2021-10-20).

- (i) inventoried their value chain GHG emissions including embodied emissions from construction and extended emissions reporting to better cover value chain emissions in scope 3;
- (ii) set (and often verified as science-based) net-zero targets that typically included halving scope 3 emissions until 2030 and started to report on the targets and the (transition) plan how to reach them;
- (iii) analyzed corporate climate risks based on mid- and long-term climate scenarios and started to report on transition risks and opportunities based on TCFD in their annual report.

These response actions from frontrunner CRE companies in turn strengthened the perception among additional CRE companies that they also would need to expand the scope and timeframe of their climate emission considerations and respond similarly to financiers' requests/pressures. Around the end of the period studied responses (i)-(iii) started to manifest from some additional large and medium-sized CRE companies.

Still at the end of the period studied, many medium-sized CRE companies continued to completely evade the issue of embodied emissions, while CRE companies having started to report on embodied emissions still tended to focus discussions on other emission sources (primarily operational energy). Although early signs of a potential discursive shift in CRE toward focusing also on embodied emissions were present, as for example, discussions about reuse in construction intensified in 2021. In an online seminar organized by Sweden Green Building Council on finance and sustainability, a CEO from one of the large CRE companies highlighted that for the property sector, the GHG emissions of building materials going into renovations, space adaptations for tenants and new buildings is the main concern (as opposed to energy). In the same seminar, a partner from another real estate company discussed why the [GHG emission] challenges on the construction material side are much greater than on the energy side, partly attributing it to the one-off project nature of construction works.¹¹⁸

A growing awareness among institutional investors and banks that climate transition risks may be financially material also in a positive way, gradually built expectations on large and medium-sized CRE companies to also experiment with low-carbon innovation in order to assess and reap climate transition opportunities. While there were not yet explicit requirements to experiment with more radical low-carbon innovation, some frontrunner CRE companies chose to experiment (beyond meeting criteria for green bonds and loans) with promising low-carbon construction innovations, such as construction with wood frame and reused materials, in collaboration with suppliers and (sometimes) researchers.

¹¹⁸ Sweden Green Building Council (2021-04-22)

Partly because they wanted to signal climate leadership to customers and financiers and to show financiers that they were actively managing transition risks by reducing transition risks and capturing transition opportunities. Also, toward the end of the period studied the increasing expectations/requirements from financiers on large CRE companies to start reporting on climate risks (in line with TCFD) contributed to that CRE companies started to assess potential climate transition opportunities, including some experimentation. For example:

It is hard somehow to separate what is really pressure from investors and what is something we do because we think they will soon have understood this and will start to tighten the requirements. [...] It is a bit like, what do we need to do to somehow remain at the forefront and what requirements will we reasonably face. And then I think that wood-framed building construction is one example.¹¹⁹

Around the end of the period studied, some commercial banks and institutional investors started to calculate and report on ‘financed emissions’ via their debt instrument portfolios. A standard (PCAF) provided guidance for accounting financed emissions but notably left out guidance regarding, and left as optional for financial institutions to account for, financed embodied emissions from construction and renovation of buildings.¹²⁰

5.2. Green bonds and loans

The transition debt amounts channeled to the CRE sector in Sweden as green bonds and loans over the period studied stood out in comparison to most geographies and sectors with its early start and strong growth.¹²¹ Large CRE companies experienced an exceptional demand for their green bonds, providing advantages such as access to a broader investor base and lower interest rates. Given the slightly lower cost of debt and refinancing risk associated with green finance, CRE companies were positioned to benefit from rolling over conventional debt finance to, and finance further growth with, green loans and bonds. After several early successful CRE company bond issuances around the start of the period studied, a continued strong market demand gradually helped convince CRE companies to pursue fully green debt and strengthened their subsequent actions to improve climate performance of their buildings to qualify more and more properties and

¹¹⁹ Informant 14A (2021-10-20)

¹²⁰ PCAF (2022). The Global GHG Accounting and Reporting Standard Part A: Financed Emissions, pp. 138-139.

¹²¹ Climate bonds initiative (2018) The Green Bond Market in the Nordics 2018, pp. 5, 14; Climate bonds initiative (2019) Green Bonds Global State of the Market 2019, pp. 3-6; Nordic Trustee (2021-02) Nordic Corporate Bond market 2020, pp. 21, 27-28.

subsequently finance them via green bond issuance and green bank loans.¹²² “It is the financing side that drives sustainability work [in CRE companies] nowadays.[...] as you can borrow green and save money it has become...the driver”.¹²³

As financier demand was stronger than the green bond supply (offered to financiers), financiers had incentives to maximize the growth of the green bond market. Banks were positioned to benefit from rapid expansion of the green bond market, both as issuers using the proceeds to provide green loans and as intermediaries profiting from helping (e.g. CRE) companies to issue bonds. Green bonds and loans also offered banks an opportunity to attract new and maintain existing debt customers that had conventional loans but whose financed assets could qualify for green loans.

In November 2013, the very first corporate green bond was issued by a Swedish CRE company named Vasakronan, with use of proceeds criteria specifying new construction and major renovation of owned buildings with a high energy-efficiency.¹²⁴ The CRE company’s green bond framework had a ‘second opinion’, an independent external review of climate risk and impact (given the criteria defined for the use of proceeds), performed by the Norwegian environmental institute Cicero. The green bond framework also promised regular impact reporting to financiers.

In the following months and years, transition debt finance in the form of corporate green bond issuance and green loans from banks to corporations grew rapidly, with Sweden and green (energy-efficient and/or certified as green) buildings spearheading the expansion of corporate green bonds.¹²⁵ While globally green finance remained a limited category of corporate debt finance even in 2021 (a few percent of the total), for Sweden and particularly CRE, it had grown to an important category of corporate debt finance. Implying a strong embedding of transition debt finance in the CRE sector in Sweden.

For example, a report from Nordic Trustee indicates that 23% of total corporate bond issuance in 2020 in Sweden was green and more than half of the outstanding (issued and not yet redeemed) corporate green bond financing was related to real estate.¹²⁶ Petreski et al. (2025) reporting on green bond issuance by Swedish real estate companies, indicated that in 2021 green bonds comprised 59% of the number of bonds and 37% of the total bond amount.

Larger municipalities and regions in Sweden have also been active issuers of green bonds while some medium-sized municipalities have used a jointly owned funding agency to aggregate green bond issuance, where a share of the

¹²² Förvaltarforum (2019-11-29) Därför certifierar Fabege 100 procent.

¹²³ Informant 13A (2019-10-18)

¹²⁴ Vasakronan (2013-11-18) Vasakronan issues the world’s first corporate green bond.

¹²⁵ Climate bonds initiative (2018) The Green Bond Market in the Nordics 2018, pp. 5, 14; Climate bonds initiative (2019) Green Bonds Global State of the Market 2019, pp. 3-6.

¹²⁶ Nordic Trustee (2021-02) Nordic Corporate Bond market 2020, pp. 21, 27-28.

proceeds has gone to CRE (e.g. city halls, primary care facilities and hospitals) new construction or renovation projects.¹²⁷

To summarize, a prominent part of the embedding of transition debt finance in the empirical setting over the period studied was green finance, involving green debt instruments (bonds, certificates, loans) with defined ‘use of proceeds’ criteria specifying eligible low-carbon assets and innovations to be financed.

5.2.1. Eligibility for green finance

While voluntary, the Green Bond Principles (GBP) have throughout the period studied been an established de facto standard, and practically all Swedish green bond issuers refer to these principles and have a green finance framework externally reviewed with a second opinion.¹²⁸ The GBP (with slight variation of wording between its versions) stated that: “All designated Green Projects should provide clear environmental benefits, which will be assessed and, where feasible, quantified by the issuer”.¹²⁹ The GBP was initially created by investment banks and commercial banks primarily interested in developing and growing a green bond market¹³⁰, facilitated by not specifying which business activities and performance criteria or thresholds were eligible for ‘use of proceeds’ from green bonds.

The GBP only provided an indicative lists of eligible green project categories, notably from 2016 also acknowledging refinancing of existing buildings: “energy efficiency (such as in new and refurbished buildings,...)” and from 2017 also “green buildings that meet regional, national or internationally recognized standards or certifications”.¹³¹ These categorizations helped legitimize whole buildings as ‘green projects’, allowing to fully finance or refinance an energy-efficient and/or green certified building with green finance (instead of only financing amounts invested in making a building more energy-efficient and/or certified as green).

Despite being indicative, the categories provided direction toward particular types of innovation in the CRE sector, and the financial advantages of green debt for CRE companies—potentially lower interest costs and lower liquidity risk—functioned as market subsidies for pursuing such innovations.

Financiers considering whether to invest in green bonds issued by CRE companies, were reassured both by stated compliance with GBP and its green

¹²⁷ Climate bonds initiative (2018) *The Green Bond Market in the Nordics 2018*, p. 11; Climate bonds initiative (2020) *Nordic Sustainable Debt – State of the Market 2020*, pp. 5, 10.

¹²⁸ Climate bonds initiative (2018) *The Green Bond Market in the Nordics 2018*, p. 5; Climate bonds initiative (2020) *Nordic Sustainable Debt – State of the Market 2020*, pp. 5, 9.

¹²⁹ ICMA (2017-06-02) *The Green Bond Principles 2017*, p. 3.

¹³⁰ Climate Bonds initiative (2014-01-13) *Thirteen major banks issue ‘Green Bond Principles’ to guide development of Green Bond market*.

¹³¹ ICMA (2016-06-16) *Green Bond Principles, 2016*, p. 3; ICMA (2017-06-02). *The Green Bond Principles 2017*, p. 3.

project categories, and as not being experts in CRE climate impact and low-carbon innovations, by the expertise of the external reviewers providing second party opinion, particularly Cicero who had originated from a climate-science institute. Some financiers also engaged with CRE company expertise on climate impact and low-carbon innovations by querying on green finance framework in discussions with issuing CRE companies.

Following the GBP update in 2016, CRE companies began to include criteria for (refinancing) their existing buildings in the green finance framework. Toward the end of the period studied, CRE corporate bond issuance was mainly targeting refinancing of existing buildings and comparably much lower amounts were allocated to finance new or majorly renovated buildings.

Swedish commercial banks (as lenders) understood that they also are exposed to transition risks (e.g. related to reputation and potential measures from supervisory authorities). They also noted the strong investor demand for green bonds and the potential to retain and attract new debt customers by offering green loan products with slightly lower interest rates.

The major commercial banks were from 2017 onward active in issuing green bonds and introducing green loans targeting e.g. energy efficient new and existing buildings.¹³² Also investment banks, such as the multilateral Nordic Investment Bank and European Investment bank issued green bonds and offered green loans, though restricting provision of green loans to new construction and major renovation projects in CRE.

The introduction of green bank loans meant that in the second half of the period studied also some medium-sized and smaller CRE owners lacking own green finance framework started to attain green finance by complying with energy performance and/or building certification criteria set by the bank.¹³³

Given a generous access for corporations to debt capital at relatively low cost during the period studied, new building investment projects were not dependent on eligibility for green finance in order to raise funds. Still toward the end of the period studied there were some new construction projects financed and carried out without aiming to qualify the new CRE buildings for green finance.

However, green debt finance constituted a highly competitive alternative to business-as-usual debt finance in CRE (except among small CRE companies and small municipalities) and the strong debt investor demand for green finance allowed also green finance frameworks with comparably lower

¹³² Based on analysis of annual and sustainability reports, green finance frameworks, impact reports and product pages, regarding green bonds and loans of 3 Swedish commercial banks.

¹³³ Ibid.

climate performance thresholds and receiving only a ‘light green’ shade in second party opinion to attain green finance at a slightly lower interest rate.¹³⁴

By beginning of 2021, most large and medium-sized CRE companies in Sweden were adopting green finance, and while there was an abundance of minor variations between companies, there was at the same time a more or less uniform core in how green finance was adopted.¹³⁵

5.2.2. Corporate green finance adoption process

Corporate adoption of green finance was gradual and typically took four to five years for a CRE company. This timeline partly reflected the time required to qualify existing buildings for green finance and was also shaped by the fact that CRE debt maturities are spread over multiple years to limit exposure to refinancing risk.

A typical five-year adoption process for a CRE company could start with a decision to pursue green finance based on potentially lower cost of debt and a more secure supply of capital (lower refinancing risk), followed by work to qualify owned building assets as green. Early on, the CRE company would inventory the status of the building portfolio and would seek to strengthen its environmental profile by improving climate disclosure to cover at least direct and energy-related (scope 1 and 2) GHG emissions, setting climate targets, and strengthening investment activities related to building energy performance, waste separation, green building certification, energy efficiency and self-produced energy. For some companies these steps would form part of a strategic reorientation toward low-carbon innovation, whereas for others the same steps would primarily fulfill an obligation to financiers and other stakeholders. The CRE company would then engage a commercial bank that would advise on how to define processes and framework for green finance and would agree to underwrite bond issuance. Before the first issuance, the CRE company would also engage an external reviewer who would scrutinize the green bond framework, would discuss it with the CRE company’s finance and sustainability managers, and would issue a second opinion verdict. Once the CRE company had buildings eligible as green (aligned with criteria in the company’s green finance framework) amounting to about 10-15% of total property value, the bank and the CRE company would offer financiers a first green bond to finance a portion of that value. A successful first issuance (often oversubscribed), together with continued success by peer CRE companies in

¹³⁴ Informant 14A (2021-10-20); Note: in Cicero’s shades of green methodology, a light green rating reflected projects and solutions that are climate friendly but not contributing to the long-term vision of a low-carbon future.

¹³⁵ Based on analysis of interviews with 5 informants and of company green finance frameworks, impact reports, annual and sustainability reports, plus second party opinions from external reviewers regarding green finance characteristics, trends, considerations and accounting of 15 Swedish CRE and construction companies, 6 Swedish Municipalities/Regions and 2 Swedish green finance Aggregators.

subsequent issuances, would provide confidence to proceed. After the first issuance and between subsequent issuances, the CRE company would seek to qualify additional buildings so that the property value becoming eligible in one year could be financed through green bond issuance in the following year.

The CRE company would typically issue impact reporting to financiers once or twice, showing allocation of funds and sustainability impacts, and would add information on green finance to annual reports. Overall sustainability impact was typically reported either as annual energy savings relative to average or mandated energy performance for Swedish CRE buildings, or as annual GHG emission reductions relative to a baseline scenario. In the latter case, the relevant guidelines on impact reporting merely proposed to disclose what GHG accounting methodology had been used.¹³⁶

The CRE company would also engage its commercial bank (and in some cases also an investment bank such as NIB or EIB) to convert some existing bank loans into green loans, using the bank's eligibility criteria for green buildings.¹³⁷

Making a majority of buildings eligible for green finance typically required several calendar years, because both building certification and energy efficiency optimization and investments require substantial engagement of scarce resources for each building and could be delayed in order to coincide with planned maintenance or construction works. In addition, to reduce liquidity risk, the CRE company would spread bond issuance over time to avoid multiple bonds becoming due within a short period.

Once a CRE company reached a green finance eligibility of about two thirds of total building value (typically a slightly lower share of total floor area), it would be in a position where most or all of its debt finance was, or could be made, green. By then, the first green bonds issued would soon begin to mature and require reissuance. To secure continued attractiveness to financiers, the CRE company would now typically update its green finance framework and invite external reviewers to provide a second party opinion. The updated green finance framework would reflect the company's current environmental performance and climate strategy, which by then often included ambitious climate targets, and would define slightly stricter criteria for buildings to qualify for green finance.

By the end of the period studied most large and many medium-sized CRE companies in Sweden were adopting green finance, and additional medium-sized CRE companies had announced it as an ambition.

¹³⁶ GHG Protocol (2005) GHG Protocol for Project Accounting, pp. 8, 61; ICMA group (2019) Suggested Impact reporting metrics for Green Building Projects.

¹³⁷ Based on interview statements from informants 13B, 15A, and analysis of company annual reports of 15 Swedish CRE and construction companies.

5.2.3. Use of proceeds

The GBP required bond issuers to separately track its pool of eligible green assets, green debt proceeds and their allocation. A CRE company issuing a green bond needed to ensure that the total asset worth of its pool of eligible green assets was higher than existing green debt, leaving room for additional allocation of green proceeds. Typically, this would be the only track/audit of the financial management of proceeds and combined with the possibility to raise green bond debt up to the full asset value, opened up for partly also financing 'brown' buildings with proceeds from green bonds.

CRE companies used the proceeds (allocated money raised) from green bonds and loans almost exclusively to finance new, and refinance existing, whole building assets. Often green debt raised via bonds amounted to 70%-85% of the total market value of the building assets eligible as green. This helped make CRE a major recipient sector of green debt. And raising debt at 70-85% of the asset value did not correspond to the interest-bearing debt-to-asset ratio considered attractive (or typical) which was around 50% (40%-60%) for CRE companies raising green debt. When keeping the overall company interest-bearing debt-to-asset ratio relatively stable, an 'over-allocation' of debt to the assets in the green pool (while less of corporate equity would finance these assets) would free up funds that in turn could be used to repay conventional loans or bonds.

This strategy was often employed in Swedish CRE and meant that in practice a significant portion of proceeds from green bonds were partially refinancing 'brown' building assets (not eligible as green). Two clear examples are: a CRE company with only 33% of its total building asset value eligible for green finance but already having 61% green debt share (of total interest-bearing debt) and another CRE company with 55% of total building asset value qualified for green finance while having 85% green debt share.

Two main categories of eligibility criteria were used by CRE companies (typically in combination) to qualify whole buildings for green finance: certification as green building and energy efficiency of the building. Energy efficiency was typically stated as a limitation of 'building energy use' but was effectively measured as purchased operational energy (excluding tenant energy use and use of self-produced operational energy). And even though green finance frameworks would often also specify additional criteria for specific investments such as electric service cars, EV parking chargers or renewable energy projects, typically only a tiny fraction of green bond proceeds would be allocated via such criteria while close to 100% of the proceeds would finance whole buildings.¹³⁸

In the first half of the period studied (2014-2017), CRE company green bond frameworks typically set relatively ambitious criteria on energy

¹³⁸ Based on analysis of company green finance frameworks and impact reports, annual and sustainability reports of 15 Swedish CRE and construction companies.

performance levels that only a few percent of the national commercial building stock met. Such as:

- (i) new buildings to have 25% lower purchased operational energy than the threshold in national regulation;
- (ii) existing buildings to have an operational energy performance of max 100 kWh purchased per sqm and year.

