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Business Models as Market Formation Devices

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Front cover: Mixed-media illustration by the author, symbolising the influence of business models on market formation.
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ABSTRACT

Many low-carbon technologies have reached technological maturity and cost competitiveness, yet their deployment remains insufficient to meet climate targets. A key explanation for this gap is slow market formation, defined as the process by which suppliers and buyers are enabled to exchange goods and services. Market formation is commonly conceptualised as unfolding through three sequential phases, each associated with distinct challenges related to technology, actors and networks, and institutions. Although cost competitiveness is often treated as a signal that markets are self-sustaining, many low-carbon technologies continue to face challenges even after technological maturity has been achieved. This ambiguity is problematic, as it risks premature withdrawal of policy support and firm strategies that are misaligned with actual market conditions.

Existing research has generated valuable insights into early market formation, but less is known about later phases. More specifically, while firms in the downstream value chain play a particularly central role in these phases by matching heterogeneous demand with technological solutions, the mechanisms through which they shape market formation remain underexplored. In particular, business models are widely acknowledged to configure how firms facilitate exchange between supply and demand, yet their roles in shaping market formation for low-carbon technologies remain insufficiently explained.

This thesis addresses this research gap by drawing on a literature review and three qualitative empirical studies of downstream firms in the Swedish solar photovoltaic market. The findings reveal that firms continue to face challenges spanning different phases of market formation even after technological maturity has been achieved. Contrary to previous assumptions, the thesis demonstrates that market formation phases overlap rather than unfold sequentially. Firms navigate these challenges through distinct business model approaches, with business models functioning as devices through which firms intentionally or unintentionally shape market formation. These findings underscore the critical role of downstream firms in market formation and highlight that managers should recognise the market-shaping potential of their business models. They also emphasise that business models can serve as important complements to policy instruments, underscoring the need for policymakers to create conditions that allow different business models to emerge to accelerate the deployment of low carbon technologies.

Keywords: market formation mechanisms, downstream firms, solar PV, technological innovation system, boundary spanning, value creation

List of Publications

This thesis is based on the work contained in the following papers:

Paper I

Mignon, I., & Bankel, A. (2023). Sustainable business models and innovation strategies to realize them: A review of 87 empirical cases. *Business Strategy and the Environment*, *32*(4), 1357-1372.

Paper II

Bankel, A. and Mignon, I. (2022). Solar business models from a firm perspective – an empirical study of the Swedish market. *Energy Policy, 166,* 113013.

Paper III

Bankel, A. and Govik, L. (2024). Networked business models on a nascent market for sustainable innovation. *Supply Chain Management: An International Journal, 29*(7), 97-111.

Paper IV

Bankel, A. and Mignon, I. (2026). How do new business models and their environment co-evolve? The importance of new entrant responses. *Manuscript under development for journal submission following two review rounds in Long Range Planning. An earlier version of the paper was presented at the Druid Conference, 13-15 June 2022, Copenhagen, Denmark, and at the Business Model Conference 22-23 June 2022, Lille, France.*

In loving memory of my grandparents, Margaretha and Kjell-Ove, lost along this journey.

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Amanda Bankel

Gothenburg, February 2026

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1. Introduction

Achieving net-zero emissions requires rapid and widespread deployment of low-carbon technologies to replace fossil-fuel-based alternatives and counter rising energy demand and growing greenhouse gas emissions (IEA, 2025a). After decades of development, many low-carbon technologies have now become technologically mature and cost competitive, yet their deployment remains insufficient to meet climate targets (Cervantes et al., 2023). Accelerating this net-zero transition requires deployment to increase both in speed and breadth (Andersen et al., 2023). A key explanation for this insufficient deployment is the slow progress in market formation for these technologies (Hyysalo et al., 2022).

Market formation refers to the opening up of a space in which suppliers and buyers can engage in the exchange of goods and services (Bergek, 2019). It encompasses processes such as articulating demand, establishing product categories, and enabling institutional change (Boon et al., 2022). Markets typically emerge through nursing, bridging, and mass-market phases (Bergek et al., 2008). Nursing markets are often small and uncertain, characterised by weak technological price-performance ratios and strong reliance on policy support (Andersson & Jacobsson, 2000). Bridging markets also depend on policy support, but they exhibit rapid market growth, production upscaling, increasing value chain specialisation and growing institutional alignment (Jacobsson & Bergek, 2004). In contrast, mass markets are comparatively stable and predictable, defined by competitive price-performance ratios, streamlined value chains, institutional alignment, and withdrawal of policy support (Markard, 2020).

When examining the current market status of mature low-carbon technologies such as solar photovoltaics (PV), however, it is not clear how far market formation has actually progressed. On the one hand, solar PV appears to have reached a mass-market phase, as suggested by its cost competitiveness, efficient manufacturing processes, slowed market growth and reduced policy support (IEA PVPS, 2025a). On the other hand, it still faces significant hurdles in terms of e.g., infrastructure buildup and institutional alignment (SolarPower Europe, 2025). Similar conflicting signals appear in markets for other mature low-carbon technologies such as wind turbines and electric vehicles (IEA, 2024a). This resulting ambiguity is problematic because it can lead policymakers and firms to assume that the market is more mature than it is and thereby withdraw support or adopt strategies that that fail to address the actual bottlenecks limiting technology deployment (Karneyeva & Wüstenhagen, 2017).

Research on market formation offers some insights into how different actors can address challenges hampering market formation, for instance by engaging in experimentation, promotion, information exchange, and lobbying (e.g., Lee et al., 2018; Ottosson et al., 2020). However, this literature has primarily concentrated on early phases of market formation (i.e., nursing and bridging phases), where policymakers, technology developers, and early adopters often constitute central actors (e.g., Dewald & Truffer, 2012; Jacobsson & Bergek, 2004). By contrast, less is known about how firms in the downstream value chain (e.g., consultants, project developers, installers, distributors) influence market formation, as they typically enter the market during later phases (Dewald & Truffer, 2011). These firms have been shown to significantly contribute to technology deployment by facilitating the matchmaking between technology suppliers and adopters (Bergek, 2020), which indicates a need for further research into their influence on market formation. This need is reinforced by growing evidence that achieving deployment levels in line with global climate goals requires substantial investment in low-carbon technologies from a wide range of private actors (IEA, 2024d, 2025b), including many with no prior experience in electricity production (Bergek et al., 2013). These investors form a heterogeneous group, including households, renters, cooperatives, local authorities, diversified firms, and professional investors, each with distinct needs, motives, and preferences (Bergek & Mignon, 2017; Lee et al., 2019). This heterogeneity underscores the need for effective matchmaking between investor characteristics and appropriate technology solutions and suppliers to support market growth (Aspeteg & Mignon, 2019).

One way in which firms can facilitate exchange between supply and demand is through their business models (Amit & Zott, 2001). Business models generally describe how firms “do business” by clarifying how they create, deliver, and capture value (Teece, 2010). Beyond this descriptive role, business models can function as devices that help transform technological features into marketable offerings that appeal to customers (Chesbrough & Rosenbloom, 2002). A device can be understood as “a piece of equipment or a mechanism designed to serve a special purpose or perform a special function” (Merriam-Webster, n.d.). In this sense, the rich body of research on business models has demonstrated that they can function as devices for multiple purposes. For instance, business models have been shown to create societal and environmental value by addressing underserved market segments and promoting resource efficiency (e.g., Lüdeke-Freund et al., 2018), to enable interorganisational communication and collaboration through boundary spanning activities (e.g., Doganova & Eyquem-Renault, 2009), and to stimulate sociotechnical transitions by helping to overcome deployment barriers and scale new technologies beyond their niche markets (e.g., Bidmon & Knab, 2018; Strupeit & Palm, 2016).

Given these developments, it becomes pertinent to ask whether business models can serve as devices for market formation. Some scholars appear to assume such a relationship, suggesting that market formation is fundamentally a business model function (Boons & Lüdeke-Freund, 2013). Yet these contributions stop short of explaining how business models and market formation are connected, leaving the mechanisms through which business models influence market formation largely unexplored. This lack of understanding is problematic given that policy-oriented scholarship calls for policymakers to support not only the development of low-carbon technologies, but also the business models through which they are commercialised (Johnson & Suskewicz, 2009; Sarasini & Linder, 2018). In the absence of a clearer account of how business models influence market formation, such policy recommendations risk resting on unexamined assumptions. As a result, policymakers and firms may design interventions and strategies that are poorly aligned with the actual challenges of market formation, potentially leading to ineffective policies or missed opportunities to stimulate markets and accelerate the deployment of low-carbon technologies.

1.1. Aim

Against this background, this thesis aims to explain the roles of business models in market formation for low-carbon technologies. It examines the case of solar PV in Sweden, focusing specifically on the business models of firms in the downstream value chain.

The thesis is structured as follows: Chapter 2 situates the work within the empirical context of the global solar PV market and the broader literature on market formation, and presents the research questions. Chapter 3 outlines the theoretical framework used to address these questions. Chapter 4 describes the research design and methodology, providing an overview of the conducted studies. Chapter 5 summarises the appended papers in relation to the research questions. Chapter 6 synthesises the findings in light of these questions, drawing connections across the papers. Chapter 7 discusses how the thesis responds to its overarching aim. Chapter 8 concludes by articulating the thesis's main contributions. Finally, Chapter 9 reflects on the practical implications of the findings and proposes directions for future research.

2. Situating the Research Problem in Its Empirical and Theoretical Context

This chapter situates the thesis within the empirical context of solar PV deployment and the literature on market formation. It first conceptualises solar PV as a low-carbon technology, then reviews market formation research with particular attention to phase characteristics, drawing on sustainability transitions, technological innovation systems, and innovation diffusion theories. The chapter subsequently examines the global solar PV market and highlights conflicting signals regarding its current stage of development. On this basis, two key research gaps are identified, motivating the research questions.

2.1. Low-Carbon Technologies

Although many of humanity's major historical advancements stem from new technologies, their benefits are only realised once people begin to use them(Rogers, 2003). This does not occur automatically, partly because technologies differ in characteristics such as complexity and the types of value they generate (Arthur, 2009).

Technological complexity is multifaceted, encompassing factors such as scale, design, customisation needs, and system embeddedness. Scale refers to differences in the physical and/or economic unit size of a technology, where more granular (i.e., smaller unit) technologies tend to be deployed more rapidly (Wilson, Grubler et al. 2020). Design complexity (i.e., the number of elements and the extent to which they interact) and customisation need (i.e., the degree to which the technology needs to be adapted to its use environment) influence the technical capabilities required to develop, produce, and use the technology (Malhotra & Schmidt, 2020). Technologies with complex designs and high customisation requirements typically demand advanced technical skills from both producers and users, which can slow down deployment. System embeddedness refers to the extent to which a technology must be integrated into existing sociotechnical systems, where highly embedded technologies often require substantial changes in infrastructural, institutional, and social arrangements, and therefore tend to diffuse more slowly (Grübler, 1991).

In addition to complexity, technologies differ in the value they generate and for whom. For a technology to be adopted, potential users must perceive it as offering advantages over existing alternatives (e.g., economic benefits, improved performance, social recognition), which vary across adopter groups (Rogers, 2003). Notably, adopters of low-carbon technologies are heterogenous with regard to their motives for acquiring these technologies (Bergek & Mignon, 2017; Lee et al., 2019). At the same time, for technologies to become available to users, firms must find it worthwhile to develop and commercialise them. Firms are unlikely to target specific market segments unless they can capture sufficient value from doing so (Teece & Linden, 2017). Such value is typically measured in economic terms (Chesbrough & Rosenbloom, 2002). Markets enable these values to be created by serving as arenas where buyers and sellers interact to exchange goods and services with the aim of maximising utility and profit (Diaz Ruiz, 2012).

Some technologies also generate value that serves the common good. Such societal value accrues beyond individual adopters and firms and includes benefits such as reduced pollution, improved public health, and mitigation of climate change (UN, 2025). Low carbon technologies exemplify this potential, as their use is associated with positive externalities in the form of lower greenhouse gas emissions (Lv and Qin 2016). However, these benefits are typically not fully reflected in market prices. As a result, technologies that generate high societal value may remain under-adopted, creating a rationale for policy interventions that support their deployment through instruments such as subsidies, regulations, or the provision of public goods(Gillingham & Sweeney, 2010). The underlying assumption behind these interventions is that the societal benefits of such technologies depend on their large-scale deployment.