Although the latter criterion was less challenging for a small portion of existing buildings mainly heated via electrical heat pumps. About halfway into the period studied differences in ambitions began to manifest, where a portion of CRE companies adopting green bond frameworks defined less ambitious eligibility criteria, for example setting only a green building certification criterion that was judged ‘light green’ in external review (second opinion by Cicero).

Toward the end of the period studied, early adopters revised their green bond framework and then typically raised the criteria thresholds, for example by lowering the max operational energy purchased per sqm and year from 100 to 90 kWh for existing buildings and by raising the level of green building certification required. In the last year of the period studied (2021) also some companies that had defined less ambitious criteria revised their green bond frameworks with more ambitious eligibility criteria in attempts to align toward criteria stated in the draft of the EU climate taxonomy.

Financiers were buying in on the prevailing CRE sector solution focus and ambition levels. Early on in the period studied, institutional investors and banks had a relatively limited knowledge/awareness regarding low-carbon solutions in CRE and were susceptible to the prevailing CRE focus and ambition levels on energy use and green building certifications.¹³⁹ Green building certifications were typically perceived as a means to secure short and long-term tenant demand as tenant climate focus increase, thus helping to address corporate exposure to transition risk of reduced demand for services due to shifts in customer preferences. Here, financiers accepted the existing requirements in green building certification systems.

Over the period studied, knowledge among financiers improved substantially.¹⁴⁰ Especially during 2020-2021 when some financiers also broadened their focus and as stated by an informant, “ask much more initiated questions about resource consumption, reuse and climate footprint from construction: ‘Are you really gonna build new? Isn’t it better to renovate the old?’, dead serious financiers say to us”.¹⁴¹

Despite increased know-how, over the period studied financiers did not intervene to make green building certification systems stricter regarding

¹³⁹ Informant 14A (2021-10-20).

¹⁴⁰ Informant 52A (2021-10-20).

¹⁴¹ Informant 14A (2021-10-20).

emission reduction measures, nor to limit which certifications (or levels within them) were eligible for green finance. External reviewers at times highlighted in the second party opinion that a building certification system and level indicated as a qualifying criterion in a green bond framework did not guarantee energy savings/efficiency, for example: “These certification levels alone do not ensure improved energy efficiency, passive or plus housing. This framework's requirements on energy efficiency mitigate this”.¹⁴²

In 2014-2020, emissions from building materials were not even mentioned in green bond frameworks or the second party opinions. Only in 2021, second party opinions started to lightly assess/comment on embodied emissions, two examples: “LEED and BREEAM certification schemes [...] fall short of guaranteeing a low-climate impact building, as they may not ensure compliance with all relevant factors e.g. [...], and sustainable building materials”.¹⁴³ and “The issuer should consider construction phase emissions”.¹⁴⁴

However, to achieve a desired ‘medium green’ overall rating of a green finance framework it was still at the end of the period studied sufficient to focus only on energy efficiency (although typically combined with building certification criterion) in new and existing buildings to be financed.¹⁴⁵ All in all, this meant that financiers while influencing CRE preferences toward specific technologies and practices, seldom questioned whether these technologies and practices worked toward a sectoral low-carbon transition.

Only a very small fraction of a building’s green finance was allocated by the CRE owner to improve climate performance of the financed building assets. This can be contrasted with financing an explicit low-carbon innovation such as a solar park. High CRE asset values, particularly for building portfolios concentrated in the largest cities, created potential room for stricter requirements in green-building finance, but neither updates to the GBP nor newer second opinions indicated stricter assessments of the green-building criteria or any consideration of the scale of the asset values financed as green. Instead, banks focused on growing the green bond market, primarily through their role as bond underwriters, even when doing so involved lowering the criteria thresholds for what qualified as green.

In addition, the accounting innovation to apply market-based method for scope 2 energy emissions when measuring progress toward corporate climate targets and impact of green finance allowed CRE companies to show decent numerical impact figures of reduced tons of GHG emissions while breaching qualitative criteria such as GRI’s balance and accuracy criteria (Bjørn et al.,

¹⁴² Cicero Shades of Green (2021-05-21) Stenvalvet AB Green Finance Second Opinion, p. 8.

¹⁴³ Cicero Shades of Green (2021-09-23) Hufvudstaden AB Green Bond Second Opinion, p. 9.

¹⁴⁴ Cicero Shades of Green (2021-05-21) Stenvalvet AB Green Finance Second Opinion, p. 9.

¹⁴⁵ Interpretation after reading a dozen second party opinion reports assessing Swedish real estate company green bond frameworks from 2021.

2022; Brander et al., 2018).¹⁴⁶ For example, a CRE company issued a green finance impact report in 2019 where about 90% of the claimed emission reduction through green finance was due to applying market-based method for scope 2 energy emissions, and in impact reports from several other CRE companies the same application contributed between 50% and 90% of the claimed emission reduction.¹⁴⁷ The widespread adoption of this accounting innovation was key in establishing impressions of climate responsiveness and material low-carbon transition impact through transition debt finance in CRE.

It is sometimes argued that allocating green finance to refinance existing buildings is unlikely to yield material reductions in GHG emissions, in contrast to allocating green finance to finance new low-carbon buildings. The difference is often framed as a matter of timing, since impact-generating performance improvements may already have occurred for existing buildings.

However, at an abstract level, and before assessing actual impacts, the Swedish CRE case suggests a different temporal logic. Green finance for existing buildings did not simply follow from past performance improvements. Only a small share of existing portfolios was typically eligible at the outset, even when companies had previously invested substantially in non-eligible buildings, for example to improve energy performance. Making additional buildings eligible therefore commonly required further action after the first green bond issuance. In this respect, the process of potential impact generation resembled the logic often attributed to new low-carbon buildings.

Furthermore, as described earlier in this section, CRE companies' motivation to proceed with such further action to some extent depended on impact-oriented financiers investing already in the first green bond issuance, even when the initial proceeds were allocated to buildings that were eligible from the outset.¹⁴⁸

¹⁴⁶ Note: balance - to provide an unbiased picture of the organization's performance with consistency between different reported information, accuracy - to enable stakeholders to make a reasoned assessment of the organization's performance.

¹⁴⁷ Based on analysis of company green finance frameworks and impact reports, annual and sustainability reports of 15 Swedish CRE and Construction companies.

¹⁴⁸ Note: only when also financiers seeking impact invested, the bonds would be oversubscribed and classified as a success by the issuing party.

6. Assessments

This chapter presents the assessed emission goal alignment of innovation in sections 6.1 and 6.2 and then covers the assessed acceleration of transformative processes in section 6.3.

6.1. Alignment by value chain

This section presents the emission goal alignment for the operations value chain and the construction value chain. Then the next section, structured per generic solution pathway, nuances how solution pathway innovation patterns contributed to the assessed alignment by value chain.

First, a short account of the analytically linked innovation patterns is provided. The innovations stimulated by transition debt finance were focused mainly on reducing the operational emissions in the CRE operations value chain, whereas largely overlooking embodied emissions in the CRE construction value chain.¹⁴⁹ Adoption mainly targeted operational energy emissions and the adoption scope tended to be limited to what was deemed profitable or enough for green debt eligibility, rather than aiming to realize the full operational energy emission reduction potential.¹⁵⁰

By the end of the period studied, informants unanimously indicated green building certifications, energy efficiency measures, rooftop solar, and renewable energy contracting as substantially accelerated through green finance. They also indicated that construction innovations such as renewable or reused materials probably had not been substantially accelerated.¹⁵¹ Further corroboration and qualification of changes to innovation patterns as analytically linked to transition debt finance did not contradict this picture.

Even among transition debt frontrunner CRE companies, analytically linked innovations in the operations value chain were consistent with the emission goal benchmark (over 5 years) only for some of the buildings, and this applied very rarely in the construction value chain. These buildings were often highlighted in impact reports.

¹⁴⁹ Informant 13B (2020-05-11);

¹⁵⁰ Informant 13B (2020-05-11); Informant 10A (2019-04-23).

¹⁵¹ Informants 10A, 10C, 11D, 14A, 51B and 52A (2021-10-20).

In the operations value chain, the assessment indicates limited emission goal alignment. The analytically linked innovation patterns exhibited fairly widespread adoption and experimentation across CRE companies and within their building portfolios (moderate extent). Collectively, the patterns addressed the dominant operational emission sources, but unevenly across that extent (moderate low-carbon scope). Among extent, low-carbon scope and depth, depth was the primary limiting analytical dimension. Overall, the innovation patterns implied a moderate mitigation strength, insufficient for strong emission goal alignment even if extent and low-carbon scope had been stronger and more consistent.

In the construction value chain, the assessment indicates absent emission goal alignment. The analytically linked innovation patterns included experimentation offering meaningful mitigation potential (depth). However, experimentation remained limited across CRE companies and building portfolios (weak extent) and targeted only a narrow subset of the emission sources in the construction value chain (weak low-carbon scope). Due to constraints in extent and low-carbon scope, the assessment does not meet the qualitative threshold for limited alignment in the construction value chain.

Figure 7 below summarizes the assessed emission goal alignment by value chain. It also indicates how solution pathways account for that alignment, and which analytical dimensions primarily constrain those pathway contributions. The figure highlights sectoral emission goal alignment challenges of transition debt finance:

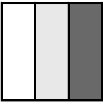
- (i) limited and absent value chain alignments with the emission goal;
- (ii) contributions to value chain alignment concentrated in a limited set of solution pathways;
- (iii) presence of innovation patterns decoupled from alignment.

Overall alignment by value chain	Lower-emission energy & fuel	Production & resource efficiency	End-use technology efficiency	System efficiency	Service efficiency	Service demand reduction	Credentialing
depth	○ extent		● depth				⊗
extent		● extent					⊗

Operations

Construction

Shading indicates assessed value chain alignment:



Absent
Limited
Strong

Symbol indicates contributor role of solution pathways:

- main contributor
- other contributor
- ⊗ decoupled from alignment

Words indicate the primary limiting dimension:

extent, scope or depth

Figure 7 Assessed emission goal alignment of innovation by value chain. Shading indicates assessed value-chain alignment. The solution pathway columns indicate each pathway's role, whether: a main contributor or other contributor to the assessed value chain alignment (along with the dimension primarily constraining the contribution); not indicated as contributing (blank cells); or present but decoupled from the assessed alignment.

The next section covers the contributions of solution pathways to the emission goal alignments (indicated in Figure 7) by characterizing the innovation patterns and their contributor role. Pathways not indicated as contributing were absent or interpreted as negligible in the analytically linked innovation patterns and are not further elaborated.

6.2. Solution pathway contributions

6.2.1. Lower-emission energy and fuel

In Figure 7, lower-emission energy and fuel is classified as an ‘other contributor’ to the assessed emission goal alignment in the operations value chain, reflecting analytically linked innovation patterns that supported the assessed alignment but played a comparatively smaller role than the main contributing pathway. The pattern consisted of adoption of renewable energy in the form of rooftop solar panels on new and existing buildings. By slightly reducing needs to purchase energy, solar panel installations could aid green building compliance, as energy-related criteria both in green finance frameworks and certain green building certification schemes were based on level of purchased energy. Adoption in the last years of the period studied (2019-2021) involved many CRE companies but rooftop solar additions were typically modest (covering only a small portion of the roof) and selectively applied within building portfolios.¹⁵² As a result, by the end of 2021, electricity generated from owned solar panels typically amounted to about 1% of total electricity used in building operations among CRE companies relying on green finance.¹⁵³

6.2.2. End-use technology efficiency

In Figure 7, end-use technology efficiency is classified as a main contributor to the assessed emission goal alignment in the operations value chain, based on analytically linked innovation patterns that account for the largest part of the assessed alignment.

Green finance guided CRE actors toward intensifying their energy-efficiency initiatives in both existing and new buildings. Because poor or average operational energy performance was widely treated as incompatible with the notion of green building or low-energy building and thus with building eligibility for green finance, the embedding of transition debt finance

¹⁵² Based on interviews and analysis of company green finance impact reports, annual and sustainability reports of 15 Swedish CRE and construction companies.

¹⁵³ Based on information in sustainability reporting for 2021 of 15 Swedish CRE and Construction companies.

was linked to additional energy efficiency improvements, e.g. optimization of ventilation and investments in heat pumps, in many of the buildings.

The mitigation strength of these innovation patterns varied across CRE companies and within building portfolios. Operational energy savings were strong (25%-35% relative to five years earlier) for some of the buildings made eligible for green finance, but more commonly fell in the 5%-20% range.¹⁵⁴

For new construction, green finance frameworks typically used a threshold of 20% below national building code requirements for purchased operational energy. However, in the second half of the period studied new buildings were often treated as eligible despite only marginally outperforming the regulatory energy requirements. Continued reliance on outdated (pre-2017) calculation method in green finance frameworks and national building certification schemes through the end of the period, meant that ‘20% below regulative requirements’ could be met under kWh-based convention even after the building code had moved on.¹⁵⁵

Some new buildings financed green were constructed with exceptional operational energy performance, for example with bedrock heat pump systems and highly energy-efficient windows. These were often used as a showcase low-energy building project for example when exemplifying something financed in a green finance impact report. Overall, the evidence suggests new buildings achieved similar operational energy savings and reductions in operational emissions as existing buildings, through transition debt finance.

6.2.3. Production and resource efficiency

Although the construction value chain is assessed as showing absent goal alignment, production and resource efficiency is indicated as the main contributor (see Figure 7). Because it captures the only analytically linked innovation patterns that addressed construction-related emission sources to any meaningful degree. These patterns remained sparse and weakly scaled, which supports the assessment of absent emission goal alignment in the construction value chain.

The innovation patterns emerged in the last years of the period studied and consisted largely of experimentation without subsequent upscaling. The contribution was therefore primarily constrained by extent, with additional limitations in low-carbon scope because only parts of the value chain emission sources were targeted.

Institutionalized high-carbon construction practices therefore remained largely intact, including continued reliance on cement-based concrete and

¹⁵⁴ Based on analysis of company green finance impact reports, annual and sustainability reports of 15 Swedish CRE and construction companies.

¹⁵⁵ Note: from 2017, the building code replaced kWh-based energy performance with a formula-based metric and adjusted regulatory thresholds accordingly. The continued use of kWh-based thresholds in green finance frameworks and widely applied national certification schemes made it easier to qualify buildings with electric heat pumps.

steel in load-bearing structures in new construction projects financed green. For most of the period studied, embodied emissions from building materials and construction processes were not even mentioned in green bond frameworks or second party opinions. Only toward the end did external reviewers begin to comment, albeit lightly, on embodied emissions. For example: “LEED and BREEAM certification schemes [...] fall short of guaranteeing a low-climate impact building, as they may not ensure compliance with all relevant factors e.g. [...] sustainable building materials”¹⁵⁶, and “the issuer should consider construction phase emissions”.¹⁵⁷ Even in 2021, neither financiers nor external reviewers challenged the eligibility of new buildings applying business-as-usual construction materials and processes. A ‘medium green’ overall framework rating for CRE companies remained feasible without substantive attention to embodied emissions.

More experimental and less mature low-carbon construction innovations, such as circular building practices and wood-framed high-rise buildings, were not effectively shielded through green finance. Where frontrunner companies experimented beyond eligibility criteria for green debt, it involved promising low-carbon construction innovations, such as construction with wood frame and reused materials, often in collaboration with suppliers and sometimes researchers. This activity was linked to anticipatory positioning and climate leadership in relation to financiers’ evolving expectations, including increased attention to transition risks including opportunities. Toward the end of the period studied, frontrunner CRE companies more systemically assessed transition risks and opportunities, which also included some experimentation. As one informant noted:

It is hard somehow to separate what is really pressure from financiers and what is something we do because we think they will soon have understood this and will start to tighten the requirements. [...] It is a bit like, what do we need to do to somehow remain at the forefront and what requirements will we reasonably face. And then I think that wood-framed building construction is one example.¹⁵⁸

6.2.4. Credentialing

Credentialing is interpreted as decoupled from alignment. Innovation activity linked to transition debt finance was prominent (high in extent), but without substantively contributing to assessed emission goal alignment in either of the value chains. A plausible interpretation, developed further in chapter 7, is that credentialing remained widely accepted because it served the contextual goal of reducing exposure to transition risks.

¹⁵⁶ Cicero Shades of Green (2021-09-23) Hufvudstaden AB Green Bond Second Opinion

¹⁵⁷ Cicero Shades of Green (2021-05-21) Stenvalvet AB Green Finance Second Opinion

¹⁵⁸ Informant 14A (2021-10-20)

The embedding of transition debt finance is analytically linked to two prominent credentialing patterns: green building certifications and market-based climate accounting combined with renewable energy contracting. Although both are classified as decoupled from alignment, any associated measures with relevance for emission goal alignment are accounted for under the relevant value chain/solution-pathway combination.¹⁵⁹

Climate accounting innovation and energy contracting

Transition debt finance created strong incentives for CRE companies to combine market-based energy emissions accounting with renewable energy contracting. This combination facilitated reporting down-trending corporate emissions, reporting substantial impacts in green finance impact reports, and setting net-zero emission targets. These signals, in turn, were relevant for sustaining financier interest in corporate green debt, thereby potentially improving financing terms.