At the same time, technologies that contribute to the common good may also generate negative externalities, particularly as deployment scales up. For low-carbon technologies, these can include extraction of rare earth minerals and land-use conflicts related to e.g., biodiversity conservation and indigenous land rights, which often only become fully visible once they are deployed at scale (Ertelt & Carlborg, 2024). These negative externalities highlight that the relationship between technology deployment and societal value is not unambiguously positive, reinforcing the importance of understanding how deployment can be achieved in more inclusive, democratic and context-sensitive ways (e.g., Robinson et al., 2025).

2.1.1. Solar PV as a Low-Carbon Technology

This thesis focuses on solar PV technology, a low-carbon technology used for electricity production (Lv & Qin, 2016). Other examples of low-carbon technologies include various renewable energy technologies, electric vehicles, energy efficiency technologies, and carbon capture, utilisation and storage (Cervantes et al., 2023). These technologies differ in complexity, with solar PV being among the least complex and therefore among the most likely to achieve rapid and widespread deployment (Malhotra & Schmidt, 2020).

Solar PV is a highly granular technology, characterised by small unit sizes (Wilson et al., 2020). It is also modular, allowing application across a wide range of scales, from small rooftop installations to large centralised solar parks (Burger et al., 2019). Moreover, solar PV is highly standardised, which reduces complexity in terms of both design and customisation, although complexity increases for large-scale applications (Malhotra & Schmidt, 2020). As a result, the level of technical skills required from producers and users is relatively low, enabling adoption across residential, commercial and industrial, and utility-scale segments (IEA PVPS, 2025b). Due to these characteristics, solar PV has long been expected to play a dominant role in future electricity systems once it becomes economically viable across these segments (Goodstein & Lovins, 2019). This threshold that has already been crossed in many parts of the world (IEA, 2024d).

Despite its low intrinsic complexity, solar PV is highly system embedded, as it is integrated with the electricity sector. Deployment requires access to existing infrastructures such as electricity grids, and may involve the development of new infrastructures, including smart grids (Rahmann & Alvarez, 2022). It is also shaped by a wide range of regulations related to grid access and management, building permits, and wholesale electricity markets (Banet & Donati, 2023; Pérez-Arriaga et al., 2017). This dependence on electricity markets means that solar PV must be competitive with established alternatives. Competitiveness is typically defined by achieving grid parity, where the cost of generating electricity is equal to or lower than the cost of purchasing electricity from the grid (Yang, 2010). The degree of system embeddedness varies across applications, where off-grid solar PV systems are relatively stand-alone, whereas large-scale solar PV parks require permits and coordination across multiple institutional levels (IEA PVPS, 2025b). As with many low-carbon technologies, the high system embeddedness of solar PV implies that widespread deployment can be constrained by existing social, infrastructural, and institutional arrangements.

As a low-carbon technology for electricity production, solar PV generates societal benefits by displacing electricity derived from fossil fuels (Lv & Qin, 2016). It also strengthens energy security by diversifying electricity supply and supports energy democracy by enabling households and communities to generate their own electricity and take a more active role in the energy transition (IEA PVPS, 2025b). At the same time, solar PV deployment can give rise to negative externalities. Like other low-carbon technologies, solar PV relies on the extraction of rare earth minerals and other critical materials, as well as associated energy use and waste generation (Ertelt & Carlborg, 2024). In addition, the development of large-scale solar PV parks have been associated with land-use conflicts, such as those related to indigenous land rights and food production security (IEA PVPS, 2025b).

Such issues underscore the need for policymakers to address both the positive and negative societal implications of solar PV in order to ensure that its widespread deployment is socially equitable and environmentally responsible (Sovacool et al., 2022). Some scholars argue that this requires policymakers to go beyond correcting market problems and actively create and shape markets toward addressing societal challenges such as climate change (e.g., Mazzucato, 2015). Regardless of the degree of intervention, achieving these aims requires a deep understanding of how markets form and evolve.

2.2. Market Formation

Before delving into the current status of the solar PV market, it is important to first establish a foundational understanding of what markets are and how they are formed. Historically, markets have been viewed as trade arenas where suppliers and buyers meet to exchange goods or services (e.g., Cournot, 1897). It is now widely acknowledged across multiple disciplines that markets are not merely places for exchange, but complex and dynamic systems that are shaped by a wide range of actors and their mental models, relationships, practices, formal and informal rules (Diaz Ruiz, 2012).

Market formation involves the opening up of a space where suppliers and buyers can engage in the exchange of goods and services, which encompasses subprocesses such as demand articulation, product positioning, and development of formal and informal rules (Bergek, 2019). Market formation constitutes a key function in the development of the innovation system surrounding a technology (Bergek et al., 2008; Hekkert et al., 2007). Such system includes the actors, networks, and institutions involved in the generation, diffusion, and utilisation of a technology (Carlsson & Stankiewicz, 1991). Technological innovation systems evolve through distinct stages, from formation to decline, with significant implications for how markets are formed (Markard, 2020).

2.2.1. *Market Formation Phases*

Market formation typically proceed over three distinct development phases: nursing, bridging, and mass-market (Bergek et al., 2008). These phases were initially defined by improvements in the technology's price-performance ratio (Andersson & Jacobsson, 2000), but were later broadened to various conditions that allow for different elements of the technological innovation system to fall in place (Jacobsson & Bergek, 2004). Factors that influence market formation are not isolated, but interrelated and mutually reinforcing (Dewald & Truffer, 2012).

In the *nursing phase*, the market is typically small, as the technology's initial price-performance characteristics tend to appeal only to a niche segment, being costly and typically outperforming alternatives in just one or a few dimensions (Andersson & Jacobsson, 2000). To shield emerging technologies from competitive pressures and provide learning spaces that allow for technical demonstration and demand articulation, these markets are often supported by policies such as subsidies (Jacobsson & Bergek, 2004). Other characteristics of the nursing phase include high uncertainty, variety in technological designs, limited value chain specialisation, formation of business networks and misalignment with existing institutions (Dewald & Truffer, 2012). The technology operates in relative isolation because the surrounding infrastructure is underdeveloped or misaligned, and complementary products or services are scarce (Negro et al., 2012). Accordingly, this phase is often said to nurse the technology through its "teething problems" (e.g., low efficiency or reliability) towards commercial viability (Erickson & Maitland, 1989).

The *bridging phase* is typically associated with technological developments that enable performance improvements and cost reductions which makes the technology attractive to a wider range of market segments (Andersson & Jacobsson, 2000). Consequently, this phase may involve the exploration of several bridging market segments, each associated with successive price-performance improvements on the path toward mass-market viability. Bridging markets are characterised by production upscaling and market growth which incentivise firms to enter various parts of the value chain (Jacobsson & Bergek, 2004). This expansion typically leads to increased competition, entry of professional capital investors, and value chain specialisation resulting in differentiation between upstream firms (e.g., technology developers and producers) and downstream firms (e.g., retailers and service providers) (Dewald & Truffer, 2011). In this phase, business networks also tend to formalise and technology-specific institutions emerge (Dewald & Truffer, 2012). Incumbent firms also typically start to get involved in the emerging market at this stage, either by actively resisting the new technology or by enabling its scaling through integration into existing product lines and production systems (Berggren et al., 2015). A dominant design often emerge at the end of this phase, stimulating market growth by reducing uncertainty as the system converges around a widely accepted technological standard (Markard, 2020). However, bridging markets continue to rely heavily on policy support (Dewald & Truffer, 2017) until they, at some point, reach a critical mass that causes a chain reaction of positive feedback loops enabling self-sustaining growth (Jacobsson & Bergek, 2004).

In the *mass-market phase*, the technology is able to compete with established alternatives and the market is considered self-sustaining, which is often seen as an indication that policy support is no longer necessary (Karneyeva & Wüstenhagen, 2017). This phase is characterised by high sales volumes, low market growth, institutional stability, low technological and market uncertainty, dominant designs, and incremental technology improvements (Markard, 2020).Value chains and networks are established and stable, and the market is often defined by competition between established players (Dewald & Truffer, 2012). The technology is legitimate and its associated products and applications are clearly defined (Markard, 2020).

In summary, market formation typically unfolds through three sequential phases, each characterised by distinct configurations of technology, actors and networks, and institutions, as illustrated in Table 1. These three categories can be understood as the dimensions of the "space" that market formation creates "for the elements in the technological system to fall in place" (Jacobsson & Bergek, 2004, p 820).

Table 1. Characteristics of market formation phases[1].

Dimension	Nursing market phase	Bridging market phase	Mass-market phase
Technology	Low price-performance. High uncertainty. Variety of competing designs. Absent and/or misaligned complementary assets.	Improved price-performance. Production upscaling. Emerging dominant design. Underdeveloped complementary assets.	Competitive price-performance. Established dominant design. Low uncertainty. Developed and aligned complementary assets.
Actors & Networks	Small market size. Niche segments. Pioneering firms dominate. Vertically integrated value chain. Informal network ties.	Rapid market growth. Expanding market segments. Incumbent firms enter or actively resist. High firm entry/exit rates. Division of labour. Networks formalise.	Large market size. Stabilised market growth. High competition between dominant players. Streamlined value chain. Highly formalised networks based on routine cooperation.
Institutions	Institutional misalignment. High uncertainty. Regulatory instability. Strong policy support. Low legitimacy.	Emergence of technology-specific institutions. Regulatory instability. Strong policy support. Increasing legitimacy.	Institutional alignment. Regulatory stability and predictability. Phased-out policy support. High legitimacy.

2.3. Current Status of the Solar PV Market

Global solar PV deployment has grown at an exponential rate over the past decade, driven largely by rapid technological cost reductions, manufacturing scale-up, and ambitious national decarbonisation commitments (IEA PVPS, 2025b). To assess the current market formation phase of solar PV, it is useful to first outline the structure of the broader market in which this development is taking place.

[1] A detailed discussion of the characteristics of each market formation phase, with particular emphasis on the associated challenges, will be presented in Chapter 3.

2.3.1. The Solar PV Market

For more than a decade, there has been a dominant design for solar PV, with crystalline silicon (c-Si) modules accounting for more than 95 percent of the global production in 2022 (IEA, 2022). Although a range of new solar PV applications has emerged (e.g., building-integrated, floating, thermal-hybrid, vehicle-integrated), the market remains primarily divided into centralised, distributed, and off-grid applications, with the grid-connected centralised and distributed applications accounting for nearly all global deployment (IEA PVPS, 2025b).

Centralised applications are predominantly large ground-mounted solar PV parks adopted by energy cooperatives, institutional investors, and corporate offtakers (i.e., large electricity buyers) (Lindahl et al., 2022). In contrast, distributed applications mainly comprise of roof-mounted solar PV systems adopted by homeowners, firms, farmers, municipalities, and associations (Lindahl & Öhgren, 2025). Reflecting this distinction, grid-connected solar PV is typically divided into three market segments based on end use: residential, commercial and industrial, and utility-scale, as shown in Table 2.

Table 2. Grid-connected solar PV market segments (based on Lindahl and Öhgren, 2025).

Application	**Market Segment**	**System Size**	**Primary Location**
Distributed	Residential	< 20 kW	Rooftop
	Commercial & Industrial	20-1000 kW	Rooftop
Centralised	Utility-scale	> 1 MW	Ground-mounted

Globally, distributed and centralised PV together account for roughly equal shares of installed capacity, though national support policies create significant differences in segment dominance across countries (IEA PVPS, 2025b). The Asia-Pacific region holds the largest share of cumulative installed capacity, with China alone representing approximately 46 percent of the global total in 2024 (IEA PVPS, 2025a). Europe is the second-largest region, led by Germany and Spain, while the Americas, driven primarily by the United States, constitute the third-largest share (SolarPower Europe, 2025).