As previously highlighted in section 4.4.3, the market-based method for energy GHG accounting combined with contracting of renewable energy is a widely used and institutionalized accounting innovation but it is decoupled from emission reductions (Bjørn et al., 2022; Brander et al., 2018; Hamburger & Harangozó, 2018; Mulder & Zomer, 2016). Market-based accounting makes the purchased electricity or heat renewable and low-carbon for the companies who pay for a renewable product attribute or origin and shifts ‘residual mix’ energy with high emissions to buyers who do not—but only in accounting terms. This made it possible to magnify the reported emission reduction for CRE companies. Over five years, a company could move from 100% residual-mix electricity with high scope 2 emission factors¹⁶⁰ to 100% ‘renewable’ contracts and reduce the emission factor to zero by paying a small premium, while consistently drawing electricity from a grid with low average emissions.

In the second half of the period studied, CRE companies often used these innovative practices to report substantial emission reductions from contracting renewable energy. They did so in corporate emissions reporting, in green finance frameworks (to highlight historic emission reductions), and in green finance impact reports.

These practices also shaped the emission goals set by CRE companies, including science-based targets adopted by some companies toward the very end of the period studied. Typically, targets were set using market-based scope 2 accounting and a baseline year before adopting renewable energy contracting. This helped CRE companies signal forward-looking ambition to

¹⁵⁹ Note: for example, patterns of energy efficiency measures associated with certifications were categorized and assessed as End-use technology efficiency.

¹⁶⁰ Energimarknadsinspektionen (n.d.) Residualmix; Energimarknadsinspektionen (n.d.) Residualmixen för tidigare år.

financiers and, in some cases, present goals as consistent with a Paris-aligned net-zero trajectory.

In the green finance context, actors rarely questioned the combination of renewable energy contracting and market-based calculations for impact reporting. A rare example from Nordic public sector bond issuers' recommendations for impact reporting:

[Green bond] Issuers are recommended not to use certificates of origin and/or residual mix as the basis for CO₂ values. The principal reason is that we do not consider such certificates to be a main driving force for deployment of more renewable energy.¹⁶¹

Overall, applying market-based approach to calculate climate impacts related to energy was accepted and increasingly applied. Swedish CRE companies preparing to issue green bonds, in their green finance frameworks often highlighted that they partially bought renewable energy and had ambitions to increase the share toward purchasing only renewable energy. Some of these frameworks also highlighted a historic reduction of company market-based emissions. The external reviewers did not via second party opinions remark on usage of market-based emissions approach.¹⁶² When providing financiers with impact reports, CRE companies (as well as banks reporting on impacts from green loans to CRE companies) often used market-based energy emission accounting to report a substantial emission reduction impact for the buildings financed green. Some impact reports show calculated operational energy emission reductions that are 15-20 times higher due to combining renewable energy contracting and market-based method energy emissions.¹⁶³

In this way, and across the empirical material, market-based accounting supported a representation of effective emission reduction in the operations value chain, whereas assessed emission goal alignment remained limited. At the same time, several mitigation levers that were visible and technically feasible during the period—such as optimizing existing ventilation and heating across building portfolios, making substantial rooftop solar investments, and experimenting with more radical low-energy solutions—were only weakly mobilized in the innovation patterns analytically linked to transition debt finance.

¹⁶¹ Nordic Public Sector Issuers (2020-02). Position paper on green bonds impact reporting, p. 21.

¹⁶² Based on a reading of seven 'Second opinions' on green finance frameworks from Swedish CRE companies issued by Cicero in 2018-2021.

¹⁶³ Based on a reading of impact reports issued by 11 Swedish CRE and Construction companies in 2017-2021. The range refers to the ratio between reported emission reductions attributed to renewable energy contracting under market-based scope 2 accounting and the reduction implied by changes in energy purchased with location-based emission factor.

Green building certifications

In this thesis, analytically linked certification pattern is treated as credentialing; any associated substantive low-carbon measures are accounted for under other pathways.

When at the end of the period studied asking informants what innovations for sustainability had been materially accelerated by green finance pressures, Swedish CRE actor representatives unanimously indicated green building certification.¹⁶⁴ The embedding of transition debt finance in the CRE sector did significantly accelerate the diffusion and adoption of green building certifications, particularly among existing buildings.

As the Green Bond Principles (GBP) explicitly indicated that buildings complying with national and international certification schemes were examples of eligible assets for green debt¹⁶⁵, CRE companies typically used green building certification criterion, often in combination with energy efficiency criterion, to make buildings eligible for green debt in their green finance frameworks.

Toward the end of the period studied, external reviewers (such as Cicero) started to note in their second opinions that certification levels alone do not ensure improved energy efficiency and that some schemes may fall short of guaranteeing low-climate-impact buildings.

Green building certifications for newly constructed buildings likely would have grown even without transition debt finance, albeit applied more selectively in a CRE market niche. Among existing buildings green finance was a key enabling condition for the rapid mainstreaming of green building certification. It was most clearly seen among later adopters of green finance that would declare a plan to certify the entire building stock and refinance all debt green over the following years. When discussing innovations for sustainability with Swedish CRE actors in 2019 and 2020 they were convinced that green finance is a main driver of environmental certification of buildings, for example:

Environmental certification of buildings was originally driven by [the results of] an American study showing that 50% of tenants were willing to pay 5% higher rent in a certified building. But is nowadays mainly driven by the opportunity for green finance.¹⁶⁶

The certification schemes used (including those recognized globally) were not designed to require low-carbon measures with clear relevance to emissions in the construction value chain. Instead, a CRE company is allowed to choose from a smorgasbord of ways to earn points, including provision of different

¹⁶⁴ Informants 10A, 10C, 11D, 14A, 51B and 52A (2021-10-20).

¹⁶⁵ ICMA (2016-06-16) Green Bond Principles, 2016, p. 3; ICMA (2017-06-02). The Green Bond Principles 2017, p. 3.

¹⁶⁶ Informant 51A (2020-01-10).

proofs of existing performance and compliance, when certifying a building. For example, a commonly used scheme for new construction projects (BREEAM) allocated only 12.5% of the total certification points to building materials and most of those points were not focusing emission reductions but instead were granted for establishing a rudimentary building life-cycle analysis, selecting primarily materials with environmental product declarations, and avoiding toxic and unethical materials.

Both individually and aggregated the adoption of green building certifications mainly implied documentation-oriented and other actions with limited direct emission relevance.

Taken together, the credentialing pathway is assessed as decoupled from emission goal alignment (see Figure 7); credentialing-related activity displayed high extent and was analytically linked to transition debt finance, but without substantive relative contribution to the assessed emission goal alignment.

A plausible interpretation of why credentialing nevertheless remained widely accepted is that it supported a contextual goal in this setting, reducing exposure to transition risks, by providing standardized, widely recognized signals of climate responsiveness to tenants, financiers and other actors. The discussion chapter returns to how this risk-oriented function and the observed decoupling, can be understood in relation to sectoral low-carbon transition impacts.

6.3. Assessed acceleration

This section covers the assessed acceleration of transformative low-carbon processes. The assessment builds on process-related changes analytically linked to the embedding of transition debt finance and is guided by the analytical logic and framework set out in sections 2.5 and 2.7. The section begins with an overview and summary of the assessed results. Thereafter, subsections following the socio-technical dimensions, add nuance regarding the assessed acceleration, by process accelerated.

6.3.1. Overview and summary

The process-by-process assessment indicates process-related changes across five of the nine ideal transformative low-carbon processes used as reference points. For these five processes, the changes involved substantial and persistent sets of actors, institutions, or technologies (moderate or strong extent). The changes had moderate relevance for their low-carbon reorientation (low-carbon scope) but showed weak transformative or disruptive focus (depth). Accordingly, the assessed acceleration is limited for these five processes and absent for the remaining four.

Taken together, despite considerable extent and low-carbon scope in individual processes and coverage across socio-technical dimensions, weak depth across the assessed processes constrains the overall assessment; overall acceleration of transformative low-carbon processes is limited.

An overview of these assessment results is provided in Table 9 below. For each process, the three analytical dimensions are indicated as absent, weak, moderate, or strong, and the assessed acceleration is indicated by shading in the last column. Four ideal processes are shown as absent and are therefore not elaborated in the following subsections. These subsections are organized by socio-technical dimension and further nuance the assessed acceleration for the remaining five processes.

Table 9 Summary of assessed acceleration of transformative low-carbon processes.

Socio-technical dimension	Ideal transformative low-carbon processes	Extent	Low-carbon scope	Depth	Assessed acceleration (Absent = white, Limited = light gray, Strong = dark gray)
Institutional	<p>Adding policy support for low-carbon niche innovations and withdrawing support for institutionalized high-emission practices and technologies, helping to destabilize the system and incentivize incumbents to engage in the transition or exnovate high-emission technologies.</p> <p>Changing social norms that influence user preferences toward low-carbon technologies and social practices.</p>	<p>moderate</p> <p>strong</p> <p>absent</p>	<p>moderate</p> <p>moderate</p>	<p>weak</p> <p>weak</p>	
Actors	<p>[Absent] Developing and institutionalizing guiding visions of low-carbon system or society and transition paths, which helps mobilize corporate agency.</p> <p>Strategic reorientation of business actors, which helps mobilize belief and investments in low-carbon technologies and business models.</p> <p>Increased adoption of low-carbon technologies or social practices by users as solutions become better, cheaper and gain attention, and as social norms change.</p>	<p>absent</p> <p>moderate</p> <p>moderate</p> <p>absent</p>	<p>moderate</p> <p>moderate</p>	<p>weak</p> <p>weak</p>	
Technology	<p>[Absent] Forming actor coalitions around low-carbon innovations and lobbying for policy change in support of low-carbon innovation.</p> <p>R&D or learning processes which improve the performance of low-carbon technologies.</p>	<p>absent</p> <p>moderate</p> <p>absent</p>	<p>moderate</p> <p>moderate</p>	<p>weak</p>	
	<p>[Absent] Scaling production and learning-by-doing, helping to make low-carbon technologies competitive on cost.</p> <p>[Absent] Making available complementary assets, technologies and infrastructure supporting low-carbon technologies.</p>	<p>absent</p> <p>absent</p>	<p>moderate</p> <p>absent</p>	<p>weak</p>	
	Overall acceleration				

6.3.2. Institutional

Related to the institutional socio-technical dimension, the assessment indicated two transformative low-carbon processes with a limited acceleration.

Policy support

The case (see Table 9) indicates limited acceleration of the process Adding policy support for low-carbon niche innovations and withdrawing support for institutionalized high-emission practices and technologies, helping to destabilize the system and incentivize incumbents to engage in the transition or exnovate high-emission technologies. In the study setting, ‘policy support’ includes policy-like steering embedded in transition debt finance. Investor and lender expectations, market principles and templates (e.g., GBP), second-party opinions, and emerging classification work (e.g. early EU taxonomy discussions) collectively conditioned which low-carbon innovations were prioritized in the sector.

Over the period studied, transition debt finance contributed to expanding and normalizing support for a set of comparatively mature low-carbon innovations related to operational energy efficiency (in existing and new buildings). This support was operationalized through company green finance frameworks with eligibility criteria, reporting routines and external reviews, and dialog with debt investors. These practices did not merely describe low-carbon options; they helped stabilize them as default routes for demonstrating climate responsiveness and improving debt terms.

By contrast, the ‘withdrawal’ side of the ideal process remained weak. The empirical material does not indicate that the embedding of transition debt finance systematically tightened boundaries around high-emission practices in ways that rendered them ineligible or increasingly costly to pursue. Even within green finance, construction-related emission hotspots such as cement-based concrete and steel in load-bearing structures remained largely compatible through most of the period. As one informant stated: “there has been extreme unawareness [among financiers] about how big an environmental impact the materials have”.¹⁶⁷ Where external reviewers began to comment on embodied emissions toward the end of the period, this was typically cautious, rather than motivating a downgrade of the shade of green awarded to the framework.¹⁶⁸

¹⁶⁷ Informant 14A (2021-10-20) BSSF workshop with real estate sustainability managers and experts on Investor sustainability requirements.

¹⁶⁸ Based on a reading of seven ‘Second opinions’ on green finance frameworks from Swedish CRE companies issued by Cicero in 2018-2021, and of statements in interviews and workshops by informants 12B, 13B and 14A.

The process changes adding support had strong extent: they diffused widely across CRE issuers, banks, institutional investors, and reviewers and became embedded in routine financing and reporting practices. The ‘withdrawal’ component showed weak extent: it was not widely operationalized in eligibility rules, review practices, or financing decisions.

Process acceleration was moderate in low-carbon scope because the added support primarily concentrated on the operations value chain and on solutions that were straightforward to document and finance, while only weakly extending to construction-related emission sources. In effect, support was uneven across the emission-generating parts of the sector’s value chains.

Furthermore, the depth was weak because the process changes did not amount to destabilization or exnovation pressure on incumbent high-emission practices. Rather than withdrawing support for institutionalized high-emission technologies, the sector could often continue ‘business-as-usual’ construction practices alongside green debt, including late in the period. The result is best interpreted as incremental strengthening of selected low-risk niches, not transformative withdrawal of support for high-emission regimes.

Taken together, transition debt finance is associated with broad reinforcement of certain low-carbon niches, but only weak process change in the direction of removing support for institutionalized high-emission practices. This combination is consistent with the overall assessment of limited acceleration of the process.

Changing norms

The case (see Table 9) indicates limited acceleration of the process Changing social norms that influence user preferences in the direction of low-carbon technologies or social practices. User preferences are here understood as preferences among and within CRE companies. Process-related change was evident (extent) but it had moderate relevance for low-carbon reorientation of norms (scope) and weak destabilizing/disruptive character (depth).

The adoption of green finance helped create dialog on climate emissions and climate risks between interested financiers and CRE companies, where suddenly the CRE company finance manager teamed up with the sustainability manager to answer the climate-related (and broader sustainability-related) questions of financiers.

As stated (with a smile) by an industry specialist: “The sustainability manager and the financial manager are nowadays best friends in CRE companies”.¹⁶⁹ This dialog with financiers meant that the CRE companies involved in green finance were the first to be exposed to financier considerations of climate risks and increased expectations on CRE companies regarding transparency on climate risks, emissions and emission targets and plans. Expectations that toward the end of the period studied (2021) started to

¹⁶⁹ Informant 52A (2019-04-23)

become common and established as norms among financiers and Swedish CRE companies. By then, frontrunner CRE companies stated that they needed to respond to broader and stricter investor requirements, e.g.:

Green finance catalyzed certain requirements and expectations from financiers regarding how we should work with sustainability. And it is only when financiers or owners come with strict requirements that the wheels are set in motion. Which in turn makes their requirements and expectations stricter over time. Look for example now at climate scenarios and TCFD reporting. [...] Now it is emerging as a requirement from our financiers and owners.¹⁷⁰

Transition debt finance embedding involved a reframing of the climate change issue to highlight climate risks and opportunities, potentially material for the availability and cost of debt finance in CRE. This reframing took foothold within frontrunner CRE companies through green finance processes (including e.g. dialog with external assessors of green finance frameworks and interested debt investors) and in the second half of the period studied, messages that energy efficient and certified buildings implied a great (green) financing opportunity diffused broadly among CRE companies in Sweden (through peer networks, industry conferences and workshops, industry and business media, etcetera).

This contributed to broaden and strengthen CRE company preferences toward energy efficiency investments, rooftop solar and environmental building certifications also among medium-sized and smaller companies not yet adopting green finance. However, the reorientation of user preferences was not toward transformative innovations and not effective in reorienting user preferences toward low-carbon innovations with potential to address embodied emissions in the CRE construction value chain.

6.3.3. Actor

Related to the actor dimension, the assessment indicated two transformative low-carbon processes with a limited acceleration.

Strategic reorientation

The case (see Table 9) indicates limited acceleration of the process Strategic reorientation of business actors, understood as shifts in the direction of innovation experimented with and adopt, thereby mobilizing belief and investments in low-carbon technologies and business models.

In this study setting, no substantial strategic reorientation was required for CRE companies to adopt green finance. Green finance largely encouraged adoption of mature innovations that did not require deviation from established CRE innovation pathways. An initial ‘fit-and-conform’ approach, making green finance compatible with existing innovation trajectories, was stabilized

¹⁷⁰ Informant 13B (2020-05-11)

and maintained over the period studied. Thus, CRE companies adopting green finance could continue to rely on familiar pathways related to energy efficiency and environmental building certification.

However, second-order learning was supported by green finance governance arrangements, specifically through deepened dialog between financiers, CRE companies, and specialized external reviewers (such as Cicero), as well as within companies (such as between finance and sustainability managers). External reviewers mainly evaluated how a green bond framework aligned with the GBP, but discussions surrounding second-party opinions also surfaced additional climate-related topics and potential improvements. As a result, second-party opinions could point to low-carbon and governance improvements, while only indirectly questioning core CRE assumptions (for example, responsibility to urgently do more was not raised).

Toward the end of the period studied, some financiers began to question established regime assumptions in dialog with CRE companies (e.g., continued demolition and new construction instead of repurposing, and how long can construction emissions continue to be disregarded while claiming assets are ‘green’). By then financier expectations and requests were also mounting: analyzing climate risks using mid- and long-term scenarios, reporting on climate risks, inventorying value-chain emissions, setting ambitious targets, and describing transition plans. When frontrunner companies responded, their actions and communications strengthened the perception among additional CRE companies that they also would need to reconsider e.g. scope and timeframes related to emissions and respond similarly to evolving financier expectations.

As a result, in the last year of the period studied and the following year (2021–2022), a substantial portion of larger and a few medium-sized CRE companies inventoried value-chain emissions, set net-zero or science-based targets, and included transition risk analysis in annual reporting. Sustainability managers described these steps as an ‘eye-opener’ in management and board discussions, making it harder to focus narrowly on energy and waste recycling while disregarding embodied emissions. For example:

I have met our group executive management and presented parts of our scope 3 emissions [related to construction]. That could be referred to as an eye-opener. They were surprised by the large amounts. So building materials is what will be our main focus.¹⁷¹

These targets, they are good because they require management teams to think through and perhaps understand a little better the real climate footprint the company has.¹⁷²

¹⁷¹ Informant 15A (2020-08-28)

¹⁷² Informant 14A (2019-10-18)

Several companies stated that longer-term climate risk analysis and target-setting covering the value chain were induced by requirements from debt and equity investors, for example:

It is only when debt or equity investors come with strict requirements that we get the ball rolling. And this makes them raise requirements and expectations over time. Look for instance now on climate scenarios and this TCFD reporting...How is climate change impacting our finances? Now it's emerging as a requirement from our financiers and owners to start working on this.¹⁷³

Around the end of the period studied, some companies also began to articulate transition opportunities and to strengthen the business case for solutions not previously prioritized, particularly those not fitting narrow green-finance eligibility criteria and instead targeting embodied emissions from materials and construction.¹⁷⁴ For example:

In larger construction projects, before being approved by the board we should account for calculated CO₂ per sqm and measures taken to reduce it. And there we have seen for example that a choice of wood [structure] instead of concrete leads to a quick reduction from about 500 kg per sqm down to at least below 200.¹⁷⁵

Even so, many companies still ducked embodied emissions, while early signs of a discursive shift emerged around the end of the period with for example intensified discussions about reuse in construction.