The solar PV industry is characterised by a pronounced divide between the upstream and downstream segments of its value chain (Figure 1). The upstream segment encompasses technology development and manufacturing activities, whereas the downstream segment includes deployment-oriented activities such as project development, sales, installation, and operation and maintenance. The upstream value chain is highly concentrated, with China accounting for over 80 percent of global solar PV manufacturing in 2022 and dominating the production of many critical minerals needed for solar PV (IEA, 2022). Since 2023, the solar PV industry has also faced substantial manufacturing overcapacity, which has intensified price competition and accelerated consolidation among upstream firms (IEA PVPS, 2025a). This concentration creates significant vulnerabilities, exposing the industry to bankruptcy risks and trade policy disruptions that can lead to supply shortages and cost increases (IEA, 2022).

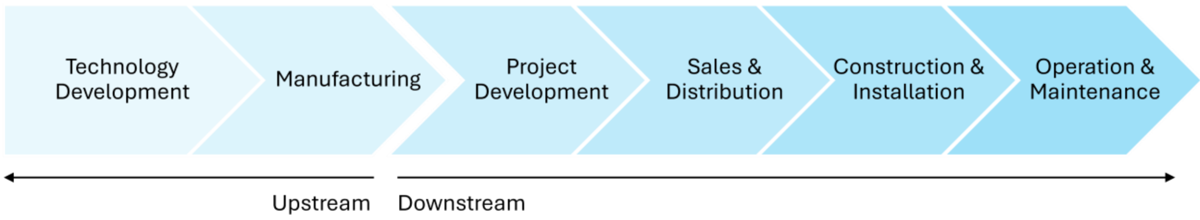

Figure 1. The solar PV value chain.

In contrast, the downstream value chain is highly fragmented and strongly shaped by national market conditions (e.g., Strupeit & Palm, 2016). The utility-scale segment is relatively consolidated, dominated by professional, capital-intensive developers and contractors that often operate at national or international scale (IEA PVPS, 2025b). The large scale and ground-mounted characteristics of their projects means that they are typically highly dependent on national tender designs, electricity-grid planning and permitting, as well as environmental and land-use regulations (IEA PVPS, 2024). Distributed segments, by contrast, are highly fragmented and dominated by small and medium-sized enterprises and local installers (IEA PVPS, 2025b). As a result, they are strongly influenced by retail electricity prices, self-consumption incentives, and local permitting policies (IEA PVPS, 2024).

Institutional frameworks for solar PV are largely designed and implemented at the national level (IEA PVPS, 2025b). Since the late 1990s, a range of direct policy support mechanisms, such as feed-in tariffs, direct subsidies, and tax credits, have been introduced to enhance the cost competitiveness of solar PV (IEA PVPS, 2024). As solar PV costs have fallen rapidly in recent years and competitiveness is no longer a major issue in many countries, policy support has increasingly shifted toward instruments such as competitive tenders and self-consumption incentives, with some support schemes being phased out entirely (IEA PVPS, 2025b). These national policy differences have produced distinct market conditions, influencing, for example, the dominant industry actors and the prevalence of particular business model types (Strupeit & Palm, 2016).

Solar PV deployment has also been influenced by various indirect policies, including mandatory solar PV installation on newbuilds, electricity market reforms, and improved grid access for prosumers (IEA PVPS, 2025b). Regarding informal institutional conditions (e.g., norms and values), solar PV generally enjoys broad social acceptance, even compared to other low-carbon technologies (Batel, 2020). However, as deployment expands, signs of declining acceptance have emerged, particularly for utility-scale installations (Cousse, 2021). These developments have led to public backlash and organised resistance in some communities, despite the overall positive societal attitude toward solar PV (IEA PVPS, 2024).

2.3.2. Market Formation Phase of Solar PV

The global solar PV market has experienced exponential growth over the past decade, making it the fastest-growing renewable energy technology by 2024 (IEA, 2025b). This growth has mainly been driven by strong policy support and declining costs of solar PV modules. Simultaneously, solar PV is widely recognised as a key technology in strategies addressing climate change and energy security (SolarPower Europe, 2025). This rapid deployment and significant contribution to limiting climate change have made solar PV an interesting case for research on market formation and technological innovation system growth. For example, Andersson and Jacobsson (2000) identify satellites as the first nursing market for solar PV in the 1960s, followed by consumer electronics and off-grid electricity production. In contrast, Dewald and Truffer (2011) consider the first attempts at on-grid applications in the 1980s as the starting point of the nursing phase of solar PV in Germany. These divergent interpretations reflect how differences in spatial context and technological application influence how markets are delineated, underscoring the importance of considering boundary conditions when analysing market formation.

When examining the current state of the solar PV market, a few phase-specific patterns related to technology, actors and networks, and institutions can be discerned. The low prices and long-term dominance of crystalline silicon (c-Si) modules have made solar PV cost competitive without subsidies in many parts of the world (IEA PVPS, 2025a). These developments suggest that the solar PV market has reached the mass-market phase. This evidence is further supported by trends such as intense competition between manufacturers (IEA PVPS, 2024), withdrawal of policy support in many countries, and slower projected market growth for the coming years (SolarPower Europe, 2025).

At the same time, solar electricity accounted for only about 10 percent of global consumption in 2024 (IEA PVPS, 2025b). Current deployment levels remain far below their full potential to make solar PV the largest source of electricity worldwide within the next decade and, more critically, fall short of what is needed to meet global climate goals (SolarPower Europe, 2025). The market is facing a range of challenges that are typically associated with the bridging phase. For instance, the rapid deployment of solar PV has led to significant issues related to grid integration and curtailment in several countries, requiring expansion of the grid infrastructure and complementary energy storage solutions (IEA PVPS, 2025a). The solar PV value chain does not display the stabilised patterns expected in a mass-market phase, as evidenced by continued need for developing a skilled workforce (SolarPower Europe, 2025), and bankruptcies in the upstream value chain risking supply shortages (IEA, 2022). Furthermore, institutional misalignments continue to hamper deployment. In many countries, permitting and grid-connection procedures remain significant bottlenecks for solar PV deployment, while renewed political support for fossil fuels contributes to an environment of uncertainty and volatility in the solar PV market (SolarPower Europe, 2025). These developments diverge sharply from the stability and self-sustaining momentum typical of the mass-market phase, aligning more closely with the dynamics of the bridging phase.

Taken together, these characteristics suggest that the current state of the solar PV market is not entirely consistent with a particular market formation phase, rather it seems to be situated somewhere in between the bridging and mass-market phase. On the one hand, many of the focal technological developments point to market maturation (e.g., dominant design, production efficiency, cost-competitiveness). On the other hand, several other elements of the technological innovation system appear to be in flux (e.g., infrastructural integration, industry shakeout, and institutional misalignment). This coexistence of market formation traits is problematic for both policy and strategy design. For instance, interventions tailored to bridging markets(e.g. sizable subsidies) are increasingly misdirected if applied in a phase where cost-competitiveness has already been achieved, as illustrated by the negative public reaction in Dewald and Truffer (2011). Conversely, assuming that the market is fully self-sustained once the technology is cost-competitive risks overlooking broader systemic challenges hindering deployment (Karneyeva & Wüstenhagen, 2017). To fully explain the current state of the solar PV market, there might therefore be a need to zoom in at the intersection of the bridging and mass-market phases to better understand how market formation shifts unfold.

Focusing on this particular period in the market formation process is important to clarify which elements of the technological innovation system have stabilised and which still require support to develop. Otherwise, policies or strategies risk being inefficient or even counterproductive in their attempts to stimulate market formation. Given the urgent need to accelerate deployment of low-carbon technologies like solar PV (IEA, 2024d), it is crucial to understand the unique characteristics of the market during the shift from bridging to mass-market, especially in terms of the challenges that are currently hampering the market formation progression and the mechanisms for overcoming them. Previous research on market formation and large-scale (i.e., mass market) diffusion of low-carbon technologies provide insights into the challenges that these technologies face in different phases (e.g., Jacobsson & Bergek, 2004; Mignon & Bergek, 2016). However, the order in which these unfold remains unclear, as does the extent to which they hamper the deployment of solar PV.

Recent research has advanced the understanding of different mechanisms that can induce market formation by examining the underlying processes that drive market formation across the different phases (Boon et al., 2022; e.g., Dewald & Truffer, 2012), as well as various strategies that firms use to shape market formation (e.g., Lee et al., 2018; Planko et al., 2017). Yet, these studies mainly focus on early phases of market formation and less is known about which mechanisms are central for later phases. In particular, more research is needed to understand how actors navigate challenges preventing acceleration of transitions (Markard et al., 2020).

In parallel with the advancement of research on market formation mechanisms, research on large-scale diffusion of low-carbon technologies has focused on the role of business models in overcoming various deployment challenges (e.g., Drury et al., 2012; Strupeit & Palm, 2016). For example, the use of new business models for solar PV have been found to attract underserved market segments, address challenges related to upfront investment cost, and enable investment in solar PV from community groups (e.g., Horváth & Szabó, 2018; O'Shaughnessy et al., 2021). The broader sustainability transitions research has also highlighted that business models can support new technologies to scale beyond their niche markets (e.g., Bidmon & Knab, 2018) and that firms use their business models to navigate threats and opportunities posed by their sociotechnical systems (e.g., Thomson et al., 2025; Wesseling et al., 2020). These insights underscores that the ways in which firms employ and adapt their business models can lead to impacts that stretch far beyond their organisational boundaries (Aagaard et al., 2021). In turn, these findings raise the question whether business models can serve as mechanisms for navigating market formation challenges, even though they have not been treated as such in past research.

2.4. Research Questions

Against this background and in line with the aim to explain the roles of business models in market formation for low-carbon technologies, the following research questions have been formulated:

RQ1: What challenges do firms face during market formation of low-carbon technologies?

RQ2: How do firms navigate market formation challenges through their business models?

By examining the challenges that occur in the shift between the bridging and mass-market phase and investigating the use of business models as a specific market formation mechanism to navigate these challenges, the thesis can offer critical insights into the broader process of market formation. Specifically, it can contribute to the understanding of how firms shape market formation, and whether the current framework of nursing, bridging, and mass-market phases can explain the dynamics of low-carbon technology markets, like that of solar PV.

3. Theoretical Framework

This chapter develops the theoretical framework that provides the basis for answering the thesis' research questions. It begins by outlining current understandings of the challenges that arise across different phases of market formation, drawing on scholarship in technological innovation systems, sustainability transitions, and innovation diffusion. It then examines the mechanisms through which these challenges may be addressed, focusing on the underlying processes and firm-level strategies that shape market formation. Particular attention is given to business models as a potential market formation mechanism, informed by research on their performative roles across multiple academic disciplines. Finally, these insights are brought together in an integrative framework.

3.1. Market Formation Challenges

The creation and evolution of markets have been examined across several research traditions, including evolutionary economics of innovation, sociology of markets, marketing, and sustainability transitions studies (Boon et al., 2022). Within this broad body of work, the concept of market formation has gained particular prominence in the technological innovation systems literature, where it is understood as a key system function shaping the emergence and growth of new technologies (Hekkert et al., 2007; Jacobsson & Bergek, 2004). Although the technological innovation systems approach constitutes a distinct theoretical framework, it has become one of the key analytical tools within sustainability transitions research (Köhler et al., 2019). At the same time, the wider transitions scholarship offers complementary perspectives on market formation by foregrounding how power relations and political contestation influence the creation and expansion of markets for low-carbon technologies (e.g., Kanger et al., 2019; Kemp et al., 1998).

Much of this research has been devoted to identifying challenges that hamper market formation (e.g., Boon et al., 2022; Jacobsson & Bergek, 2004). However, these studies have predominantly examined the early phases of market formation (i.e., nursing and bridging phases), while challenges associated with the emergence of mass markets have received comparatively limited attention. Insights from innovation diffusion research can help address this gap, as this field has a long tradition of analysing challenges associated with the deployment of more mature technologies (e.g., Rogers, 2003). These studies mainly emphasise the importance of adopter characteristics, but also contextual factors like spatial, social, cultural and political characteristics (Grübler, 1996; Peres et al., 2010; Wejnert, 2002).

Accordingly, this thesis draws on three complementary theoretical lenses to conceptualise market formation for low-carbon technologies. It builds primarily on technological innovation systems research, while incorporating insights from broader sustainability transitions scholarship and innovation diffusion research, as shown in Figure 2.

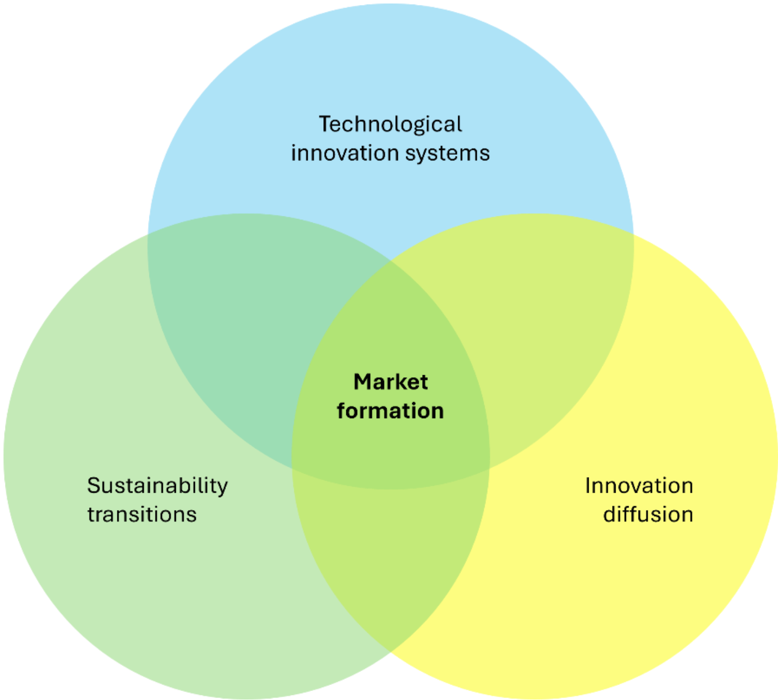

Figure 2. Conceptual perspectives on market formation.

As outlined in Section 2.2.1, market formation is commonly understood as unfolding over three consecutive phases (nursing bridging, and mass-market), each characterised by distinct configurations and challenges across three overarching dimensions: technology, actors and networks, and institutions. These dimensions correspond to the elements of a technological innovation system that gradually "fall into place" as market formation progresses (Jacobsson & Bergek, 2004). In this sense, market formation reflects a sequential build-up of technological innovation system elements that becomes progressively structured (Markard, 2020), a process that also gives rise to a range of phase-specific challenges.

Technological challenges mainly relate to limitations in the development of the focal technology. These include high technological uncertainty and risk, low performance, high cost, and access to natural resources which restrict the competitiveness of the technology with established alternatives (Andersson & Jacobsson, 2000). Technological challenges also include limitations in the development of complementary assets such as infrastructure, technologies, products and services, as well as their linkages with the focal technology (Jacobsson & Bergek, 2004).

Actor and network challenges include issues within and between actors on the supply and demand side of the technology. Such challenges can relate to problems associated with the individual resources and behaviours of both adopters and firms, such as unarticulated user demands, limited access to capital, and incumbent opposition or dominance (Apajalahti et al., 2018; Boon et al., 2022; Mignon & Bergek, 2016). Too weak or too strong connectivity between network actors can also cause problems, as the former may hinder learning and coordination while the latter risks leading to strategic conformity (Negro et al., 2012). Additional challenges include risks associated with firm entries and exits and supply chain gaps (Jacobsson & Bergek, 2004).

Institutional challenges relate to obstacles caused by formal (e.g., policies, rules, regulations) and informal institutional arrangements (e.g., norms, values). Such challenges include institutional misalignment such as incumbent-friendly regulations, lack of standards, incoherence between policies, or absence of legitimacy (Jacobsson & Bergek, 2004). They may also relate to high regulatory uncertainty caused by e.g., lack of long-term goals or policy instability (Negro et al., 2012).

The following subsections introduce the challenges identified in previous research on market formation across the nursing, bridging, and mass-market phases, with particular attention to the three dimensions outlined above.

3.1.1. Nursing Market Challenges

As the earliest phase of market formation, the nursing market is characterised by high uncertainty and significant challenges related to all elements of the technological innovation system (Jacobsson & Bergek, 2004). The technology is immature and costly (Andersson & Jacobsson, 2000), necessary complementarities are missing (Negro et al., 2012), potential users are unaware or unconvinced by the technology (Bergek et al., 2008), suppliers and networks are typically few and weak (Jacobsson & Bergek, 2004), and institutions tend to impede rather than enable the development of the nursing market (Kemp et al., 1998). As such, many of the challenges that must be overcome in the nursing phase concern the development of the technology and the initial formation of its surrounding innovation system.

In terms of *technological challenges*, it is important to recognise that one of the main objectives of the nursing phase is to provide a learning space for technology development (Erickson & Maitland, 1989). As such, this phase is associated with high technological uncertainty as a variety of technology designs and applications are experimented with (Bergek et al., 2008). This technological uncertainty is problematic as it often deters suppliers and adopters from entering the market. For instance, suppliers may struggle to select among various competing designs, while adopters hesitate to acquire a technology that has yet to be proven effective (Jacobsson & Bergek, 2004). Furthermore, the technology is characterised by limited performance and high costs in comparison to established alternatives, restricting its appeal to only a small segment of the market (Andersson & Jacobsson, 2000). In the nursing phase, market formation is also typically impeded by the absence or high cost of complementary assets, such as charging infrastructure for battery electric vehicles (Kemp et al., 1998).

Regarding *actor and network challenges*, the nursing phase is characterised by significant information asymmetries between suppliers and potential users (Boon et al., 2022). Neither suppliers nor potential users may know how the technology can meet user needs, and so the formation of a nursing market is often necessary to enable these actors to learn from each other (Bergek et al., 2008). However, such learnings are often difficult to achieve. Unarticulated demands pose significant challenges for firms to identify an initial market as well as to adjust their offerings to meet potential user needs (Jacobsson & Bergek, 2004). Users also need to domesticate the technology, which may require alterations in their demands and practises – something that only a limited number of users might be willing to undertake at this early stage (Kemp et al., 1998). Furthermore, the nursing market is typically too small and risky to attract incumbent firms and downstream specialists, leaving less resourceful pioneering firms to manage the entire value chain (Dewald & Truffer, 2012). Such lack of specialisation and economies of scale lead to higher costs and overall inefficiency in the value chain. Suppliers may face difficulties in mobilising sufficient capital for commercialisation, since they must either make substantial investments themselves or secure private investors willing to commit to high-risk options (Karltorp, 2016). In the nursing phase, new networks typically start to form, creating initial linkages between actors that facilitate the collective efforts required for market formation (Dewald & Truffer, 2012). This emergent nature means that connectivity between network actors is often weak, resulting in missed opportunities for cooperation and collective lobbying (Negro et al., 2012). Consequently, technology proponents struggle to build legitimacy and advocate for the regulatory changes that are often prerequisites for markets to form (Bergek et al., 2008).

In terms of *institutional challenges*, both formal and informal institutions often constitute barriers for initial market formation (Jacobsson & Bergek, 2004). Formal institutions such as regulatory frameworks and policies typically favour established technologies and therefore inadvertently disadvantage new technologies, even when targeted policy supports are in place (Kemp et al., 1998). Moreover, nursing markets often lack technology-specific institutions, such as standards, which lead to market fragmentation (Bergek et al., 2008). Such fragmentation reinforces technological uncertainty and isolation of learning processes, thereby undermining the knowledge sharing that the nursing phase is intended to foster. Regarding informal institutions, the absence of legitimacy for new technologies often constitutes a barrier to market formation in nursing markets (Jacobsson & Bergek, 2004). This absence means that society has not yet accepted these technologies. Potential adopters evaluate new technologies against prevailing societal norms and values, and if misaligned, they are often met with scepticism (Kemp et al., 1998). Moreover, new technologies are not only assessed in relation to established institutions but also through the narratives employed to justify their growth (Ottosson et al., 2020). Accordingly, a key challenge in the nursing phase concerns the establishment of legitimate market boundaries (Boon et al., 2022). For instance, proponents of new low-carbon technologies often have to frame them in terms of their broader societal values to gain normative approval. Importantly, building legitimacy requires considerable time and the conscious efforts of various market actors, leaving nursing markets inherently fragile until such legitimacy is established (Bergek et al., 2008).

3.1.2. Bridging Market Challenges

The bridging phase represents a period of market take-off, but with that growth also come new challenges with upscaling (Jacobsson & Bergek, 2004). These challenges encompass financial risks linked to technology characteristics (Iyer et al., 2015), insufficient scaling of complementary assets (Markard et al., 2020), the enrolment of mainstream investors and adopters (Mignon & Bergek, 2016), maintaining and increasing legitimacy in the face of industry turbulence and societal contestation (Kanger et al., 2019), and the alignment of formal institutions (Negro et al., 2012). As such, the bridging phase does not simply provide market spaces that allow for the gradual development of various elements of the technological innovation system, it is a period marked by conflict and coordination challenges.

In terms of *technological challenge*s, significant improvements in price-performance has enabled a broader market appeal, yet the uncertainty associated with the existence of multiple competing technology design remains an impediment to further market growth (Andersson & Jacobsson, 2000). For instance, uncertainty over which design will ultimately become the industry standard may cause both suppliers and adopters to hesitate in committing, as they fear investing in the wrong technology. A dominant design typically emerges at the end of the bridging phase, reducing both technological variation and uncertainty (Markard, 2020). Even after a dominant design has been established, it is not uncommon for technological challenges to persist. For instance, many low-carbon technologies require substantial upfront investment and face risks associated with fluctuations in electricity prices, which can undermine their revenue potential (Iyer et al., 2015; Mignon & Bergek, 2016). These economic challenges typically become visible at the end of the bridging phase, once more fundamental barriers have been addressed. Another challenge that becomes more apparent once the focal technology starts to take off, is to ensure that complementary assets (e.g., infrastructure, technologies, products, and services) scale up rapidly enough to match its growth (Bergek et al., 2008). Without such alignment, these complementary assets risk becoming bottlenecks that constrain the overall market growth (Markard et al., 2020). Thus, scaling the complementary assets around the technology can be as important as scaling the technology itself in the bridging phase.

Many of the previous *challenges related to actors and networks* have been resolved in the bridging phase as the technological improvements and initial market success attract more suppliers and adopters to the market (Bergek et al., 2008). However, the rapid market growth and associated upscaling introduce new challenges. On the one hand, it encourages firm entry across the value chain, leading to specialisation and increased efficiency that enables growth (Jacobsson & Bergek, 2004). On the other hand, it may attract opportunistic new entrants that lack the necessary skills and experience, resulting in quality issues which risks undermining the credibility of the entire industry (Kangas et al., 2018). It might also attract attention from incumbent firms who may respond defensively if perceiving the technology as a threat, for instance by influencing institutions or restricting access to existing infrastructure (Negro et al., 2012). The rapid market growth also places new demands on suppliers to secure substantial capital for scaling up production. While some suppliers may have been able to finance parts of commercialisation during the nursing phase, the scale of investment required in the bridging phase typically necessitates external funding from mainstream investors (e.g., banks, pension funds), who tend to be risk-averse (Karltorp, 2016). Securing such investments is often a major challenge, as the market (though growing) is not yet perceived as sufficiently stable or safe among mainstream investors (Mignon & Bergek, 2016).

Besides struggles to enrol investors, the bridging phase also brings new challenges related to actor networks. In general, bridging markets are associated with the strengthening and formalisation of networks, which is beneficial for market formation as it broadens their reach and influence over market actors and institutions (Dewald & Truffer, 2012). However, too strong connectivity between firms can also be problematic at this stage, as it may lead to strategic conformity in technology or market choices, leaving the network exposed to uncertainty (Jacobsson & Bergek, 2004). This risk is especially pronounced before a dominant design has emerged, when technological pathways remain highly uncertain. With regard to adopters, bridging markets expand beyond the initial segments of nursing-phase enthusiasts to include early adopters who are willing to accept certain inconveniences or risks in exchange for the benefits of the new technology (Rogers, 2003). A central challenge, however, lies in engaging the broader mass of potential adopters, many of whom may be reluctant to alter established habits or preferences to accommodate the new technology (Markard et al., 2020). If left unaddressed, this reluctance can constrain market growth and hinder progression toward the mass-market phase. Moreover, Mignon and Bergek (2016) emphasise that the high firm exit rates typically observed as competition intensifies at the end of the bridging phase pose significant risks for adopters, potentially deterring them from committing to the technology. Specifically, they found that high firm exit rates limited opportunities for potential adopters to benefit from peer recommendations and guarantees, thereby weakening confidence in the reliability of the industry.