The process shows moderate extent: strategic and interpretive shifts were evident across several large actors late in the period. It shows moderate low-carbon scope as the reorientation broadened attention to include value-chain emissions, transition risks and opportunities, and (to some degree) construction-related mitigation; however, this broadening remained partial. It shows weak depth as the changes largely took the form of expanded analysis, disclosure, and anticipatory positioning rather than sustained strategic disruption of incumbent construction practices or scaling of more transformative mitigation pathways. Taken together, this pattern supports the overall assessment of limited acceleration of strategic reorientation.

Increased adoption

The case (see Table 9) indicates limited acceleration of the process Increased adoption of low-carbon technologies or social practices by users, here understood as CRE companies and collectives within and across them, as

¹⁷³ Informant 13B (2020-05-11)

¹⁷⁴ Note: partly because such solutions could more clearly be highlighted to financiers as ways to mitigate transition risks or leverage transition opportunities, and partly because their potential to help secure financing at lower cost of debt could be highlighted to internal decision-makers.

¹⁷⁵ Informant 14A (2020-08-28)

solutions become better, cheaper and gain attention, and as social norms change. In this study setting, the embedding of transition debt finance is analytically linked to broader adoption of a defined set of technologies and practices, most clearly energy-efficiency measures and environmental building certification, across many companies and parts of their building portfolios. One informant illustrated how attention and adoption were channeled toward solutions that helped meet eligibility criteria for green finance, rather than toward other low-carbon solutions:

It's done a bit unconsciously. Now we are starting to get a better idea of our emissions from tenant adaptations, for example. And there one can see that focus has been on innovations linked to eligibility for green finance. Rather than perhaps focusing tenant adaptations.¹⁷⁶

In terms of analytical dimensions, the process shows moderate extent, as adoption over time engaged a fairly broad set of actors, whereas penetration within building portfolios remained uneven. It shows moderate low-carbon scope, because adoption primarily reinforced actors' operational-energy orientation while also normalizing signaling practices (certification and accounting) with questionable low-carbon substance. It shows weak depth, because adoption largely followed established innovation pathways and standardized eligibility and reporting practices and rather than driving a transformative shift toward construction-related mitigation and changes in incumbent construction practices. Taken together, diffusion occurred, but its constrained scope and limited transformative character support an overall assessment of limited acceleration of this ideal process.

6.3.4. Technology

Related to the technological dimension, the assessment indicated one transformative low-carbon process with a limited acceleration.

R&D or learning processes

The case (see Table 9) indicates limited acceleration of the process Performance improvements of low-carbon technologies through R&D and learning. The analytically linked changes primarily involved learning and incremental performance improvements in mature operational technologies, where repeated adoption and refinement supported better energy performance in parts of building portfolios. The changes also encompassed some late-stage experimentation with less mature innovations, including construction-related (e.g., wood-frame), but with little project replication. Furthermore, linked changes also strengthened learning about emissions of existing value-chain activities and low-carbon alternatives.

¹⁷⁶ Informant 13B (2020-05-11).

In terms of analytical dimensions, the process shows moderate extent and moderate low-carbon scope, because solution refinement and learning concentrated in operational technologies, while remaining sparse and late regarding low-carbon construction technologies. It shows weak depth, because technology learning largely reinforced established technology pathways rather than supporting disruptive shifts such as systematic replication and upscaling of lower-carbon construction solutions (e.g., circular building practices or wood-framed structures).

7. Discussion

This chapter synthesizes the thesis' findings and discusses their implications. It first interprets the assessment results as sectoral low-carbon transition impacts in the Swedish CRE sector, organized around two analytically distinct types: emission goal alignment of innovation and acceleration of transformative low-carbon process. It then interprets why assessed impacts remain constrained and discusses what the case adds to debates on impact investment and the role of finance in sustainability transitions. Before summarizing answers to the research questions and discussing analytical contributions to retrospective assessment. The chapter is organized to first address RQ2 and then turn to RQ1.

7.1. Assessed low-carbon transition impacts

This section interprets the assessment results as low-carbon transition impacts in line with the thesis' retrospective logic and reference points. Two impact types structure the interpretation. First, emission goal alignment of innovation addresses whether analytically linked changes to innovation patterns are plausibly oriented toward emission trajectories consistent with climate goals, in line with calls to move beyond assuming that 'green' innovation is intrinsically sufficient (Geels, 2019; Köhler et al., 2019). Second, acceleration of low-carbon transition processes addresses whether processes that can accelerate transitions are strengthened, drawing on ideal-typical transition-acceleration processes adapted from Andersen et al. (2023).

Combining these two assessments matters because emission goal alignment without process acceleration risks remaining incremental, while process acceleration without goal alignment risks accelerating change in directions that do not reduce sectoral emissions.

7.1.1. Emission goal alignment

The goal-alignment assessment indicates that the embedding of transition debt finance is associated with constrained low-carbon transition impacts in the Swedish CRE sector. Emission-goal alignment is assessed as limited in the operations value chain and absent in the construction value chain. This pattern is substantively important because it illustrates a broader challenge raised in

transitions research. Transitions scholarship has often emphasized system change dynamics while saying less about whether changes are sufficient to address climate change at the speed implied by climate goals (Geels, 2019; Köhler et al., 2019).

Interpreting this impact as limited in the operations value chain requires keeping the thesis' analytical dimensions in view. The constraint is not primarily that there is no activity, but that the observed activity does not imply mitigation strength that meets the reference point logic used for emission goal alignment. This interpretation resonates with the thesis' emphasis that low-carbon transitions are not only about innovation in general, but about directionality and goal orientation, that is, whether innovation trajectories are oriented toward the problem of climate change in a way that is compatible with explicit goals (Geels and Turnheim, 2022; Hale et al., 2020).

The assessment indicates absent low-carbon transition impact in the construction value chain. This absence is particularly noteworthy in this case, as embodied emissions become increasingly consequential for sector emission goals with improving operational energy performance and low-carbon operational energy (Röck et al., 2020; Birgisdottir et al., 2017). Empirically, green debt frameworks and reporting centered on operational energy and emissions, with no comparable criteria or metrics for embodied emissions. New buildings were often financed as green despite conventional material selection, and green building certification practices were frequently used to signal green status. At the same time, some promising experimentation, categorized under production and resource efficiency, was identified, but it remained constrained in extent and narrow in low-carbon scope. Taken together, the pattern suggests that the embedding of transition debt finance proceeded without substantially reorienting construction toward low-carbon materials and practices (see Figure 7 and section 6.2.3).

7.1.2. Process acceleration

The process-acceleration assessment suggests that analytically linked process changes are associated with constrained low-carbon transition impacts in terms of process acceleration. Analytically linked process changes are present, but they do not add up to strong process acceleration relative to the ideal transformative low-carbon processes used as reference points (adapted from a typology in Andersen et al., 2023). This should not be read as an absence of impact. Rather, it indicates that what is strengthened most clearly is not necessarily system reconfiguration, but socio-technical changes that are compatible with the sectoral embedding of transition debt finance and its criteria-based logic.

This interpretation is strengthened by the thesis' conceptualization of finance as an object of transition assessment and by the literature it mobilizes on the difficulty of demonstrating impact through capital allocation strategies.

While capital allocation can, in principle, contribute to change, there remains limited empirical clarity regarding how such allocation translates into corporate investment and management decisions over time (Kölbel et al., 2020), and several studies highlight constraints on finance acting as a driver of transitions under prevailing mandates and incentives (Nykivist and Maltais, 2022; Naidoo, 2020; Penna et al., 2023).

Taken together, the embedding of transition debt finance in Swedish CRE presented constrained sectoral low-carbon transition impacts across the two impact types. Analytically linked changes are most visible in operations and credentialing-related domains, while construction and embodied-emissions domains remain weakly activated as assessed impacts. In an extreme case, where extensive embedding and favorable conditions should make discernible low-carbon transition impacts likely, this pattern sharpens the question of what constrains impact generation and what becomes visible and actionable for financiers through transition debt finance. In that sense, the case also has critical leverage by exposing potential weaknesses and counteracting conditions, which motivates closer attention to why assessed impacts remained constrained.

7.2. Why assessed impacts remain constrained

This section develops plausible interpretations of why assessed impacts remain constrained and discusses how extensive sectoral embedding and diffusion of transition debt finance can coexist with constrained sectoral low-carbon transition impacts.

7.2.1. Reallocation of financial flows

A core expectation in climate and green finance discourse is that sustainable and transition debt finance will redirect capital flows, aligning finance with low-emission pathways, and thereby supporting transitions (IPCC, 2023). Yet the assessments of low-carbon transition impacts provide limited grounds for interpreting that reallocation of financial flows was realized in such a way.

This is in line with research highlighting constraints on allocative impact. Ante (2024) summarizes uncertainties and constraints in sustainable finance outcomes, and the thesis' review of transition risk considerations emphasizes that transition risks are hard to price and manage under deep uncertainty and long time horizons, producing barriers to rapid and decisive allocative shifts (Battiston et al., 2017; Schoemaker and Schramade, 2019). Under such conditions, transition debt can expand and embed without necessarily generating strong reallocation outcomes that become visible at the sectoral level of transition impacts.

The assessment results indicate that transition debt finance tended to stimulate sectoral adoption of comparatively mature innovations rather than reorienting innovation toward experimentation with strong mitigation potential and disruptive character. Even though CRE companies as borrowers were responsive to financier requirements, financiers' risk aversion, competition, and incentives to expand green debt markets constrained requirements that could have strengthened low-carbon transition impacts (Nykqvist & Maltais, 2022). This suggests that transition debt finance has more leverage where value-chain low-carbon alternatives have reached a stage of maturity, e.g. operations rather than construction in the Swedish CRE sector.

Transition debt finance could have removed policy support for high-emission technologies (David, 2017) by redirecting financial flows away from actors whose value chains are not transitioning, but it was absent in the case studied. Rather than constituting a separate financial outcome, the (largely unrealized) redirection of capital away from high-emission actors and value chains may be understood as a key condition for strong sectoral low-carbon transition impacts.

Even discourse about future reductions of financial flows to high-carbon CRE asset portfolios/companies was scarce and cautious. Here competitive reasons may have created a deadlock as banks signaling redirection may lose debt customers to competitors staying quiet (Rickman et al., 2024). In parallel with engaging in transition debt finance, commercial banks and institutional investors typically continued to support high-carbon CRE assets and activities, thereby stabilizing business-as-usual. CRE companies remaining passive could still secure high levels of debt finance via corporate bonds and bank loans. And their financiers did not clearly signal plans of future divestment (absence of pledges to refuse renewal of debt to high-carbon CRE assets and companies).

7.2.2. Eligibility and credentialing

Accounting representations and certifications can create strong, standardized signals of climate responsiveness that are coupled to symbolic compliance rather than biophysical emissions outcomes (Brander et al., 2018; Bjørn et al., 2022; Greer et al., 2019; Nygaard, 2023). In the case, two such credentialing practices were widely applied: renewable energy contracting combined with market-based energy emission accounting, and green building certification. Market-based energy emissions accounting combined with renewable energy contracting enabled favorable operational emissions figures and ambitious targets in reporting and target-setting (Brander et al., 2018; Bjørn et al., 2022). This, combined with certification practices, contributed to meeting financiers' requirements for green finance eligibility, partly substituting for substantive low-carbon innovation by CRE companies. This constrained the focus and

resources devoted to deeper cuts in operational energy (e.g., investments in energy efficiency and rooftop solar) and to multiple, scaled experimentation in construction. In turn, this constrained emission goal alignment of innovation and the acceleration of transformative low-carbon processes.

Against that backdrop, the widespread use of credentialing practices appears to have provided financiers with credible and standardized bases for treating lending as green and transition aligned. Financiers were susceptible to these credentials in part because they supported the contextual goal of transition debt finance: reducing exposure to transition risks (Battiston et al., 2017). More broadly, the results suggest that financiers prioritized expanding the green debt market over tightening eligibility criteria. Taken together, these dynamics plausibly helped sustain strong allocation of transition debt finance flows to the Swedish CRE sector even as assessed impacts remained constrained.

Widely accepted credentialing solutions in sectors where transition debt finance is embedded can reinforce a sense that emission goal alignment is already being managed, making it harder for financiers to require innovation that is actually aligned with emission goals. The results also suggest that financiers' prioritization of expanding transition debt finance, particularly the green bond market, rather than tightening low-carbon or transition criteria, limited their capacity to act as drivers of transition change with strong low-carbon scope and depth. In this respect, the findings complement Nykvist and Maltais' (2022) account of barriers that constrain financiers' role in accelerating low-carbon transitions in financed sectors.

7.2.3. Embodied emissions boundary

A central boundary concerns the construction and embodied emissions domain, where assessed emission goal alignment remains absent. This assessed absence indicates a boundary in what transition debt finance specified and required during the period studied, given prevailing accounting conventions (Blanco, 2021) and eligibility logics. Embodied emissions largely fell outside eligibility criteria. This reinforced an operational focus while construction-related changes to innovation patterns and processes contributing to low-carbon transition impacts remained weak in extent despite the extensive embedding of transition debt finance.

7.2.4. Context dependence

In a CRE context, it is worth noting that, in contrast to the empirical setting and results of this study, in countries where fossil-based electricity and heat dominate operational energy, changes to innovation patterns linked to transition debt finance may be sufficient for strong emission goal-alignment overall across value chains. This underscores the importance for financiers to consider the different sectoral transition baselines when applying rules and

benchmarks for transition debt. It aligns with Naidoo's (2020) argument that the financial system needs "adaptive approaches to address the contextual needs of sustainability transition processes" (p. 278).

7.3. Impact investment and finance in transitions

This section discusses what the case adds to debates on impact investment and the role of finance in sustainability transitions.

7.3.1. Implications for impact investment

Findings are here discussed in relation to debates on how 'impact' is conceptualized and evidenced in sustainable finance and impact investment. Although impact investing research often centers on equity, its conceptual work on impact, additionality, and evidence standards is directly relevant to assessing transition debt finance.

This study partly addresses the knowledge gap highlighted by Kölbel et al., (2020) regarding company responses to investor capital allocation strategies, in two ways. First, the case analysis (Chapter 5) shows how capital allocation strategies created favorable financing conditions that effectively incentivized CRE companies and provides insight into how companies responded in that context; the impact assessments (Chapter 6) then link those response patterns to sectoral low-carbon transition impacts. Second, the study adds to debates in the sustainable finance literature stream on sustainability impact (Busch et al., 2021; Kölbel et al., 2020; Marti et al., 2024; Schlütter et al., 2024).

Based on the differentiation by Busch et al. (2021) between impact-generating and impact-aligned investments, an investor seeking to generate actual impact may prematurely conclude that buying green bonds is a poor choice since proceeds from a green bond issuance are often used to finance existing impact-aligned assets (that already have undergone change to make them eligible).

However, the case (see section 5.2) indicates that, as Swedish CRE companies began adopting green finance at different points in time, only a limited share of each company's building portfolios could be readily classified as eligible. At the same time, early green bond issuances by these companies were characterized by strong financier demand and were often described as oversubscribed. Within the CRE sector, this was commonly interpreted as reflecting financiers' willingness to accept slightly lower nominal returns on green bonds and loans. For CRE companies this implied an opportunity to lower their cost of debt and reduce refinancing risk, providing motivation to take further action (potentially impact-generating) in order to make, over time, a high proportion of their buildings eligible for green finance. Importantly this

motivation plausibly depended in part on impact-oriented investors who helped to create strong early demand.

Thus, what may (looked upon synchronically or as a single investment) be classified as impact-aligned investment may also be impact-generating from a diachronic or systems perspective. In sectoral settings where transition debt finance becomes embedded over time, early financing of impact-aligned assets can, under some conditions, contribute to sectoral low-carbon transition impacts by strengthening incentives for changes that expand eligibility over time. In Busch et al.'s (2021) terms, this suggests an additional way for impact-oriented financiers to contribute to impact generation: prioritizing and discounting debt finance for (impact-aligned) assets meeting ambitious sustainability benchmarks.

At the same time, the 'further actions' taken need to be scrutinized to ensure impact. Additionally, the way that raising green debt at a high percentage of eligible asset values resulted in the partial green financing of non-eligible buildings highlights the need to scrutinize whether the level of impact-aligned debt (compared to eligible asset values) exceeds the borrower's overall interest-bearing debt-to-asset ratio.

7.3.2. Implications for finance in sectoral transitions

Nykvist & Maltais (2022) cautioned that financiers being mandated to maximize risk-adjusted return rates makes them hesitant to finance less proven sustainability solutions (hard to judge risks due to component of uncertainty) and slower at withdrawing finance from unsustainable solutions. This study showed a generous supply of transition debt finance toward Swedish CRE bonds and loans (higher supply than demand) to finance entire green buildings, where the asset's financial value would be only marginally at stake with respect to the success or failure in incorporating a semi-proven sustainability solution. Potentially, this created room for experimentation with semi-proven low-carbon solutions, since the whole building could still be a proven, low-risk, financial investment. Structurally, this created a latent opportunity for transition debt financiers to strengthen low-carbon transition impacts by explicitly requiring CRE borrowers to also incorporate less mature low-carbon solutions.

Furthermore, in response to financiers' dilemma to focus financing to investments supporting system change while avoiding to finance less proven solutions, I argue in line with Penna et al. (2023) that the dilemma may partly be resolved if financiers stop assessing risks per investment and instead take a more systemic risk perspective at aggregated portfolio/s level. It may then be in the best interest of savers that every debt portfolio dedicates a small portion of investments to experiments with transformative focus and innovative low-carbon solutions supporting system change (orderly transition)

in CRE. This can reduce the risk of delayed or ‘disorderly’ transition, which could expose substantial portions of debt investments in CRE to devaluation and lower rates of return, translating into credit and market risk in debt portfolios (Campiglio et al., 2023; Semieniuk et al., 2021).

At the same time, taking a system perspective can be challenging. For sustainable investment to support transitions, Penna et al. (2023) points out the need to focus financial investment on supporting system change rather than system optimization. The results in this study do not contradict this claim, but they indicate challenges to adopting a systems perspective. A strong example is how market-based climate accounting rules applied at the (lower) corporate level can act as a barrier to a systems perspective within transition debt finance.

The study also suggests key conditions for transition debt finance to translate into strong sectoral transition impacts: when finance eligibility is aligned with sectoral emission hotspots in all relevant value chains, when low-carbon depth is demonstrable rather than assumed or signaled, and when conditionality is strong enough to delegitimize established high-emission sectoral practices. This is also why the assessment approach distinguishes between alignment and acceleration and treats boundaries and reference points as central to impact interpretation.

7.4. Answering the research questions

The second research question concerned how the embedding of transition debt finance is related to sectoral low-carbon transition impacts in the Swedish CRE sector. It can partly be answered by the observed pattern: analytically linked innovation and process changes are more visible in operations and in credentialing-related domains than in the construction domain. This yields limited goal alignment in operations and absent goal alignment in construction, alongside limited acceleration of transformative processes.

These constrained low-carbon transition impacts can be understood as a product of how transition debt finance became embedded through eligibility and credentialing logics. It reinforced adoption of comparatively mature operational solutions, while standardized credentials (accounting and reporting practices and certifications) often substituted for more demanding requirements on substantive low-carbon innovation. Embodied emissions largely remained outside the boundaries of measurement, review, and finance eligibility, which limited incentives for construction-related innovation aligned with sector emission goals. Finally, there is limited evidence of finance reallocation away from high-emission assets or of conditionality strong enough to destabilize business-as-usual practices. This reduced the likelihood of sector-level shifts to low-carbon innovation patterns and transformative processes.

The first research question concerned how low-carbon transition impacts can be retrospectively assessed, with separate attention to the emission goal alignment of innovation and the acceleration of transformative low-carbon processes. The thesis answers this by developing an analytically grounded assessment approach and applying it to the case studied. The approach separates two impact types and uses two frameworks: an emission goal alignment framework for innovation-related change and a framework for acceleration of transformative low-carbon processes. Across both, the assessment is restricted to analytically linked changes rather than treating observed change as impact by default. The approach specifies its reference points explicitly: a minimum indicative emission benchmark for alignment assessment (at least a 21% reduction over five years; Sections 2.6 and 6.1) and ideal-typical reference points for acceleration assessment (Sections 2.7 and 6.3). In both frameworks, assessed change is interpreted through the shared qualitative dimensions of extent, low-carbon scope, and depth. The value of the approach is that it enables retrospective assessment without presupposing that ‘green’ activity, finance-labelled initiatives, or widely diffused solutions translate into impact consistent with emission goals, and it makes visible when measures function as credentialing that is weakly coupled to emission goal alignment (Brander et al., 2018; Nygaard, 2023).

7.5. Analytical contributions to retrospective assessment

7.5.1. What the assessment approach adds and its limitations

The assessment approach contributes a practical way to operationalize low-carbon transition impacts in retrospective, qualitative sector studies where heterogeneous evidence is available but where it cannot be assumed a priori that observed change aligns with climate goals. It resolves the problem identified in the problematization, namely the absence of an explicit logic for what counts as impact and relative to what, by making impact types and analytical reference points explicit, and by separating analytical linking and assessment.

The analytical logic and frameworks (Sections 2.5-2.7) were designed to be adaptable for researchers retrospectively assessing how low-carbon interventions relate to sectoral low-carbon transition impacts. The approach is particularly well suited to sectors where such interventions have been embedded over time and where the task is to interpret linked innovation patterns and process changes as low-carbon transition impacts.

A second contribution is that the approach makes constraints diagnostically visible. Because alignment and acceleration are assessed through extent, low-carbon scope, and depth, the analysis can specify what dimension constrains assessed impacts. By organizing assessment by value chain, the emission goal

alignment framework reduces the risk of overlooking key emission sources. This is particularly important when relevant emission sources are systematically underemphasized in sectoral discourse and literature, such as embodied emissions (Röck et al., 2020).

Beyond full assessments, the approach offers a structured way for policy makers and financiers to interrogate design and monitoring of interventions intended to support sectoral low-carbon transitions. It facilitates explicit questions about which value-chain emission hotspots are covered, what qualifies as low-carbon depth rather than credentialing, or how to stimulate additional transformative low-carbon processes. Used in this way, the approach may function as a diagnostic aid for revising criteria, metrics, and conditionality.

The analytical approach developed has clear limitations. First, the emission goal alignment of innovation is not a substitute for quantification of achieved emissions outcomes; it supports qualitative assessment of innovation alignment relative to an explicitly specified benchmark. Second, the approach depends on empirical material that enables credible analytical linking and triangulation; where linking is weak, the approach appropriately constrains what can be claimed about impact (Maxwell, 2012). Third, because the approach relies on explicitly specified reference points and is context-aware, some tailoring may be needed across settings (e.g., value-chain delineation, specification of contextual goal(s), and the operational reference points used). Conclusions should be interpreted in light of these choices and the broader methodological limits.

7.5.2. A note on credentialing as pathway

Finally, the thesis treats credentialing as analytically central because accounting representations and certifications mediate how alignment is articulated and legitimized in transition debt finance. Yet the literature reviewed in the thesis indicates how such representations may be misleading or only weakly coupled to biophysical emissions outcomes, especially under market-based energy accounting (Brander et al., 2018; Bjørn et al., 2022). Similarly, building certifications can motivate measures that are not directly linked to emission reductions and can contribute to symbolic compliance (Nygaard, 2023; Greer et al., 2019). This supports interpreting credentialing as a generic pathway. This study has demonstrated the relevance of conceptualizing credentialing as a generic solution pathway when analyzing emission goal alignment of innovation in a low-carbon transition context, where other objectives tend to be salient (Geels et al., 2017).

Including credentialing as a generic solution pathway, also forces the analyst to reflect further on both how to classify solutions and which solutions may serve contextual goals rather than the assessed.

8. Conclusion

Based on the analytical challenge motivating this thesis, the study developed and applied an analytically grounded approach for retrospectively assessing low-carbon transition impacts in a sectoral case where a low-carbon intervention has been embedded over time. In light of the assessment results, the thesis also interpreted how the embedding of transition debt finance relates to sectoral low-carbon transitions.

The approach treated impact as a two-part assessment problem: emission goal alignment of innovation and acceleration of transformative low-carbon processes relative to defined reference points. It was applied to the embedding of transition debt finance in the Swedish commercial real estate sector (CRE), an extreme case where discernible impacts would be comparatively likely.

In the Swedish CRE case, sectoral low-carbon transition impacts are interpreted as constrained: emission goal alignment is limited in operations and absent in construction, alongside limited acceleration of transformative low-carbon processes.

The case shows that, even when conditions are favorable for transition debt finance to matter, sectoral low-carbon transition impacts can remain constrained when assessed against explicit emission-goal benchmarks and process reference points. The case therefore motivates core analytical moves made in the thesis, including treating sectoral low-carbon transition impacts as something to be assessed against explicitly specified reference points rather than inferred from innovation adoption, credentials, or criteria compliance. It also reinforces the thesis' concerns regarding the conditions identified as constraining low-carbon transition impacts of transition debt finance, and thus its plausible transition relevance.

8.1. Substantive conclusions from the case study

First, strong sectoral embedding of transition-oriented debt finance can coexist with constrained sectoral low-carbon transition impacts when impacts are assessed against explicit emission-goal benchmarks and reference points for transformative low-carbon process change (Geels, 2019). In the Swedish

commercial real estate sector, transition debt finance became widely embedded and was linked with substantial changes in processes and innovation patterns. Yet, when the thesis' two-part impact assessment is applied, emission goal alignment of innovation and acceleration of transformative low-carbon processes, the assessed impacts remain constrained. The case therefore supports a central implication of the analytically grounded approach developed in this thesis: sectoral transition impacts must be demonstrated through assessment against explicitly specified reference points, rather than inferred from the scale of embedding or from indicators of low-carbon change.

Second, the case indicates that, at the sector level, the embedding of transition-oriented debt finance was accompanied by two prominent organizing features in how transition orientation was qualified and evidenced through eligibility criteria and reporting routines: a focus on the operations value chain and the use of standardized credentials. In the Swedish commercial real estate case, operational energy criteria, market-based accounting conventions, and building certification schemes became recurring reference points for qualification and reporting across actors. Within this qualification and reporting logic, emission hotspots in the construction value chain remained less consistently targeted. At the same time, accounting conventions and certification schemes enabled credentialing to signal low-carbon change through standardized documentation (Kölbel et al., 2020), which can make it more difficult for financiers to require substantive low-carbon change beyond what prevailing criteria and reporting formats already recognize (Nykvist & Maltais, 2022; Penna et al., 2023).

Third, the case supports a calibrated interpretation of transition debt finance's plausible transition relevance. The results indicate that it can contribute to incremental improvement and to the diffusion of practices that fit prevailing criteria and reporting formats, but that it is less well suited to supporting the kind of shifts that would be required to align innovation patterns with emission goals and to strongly accelerate transformative low-carbon processes (Nykvist & Maltais, 2022; Penna et al., 2023). This suggests that the transition relevance of transition debt finance is contingent: it depends on how boundaries, criteria, and conditionality connect finance to the sector's most consequential emission domains.

8.2. Theoretical contributions

The thesis' main ambition has been to develop and apply an analytically grounded approach that makes low-carbon transition impacts empirically assessable in sectoral cases. Any theoretical contributions should therefore be understood as modest and closely tied to what is enabled by the assessment approach and what the case indicates regarding the embedding of transition

debt finance and regarding low-carbon transition impacts when applying the developed assessment approach. With this caveat, the thesis makes three contributions to research on sustainability transitions and sustainable finance.

First, it advances a sector-level framing of low-carbon transition impacts that treats emission goal alignment of innovation and acceleration of transformative low-carbon processes as two analytically distinct types, both assessed relative to explicit reference points (Geels, 2019). This clarifies what is meant by impact on sectoral low-carbon transitions.

Second, the thesis contributes an operationalized approach for retrospective impact assessment, with Andersson and Hellsmark (2024) and Andersen et al. (2023) as key points of departure. By specifying structured assessment criteria and grounding assessment in explicitly specified reference points, the approach provides a transparent basis for assessing whether linked innovation and process changes plausibly amount to strong low-carbon transition impacts in terms of extent, low-carbon scope, and depth. This matters because it addresses a recurring assessment problem: how to evaluate whether and how low-carbon transition interventions support sectoral low-carbon transitions without treating a single dimension of change or reported indicator as proxy for impact (Kölbel et al., 2020; Busch et al., 2021).

Third, the thesis suggests that how emission accounting standards and certification schemes set the terms for credentialing, and how credentialing is then used in eligibility criteria and reporting routines, warrants analytical attention when assessing low-carbon transition impacts. The analysis indicates that this interplay can stabilize claims of low-carbon transition alignment and routinize what counts as transition-relevant change, while remaining weakly connected to emission mitigation at the sector level. It can also shape which changes are treated as evidentiary and rewarded, thereby influencing the scope and depth of changes that are likely to be pursued in response to low-carbon interventions. By integrating credentialing into the treatment of solution pathways and assessment boundaries, the analytical approach helps clarify how the governance of criteria, accounting, and certification can shape assessed impacts under explicit reference points.

8.3. Policy implications

The results suggest practical implications for both policy creators and financial actors. While the analysis focuses on transition debt finance in one sectoral setting, the implications are framed at the level of how transition-oriented debt finance is governed and assessed in sectors with value-chain-divided emissions profiles.

For policy makers, a central implication is that eligibility and monitoring need to be aligned with sectoral emissions hotspots across relevant value chains. Where major emissions sources sit outside the operational domain,

reliance on operational proxies and certification-based credentialing is unlikely to be sufficient as the main basis for eligibility. Policy frameworks can therefore strengthen expectations on value-chain coverage and clarify what qualifies as low-carbon depth, so that transition orientation is not reduced to documentation-driven compliance.

The thesis also highlights a governance risk: market-based accounting and proxy credentials can support claims of transition orientation without requiring commensurate changes in material practices. Certifications and accounting conventions can be useful, but they are not sufficient indicators of low-carbon transition impacts on their own. Policymakers and standard setters can reduce this risk by tightening what qualifies as transition-oriented activity and by strengthening disclosure and verification requirements, particularly where current conventions allow high claims with limited material change. For financiers, a key implication is that standardized credentials are insufficient indicators of transition impact. A practical response is to strengthen conditionality where impact is expected by requiring evidence of low-carbon depth and ensuring that eligibility criteria cover the full low-carbon scope that is relevant for the sector in question.

In the case examined in this thesis, these general implications translate into a specific issue of hotspot coverage: construction- and materials-related emissions were consequential for the assessed impacts, while prevailing eligibility practices and monitoring routines were more strongly oriented toward operational performance. This illustrates why policy and finance governance needs to be explicit about which emissions domains are targeted, and why eligibility that is adequate in one context may be too narrow in another.

More broadly, the case underscores the importance of context-sensitive baselines. Criteria that plausibly support goal alignment in settings with fossil-based operational energy may be too narrow in contexts where operational performance and operational energy supply already yield comparatively strong reported emissions profiles, shifting the transition challenge toward other parts of the value chain. This strengthens the practical case for periodically revising eligibility criteria and monitoring practices so they remain aligned with where mitigation is most consequential in the specific sector and context.

In addition to full-scale evaluations, the analytical approach developed in this thesis can be used as diagnostic support for policy creators and financiers when interventions are designed, implemented, and followed up. Rather than starting from volumes, labels, or reported indicators, the approach can help to test whether governance is actually targeting the parts of a sector and processes consequential for low-carbon transition. In practice this means that intervention design can be tested against questions such as: How do the criteria cover emission hotspots across value chains? In sectors where important emission sources have historically been weakly governed, for example

construction emissions in the case, this becomes particularly relevant to ensure coverage of sectoral low-carbon scope. Furthermore, the approach supports interrogating whether criteria and metrics stimulate innovations exhibiting low-carbon depth or rather enable credentialing through standardized documentation, and whether additional transformative low-carbon processes may be stimulated. In this sense, it may offer a diagnostic basis for adjusting criteria, metrics, and follow-up practices.

8.4. Suggestions for future research

A first direction for future research is to apply the assessment approach in additional sectoral settings and to other types of embedded low-carbon interventions. Such applications would test the approach's broader applicability without assuming that key components, such as value chains, can be carried over unchanged. This would strengthen the approach's robustness and support further theorizing about how such interventions can be assessed and interpreted in relation to sectoral low-carbon transition impacts.

A second direction concerns what changes in the financial system may be required to more strongly support low-carbon transitions, including the governance of transition debt finance. This thesis indicates that transition debt finance can become extensively embedded without translating into strong sectoral low-carbon transition impacts, and it points to conditions that plausibly constrain such impacts. Further research in other settings is warranted to examine whether similar challenges persist for transition debt finance and to complement assessments with mechanism-based explanations.

References

- Akomea-Frimpong, I., Senanu Kukah, A., Jin, X, Osei-Kyei, R., & Pariafsai, F. (2022) Green finance for green buildings: A systematic review and conceptual foundation. *Journal of Cleaner Production*, 356, 131869.
- Amiri, A., Emami, N., Ottelin, J., Sorvari, J., Marteinson, B., Heinonen, J., & Junnila, S. (2021). Embodied emissions of buildings - A forgotten factor in green building certificates. *Energy and Buildings*, 241, 110962.
- Ante, L. (2024) The scope of green finance research: Research streams, influential works and future research paths. *Ecological Economics*, 224, 108302.
- Andersen, A.D., Geels, F.W., Coenen, L., Hanson, J., Korsnes, M., Linnerud, K., Makitie, T., Nordholm, A., Ryghaug, M., Skjolsvold, T., Steen, M., & Wiebe, K. (2023) Faster, broader, deeper! Suggested directions for research on net-zero transitions. *Oxford Open Energy*, 2, 1-7.
- Anderson, K., Broderick, J.F., & Stoddard, I. (2020) A factor of two: how the mitigation plans of ‘climate progressive’ nations fall far short of Paris-compliant pathways. *Climate policy*, 20(10), 1290–1304.
- Andersson, J., & Hellsmark, H. (2024) Directionality in transformative policy missions: The case of reaching net zero emissions in the Swedish process industry. *Journal of Cleaner Production*, 437, 140664.
- Andersson, J., Hellsmark, H., & Sandén, B. (2021) The outcomes of directionality: Toward a morphology of sociotechnical systems. *Environmental Innovation and Societal Transitions*, 40, 108-131.
- Archer, M.S. (1995) *Realist social theory: the morphogenetic approach*. Cambridge University Press.
- Arthur, W.B. (1989) Competing technologies, increasing returns, and lock-in by historical events. *The Economic Journal*, 99(394), 116–131.
- Axsen J, Plötz P., & Wolinetz M. (2020) Crafting strong, integrated policy mixes for deep CO2 mitigation in road transport. *Nature Climate Change*, 10, 809–818.
- Battiston, S., Mandel, A., Monasterolo, I., Schütze, F., & Visentin, G. (2017) A climate stress-test of the financial system. *Nature Climate Change*, 7, 283–288.
- Baur, D., & Lagoarde-Segot, T. (2016) The Contradiction between the Time Value of Money and Sustainability. In S. Aljani & C. Karyotis (Eds.). *Finance and Economy for Society: Integrating Sustainability* (pp. 75–92). Emerald Group Publishing.
- Bergek A, Jacobsson S, Carlsson B, Lindmark, S., & Rickne, A. (2008) Analyzing the functional dynamics of technological innovation systems: a scheme of analysis. *Research Policy*, 37(3), 407–429.