Institutional challenges play a decisive role in the bridging phase, where policy support (e.g., subsidies) often act as a catalyst for market expansion (Jacobsson & Bergek, 2004). However, such growth may also trigger societal and political backlash that constrain further market development (Kanger et al., 2019). When technologies lack broad legitimacy, rapid expansion driven by policy incentives can provoke public opposition and lead to sudden policy reversals (Markard et al., 2016). In turn, such dynamics may produce boom-and-bust cycles that further erodes the legitimacy of the technology (Dewald & Truffer, 2011). Institutional volatility thus represents a critical challenge in bridging markets, as heightened institutional uncertainty and risk can discourage market actors from committing to technology investments (Negro et al., 2012). Formal institutional misalignment also constitutes a major challenge in the bridging phase, though its manifestation differs from that observed during the nursing phase. In the nursing phase, misalignment primarily stems from the absence of technology-specific institutions and from regulatory frameworks favouring established alternatives (Bergek et al., 2008; Kemp et al., 1998). In contrast, in the bridging phase, technology-specific institutions like standards and regulations typically emerge (Markard, 2020). Here, market growth is instead more often hampered by poor coordination between policies, both horizontally (e.g., across sectors) and vertically (e.g., across international, national, and local levels) (Markard et al., 2020). Such misalignment is problematic because it produces contradictory signals that confuse market actors (Jacobsson & Bergek, 2004). Moreover, the emergence of technology-specific institutions is often accompanied by contestation in the form of intense debates and political struggles guided by the agendas of various interest groups (Kanger et al., 2019). These patterns underscore how the bridging phase is inherently marked by conflict and negotiation over the rules governing market exchanges (Markard et al., 2020).

3.1.3. Mass-Market Challenges

The mass market constitutes the final phase of market formation (Jacobsson & Bergek, 2004). At this stage, the technology has matured into a commodity, with competitive price-performance and largely self-sustaining development (Andersson & Jacobsson, 2000). As a result, the focus shifts away from learning and upscaling towards ensuring widespread deployment (Bergek, 2019), supported primarily by incremental technological improvements rather than fundamental innovation (Markard, 2020). While challenges from the bridging phase may persist into the early mass market (Hyysalo et al., 2022), this phase also faces distinct challenges related to large-scale deployment, including securing critical resources (Andersson & Jacobsson, 2000), managing recycling and waste (Atasu et al., 2021), navigating incumbent involvement (Apajalahti et al., 2018), addressing heterogeneous adopter needs (Mignon & Bergek, 2016), and ensuring equitable access (Sovacool et al., 2022). These issues highlight how the negative externalities of low-carbon technologies (e.g., resource extraction, end-of-life responsibility, equity concerns) becomes increasingly apparent as deployment scales up (Ertelt & Carlborg, 2024). As the market further stabilises, challenges increasingly relate to inertia and path dependence, signalling that the market has moved beyond its formative phases (Markard, 2020).

Although mass-market development is largely driven by its own momentum, this phase is not free from *technological challenges* hampering market formation. Notably, economic challenges such as revenue risks from fluctuating electricity prices may persist beyond the bridging phase, accompanied by bottlenecks in complementary assets that limit capacity to manage the high volumes needed for mass-market technology deployment (Karneyeva & Wüstenhagen, 2017). In particular, significant infrastructure expansion may be necessary and typically requires policy support and investment, as illustrated by the historical example of public road construction, which proved essential for the widespread use of automobiles (Kanger et al., 2019). Furthermore, ensuring a stable supply of critical natural resources to accommodate the mass-market scale may become an issue (Andersson & Jacobsson, 2000). Importantly, the negative externalities of low-carbon technologies, such as resource depletion and waste, only become truly apparent when technology deployment reaches a large scale (Ertelt & Carlborg, 2024). These developments introduce new challenges related to technology re-optimisation, recycling, and waste management, especially in terms of who should bear the costs of such efforts (Atasu et al., 2021).

Regarding *actor and network challenges*, gaps in the value chain may persist initially during the mass-market phase. For instance, Hyysalo et al. (2022) found that market formation was hampered by the lack of actors who could match adopters with appropriate suppliers and integrated solutions (e.g. consultancy firms), despite the technology already being cost-competitive. The competitiveness of the new technology also makes it a real threat to incumbent firms who might intensify their opposition to its deployment (Markard et al., 2020). For instance, they might improve the price-performance of their established technology, effectively delaying widespread market expansion of the new one (Markard, 2020). Alternatively, an increasing number of incumbents may embrace the new technology as it has become a viable option at this stage, and use their established positions to promote it (Saleh, 2025). This engagement might also lead them to steer market trajectories in directions that favour their existing businesses (Altunay et al., 2021). Such incumbent involvement can be problematic as it risks reinforcing existing market and power structures and prevent more radical shifts that could benefit society as a whole (Apajalahti et al., 2018). In the mass-market phase, actor-level challenges become more prominent as many structural and functional misalignments in the technological innovation system are resolved (Mignon, 2016). These challenges arise from limitations in adopters' resources, capabilities, or behaviours, as extensively discussed in innovation diffusion research (Rogers, 2003). For example, adopters vary in their ability, willingness, and approach to acquiring new technologies due to differences in e.g., knowledge and capital (Mignon & Bergek, 2016). Importantly, mainstream adopters exhibit distinct characteristics, needs, and motives for investing in low-carbon technologies (Bergek & Mignon, 2017; Vibrans et al., 2023). This heterogeneity requires addressing multiple actor-level challenges to enable adoption across the various segments of the mass market.

In terms of *institutional challenges*, the cost-competitiveness of the new technology often means that supportive policies are being phased out at the beginning of the mass-market phase. Such policy withdrawals can lead to significant uncertainty and risk regarding how such changes will impact the return on investment for the technology, which hampers further market expansion (Karneyeva & Wüstenhagen, 2017). Continued policy support might therefore be needed to stimulate market formation even after the technology has matured (Hyysalo et al., 2022). While some institutional challenges from the bridging phase might linger into the early mass market, the intensity of contestation and political struggles have typically reduced at this stage (Kanger et al., 2019). Market actors and networks are increasingly seen as legitimate, and the technology is often widely known and taken for granted (Markard, 2020). However, alongside growing social acceptance and increased visibility, new challenges emerge. For low-carbon technologies in particular, concerns related to fairness and equitable access become increasingly salient (Ertelt & Carlborg, 2024). For example, wealthier households may benefit disproportionately from adopting rooftop solar PV through reduced energy bills, while lower-income households or renters are often excluded due to financial constraints or lack of access to suitable properties (Andreas et al., 2018). At the same time, the heightened visibility and spatial presence of these technologies tend to generate local contestation over who should bear the associated burdens (e.g., visual impact, land use, landscape transformation) (Cousse, 2021). Addressing these challenges often calls for policy intervention to mitigate demographic and spatial inequalities in technology deployment (Sovacool et al., 2022).

3.1.4. Overview of Market Formation Challenges

The preceding sections demonstrate that the nursing, bridging, and mass-market phases are not merely sequential stages but dynamic arenas where distinct challenges emerge, as shown in Table 3. While each phase is characterised by specific challenges linked to the gradual establishment of the technological innovation system, the boundaries between phases are not always clear. This ambiguity is particularly evident in the shift from the bridging to mass-market phase. For instance, the bridging phase initially revolves around uncertainty regarding dominant designs (Markard, 2020), whereas later stages are dominated by challenges of scaling complementary assets and securing mainstream investment (Karltorp, 2016; Markard et al., 2020). Similarly, the mass-market phase begins with residual gaps in the value chain (e.g., lack of matchmaking actors) (Hyysalo et al., 2022), before shifting toward more mature issues such as resource constraints and waste management (Atasu et al., 2021). These variations suggest that the shifts between market formation phases need to be examined more closely, as limited attention to transitional dynamics complicates decisions about when and how policy support can be adjusted without undermining ongoing market formation processes.

Table 3. Overview of challenges across market formation phases.

Challenges	Nursing phase	Bridging phase	Mass-market phase
Technology	Low price-performance. High uncertainty. Variety of competing designs. Absent and/or misaligned complementary assets.	High uncertainty until dominant design emerges. High financial risks. Underdeveloped complementary assets.	Need for expansion of complementary assets. Resource supply issues. Recycling responsibility gap.
Actors & Networks	Lack of specialisation. Information asymmetries. Unarticulated demands. Weak network ties. Limited investor interest.	Entry of unskilled firms. Incumbent resistance. Industry shakeout risks. Need for external funding from risk-averse investors. Strong network ties increase vulnerability to uncertainty.	Heterogeneity of adopter-specific challenges. Remaining value chain gaps. Intensified incumbent resistance or attempts to steer market towards their existing businesses.
Institutions	Institutional misalignment. High uncertainty. Regulatory instability. Low legitimacy.	Contestation, public backlash and political struggle. Policy misalignment. Regulatory instability.	Policy phase-out risks. Equity concerns as the technology becomes legitimate.

Focusing more closely on this shift allows attention to be directed toward which elements of the technological innovation system have stabilised and which remain in flux as markets mature. Such an approach would not only enhance theoretical precision but also improve the diagnostic capacity of policymakers and firms. When challenges display conflicting patterns, interventions risk being misaligned with actual market conditions. For example, premature withdrawal of policy support based on cost-competitiveness alone may ignore persistent bridging-phase risks such as institutional volatility or investor hesitancy (e.g., Karneyeva & Wüstenhagen, 2017). Conversely, assuming that technological uncertainty has been resolved may lead firms and their networks to commit prematurely to particular designs before a dominant standard has emerged, thereby increasing market risk (e.g., Jacobsson & Bergek, 2004).

The urgency of this issue is amplified by the pressing need to accelerate low-carbon technology deployment to meet climate targets (Cervantes et al., 2023). Slow market formation remains a major barrier for mature low-carbon technologies (Hyysalo et al., 2022), and misdiagnosis of market maturity can exacerbate this problem. Many mature low-carbon technologies are perceived as being mass-market ready due to being cost-competitive, yet they continue to face bridging-phase challenges, including policy coordination barriers and underdeveloped complementary assets (IEA, 2024a). This misalignment between perceived and actual market conditions calls for a more granular understanding of when and why specific challenges occur. These challenges are not isolated; they are interrelated and mutually reinforcing (Dewald & Truffer, 2012). As such, they cannot be addressed in isolation; rather, they need to be understood in relation to the broader market formation phase in which they occur to design effective interventions.

Moreover, an interesting pattern in the evolution of these challenges is the increasing emphasis on actor-level challenges as market formation progresses (Mignon, 2016). This shift is perhaps not surprising given that many structural elements of the technological innovation system gradually fall into place as markets mature (Jacobsson & Bergek, 2004), thereby reducing system-level bottlenecks. Yet, recognising the nature and timing of these challenges remains critical for understanding how they can be effectively addressed. Research on large-scale technology diffusion highlights that successful deployment requires attention to both system-level and actor-level challenges (e.g., Cardol et al., 2025; Mignon & Bergek, 2016; Palm, 2022). Neglecting either perspective risks incomplete or counterproductive interventions or strategies.

At this stage, the actor-level perspective in these studies has primarily focused on adopters (e.g., Mignon & Bergek, 2016), leaving challenges faced by supply-side firms comparatively underexplored. This research gap is particularly pronounced for firms in the downstream value chain, which typically enter during the bridging phase (Dewald & Truffer, 2011). These firms play a pivotal role in the market as they operate between technology suppliers and adopters (Bergek, 2020). Yet, evidence indicates that gaps in the downstream value chain may persist well into the mass-market phase (Hyysalo et al., 2022). Consequently, examining market formation challenges from the perspective of downstream firms is essential for developing a more nuanced understanding of the factors that hamper technology deployment as well as the mechanisms for overcoming them.

Notably, adopters have been shown to employ different strategies to overcome both system- and actor-level challenges (Mignon & Bergek, 2016). For instance, adopters of battery-electric vessels have been found to install on-shore batteries for charging as a way to circumvent inadequate electricity grid access in remote areas (Mäkitie et al., 2022). Likewise, adopters of wind turbines were found to compensated for their lack of project development knowledge by hiring consultants to implement their wind power projects (Mignon, 2017). However, more research is needed to understand how other actors (such as downstream firms) navigate challenges for accelerating technology deployment (Markard et al., 2020). Here, sustainability transitions research provides some insight into the mechanisms that shape market formation.

3.2. Market Formation Mechanisms

Market formation is often described as creating a space for elements of a technological innovation system to fall into place (Jacobsson & Bergek, 2004). In practice, however, these elements rarely emerge on their own; they are typically shaped through deliberate efforts by actors seeking to influence their development (Musiolik & Markard, 2011). Firms and other actors engage in a range of activities that shape market formation (Ottosson et al., 2020).

To clarify how such shaping occurs, the thesis distinguishes between three mechanisms. *Market formation processes* refer to the high-level, systemic developments required for market formation to progress, while *strategies shaping market formation* capture the purposeful actions undertaken by firms and other actors to influence these processes. *Business models* are introduced as a potential third mechanism. Although not previously theorised in this way, business models provide a useful lens for understanding how firms navigate market formation challenges. The following subsections elaborate on each mechanism in turn.

3.2.1. Market Formation Processes

While the sequential phase-based model captures market formation at an aggregate level, a more detailed approach is required to explain the mechanisms through which these developments unfold (Dewald & Truffer, 2011). To this end, sustainability transition scholars have focused on the processes and related activities that drive market formation, drawing on the wealth of research on markets in disciplines such as evolutionary economics, marketing, and sociology of markets.

In their early research on the German solar PV market, Dewald and Truffer (2012) elaborate on how market formation processes unfold over nursing, bridging and mass-market phases. In particular, they distinguish three market formation processes and their underlying activities: formation of *market segments* (through innovating, associating, institutionalising), formation of *market transactions* (commodifying, communicating, competing), and formation of *user profiles* (determining consumer images, use patterns, preference structures). They show that the configuration of these processes varies across space and time, as each process depends on locally grounded actor constellations, institutional conditions, and interaction patterns that evolve as market formation progresses. For example, competitive dynamics tend to intensify in more mature phases, whereas articulation of user preferences is essential already in early, localised market niches. Dewald and Truffer (2011) also highlight that market formation can differ between market segments because each segment is associated with different actors, networks, and institutions. Such uneven development implies that a broad portfolio of market segments is necessary to stabilise the overall technological innovation system.

Building on a more explicitly constructivist understanding of markets (e.g., Kjellberg & Helgesson, 2007; Nenonen et al., 2019), Ottosson et al. (2020) emphasise that both public and private actors shape market formation through three interrelated processes. *Enabling exchange practices* encompass activities that facilitate trade (e.g., demanding, supplying, investing, subsidising). *Proving the system* refers to activities that establish the material and organisational arrangements necessary for technology production, distribution and use (e.g., experimenting, validating, producing). *Constructing the narrative* involves discursive activities that make the technology comprehensible, plausible and attractive (e.g., promoting, lobbying, informing). Each of these processes generate distinct forms of value (traded, demonstrated, and expected value) that feed into one another, thereby interlinking the processes.

Expanding on previous accounts, Boon et al. (2022) present a framework of five market formation processes aimed at identifying entry points for policy intervention. *Demand articulation and empowerment* define user preferences and aligns them with offerings enabled by the technology though activities such as market segmentation and marketing. *Formation of new user practices and experimentation* refer to the user domestication of a technology involving activities such as collective experimentation and user innovation. *Formation of institutions and institutional entrepreneurship* involve changing formal institutions related to e.g., rules of exchange in ways that accommodates for the new technology. *Defining legitimate market boundaries and establishing product categories* instead focus on changing informal institutions through activities that legitimise the new market, its segments and product categories. *Formation of dominant product or service design* refer to activities leading up to the emergence of standard market offerings. While these five processes are conceptually applicable across all market formation phases, their practical emphasis tends to be on early phases (e.g., before a dominant design has emerged).

Taken together, these frameworks shed light on a variety of activities required to address the market formation challenges outlined in Section 3.1. Across all three frameworks, *technology-related processes* emphasise activities linked to technology development and standardisation. Boon et al. (2022) highlight the importance of experimentation with users and developments leading up to the development of a dominant design. Dewald and Truffer (2012) emphasise innovating and commodifying technologies for formation of market segments and transactions. Ottosson et al. (2020) stress that the technological system needs to be proven through experimentation, validation, and production activities.

Likewise, they all underscore the importance of *actor accumulation and network building processes*. Boon et al. (2022) emphasise the interaction between actors on the supply and demand-side of the technology for demand articulation and user domestication. Dewald and Truffer (2012) highlight the necessity of communication, competition, and association of actors, as well as the formation of user profiles for all market formation processes. Ottosson et al. (2020) focus more on actors' individual activities that enable exchange practices, such as supplying or investing in the technology.

Finally, *institutional processes* are central to all three frameworks, though emphasised differently. Boon et al. (2022) distinguish between entrepreneurial activities linked to changing formal institutions and ones associated with informal legitimation through defining market boundaries and product categories. Dewald and Truffer (2012) link institutionalisation to market segment formation, highlighting how rules and norms need to be stabilised as market formation progresses. Ottosson et al. (2020) instead focus on discursive activities, such as lobbying, promotion and information campaigns, for influencing the development of formal and informal institutions.

While no single framework fully captures the complexity of market formation, together they provide a rich understanding of the underlying processes involved in market formation. The framework by Dewald and Truffer (2012) is particularly useful for illustrating how market segments develop over nursing, bridging and mass-market phases. However, aside from its treatment of user networks, it provides limited insight into the roles of different actors in shaping market formation. The framework proposed by Ottosson et al. (2020) emphasises how a variety of actors and networks shape market formation. Yet, it primarily addresses the early phases of market formation in which developments heavily depend on public actors and upstream firms (cf. Bergek, 2020). Boon et al. (2022) extend the discussion by offering a systematic, multidisciplinary account of market formation. Nevertheless, their framework also focuses predominantly on early phases and policy intervention, leaving gaps in the understanding of how market formation processes unfold over time.

A critical limitation shared across these frameworks is their insufficient attention to the strategic intent that drives these market formation processes. While all recognise that actors matter, they stop short of systematically considering their heterogeneity, power relations, and strategic behaviours. For instance, while Ottosson et al. (2020) acknowledge the agency in *how* both public and private actors shape market formation, they offer limited explanations for *why* these actors engage in particular market-shaping activities. This gap is significant because both demand- and supply-side actors differ in their motivations, capacities, and strategies for influencing market formation (Lee et al., 2018). Without an explicit account of such variations, analyses risk oversimplifying market formation mechanisms and underestimating the influence of firm agency.

3.2.2. Strategies Shaping Market Formation

Beyond studies that focus specifically on market formation, the broader literature on sustainability transitions has identified a variety of strategies that actors employ to shape market formation (e.g., Musiolik et al., 2020; Planko et al., 2016). While processes suggest a sequence of activities, strategies imply intentionality, i.e., the purpose and direction behind those activities. This distinction matters because processes describe what happens, whereas strategies explain why it happens and who drives it. As Farla et al. (2012) emphasise: "[s]trategies refer to the goals actors want to achieve as well as to the activities they pursue and the resources they deploy to achieve these goals" (pp. 994-995). A strategic perspective on market formation thus introduces questions such as: Who shapes market formation processes? How do they go about it, and why?

With regards to the first question, sustainability transitions research has traditionally paid limited attention to the roles of various actors in market formation (Boon et al., 2020), and the strategies of actors in general (Farla et al., 2012). However, in recent years, scholars have started to draw on insights from organisational studies to address this gap (Köhler et al., 2019). Studies reveal that market formation is not the work of a single actor but a distributed process involving different firms across the value chain, users, policymakers, and other actors (e.g., Dewald & Truffer, 2012; Hyysalo et al., 2022; Ottosson et al., 2020). Each of these actors have their own resources, capabilities, interests, and strategies that guide their actions (Köhler et al., 2019).

Consequently, scholars argue for distinguishing market formation dynamics based on who drives them (Planko et al., 2017). For instance, Ottosson et al. (2020) show that public actors primarily shape market formation through infrastructure investments, supportive policies, and public procurement, whereas upstream firms focus on technology development and distribution. Overall, the role of firms in market formation remains underexplored (Planko et al., 2017), particularly with regard to those in the downstream value chain. This oversight limits the understanding of how the strategic behaviour of different actors influences which market formation challenges are addressed.

When it comes to the second questions (i.e., how firms shape market formation), two main modes of strategic action has been identified: individual and collective approaches (Boon et al., 2020). *Individual strategies* typically involve firm-specific initiatives such as development of products and services, capability development and deployment, customer communication, organisational change, and lobbying (e.g., Lee et al., 2018; Planko et al., 2017; Werner et al., 2022). Such strategies may intentionally aim to address specific market formation challenges or they may be firm-centric business strategies that create spillover effects that eventually influence market formation (Lee et al., 2018). Intentional efforts typically require the individual firm to possesses all the necessary resources needed to address the market formation challenge (Musiolik et al., 2020).

In contrast, *collective strategies* emphasise collaboration and coordinated action between firms, which is often necessary for achieving the far-reaching system changes required for market formation (Planko et al., 2016). Such actions involve collective promotion to raise awareness for the technology, organisation and negotiation of standard-setting, information exchange, and collective lobbying through networks such as industry associations (Lee et al., 2018). Firms often need to pursue collective strategies to mobilise resources that are distributed among different actors or to create new resources needed for the development of the technological innovation system (Musiolik et al., 2020). Such strategies may (at least initially) involve collaborations with incumbent firms, as a way to access resources or circumvent hindering regulations (Kangas et al., 2021). However, as market formation progresses, collaborative approaches may no longer be necessary and firms strategies may become misaligned as they increasingly compete for market share (Altunay & Bergek, 2023; Planko et al., 2019). For instance, once potential users have been made aware of the new technology, collaborative promotion may no longer be necessary; instead firms may want to pursue their own marketing strategies to highlight the specific benefits of their offerings (Planko et al., 2016). As such, the strategies firms use to shape market formation tend to evolve as the market matures.

Lastly, the question of why firms engage in market formation has received limited attention in sustainability transitions research. Although firms are known to deploy different strategies toward different targets (e.g., lobbying to influence institutions) (Farla et al., 2012), evidence suggests that these strategies are driven less by specific market formation challenges and more by resource availability and development (Musiolik et al., 2020). Ultimately, firms are likely to undertake market formation efforts when they perceive such actions will enhance future prospects and deliver returns (Lee et al., 2018). For collective strategies, the primary objective is often to access resources controlled by other actors (Musiolik et al., 2020), whereas individual strategies have predominantly been associated with incumbent firms seeking to secure or reinforce their position in emerging markets (e.g., Werner et al., 2022).

While research on market formation highlight key processes and strategies that shape market formation, it provides limited insight into how and why firms engage in these processes in practice. Starting with the question of why, existing work has only begun to unpack the underlying firm logics that motivate firms' market shaping behaviours. Continuing with the question of how, prevailing frameworks tend to portray firms as actors performing discrete activities, without considering the mechanisms that enable, direct, or constrain those activities. At the same time, business models are increasingly referenced as important for overcoming technology deployment challenges (e.g., Drury et al., 2012; Strupeit & Palm, 2016), yet their role in market formation remains conceptually underdeveloped. This gap is surprising given that some scholars go so far as to claim that market formation essentially is "a typical business model function" (Boons & Lüdeke-Freund, 2013, p. 11). These observations point to the need for closer examination of business models as potential market formation mechanisms.