- Bhaskar, R. (1998) *The Possibility of Naturalism*. (3rd ed.). Routledge.
- Birgisdottir, H., Moncaster, A., Houlihan Wiberg, A., Chae, C., Yokoyama, K., Balouktsi, M., Seo, S., Oka, T., Lützkendorf, T., & Malmqvist, T. (2017) IEA EBC annex 57 'Evaluation of embodied energy and CO₂eq for building construction'. *Energy and Buildings*, 154, 72-80.
- Bjørn, A., Lloyd, S.M., Brander, M., & Matthews, H.D. (2022) Renewable energy certificates threaten the integrity of corporate science-based targets. *Nature Climate Change*, 12, 539-546.
- Blanco, C.C. (2021). Supply Chain Carbon Footprinting and Climate Change Disclosures of Global Firms. *Production and Operations Management*, 30(9), 3143-3160.
- Bowles, S. (1998) Endogenous preferences: the cultural consequences of markets and other economic institutions. *Journal of Economic Literature*, 36, 75-111.
- Brander, M., Gillenwater, M., & Ascui, F. (2018) Creative accounting: a critical perspective on the market-based method for reporting purchased electricity (scope 2) emissions. *Energy Policy* 112, 29-33.
- Buch-Hansen, H. & Nielsen, P. (2020) *Critical Realism: Basics and Beyond*. Bloomsbury Publishing.
- Busch, T., Bruce-Clark, P., Derwall, J., Eccles, R., Hebb, T., Hoepner, A., Klein, C., Krueger, P., Paetzold, F., Scholtens, B., & Weber, O. (2021) Impact investments: a call for (re)orientation. *SN Business & Economics*, 1, 33.
- Campiglio, E., Dumas, L., Monnin, P., & von Jagow, A. (2023) Climate-related risks in financial assets. *Journal of Economic Surveys*, 37(3), 950-992.
- Caragnano, A., Mariani, M., Pizzutilo, F., & Zito, M. (2020) Is it worth reducing GHG emissions? Exploring the effect on the cost of debt financing. *Journal of environmental management*, 270, 110860.
- Choi, J., Hackbarth, D., & Zechner, J. (2018) Corporate debt maturity profiles. *Journal of Financial Economics*, 130(3), 484-502.
- Creutzig, F., Roy, J., Lamb, W. F., Azevedo, I. M. L., Bruine de Bruin, W., Dalkmann, H., Edelenbosch, O. Y., Geels, F. W., Grubler, A., Hepburn, C., Hertwich, E. G., Khosla, R., Mattauch, L., Minx, J. C., Ramakrishnan, A., Rao, N. D., Steinberger, J. K., Tavoni, M., Ürge-Vorsatz, D., & Weber, E. U. (2018) Toward demand-side solutions for mitigating climate change. *Nature Climate Change*, 8(4), 260-263.
- Danermark, B., Ekström, M., Jakobsen, L., & Karlsson, J.C. (2002) *Explaining Society: Critical realism in the social sciences*. Routledge.
- David, M. (2017) Moving beyond the heuristic of creative destruction: Targeting exnovation with policy mixes for energy transitions. *Energy Research & Social Science*, 33, 138-146.
- Delmas, M. A., & Burbano, V. C. (2011). The drivers of greenwashing. *California Management Review*, 54(1), 64-87.
- Eliwa, Y., Aboud, A., & Saleh, A. (2021) ESG practices and the cost of debt: Evidence from EU countries. *Critical Perspectives on Accounting*, 79, 102097.
- Flammer, C. (2021). Corporate green bonds. *Journal of Financial Economics*, 142(2), 499-516

- Flyvbjerg, B. (2006). Five misunderstandings about case-study research. *Qualitative Inquiry*, 12(2), 219–245.
- Fünfschilling, L., & Truffer, B. (2014) The structuration of socio-technical regimes – Conceptual foundations from institutional theory. *Research Policy*, 43(4), 772-791.
- Geddes, A., & Schmidt, T.S. (2020) Integrating finance into the multi-level perspective: Technology niche-finance regime interactions and financial policy interventions. *Research Policy*, 49(6), 103985.
- Geels, F.W. (2002) Technological transitions as evolutionary reconfiguration processes. A multi-level perspective and a case-study. *Research Policy*, 31(8-9), 1257-1274.
- Geels, F.W. (2004) From sectoral systems of innovation to socio-technical systems: insights about dynamics and change from sociology and institutional theory. *Research Policy*, 33(6–7), 897-920.
- Geels, F.W., & Schot, J.W. (2007) Typology of sociotechnical transition pathways. *Research Policy*, 36(3).
- Geels, F.W. (2011) The multi-level perspective on sustainability transitions: responses to seven criticisms. *Environmental Innovation and Societal Transitions*, 1(1), 24-40.
- Geels, F.W. (2018) Disruption and low-carbon system transformation: progress and new challenges in socio-technical transitions research and the multi-level perspective. *Energy Research & Social Science*, 37, 224-231.
- Geels, F.W. (2019) Socio-technical transitions to sustainability: a review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability*, 39, 187-201.
- Geels, F.W., & Ayoub, M. (2023) A socio-technical transition perspective on positive tipping points in climate change mitigation: Analysing seven interacting feedback loops in offshore wind and electric vehicles acceleration. *Technological Forecasting and Social Change*, 193, 122639.
- Geels, F.W., Sovacool, B.K., Schwanen, T., & Sorrell, S. (2017) The Socio-Technical Dynamics of Low-Carbon Transitions. *Joule*, 1(3), 463-479.
- Geels, F.W., & Turnheim, B. (2022) *The Great Reconfiguration: A Socio-Technical Analysis of Low-Carbon Transitions in UK Electricity, Heat, and Mobility Systems*. Cambridge University Press.
- Greer, F., Chittick, J., Jackson, E., Mack, J., Shortlidge, M., & Grubert, E. (2019) Energy and water efficiency in LEED: How well are LEED points linked to climate outcomes? *Energy and Buildings*, 195, 161-167.
- Hale, T. N., Chan, S., Hsu, A., Clapper, A., Elliott, C., Faria, P., Kuramochi, T., McDaniel, S., Morgado, M., Roelfsema, M., Santaella, M., Singh, N., Tout, I., Weber, C., Weinfurter, A., & Widerberg, O. (2020) Sub- and non-state climate action: a framework to assess progress, implementation and impact. *Climate Policy*, 21(3), 406–420.
- Hamburger, Á., & Harangozó, G. (2018) Factors affecting the evolution of renewable electricity generating capacities: a panel data analysis of European countries. *Journal of Energy Economics and Policy*, 8, 161–172.

- IPCC (2023) *Climate Change 2023: Synthesis Report. Contribution of Working Groups I, II and III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change* [Core Writing Team, H. Lee and J. Romero (Eds.)]. IPCC.
- IPCC (2022) *Climate change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change*. [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (Eds.)]. Cambridge University Press.
- IPCC (2014a) *Climate Change 2014: Synthesis Report. Contribution of Working Groups I, II and III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Core Writing Team, R.K. Pachauri and L.A. Meyer (Eds.)]. IPCC.
- IPCC (2014b) *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*. [Edenhofer, O., R. Pichs-Madruga, Y. Sokona, E. Farahani, S. Kadner, K. Seyboth, A. Adler, I. Baum, S. Brunner, P. Eickemeier, B. Kriemann, J. Savolainen, S. Schlömer, C. von Stechow, T. Zwickel and J.C. Minx (Eds.)]. Cambridge University Press.
- Johnstone, P., & Kivimaa, P. (2018) Multiple dimensions of disruption, energy transitions and industrial policy. *Energy Research & Social Science*, 37, 260-265.
- Kemp, R., Schot, J., & Hoogma, R. (1998) Regime shifts to sustainability through processes of niche formation. The approach of strategic niche management. *Technological Analysis and Strategic Management*, 10(2), 175-198.
- Kivimaa P., & Kern F. (2016) Creative destruction or mere niche support? Innovation policy mixes for sustainability transitions. *Research Policy*, 45, 205–217.
- Köhler, J., Geels, F. W., Kern, F., Markard, J., Onsongo, E., Wieczorek, A., Alkemade, F., Avelino, F., Bergek, A., Boons, F., Funfschilling, L., Hess, D., Holtz, G., Hyysalo, S., Jenkins, K., Kivimaa, P., Martiskainen, M., McMeekin, A., Muhlemeier, M. S., ... Wells, P. (2019) An agenda for sustainability transitions research: State of the art and future directions. *Environmental Innovation and Societal Transitions*, 31, 1-32.
- Kölbel, J. F., Heeb, F., Paetzold, F., & Busch, T. (2020) Can Sustainable Investing Save the World? Reviewing the Mechanisms of Investor Impact. *Organization & Environment*, 33(4), 554-574.
- Langley, A. (1999). Strategies for Theorizing from Process Data. *The Academy of Management Review*, 24(4), 691–710.
- Löffler, K.U., Petreski, A., & Stephan, A. (2021) Drivers of green bond issuance and new evidence on the “greenium”. *Eurasian Economic Review*, 11, 1–24.
- MacAskill, S., Roca, E., Liu, B., Stewart, R.A., & Sahin, O. (2021) Is there a green premium in the green bond market? Systematic literature review revealing premium determinants. *Journal of Cleaner Production*, 280, 124491.
- Malhotra, A., & Schmidt, T.S. (2020) Accelerating Low-Carbon Innovation. *Joule*, 4(11), 2259-2267.

- Maltais, A., & Nykvist, B. (2020) Understanding the role of green bonds in advancing sustainability. *Journal of Sustainable Finance & Investment*, 1-20.
- Markard, J., Raven, R., & Truffer, B. (2012) Sustainability transitions: An emerging field of research and its prospects. *Research Policy*, 41, 955-967.
- Marti, E., Fuchs, M., DesJardine, M.R., Slager, R. & Gond, J-P. (2024) The Impact of Sustainable Investing: A Multidisciplinary Review. *Journal of Management Studies*, 61(5), 2181-2211.
- Maxwell, J. A. (2012). *A realist approach for qualitative research*. Sage Publications.
- Maxwell, J. A. (2013). *Qualitative research design: An interactive approach*. Sage Publications.
- Maxwell, J.A. & Miller, B.A. (2008) Categorizing and Connecting Strategies in Qualitative Data Analysis. In P. Leavy and S. Hesse-Biber (Eds.) *Handbook of Emergent Methods* (pp. 461–477). Guilford Press.
- Meckling J., Kelsey N., Biber, E., & Zysman, J. (2015) Winning coalitions for climate policy. *Science*, 349, 1170–1171.
- Morgan, D. L. (1997) *Focus groups as qualitative research* (2nd ed.). Sage Publications.
- Mulder, M., & Zomer, S.P.E. (2016) Contribution of green labels in electricity retail markets to fostering renewable energy. *Energy Policy*, 99, 100-109.
- Naidoo, C.P. (2020) Relating financial systems to sustainability transitions: challenges, demands and design features. *Environmental Innovation and Societal Transitions*, 36, 270-290.
- Nygaard, A. (2023) Is sustainable certification’s ability to combat greenwashing trustworthy? *Frontiers in Sustainability*, 4, 1188069.
- Nykvist, B., & Maltais, A. (2022). Too risky – The role of finance as a driver of sustainability transitions. *Environmental Innovation and Societal Transitions*, 42, 219-231
- Palea, V., & Drogo, F. (2020) Carbon emissions and the cost of debt in the eurozone: The role of public policies, climate-related disclosure and corporate governance. *Business Strategy and the Environment*, 29(8), 2953-2972.
- Penna, C.C.R., Schot, J., & Steinmueller, W.E. (2023) Transformative investment: New rules for investing in sustainability transitions. *Environmental Innovation and Societal Transitions*, 49,100782.
- Petreski, A., Schäfer, D., & Stephan, A. (2025) The Reputation Effect of Repeated Green-Bond Issuance and Its Impact on the Cost of Capital. *Business Strategy and the Environment*, 34(2), 2436–2448.
- Piekkari, R., Welch, C., & Paavilainen, E. (2009) The Case Study as Disciplinary Convention: Evidence From International Business Journals. *Organizational Research Methods*, 12(3).
- Porpora, D. V. (1998). Four concepts of social structure. In M. Archer et al. (Eds) *Critical Realism : Essential Readings* (pp. 339–355). Taylor & Francis Group.

- Ragin C.C. (1992), "Casing" and the Process of Social Inquiry. In C.C. Ragin and H.S. Becker (Eds.) *What is a Case? Exploring the Foundations of Social Inquiry* (pp. 217-226). Cambridge University Press.
- Ramesh, T., Prakash, R., & Shukla, K. (2010) Life cycle energy analysis of buildings: An overview. *Energy and Buildings*, 42, 1592-1600.
- Reike, D., Vermeulen, W.J.V., & Witjes, S. (2018) The Circular Economy: New or Refurbished as CE 3.0? — Exploring Controversies in the Conceptualization of the Circular Economy through a Focus on History and Resource Value Retention Options. *Resources, Conservation, and Recycling*, 135, 246–264.
- Rickman, J., Falkenberg, M., Kothari, S., Larosa, F., Grubb, M., & Ameli, N. (2024) The challenge of phasing-out fossil fuel finance in the banking sector. *Nature Communications*, 15, 7881.
- Rip, A., & Kemp, R. (1998) Technological change. In S. Rayner, E.L. Malone (Eds.) *Human Choice and Climate Change Volume: Vol. II, Resources and Technology* (pp. 327-399). Battelle Press.
- Ripple, W.J., Wolf, C., Newsome, T.M., Barnard, P. & Moomaw, W.R. (2019) World Scientists' Warning of a Climate Emergency. *BioScience*, 70, 8–12.
- Roberts, C., & Geels, F.W. (2019) Conditions for politically accelerated transitions: Historical institutionalism, the multi-level perspective, and two historical case studies in transport and agriculture. *Technological Forecasting and Social Change*, 140, 221-240.
- Rogers, E.M. (2003) *Diffusion of Innovations* (5th ed.). Free Press.
- Rohleder, M., Wilkens, M., & Zink, J. (2022) The effects of mutual fund decarbonization on stock prices and carbon emissions. *Journal of Banking & Finance*, 134, 106352.
- Rolfö, L. (2018) *Activity-based Flexible Office work environments: Design and implementation processes and outcomes* (Publication No. 239417) [PhD dissertation, KTH Royal Institute of Technology]. Diva.
- Rosenberg, N. (1976) *Perspectives on Technology*. Cambridge University Press.
- Röck, M., Ruschi Mendes Saade, M., Balouktsi, M., Nygaard Rasmussen, F., Birgisdottir, H., Frischknecht, R., Habert, G., Lützkendorf, T., & Passer, A. (2020) Embodied GHG emissions of buildings – The hidden challenge for effective climate change mitigation. *Applied Energy*, 258, 114107.
- Sayer, A. (2000) *Realism and Social Science*. Sage Publications.
- Schoenmaker, D., & Schramade, W. (2019) *Principles of Sustainable Finance*. Oxford University Press.
- Schot, J., & Geels, F.W. (2008) Strategic niche management and sustainable innovation journeys: theory, findings, research agenda, and policy. *Technology Analysis & Strategic Management*, 20, 537–554.
- Schlütter, D., Schätzlein, L., Hahn, R., & Waldner, C. (2024) Missing the Impact in Impact Investing Research – A Systematic Review and Critical Reflection of the Literature. *Journal of Management Studies*, 61(6), 2700–2752.
- Semieniuk, G., Campiglio, E., Mercure, J., Volz, U., & Edwards, N. R. (2021) Low-carbon transition risks for finance. *WIREs Climate Change*, 12(1).

- Shleifer, A., & Vishny, R. (2011). Fire Sales in Finance and Macroeconomics. *The Journal of Economic Perspectives: A Journal of the American Economic Association*, 25(1), 29–48.
- Smith, A., Stirling, A., & Berkhout, F. (2005) The governance of sustainable sociotechnical transitions. *Research Policy*, 34, 1491–1510.
- Smith, A., Voß, J-P., & Grin, J. (2010). Innovation studies and sustainability transitions: the allure of the multi-level perspective and its challenges. *Research Policy*, 39, 435-448.
- Smith, A., & Raven, R. (2012) What is protective space? Reconsidering niches in transitions to sustainability. *Research Policy*, 41(6), 1025-1036.
- Sorrell, S. (2018) Explaining sociotechnical transitions: A critical realist perspective. *Research Policy*, 47(7), 1267-1282.
- Späth, P., & Rohracher, H. (2010) ‘Energy regions’: The transformative power of regional discourses on socio-technical futures. *Research Policy*, 39(4), 449–458.
- Spence, M. (1974) *Market Signaling: Informational Transfer in Hiring and Related Screening Processes*. Harvard University Press.
- Stalmokaitė, I., & Hassler, B. (2020) Dynamic capabilities and strategic reorientation toward decarbonisation in Baltic Sea shipping. *Environmental Innovation and Societal Transitions*, 37, 187-202.
- Steffen, B., & Schmidt, T.S. (2021) Strengthen finance in sustainability transitions research. *Environmental Innovation and Societal Transitions*, 41, 77-80.
- Svensson, O., & Nikoleris, A. (2018) Structure reconsidered: Toward new foundations of explanatory transitions theory. *Research Policy*, 47(2), 462-473.
- Teece, D.J. (1986) Profiting from technological innovation: Implications for integration, collaboration, licensing and public policy. *Research Policy*, 15(6), 285-305.
- Ürge-Vorsatz, D., Khosla, R., Bernhardt, R., Chan, Y.C., Vérez, D., Hu, S., & Cabeza, L.F. (2020) Advances Toward a Net-Zero Global Building Sector. *Annual Review of Environmental Resources*, 45, 227–269.
- van der Ploeg, F., & Rezai, A. (2020) Stranded Assets in the Transition to a Carbon-Free Economy. *Annual Review of Resource Economics*, 12(1), 281–298.

Empirical sources

All empirical and institutional sources cited in the chapters with a brief footnote are here listed in alphabetical order - inspired by the Oxford style of referencing –with details to enable their identification, except for informants whose names and workplaces are expressed with codes to uphold confidentiality:

- Alfelt, G., Olsén Ingerfeldt, N., & Regnér, M. (2022). Financial stability risks following reduced demand for offices. Economic Commentary no. 6, Sveriges Riksbank. Retrieved from:
<https://www.riksbank.se/globalassets/media/rapporter/ekonomiska-kommentarer/engelska/2022/financial-stability-risks-following-reduced-demand-for-offices.pdf>
- Boverket (n.d.) Öppna data – Miljöindikatorer. Retrieved from:
<https://www.boverket.se/sv/om-boverket/publicerat-av-boverket/oppna-data/miljoindikatorer/>
- Boverket (2023) Kontrollstation av reglerna för byggnaders energiprestanda, p. 8. Retrieved from:
<https://www.boverket.se/globalassets/publikationer/dokument/2023/kontrollstation-av-reglerna-for-byggnaders-energi-prestanda.pdf>
- Boverket. (2022) Implementation of the EPBD in Sweden, pp. 7-11. Retrieved from: <https://epbd-ca.eu/wp-content/uploads/2022/10/Implementation-of-the-EPBD-in-Sweden.pdf>
- Boverket (2020-10-16) Energistatistik för lokaler 2019. Retrieved from:
<https://www.energimyndigheten.se/statistik/den-officiella-statistiken/statistikprodukter/energistatistik-for-lokaler/>
- Boverket (2020-07-01) BFS 2020:4, BBR29. Retrieved from:
<https://rinfo.boverket.se/BFS2011-6/pdf/BFS2020-4.pdf>
- Boverket (2013) Analys av delade incitament för energieffektivisering, rapport 2013:32. Retrieved from: <https://energimyndigheten.a-w2m.se/System/TemplateView.aspx?p=Arkitektkopia&id=dc83420ef10a43cd8b51833c82e3019b&q=V%C3%A4rme-pump%20f%C3%B6r%20duschvattnet%20sparar%20energi%20i%20kombian%20A4ggningen&lstqty=1>
- BPIE (2020-08-24) A guidebook to European Building Policy. Retrieved from:
<https://www.bpie.eu/publication/a-guidebook-to-european-building-policy-key-legislation-and-initiatives/>
- Breitenstein, M., Ciummo, S. & Walch, F. (2022-07) Disclosure of climate change risk in credit ratings. Occasional Paper Series, No 303, European Central Bank. Retrieved from:
<https://www.ecb.europa.eu/pub/pdf/scpops/ecb.op303~eaa6fe6583.en.pdf>
- Business Sweden (2021) Commercial leases and rents. Retrieved from:
<https://business->

- sweden.com/contentassets/f3be340ca8804de2ba5ee112c9b6d970/commercial-leases-and-rents-2021-publ.pdf
- Carney, M. (2015-09-29) Breaking the Tragedy of the Horizon – climate change and financial stability. Speech at Lloyd’s of London. Bank of England. Retrieved from: <https://www.bankofengland.co.uk/speech/2015/breaking-the-tragedy-of-the-horizon-climate-change-and-financial-stability>
- CDP (2022-03-14) More than 680 financial institutions with US\$130+ trillion in assets call on nearly 10,400 companies to disclose environmental data through CDP. <https://www.cdp.net/en/articles/media/More-than-680-financial-institutions-call-on-nearly-10400-companies-to-disclose-environmental-data-through-CDP>
- CDP (n.d.) What we do. <https://www.cdp.net/en/info/about-us/what-we-do>
- Cicero Shades of Green (2020) Sustainable Edge Sector Brief: Real Estate. Retrieved from: [https://cicero.oslo.no/en/articles/assessments-of-six-key-norwegian-sectorsd9bd12c7cf1a:5d60a443e2b37daa93ff35ff33d5c1f151ccfe82/sectorbriefs_realestate_17_12%20\(1\).pdf](https://cicero.oslo.no/en/articles/assessments-of-six-key-norwegian-sectorsd9bd12c7cf1a:5d60a443e2b37daa93ff35ff33d5c1f151ccfe82/sectorbriefs_realestate_17_12%20(1).pdf)
- Cicero (2018) Cicero milestones 2018. Retrieved from: <https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/Public-research-resources/Cicero2018-09Milestones-Report-2018-010319.pdf>
- Cicero Shades of Green (2021-09-23) Hufvudstaden AB Green Bond Second Opinion. Retrieved from: <https://www.spglobal.com/ratings/en/research/pdf-articles/210923-hufvudstaden>
- Cicero Shades of Green (2021-05-21) Stenvalvet AB Green Finance Second Opinion. Retrieved from: <https://stenvallvet.se/wp-content/uploads/2023/02/Second-Opinion-Stenvalvet-10May2021.pdf>
- CIT Energy management (2022-12-14) Topp 15 och 30 procent av de bästa byggnaderna. Retrieved from: https://www.fastighetsagarna.se/globalassets/bilder/nyheter/sverige/topp-15-och-30-sverige-_221214.pdf?bustCache=1675872668050
- Climate bonds initiative (2020) Nordic Sustainable Debt – State of the Market 2020. Retrieved from: <https://www.climatebonds.net/2021/04/nordic-sustainable-debt-state-market-2020-special-regional-report>
- Climate bonds initiative (2019) Green Bonds Global State of the Market 2019. Retrieved from: <https://www.climatebonds.net/resources/reports/green-bonds-global-state-market-2019>
- Climate bonds initiative (2018) The Green Bond Market in the Nordics 2018. Retrieved from: <https://www.climatebonds.net/resources/reports/green-bond-market-nordics>
- Climate bonds initiative (2014-01-13) Green Bond Principles 2014 Voluntary Process Guidelines for Issuing Green Bonds. Retrieved from: <https://www.climatebonds.net/files/uploads/2014/01/Green-Bond-Principles-FINAL.pdf>
- Draghi, M. (2016) Addressing the causes of low interest rates [speech transcript]. European Central Bank. Retrieved from: <https://www.ecb.europa.eu/press/key/date/2016/html/sp160502.en.html>
- Energiföretagen (2024-08-20) Miljövärdering av fjärrvärme. <https://www.energiforetagen.se/statistik/fjarrvarmestatik/miljovardering-av-fjarrvarme/>
- Energimarknadsinspektionen (n.d.) Residualmix. <https://www.ei.se/bransch/ursprungsmarkning-av-el/residualmix>
- Energimarknadsinspektionen (n.d.) Residualmixen för tidigare år. <https://ei.se/bransch/ursprungsmarkning-av-el/residualmix/residualmixen---tidigare-ar>

- EUR-Lex (2014-10-22) Directive 2014/95/EU of the European Parliament and of the Council of 22 October 2014 amending Directive 2013/34/EU as regards disclosure of non-financial and diversity information by certain large undertakings and groups. <https://eur-lex.europa.eu/eli/dir/2014/95/oj>
- European Commission Climate Action (n.d) Increasing the ambition of EU emission trading. https://climate.ec.europa.eu/eu-action/european-green-deal/delivering-european-green-deal/increasing-ambition-eu-emissions-trading_en
- European Commission – Joint Research Cent (2024) GHG Emission Factors for Electricity Consumption. Retrieved from: <https://publications.jrc.ec.europa.eu/repository/handle/JRC136340>
- European Investment Bank (2018-04-11) Proof of Europe’s crazy aversion to equity. <https://www.eib.org/en/stories/proof-of-europe-crazy-aversion-equity#:~:text=Firms%20in%20Europe%20largely%20rely,They%20rarely%20consider%20external%20equity>
- Finansinspektionen (2019) Den kommersiella fastighetsmarknaden och finansiell stabilitet. Retrieved from: https://www.fi.se/contentassets/f0b2175448734d998679a33d8eaf8f6e/komm_fastighet_finstab.pdf
- Fossilfritt Sverige (n.d.) Electricity sector. <https://fossilfritt Sverige.se/en/roadmap/the-electricity-sector/>
- Fossilfritt Sverige (2022) Färdplaner för fossilfri konkurrenskraft – uppföljning 2022. Retrieved from: https://fossilfritt Sverige.se/wp-content/uploads/2022/10/Uppfo%CC%88ljningsrapport_2022.pdf
- Fossilfritt Sverige (2021) Strategi för fossilfri konkurrenskraft – bioenergi och bioråvara i industrins omställning, pp. 20, 23. Retrieved from: <https://fossilfritt Sverige.se/wp-content/uploads/2021/11/Fossilfritt-Sveriges-biostrategi.pdf>
- Fossilfritt Sverige (2018-12-28) Färdplan för fossilfri konkurrenskraft: Bygg- och anläggningssektorn. Retrieved from: https://fossilfritt Sverige.se/wp-content/uploads/2021/10/Fardplan_for_fossilfri_bygg_och_anlaggningssektor_20181228-1.pdf
- Förvaltarforum (2019-11-29) Därför certifierar Fabege 100 procent. Retrieved from: <https://forvaltarforum.se/2019/11/29/darfor-certifierade-fabege-100-procent>
- FSB (2015-11-09) FSB to establish Task Force on Climate-related Financial Disclosures. Retrieved from: <https://www.fsb.org/2015/12/fsb-to-establish-task-force-on-climate-related-financial-disclosures/>
- G20 Sustainable Finance Working Group (2022) 2022 G20 Sustainable Finance Report. Retrieved from: <https://g20sfwg.org/wp-content/uploads/2022/10/2022-G20-Sustainable-Finance-Report-2.pdf>
- GHG Protocol (2015) GHG Protocol Scope 2 Guidance. Retrieved from: <https://ghgprotocol.org/scope-2-guidance>
- GHG Protocol (2005) GHG Protocol for Project accounting. Retrieved from: <https://ghgprotocol.org/project-protocol>
- GHG Protocol. (n.d.) About us. <https://ghgprotocol.org/about-us>
- Global Footprint Network (n.d.) Country overshoot days. (Accessed in August 2023 when the date calculated was based on resource data from 2018) <https://www.overshootday.org/newsroom/country-overshoot-days/>
- Global Reporting initiative (n.d) About GRI. <https://www.globalreporting.org/about-gri/>

- Global Reporting initiative (2016) GRI 101: Foundation 2016. Retrieved from: <https://www.globalreporting.org/standards/media/1036/gri-101-foundation-2016.pdf>
- GRESB (n.d) 2022 Real Estate Assessment Results. <https://www.gresb.com/nl-en/2022-real-estate-results/>
- Integritetsskyddsmyndigheten (n.d.) Känsliga personuppgifter. <https://www.imy.se/verksamhet/dataskydd/det-har-galler-enligt-gdpr/introduktion-till-gdpr/personuppgifter/kansliga-personuppgifter/>
- Handelsbanken (2021-02-28) Annual and Sustainability report 2020. Retrieved from: <https://vp292.alertir.com/afw/files/press/handelsbanken/202102237659-1.pdf>
- ICMA (2021) The Green Bond Principles (GBP) 2021. Retrieved from: <https://www.icmagroup.org/assets/documents/Sustainable-finance/2021-updates/Green-Bond-Principles-June-2021-140621.pdf>
- ICMA (2019) Suggested Impact reporting metrics for Green Building Projects. Retrieved from: <https://www.icmagroup.org/sustainable-finance/impact-reporting/green-projects/>
- ICMA (2017-06-02) The Green Bond Principles 2017. Retrieved from: <https://www.icmagroup.org/assets/documents/Regulatory/Green-Bonds/GreenBondsBrochure-JUNE2017.pdf>
- ICMA (2016) The Green Bond Principles, 2016. Retrieved from: <https://www.icmagroup.org/assets/documents/regulatory/green-bonds/gbp-2016-final-16-june-2016.pdf>
- IMF (2021) Global Financial Stability Report, April 2021: Preempting a Legacy of Vulnerabilities. Retrieved from: <https://www.imf.org/-/media/Files/Publications/GFSR/2021/April/English/text.ashx>
- Informant 10A (2019-04-23) BSSF workshop with real estate sustainability managers and experts on landlord sustainability work and tenant engagement. Stockholm.
- Informant 12B (2022-02-18) BSSF project interview with CRE company sustainability manager. Stockholm.
- Informant 13A (2019-10-18) BSSF workshop with real estate sustainability managers and experts on playing rules for CRE companies' sustainability engagement. Stockholm.
- Informant 13B (2020-05-11) Interview with CRE company sustainability manager. Online meeting.
- Informant 14A (2021-10-20) BSSF workshop with real estate sustainability managers and experts on Investor sustainability requirements. Stockholm.
- Informant 14A (2020-08-28) BSSF workshop with real estate sustainability managers and experts on their corporate climate targets. Online meeting.
- Informant 14A (2019-10-18) BSSF workshop with real estate sustainability managers and experts on playing rules for CRE companies' sustainability engagement. Stockholm.
- Informant 15A (2020-08-28) BSSF workshop with real estate sustainability managers and experts on their corporate climate targets. Online meeting.
- Informant 51A (2020-01-10) Interview with the head of business development for an association of real estate owners. Stockholm.
- Informant 52A (2021-10-20) Workshop with CRE company sustainability managers on Investor sustainability requirements. Stockholm.

- Informant 52A (2019-04-23) BSSF workshop with real estate sustainability managers and experts on sustainability considerations in investment decisions. Stockholm
- Informants 10A, 10C, 11D, 14A, 51B and 52A (2021-10-20) BSSF workshop with real estate sustainability managers and experts on investor sustainability requirements. Stockholm.
- Lokalnytt (2016-06-02). Hur lågt kan det bli? Retrieved from: <https://www.lokalnytt.se/artiklar/1783/hur-lagt-kan-det-bli>
- MCSI (2020-07-08) Measuring Climate Risk in Real Estate Portfolios. Retrieved from: <https://www.msci.com/www/blog-posts/measuring-climate-risk-in-real/01973063966>
- IVL Svenska Miljöinstitutet (2020) Återanvändning av bygg- och rivningsmaterial och produkter i kommuner. Retrieved from: <https://www.ivl.se/download/18.34244ba71728fcb3f3f936/1591705295479/B2370.pdf>
- Moody's investor service (2020-12-14) Moody's Environmental Credit Risk - Sector in-depth. Retrieved from: <https://www.politico.com/f/?id=00000176-6343-df7e-a37f-f7d32a810000>
- Naturvårdsverket (n.d) Vägledning Bygg- och rivningsavfall. <https://www.naturvardsverket.se/vagledning-och-stod/avfall/bygg--och-rivningsavfall/utsortering/>
- Naturvårdsverket (n.d) Konsumtionsbaserade utsläpp per person. <https://www.naturvardsverket.se/data-och-statistik/konsumtion/vaxthusgaser-konsumtionsbaserade-utslapp-per-person>
- Naturvårdsverket (n.d) Sveriges utsläpp och upptag av växthusgaser. <https://www.naturvardsverket.se/data-och-statistik/klimat/sveriges-utslapp-och-upptag-av-vaxthusgaser>
- Nordea (2021-04-02) Nordea sets target to become a net zero emissions bank by 2050. Retrieved from: <https://www.nordea.com/en/press/2021-02-04/nordea-sets-target-to-become-a-net-zero-emissions-bank-by-2050>
- Nordic Public Sector Issuers (2020-02). Position paper on green bonds impact reporting. Retrieved from: https://www.kuntarahoitus.fi/app/uploads/sites/2/2020/02/NPSI_Position_paper_2020_fin_al.pdf
- Nordic Trustee (2021-02) Nordic Corporate Bond market 2020. Retrieved from: https://nordictrustee.com/app/uploads/2021/02/NordicTrustee_CorporateBondMarketReport_2020.pdf
- PCAF (2022). The Global GHG Accounting and Reporting Standard Part A: Financed Emissions. Second Edition. Retrieved from: <https://carbonaccountingfinancials.com/files/downloads/PCAF-Global-GHG-Standard.pdf>
- Plant (2018-08-26) Materialrapport Hubben. Retrieved from: <https://www.vasakronan.se/cdn.triggerfish.cloud/uploads/2018/10/materialrapport-hubben.pdf>
- Propmodo (2022-09-13) Embodied Carbon is a Pesky Real Estate Decarbonization Challenge. <https://www.propmodo.com/embodied-carbon-is-a-pesky-real-estate-decarbonization-challenge>
- RE-Source (2021) Guarantees of Origin and Corporate Procurement Options, RE-Source. Retrieved from: <https://resource-platform.eu/wp-content/uploads/Guarantees-of-Origin-and-Corporate-Procurement-Options.pdf>