3.3. Business Models Shaping Market Formation

The business model concept gained prominence during the internet boom of the 1990s, particularly within technology and innovation management and strategic management research (Zott et al., 2011). It has since been adopted across a wider range of research fields, including entrepreneurship, corporate sustainability, industrial marketing, and sustainability transitions (e.g., Aagaard et al., 2021; Bankvall et al., 2017; Massa et al., 2017). This widespread use has led to a diverse and sometimes inconsistent understanding of what business models are and what roles they play (Wirtz et al., 2016).

A business model generally describes how a firm creates, delivers and captures value (Teece, 2010). This description includes defining what the firm offers to its target customer segments, how it organises its resources, activities, and partnerships to create and deliver this offering, and how it generates revenues and profit (Osterwalder & Pigneur, 2010; Richardson, 2008). Common definitions typically frame business models as descriptions, architectures, conceptual models, or structural templates that explain how firms 'do business', with a focus on value generation (Zott et al., 2011). However, significant variation exists in terms of what kinds of value are considered (economic, social, environmental), for whom value is created (the focal firm, customers, business networks, or society), and where the boundaries of the business model are drawn (firm-centric or network-centric) (e.g., Casadesus-Masanell & Ricart, 2010; Jocevski et al., 2020; Stubbs & Cocklin, 2008).

These variations not only reflect different research traditions but also stem from contrasting assumptions about the purpose of a business model. The definition by Teece (2010), for example, emphasises that a business model's purpose is tied to its underlying value mechanisms. In this regard, the business model can be conceptualised as a device. A device is generally defined as "a piece of equipment or a mechanism designed to serve a special purpose or perform a special function" (Merriam-Webster, n.d.). Viewing business models as devices emphasises their purposive and strategic nature: they are mechanisms intentionally constructed by actors to achieve particular objectives. This perspective shifts attention from static descriptions to the performative roles of business models, thereby offering a useful lens for understanding how they can serve as market formation mechanisms.

Drawing on insights about the performative roles of business models from research in technology and innovation management, strategic management, corporate sustainability, entrepreneurship, industrial marketing, and sustainability transitions, three overarching perspectives can be identified: business models as value creation devices, business models as boundary spanning devices, and business models as sociotechnical transition devices.

3.3.1. Business Models as Value Creation Devices

Building on the definition by Teece (2010), a business model represents a conceptual device that enables firms to create, deliver, and capture value. This perspective is widely used across research in technology and innovation management, strategic management, and corporate sustainability, although each field emphasises different aspects. Research in technology and innovation management and in strategic management both highlight the role of business models in generating economic value. However, the former tends to focus on how firms can gain economic benefits from creating value for customers (e.g., Johnson et al., 2008), whereas the latter concentrates more on how firms appropriate value for themselves (e.g., Casadesus-Masanell & Ricart, 2010). In contrast, corporate sustainability research emphasises the potential of business models to support holistic value creation that integrates economic, social, and environmental dimensions (e.g., Schaltegger et al., 2012) [2]. These differing emphases reveal distinct ways in which business models function as value creation devices.

Studies that foreground the role of business models in generating economic value through superior customer value often examine how business models translate the attributes of new technologies into marketable offerings that address the diverse needs and preferences of prospective customers (Chesbrough & Rosenbloom, 2002). A common approach for creating such value involves bundling the technology with complementary products and services (Teece, 2010). In this way, business models help firms unlock latent value embedded in their technologies by enabling them to articulate value propositions, define relevant market segments, specify value chain activities, understand cost structures, and position themselves within the broader value network (Chesbrough & Rosenbloom, 2002). Another common approach in which business models enable firms to create value is by identifying a specific customer problem and structuring the organisation around solving that problem (Johnson et al., 2008).

Research that focuses more explicitly on value capture tend to emphasise that creating value for customers is necessary but not sufficient; business models must also generate profits in order to be viable and attractive for firms (Teece & Linden, 2017). This perspective aligns with the broader strategy literature, which examines how firms capture value relative to competitors (Massa et al., 2017). From this viewpoint, the business model enables firms to create value for themselves by organising activities and accumulating resources in ways that enhance efficiency (e.g., by reducing costs through outsourcing) or increase effectiveness in generating revenues (Gambardella & McGahan, 2010).

The interest in how business models can be used to create holistic value has largely been driven by the increasing awareness that conventional business practices are insufficient for achieving a sustainable future (Bocken et al., 2014; Boons et al., 2013). To address sustainability challenges and secure long-term business success, firms must therefore design or redesign their business models with holistic value creation as a central consideration (Geissdoerfer et al., 2018). Doing so requires business models that account for a wider set of stakeholders than conventional ones and that embed a long-term perspective into the value mechanisms (Boons & Lüdeke-Freund, 2013; Lozano, 2018).

Although holistic value creation encompasses economic, social, and environmental dimensions (Stubbs & Cocklin, 2008), firms often prioritise these differently in practice. For instance, firms aiming to create social value may focus on targeting underserved communities or enabling a more equitable distribution of captured value through cooperative forms of ownership (Lüdeke-Freund et al., 2018). In contrast, business models that prioritise environmental value creation

[2] This line of inquiry has given rise to a dedicated subfield on business models for sustainability, sometimes referred to as sustainable business models (e.g., Schaltegger, Hansen et al. 2016).

typically emphasise the use of renewable resources or access-based consumption (e.g., delivering functionality rather than ownership) to enhance resource efficiency (Bocken et al., 2014). By broadening the notion of value beyond economic returns alone, business models can simultaneously strengthen economic performance by unlocking new business opportunities, reducing costs, managing risks, strengthening customer loyalty, and fostering employee engagement, thereby enhancing long-term competitiveness and growth (Whelan & Fink, 2016).

3.3.2. Business Models as Boundary Spanning Devices

In addition to shaping how firms create and capture value, the business model is increasingly recognised for its performative role as a boundary spanning device that supports communication and collaboration across organisational boundaries. This function is particularly salient in fields such as entrepreneurship (e.g., Doganova & Eyquem-Renault, 2009) and industrial marketing (e.g., Bankvall et al., 2017).

In their seminal work, Doganova and Eyquem-Renault (2009) explore the performative roles of business models in entrepreneurial practice. They demonstrate that entrepreneurial firms use business models as devices to enrol key stakeholders (e.g., potential customers, resource providers, regulators) into the emerging venture. Expressed through both material artefacts (e.g., business plans, websites) and discursive elements (e.g., narratives), business models help firms demonstrate the feasibility and benefits of the venture to these stakeholders, whose enrolment is necessary to bring the venture and its supply network into existence. This perspective extends the function of business models beyond value creation, positioning them as tools for communication, coordination, and legitimation (Boons & Lüdeke-Freund, 2013). In this demonstrative capacity, business models also serve as templates that other firms can imitate or use as points of comparison (Doganova & Eyquem-Renault, 2009).

Industrial marketing research instead emphasise the boundary spanning function of a business model from a different view, departing from the notion that firms often need to collaborate in early market stages to overcome limited resources and high uncertainty around new technologies (Möller & Svahn, 2009). In such contexts, business models often need to be conceptualised at the network level, as firm-centric models tend to overlook the interdependencies among actors that shape value creation and delivery (Bankvall et al., 2017). Rather than being centred around the business logic of a single firm, networked business models focus on the market offering of a technology and the network of actors that provide key resources or perform necessary activities for it to be commercialised (Jocevski et al., 2020).

From this perspective, business models function as collaborative devices that enable the coordination of distributed resources, activities, and responsibilities that no single firm can manage alone (Palo & Tähtinen, 2011). They help actors align around a shared value proposition, structure interactions, and orchestrate value flows across organisational boundaries (Jocevski et al., 2020). As such, networked business models do not simply aggregate individual firms' business models, they support firms in planning and coordinating the business network around a new technology and contribute to the creation of a market for it (Palo & Tähtinen, 2013).

3.3.3. *Business Models as Sociotechnical Transition Devices*

While the business model concept has been the focus of extensive scholarship for more than three decades, it has only recently begun to attract attention within sustainability transitions research (e.g., Aagaard et al., 2021; Bolton & Hannon, 2016; Sarasini & Linder, 2018). This delayed uptake may reflect the field's longstanding emphasis on system-level dynamics, which has only in the past decade been complemented by a growing interest in actor-level perspectives (Köhler et al., 2019). Nevertheless, recent advancements indicate that business models can serve as catalysts for sociotechnical transitions (Aagaard et al., 2021). For instance, business models can help firms scale new technologies beyond niche markets by building legitimacy, attracting investment, enabling interorganisational knowledge transfer, and building social networks that connect the technology to a critical mass of actors (Bidmon & Knab, 2018). Moreover, certain types of business models have been found to overcome deployment challenges that typically arise during more mature market formation phases, such as financial constraints, legitimacy deficits, policy and revenue risks, and limitations in adopter resources (Drury et al., 2012; Karneyeva & Wüstenhagen, 2017; Strupeit & Palm, 2016).

However, this body of research also shows that business models are shaped by the sociotechnical systems in which they are embedded (Wesseling et al., 2020). Consequently, they face their own set of barriers, including limited availability or high costs of complementary assets, regulatory uncertainty, and insufficient capabilities or knowledge within firms (De Rubens et al., 2020; Engelken et al., 2016). As contextual conditions vary across countries, they have also been shown to give rise to distinct business model configurations (Strupeit & Palm, 2016). Business models therefore often need to be translated in order to be effectively implemented in new contexts (Ode & Wadin, 2019).

Research further shows that firms use their business models to navigate opportunities and constraints posed by their sociotechnical systems, either by conforming to existing boundaries or by attempting to transform them (Wesseling et al., 2020). For instance, firms have been shown to stretch regulatory boundaries though their business models by setting up new legal entities, collaborating with licensed partners, and creating billing structures that fit regulatory loopholes (Huijben et al., 2016). Importantly, recent research demonstrates that firms are heterogeneous in how they perceive and respond to such opportunities and constraints, leading them to pursue markedly different business model approaches (Thomson et al., 2025). This finding highlights the need to account for firm agency when examining business models as devices for sociotechnical transitions. Despite recent attempts to integrate the perspectives of actors and agency into sustainability transitions research, business models remain insufficiently understood (Köhler et al., 2019). In turn, this limited understanding has resulted in rather cursory explanations of the business model concept (Aagaard et al., 2021), often conflating it with so-called deployment models (Sauter & Watson, 2007) which focus more on the configuration of deployment projects than the underlying business logics of the actors involved.

3.3.4. *Overview of the Performative Roles of Business Models*

These three perspectives offer distinct insights into how and why business models are used. Viewing business models as value creation devices highlights the underlying rationale guiding firms' choices, emphasising that business models reflect different value priorities. From this standpoint, firms use different business model approaches depending on the type of value they seek to create and for whom. For example, firms create customer value by bundling technologies with complementary products and services (Teece, 2010), enhance their own economic value by outsourcing activities(Gambardella & McGahan, 2010), and pursue holistic value by engaging underserved adopter groups (Lüdeke-Freund et al., 2018), promoting resource efficiency (Bocken et al., 2014), or prioritising long-term competitiveness (Whelan & Fink, 2016). A key limitation of this perspective, however, is its strong firm-centric orientation: it tends to portray stakeholders as passive recipients of value rather than as active participants capable of shaping business model design (Freudenreich et al., 2020). As a result, this view offers limited insight into the interactive dimensions of business models that help explain how firms connect with their broader context.

In contrast, the perspective on business models as boundary spanning devices foregrounds these interactive dimensions emphasising how firms use business models for communicative and collaborative purposes. For example, business models help firms enrol prospective customers, partners, and regulators by demonstrating the feasibility and value of their venture (Doganova & Eyquem-Renault, 2009). When conceptualised at the network level (rather than the conventional firm level), business models also clarify the underlying business logic of multi-actor collaborations, showing that firms often engage in such arrangements to mobilise resources that no single firm can secure independently (Palo & Tähtinen, 2011). In these settings, the networked business model enables participants to align around a shared value proposition, structure their interactions, and orchestrate value flows (Jocevski et al., 2020). However, despite its focus on interaction, this perspective still offers limited insight into how such boundary spanning approaches contribute to broader system-level outcomes.