- Regeringskansliet (2017-06-17) Det klimatpolitiska ramverket.
<https://www.regeringen.se/artiklar/2017/06/det-klimatpolitiska-ramverket/>
- Riksrevisionen (2022) Skolpengen – effektivitet och konsekvenser. Retrieved from:
<https://www.riksrevisionen.se/granskningar/granskningsrapporter/2022/skolpengen---effektivitet-och-konsekvenser.html>
- Science Based Target initiative (2020) Science-Based Target Setting Manual, version 4.1. Retrieved from: <https://sciencebasedtargets.org/wp-content/uploads/2017/04/SBTi-manual.pdf>
- Science Based Target initiative (n.d.) What role do market-based accounting approaches play in target-setting with the SBTi?
<https://sciencebasedtargets.org/faqs#what-role-do-market-based-accounting-approaches-play-in-target-setting-with-the-sbti>
- Sigblad, A. (2020-04-22) Det innebär TCFD-ramverket. Finansliv.
 Retrieved from: <https://www.finansliv.se/artikel/det-innebar-tcfd-ramverket/>
- Stockholm Exergi (2022-03) Års- och hållbarhetsredovisning 2021.
 Retrieved from: <https://www.stockholmexergi.se/nyheter/ars-och-hallbarhetsredovisning-2021/>
- Strand Nyhlin, M. (2022-01-19) Extremt koldioxidsnålt forskolebygge ger framtidshopp, Byggindustrin. Retrieved from:
<https://www.byggindustrin.se/byggprojekt/arets-bygge/extremt-koldioxidsnalt-forskolebygge-ger-framtidshopp>
- Svensk betong (2022) Vägledning Klimatförbättrad betong – utgåva 2.
 Retrieved from: https://www.svenskbetong.se/images/pdf/SvenskBetong_-_V%C3%A4gledning_Klimatf%C3%B6rb%C3%A4ttad_betong_Utg%C3%A5va_2_-_Digital.pdf
- Sveriges Riksbank (2017) Fördjupning - Kommersiella fastigheter och finansiell stabilitet. Retrieved from:
<https://www.riksbank.se/globalassets/media/rapporter/fsr/fordjupningar/svenska/2017/kommersiella-fastigheter-och-finansiell-stabilitet-fordjupning-i-finansiell-stabilitetsrapport-maj-2017.pdf>
- Sveriges Riksbank (n.d.) Åtgärder under Coronapandemin.
<https://www.riksbank.se/sv/marknader/atgarder-vid-finansiell-oro/atgarder-under-coronapandemin/#:~:text=L%C3%A4ttade%20krav%20p%C3%A5%20s%C3%A4kerhet%20f%C3%B6r%20att%20i%C3%A5na%20hos%20Riksbanken>
- SVT Nyheter (2021-05-30) Byggnader stora klimatbovar – energieffektivisering en del av lösningen. Retrieved from: <https://www.svt.se/nyheter/inrikes/byggnader-stora-klimatbovar-energieffektivisering-en-del-av-losningen>
- Sweden Green Building Council (2021-04-22) ‘Finance - the driving force for sustainability’ [Webinar]. Youtube.
<https://www.youtube.com/watch?v=rw3wwg5A2r8&t=5045s>
- Task Force on Climate-related Financial Disclosures (n.d) About us. <https://www.fsb-tcfd.org/about/>
- Task Force on Climate-related Financial Disclosures (2022-10) 2022 TCFD Status report. Retrieved from: <https://assets.bbhub.io/company/sites/60/2022/10/2022-TCFD-Status-Report.pdf>
- UNEP FI (2020) Beyond the Horizon: New Tools and Frameworks for transition risk assessments from UNEP FI’s TCFD Banking Program.
 Retrieved from: <https://www.unepfi.org/wordpress/wp-content/uploads/2020/10/Beyond-the-Horizon.pdf>

- United Nations / Framework Convention on Climate Change (2015-12-12) The Paris Agreement. Retrieved from:
https://unfccc.int/sites/default/files/resource/parisagreement_publication.pdf
- United Nations / Framework Convention on Climate Change (n.d.) Introduction to Climate Finance. <https://unfccc.int/topics/introduction-to-climate-finance>
- Vasakronan (2013-11-18) Vasakronan issues the world's first corporate green bond. Retrieved from: <https://vasakronan.se/pressmeddelande/vasakronan-issues-the-worlds-first-green-corporate-bond/>
- Vetenskapsrådet (2024) God forskningssed 2024. Retrieved from:
<https://www.vr.se/analys/rapporter/vara-rapporter/2024-10-02-god-forskningssed-2024.html>
- Westerberg, J., Sundberg, J., Rensfeldt, A. & Grubbström, C. (2023) Miljöprodukter för fjärrvärme i ett systemperspektiv. Energiforsk. Retrieved from:
<https://energiforsk.se/media/33016/2023-278-miljoprodukter-for-fjarrvarmen-i-ett-systemperspektiv.pdf>
- Wollert (2020) Svenska företagsobligationer under coronapandemin. Staff Memo, Avdelningen för finansiell stabilitet, Sveriges Riksbank. Retrieved from:
<https://www.riksbank.se/globalassets/media/rapporter/staff-memo/svenska-foretagsobligationer-under-coronapandemin.pdf>
- World Bank Group (n.d.) Total greenhouse gas emissions excluding LULUCF per capita. <https://data.worldbank.org/indicator/EN.GHG.ALL.PC.CE.AR5?view=chart>
- World Economic Forum (2021-11-01) Why building greener is crucial to meeting Paris climate targets. Retrieved from:
<https://www.weforum.org/agenda/2021/11/green-building-global-warming-climate-change/>



The Swedish Research School of Management and Information Technology MIT

The *Swedish Research School of Management and Information Technology* (MIT) is one of 16 national research schools supported by the Swedish Government. MIT is jointly operated by the following institutions: Blekinge Institute of Technology, University of Gothenburg, Jönköping International Business School, Karlstad University, Linköping University, Linnaeus University Växjö, Lund University, Mälardalen University, Stockholm University, Umeå University, Örebro University, and Uppsala University, host to the research school. At the Swedish Research School of Management and Information Technology (MIT), research is conducted, and doctoral education provided, in three fields: management information systems, business administration, and informatics.

Licentiate Theses

1. **Johansson, Niklas E. (2004)** *Self-Service Recovery: Towards a Framework for Studying Service Recovery in a Self-Service Technology Context from a Management and IT Perspective*, Licentiate Thesis KUS 2004:3, Karlstad University.
2. **Ekman, Peter (2004)** *Affärssystem & Affärsrelationer: En fallstudie av en leverantörs användning av affärssystem i interaktionen med sina kunder*, Licentiate Thesis No.25, Mälardalens universitet.
3. **Wrenne, Anders (2004)**. *Tjänsteplattformar: Vid utveckling av mobila tjänster inom telekommunikation*, Licentiatavhandling, KUS 2004:4, Karlstads universitet, Centrum för tjänsteforskning.
4. **Wismén, May (2004)**. *Kunskapsprocesser inom hälso- och sjukvård: En studie av kunskapsintegrering mellan laboratorium och dess kunder*, Licentiatavhandling, KUS 2004:10, Karlstads universitet.
5. **Stoltz, Charlotte (2004)**. *Calling for Call Centres: A Study of Call Centre Locations in a Swedish Rural Region*, Licentiate Thesis, No. 1084, IDA-EIS, Linköping University, Institute of Technology.
6. **Abelli, Björn (2004)**. *Theatre Production: A System Development Process*, Licentiate thesis No. 30, Mälardalen University.

7. **Maaninen-Olsson, Eva (2004).** *Det gränslösa projektet: En studie om förmedling och skapande av kunskap i tid och rum*, Licentiatavhandling nr. 41, Företagsekonomiska institutionen, Uppsala Universitet,.
8. **Sällberg, Henrik (2004).** *On the value of customer loyalty programs: A study of point programs and switching costs*, Licentiate Thesis, No. 1116, IDA-EIS, Linköping University, Institute of Technology.
9. **Stockhult, Helén (2005).** *Medarbetaransvar - ett sätt att visa värderingar: En konceptualisering av medarbetarnas ansvar och ansvarstagande i callcenter*, Licentiatavhandling nr. 1, Örebro universitet, Institutionen för ekonomi, statistik och informatik.
10. **Vascós Palacios, Fidel (2005).** *On the information exchange between physicians and social insurance officers in the sick leave process: An Activity Theoretical perspective*, Licentiate Thesis, No. 1165, IDA-EIS, Linköping University, Institute of Technology.
11. **Keller, Christina (2005).** *Virtual Learning Environments in higher education: A study of students' acceptance of educational technology*, Licentiate Thesis, No. 1167, IDA-EIS, Linköping University, Institute of Technology.
12. **Ahlström, Petter (2005),** *Affärsstrategier för seniorbostadsmarknaden*, Licentiatavhandling, No. 1172, IDA-EIS, Linköpings universitet, Tekniska Högskolan.
13. **Dahlin, Peter (2005).** *Structural Change of Business Networks: Developing a Structuration Technique*, Licentiate Thesis No. 49, Mälardalen University.
14. **Granebring, Annika (2005).** *ERP Migration Structure : An Innovation Process Perspective*, Licentiate Thesis No. 50, Mälardalen University.
15. **Cöster, Mathias (2005).** *Beyond IT and Productivity: How Digitization Transformed the Graphic Industry*, Licentiate Thesis, No. 1183, IDA-EIS, Linköping University, Institute of Technology.
16. **Horzella, Åsa (2005).** *Beyond IT and Productivity: Effects of Digitized Information Flows in Grocery Distribution*, Licentiate Thesis, No. 1184, IDA-EIS, Linköping University, Institute of Technology.
17. **Kollberg, Maria (2005).** *Beyond IT and Productivity: Effects of Digitized Information Flows in the Logging Industry*, Licentiate Thesis, No. 1185, IDA-EIS, Linköping University, Institute of Technology.
18. **Hansson, Magnus (2005).** *From Dusk till Dawn: Three Essays on Organizational Closedowns*, Licentiate Thesis, No. 3, Örebro University.

19. **Verma, Sanjay (2005).** *Product's Newness and Benefits to the Firm: A qualitative study from the perspective of firms developing and marketing computer software products*, Licentiate thesis, No. 54, Mälardalen University.
20. **Sundén, Susanne & Wicander, Gudrun (2005).** *Information and Communication Technology Applied for Developing Countries in a Rural Context: Towards a Framework for Analyzing Factors Influencing Sustainable Use*, Licentiate thesis, KUS 2006:69, Karlstad University.
21. **Käll, Andreas (2005).** *Översättningar av en managementmodell: En studie av införandet av Balanced Scorecard i ett landsting*, Licentiatavhandling, No.1209, IDA-EIS, Linköpings universitet, Tekniska Högskolan.
22. **Mihailescu, Daniela (2006).** *Implementation Methodology In Action: A study of an Enterprise Systems implementation methodology*, Licentiate Thesis, No.1233, IDA-EIS, Linköping University, Institute of Technology.
23. **Flodström, Raquel (2006).** *A Framework for the Strategic Management of Information Technology*, Licentiate Thesis, No.1272, IDA-EIS, Linköping University, Institute of Technology.
24. **Werelius, Sofie (2006).** *Consumer Business Relationship with Retailer and Etailer for the Purchase of Clothing: A Network Perspective*, Licentiate Thesis No. 45, Uppsala University, Department of Business Studies.
25. **Fryk, Pontus (2007).** *Beyond IT and Productivity: Effects of Digitized Information Flows in Health Care*, Licentiate Thesis, No. 1328, Linköping University, Institute of Technology.
26. **Sandström, Sara (2008).** *Technology-based service experiences: A study of the functional and emotional dimensions of telecom services*, Licentiate Thesis, KUS 2008:3, Karlstad University, Faculty of Economic Sciences, Communication and IT.
27. **Lundmark, Erik (2008).** *Organisational Adoption of Innovations: Management Practices and IT*, Licentiate Thesis, No. 1352, Linköping University, Institute of Technology.
28. **Anjou, Anette (2008).** *Scantias framgång: Betydelsen av strategisk kongruens och integrerad styrning*, Licentiatavhandling, No. 1364, Linköpings universitet, Tekniska högskolan.
29. **Numminen, Emil (2008).** *Software Investments under Uncertainty: Modeling Intangible Consequences as a Stochastic Process*, Licentiate Dissertation Series, No. 2008:7, Blekinge Institute of Technology.
30. **Bergqvist, Linda (2008).** *A Conceptual Framework for Studying the Successful Outcome of the IS Outsourcing Process from a Relationship Perspective*,

Licentiate Thesis, KUS 2008:30, Karlstad University, Information Systems, Faculty of Economic Sciences, Communication and IT.

31. **Wingkvist, Anna (2008).** *The Quest for Equilibrium. Towards an Understanding of Scalability and Sustainability for Mobile Learning*, Licentiate Thesis, No. 08118, Växjö University, Center for Learning and Knowledge Technologies, Department of Information Systems, School of Mathematics and System Engineering.
32. **Sundberg, Klas (2009).** *Atlas Copcos strategi och styrning: Verktyg som ger guld*, Licentiate Thesis, No. 48, Uppsala universitet, Företagsekonomiska institutionen.
33. **Mörndal, Marie (2009).** *"Hallå! Jag känner mig ensam här": En studie om studieovana studenters interaktion på ett webbaserat diskussionsforum*, Licentiate Thesis No. 113, Mälardalens högskola.
34. **Svensson, Martin (2010).** *Routines for Engagement: Emotions and Routines when Communicating through ICTs*, Linköping Studies in Science and Technology, Thesis No. 1444 LiU-TEK-LIC 2010:15.
35. **Mansour, Osama (2011).** *Share with Social Media: The Case of a Wiki*, Licentiate Thesis, School of Computer Science, Physics, and Mathematics, Linnaeus University, Växjö.
36. **Gullberg, Cecilia (2011).** *Puzzle or Mosaic? On Managerial Information Patterns*, Licentiate Thesis, Linköping University, Institute of Technology. Licentiate Thesis, ISSN 0280-7971; 1483.
37. **Kajtazi, Miranda (2011).** *An Exploration of Information Inadequacy: Instances that Cause the Lack of Needed Information*, Licentiate Thesis, School of Computer Science, Physics, and Mathematics, Linnaeus University, Växjö.
38. **Eklinder-Frick, Jens (2011).** *Building Bridges and Breaking Bonds: Aspects of Social Capital in a Regional Strategic Network*, Licentiate Thesis No 139, Mälardalen University.
39. **Hansen, Therese (2012).** *Internet or Traditional Stores: Identifying Influences on Consumers' Mobile Phone Purchases*, Licentiate Thesis No. 50, Department of Business Studies, Uppsala University.
40. **El-Mekawy, Mohamed (2012).** *From Societal to Organizational Culture: The Impact on Business-IT Alignment*, Licentiate Thesis, Department of Computer and Systems Sciences, Stockholm University.
41. **Hadjikhani, Annoch (2013).** *Expectations in the Internationalization Process: The case of two Swedish banks' foreign activities 1995-2010*, Licentiate Thesis, Mälardalen University.

42. **Salavati, Sadaf (2014).** *Novel Use of Mobile and Ubiquitous Technologies in Everyday Teaching and Learning Practices: A Complex Picture*, Licentiate Thesis, Linnaeus University.
43. **Williamsson, Ia (2014).** *On the Possibility of Improving Software Quality: By Improving Software Maintenance*, Licentiate Thesis, Linnaeus University.
44. **Lagin, Madelen (2015).** *Assumptions of Retail Price Strategy and Price Tactic Decisions*, Licentiate Thesis, Örebro University.
45. **Aasi, Parisa (2016).** *Organizational Culture and Structure Influence on Information Technology Governance*, Licentiate Thesis, Department of Computer and Systems Sciences, Stockholm University.
46. **Eriksson, Emelie (2017).** *Patterns of Corporate Visual Self-representation in Accounting Narratives*, Licentiate Thesis, Department of Management and Engineering (IEI), Linköping University.
47. **Golshan, Behrooz (2018).** *Digital Capability and Business Model Reconfiguration: A co-evolutionary perspective*, Licentiate Thesis, Department of Informatics, Faculty of Technology, Linnaeus University.
48. **Svensson de Jong, Ilse (2018).** *Explorative study on Measurement of Innovation*, Licentiate Thesis, Department of Design Sciences, Faculty of Engineering, Lund University.
49. **Haglund, Lennart (2019).** *Affärsrelationer på den svenska elmarknaden*, Mälardalen University Press Licentiate Thesis, L-279, School of Business, Society and Engineering, Division of Marketing and Strategy, Mälardalen University.
50. **Panahi, Parisa (2019).** *The role of information technology in supporting management control systems for corporate social responsibility*, The Department of Business Administration, School of Business, Economics and Law, University of Gothenburg.
51. **Lindeberg, Fredrik (2019).** *Coordinating the Internet*, Licentiate Thesis, Department of Management and Engineering (IEI), Linköping University.
52. **Jonathan, Gideon Mekonnen (2020).** *Information Technology Alignment: The Role of Organisational Structure*, Licentiate Thesis, Department of Computer and Systems Sciences, Stockholm University.
53. **Hönel, Sebastian (2020).** *Efficient Automatic Change Detection in Software Maintenance and Evolutionary Processes*, Licentiate Thesis, Department of Computer Science and Media Technology, Linnaeus University.

54. **Van, Thi-Phuong (2022).** *Understanding Business Model Innovation From An Ecosystem Perspective: The Case of Electric Utility Industry*, Licentiate Thesis, Örebro University School of Business, Örebro University.
55. **Nopparat, Nanond (2022).** *Business models for the 3D food printing industry*, Licentiate Thesis, Department of Design Sciences, Lund University.
56. **Hamidi, Ali (2023).** *Systems Thinking Approach to Computational Thinking in Education*, Licentiate Thesis, Department of Informatics, Linnaeus University.
57. **Gharaie, Amirhossein (2025).** *Digitalizing consumer engagement within smart grids – Role of smart service providers*, Licentiate Thesis, Department of management and engineering, Linköping University.
58. **Rajaguru, Shashini (2026).** *Making Sense of Smart Electricity Meters - A Socio-Technical Perspective*. Licentiate Thesis, Department of management and engineering, Linköping University.
59. **Berglind, Magnus (2026).** *Assessing Sectoral Low-Carbon Transition Impacts - an assessment approach applied to the embedding of transition debt finance in Swedish commercial real estate*. Licentiate Thesis, Department of Business and Mathematics, Mälardalen University.



Contact person: Professor Christina Keller, Director of MIT, Uppsala University
christina.keller@im.uu.se

Address: The Swedish Research School of Management and
Information Technology, Department of Informatics and Media,
Uppsala University, Box 513, 751 20 Uppsala

Web site: www.mit.uu.se

ISBN 978-91-7485-751-1
ISSN 1651-9256

Address:

P.O. Box 883, SE-721 23 Västerås. Sweden
P.O. Box 325, SE-631 05 Eskilstuna. Sweden
E-mail: info@mdu.se **Web:** www.mdu.se