The perspective on business models as devices for sociotechnical transitions addresses this gap by linking business models to system dynamics. This view shows how business models support the scaling of technologies beyond niche markets by fostering legitimation and learning and by building social networks that mobilise a critical mass of actors around a technology (Bidmon & Knab, 2018). It also illustrates how business models can be used to overcome barriers to technology deployment, such as high upfront investment costs, policy risk, and limited adopter resources (e.g., Karneyeva & Wüstenhagen, 2017; Strupeit & Palm, 2016). Moreover, this perspective highlights the embedded nature of business models, emphasising that they both shape and are shaped by their sociotechnical context (Wesseling et al., 2020). Despite recent advancements (e.g., Thomson et al., 2025), this perspective still offers limited insight into the underlying rationale for actors to use business models as devices for sociotechnical transition, often leaving it unclear whose business model is actually being referenced.

Taken together, these perspectives provide a richer understanding of the performative roles of business models and offer a foundation for examining how and why firms engage in market formation. However, to assess whether business models can function as mechanisms for market formation, it is necessary to clarify how these performative roles connect to specific market formation challenges. Without such understanding, there is a risk that scholars and practitioners over- or underestimates the role of business models in market formation.

3.4. Integrative Framework: Proposed Roles of Business Models in Market Formation

To summarise, slow market formation is hampering the deployment of mature low-carbon technologies (Hyysalo et al., 2022). Addressing this issue requires a clearer understanding of the market formation challenges faced by firms commercialising these technologies, since they are central market actors, particularly in later phases of market formation when policymakers begin withdrawing support (IEA, 2024d).

Market formation is associated with a range of challenges related to the development of the technological innovation system (Bergek et al., 2008). Technological challenges stem from limitations in developing the focal technology and complementary assets, including high uncertainty and risk, low performance, high cost, resource constraints, underdeveloped infrastructure and complementary technologies, products, and services (Jacobsson & Bergek, 2004). Actor and network challenges relate to systemic issues among supply and demand actors, such as unclear user needs, limited capital, incumbent resistance, supply chain gaps, and too strong or weak network interactions (e.g., Negro et al., 2012). They also relate to actor-level challenges associated with the specific resources and behaviours of adopters (Mignon & Bergek, 2016). Institutional challenges arise from misaligned formal and informal arrangements, such as unfavourable regulations, lack of standards, unstable and misaligned policies, and absence of legitimacy (e.g., Jacobsson & Bergek, 2004). These challenges differ significantly between market formation phases (Dewald & Truffer, 2012), but it is not clear which challenges firms are facing in the shift between the bridging and mass-market phase for low-carbon technologies. As such, it is not clear what challenges need to be addressed to accelerate the deployment of these technologies.

To address these challenges, a range of different actors must engage in activities that advance the underlying processes of market formation (Ottosson et al., 2020). Firms, in particular, employ various strategies to influence these processes, both individually and collectively (e.g., Musiolik et al., 2020; Planko et al., 2016). Yet little is known about how and why firms engage in market formation or about the specific role their business models play in this process. This gap is notable given that business models are increasingly recognised as central for overcoming barriers to technology deployment (e.g., Strupeit & Palm, 2016) and for enabling scaling of technologies beyond niche markets (e.g., Bidmon & Knab, 2018).

Here, insights from the broader business model literature offer valuable perspectives by emphasising the performative roles of business models. When conceptualised as devices, i.e., mechanism designed to serve a special purpose (Merriam-Webster, n.d.), business models have been shown to enable value creation, boundary spanning, and sociotechnical transitions. Comparing these insights with research on market formation challenges reveals several patterns that illustrate how business models can potentially serve as mechanisms for market formation, as shown in Table 4.

Table 4. Potential ways in which business models can address market formation challenges.

Challenges	Business models as value creation devices	Business models as boundary spanning devices	Business models as socio-technical transition devices
Technology	Translate technological features into offerings. Bundle with complementary technologies and services. Encourage resource efficiency.	Mobilise and coordinate providers with complementary assets around a shared value proposition.	Overcome technology deployment barrier by transferring upfront costs from adopters to firms.
Actors & Networks	Tailor offerings to specific adopter groups. Increase value chain efficiency and specialisation.	Enrol investors and incumbent firms. Mobilise and coordinate firms' distributed resources and activities.	Facilitate knowledge sharing among market actors. - Build social networks that enable technology scaling beyond niche markets.
Institutions	Build legitimacy through holistic value creation.	Build legitimacy and enrol regulators by demonstrating value and feasibility.	Manage policy risk. Strech regulatory boundaries.

In terms of *technological challenges*, the perspective of business models as value creation devices underscores their role in translating technological features into market value propositions (Chesbrough & Rosenbloom, 2002). In doing so, they can enhance the perceived appeal of a technology, compensating for initial drawbacks linked to low performance or high price (e.g, Andersson & Jacobsson, 2000). In this capacity, business models may also mitigate weak alignment between the focal technology and complementary assets (e.g., Bergek et al., 2008) by enabling offerings that bundle technologies, products, and services (Teece, 2010). As boundary spanning devices, business models may also help to mobilise and coordinate complementary asset providers by aligning them around a shared value proposition (e.g., Jocevski et al., 2020).

When considering holistic value creation, business models can promote resource efficiency, for instance by selling technology access rather than ownership (Bocken et al., 2014). Such business model approaches can help address technological market formation challenges related to resource constraints and waste (e.g., Ertelt & Carlborg, 2024) as well as high upfront investment cost (e.g., Iyer et al., 2015). By transferring these upfront cost from adopters to firms, third-party-ownership models have been shown to reduce barriers to technology deployment (Strupeit & Palm, 2016), thereby functioning as devices for sociotechnical transitions.

With regard to *actor and network challenges*, the value creation function of business models plays an important role in identifying and addressing specific customer problems (Johnson et al., 2008). By tailoring offerings to the needs and preferences of distinct adopter groups, business models may overcome adopter-related limitations and thereby engage a broader mass of potential adopters (e.g., Mignon & Bergek, 2016). At the same time, efforts to increase the value captured by firms (e.g., through outsourcing) can influence broader industry structures

(Gambardella & McGahan, 2010), for instance by enhancing value chain efficiency and fostering firm specialisation (e.g., Jacobsson & Bergek, 2004).

As boundary spanning devices, business models also support the enrolment of key stakeholders by demonstrating the feasibility and benefits of a venture (Doganova & Eyquem-Renault, 2009). In doing so, they may help persuade investors and incumbent firms to support new technologies, thereby addressing market formation challenges such as limited access to capital (e.g., Karltorp, 2016) and incumbent resistance (e.g., Negro et al., 2012). Collaborative business models can further mitigate capability constraints among firms (e.g., Kangas et al., 2018) by enabling interorganisational mobilisation and coordination of distributed resources and activities (Palo & Tähtinen, 2011). Moreover, as catalysts of sociotechnical transitions, business models have been shown to facilitate knowledge sharing and the building of social networks helping to mitigate knowledge asymmetries among market actors and strengthen weak network ties (e.g., Jacobsson & Bergek, 2004).

Lastly, the three perspectives illuminate how business models can help firms navigate *institutional challenges*. From a value creation perspective, business models that foreground holistic value (Lüdeke-Freund et al., 2018) may strengthen technological legitimacy by promoting more equitable access (e.g., Ertelt & Carlborg, 2024) and by articulating value propositions that align with the wider societal narratives and expectations that are used to justify its growth (e.g., Ottosson et al., 2020). As boundary spanning devices, business models also support legitimation by facilitating the enrolment of key stakeholders (e.g., policymakers) into the venture (Doganova & Eyquem-Renault, 2009). Such legitimacy building and regulatory advocacy are often essential for overcoming market formation challenges rooted in institutional misalignment (e.g., Bergek et al., 2008). From a sociotechnical transitions perspective, business models also offer ways to navigate institutional misalignment, for instance by exploiting institutional voids (Huijben et al., 2016). This perspective further highlights how business models can help firms manage risks associated with policy volatility (Karneyeva & Wüstenhagen, 2017), a known market formation challenge (Negro et al., 2012).

While these patterns highlight the potential for business models to shape market formation, it remains unclear whether firms actually encounter such market formation challenges in practice, how they use their business models to navigate these challenges, and why they do so in particular ways. Without addressing this gap, existing research risks relying on assumptions about how business models influence market formation and misidentifying the actual challenges firms face in later phases of market formation. This calls for further investigation into both the nature of market formation challenges and the role of business models in addressing them.

4. Method

This chapter provides an overview of the studies included in the thesis and the methodological choices underpinning them. The thesis comprises four studies, corresponding to the appended papers: a literature review (Study I), a typology analysis of Swedish solar PV business models (Study II), a comparative case study of solar PV parks (Study III), and a temporal multiple case study of downstream firms (Study IV). The chapter begins by situating the research process within its broader research setting and outlining how the thesis's focus and approach evolved over time. This is followed by a discussion of the overarching research design and an account of the chosen Swedish solar PV context. The chapter then outlines the methods applied in each of the individual studies before concluding with a set of overarching methodological reflections. Full methodological details for each study are presented in the appended papers.

4.1. Research Journey

The thesis was developed as part of the research project *Innovative business models for a large-scale diffusion of solar PV*, funded by the Swedish Energy Agency[3]. The project aimed to understand how innovative business models can contribute to large-scale diffusion of solar PV by identifying business models used abroad, analysing context-specific factors that explain their diffusion, and determining the conditions necessary for their broader implementation in Sweden. Led by my main supervisor, Ingrid Mignon, with the involvement of my co-supervisors Lisa Govik and Johan Lindahl, the project began in January 2020. By the time I joined in February, the overall objective and research questions had already been defined. From the outset, the project played a central role in shaping my research focus. I actively contributed to refining the direction of the studies, and several key adjustments to the original project plan were made.

The thesis originally aimed to compare business models for solar PV in Sweden and abroad. However, due to difficulties in establishing international interview contacts during the Covid-19 pandemic, the scope was narrowed to focus solely on the Swedish context for the research proposal. This focus remained throughout the research process. Although a cross-country comparison would have been feasible for Study II, the availability of an exceptionally comprehensive database of Swedish solar PV firms enabled a depth and level of systematic analysis that would have been difficult to achieve elsewhere. The decision not to expand the empirical scope later in the process was therefore a deliberate methodological choice, intended to leverage these data advantages to produce richer contextual understanding and more nuanced interpretations. Given the initial constraints imposed by Covid-19 and the uneven availability of comparable secondary data across countries, concentrating on a single national context allowed for a more rigorous and systematic investigation, even if it limited the transferability of the findings. Methodologically, this shift made the thesis more deeply embedded in the Swedish context and better suited to explaining national market dynamics rather than cross-country differences.

[3] Grant number P48527-1.

Following discussions on the research proposal, the scope of Study IV was broadened to adopt a more exploratory orientation that allowed not only contextual factors but also firm-internal sources of influence to emerge. This shift was made to avoid the possibility that a predefined focus on external conditions would impose unnecessarily limiting boundaries on the empirical inquiry. However, although this broader framing offered valuable insights into firm heterogeneity and agency, it also widened the empirical scope to a point where systematic comparison became difficult.

As these insights were being developed into a research paper, the Swedish solar PV market underwent major changes, making temporal responses more analytically salient. To maintain analytical coherence while still capturing variation in how firms navigated their environments, Study IV was therefore refocused on firm responses to environmental conditions over time, which also influenced the overall focus of the thesis. The temporary broadening of the empirical scope was crucial for revealing the importance of firm-specific capabilities, strategic orientations and agency, which would have remained obscured under a strictly contextual framing. The subsequent refocusing on firms' responses over time enabled systematic comparison that strengthened the explanatory power of the thesis.

The original research plan for Study III focused on a single in-depth case study of actor collaboration around one solar PV business model. This focus was later expanded into a comparative design centred on collaborations around business models for solar PV parks. The shift was motivated by insights emerging from the other studies. Study II showed that collaboration was particularly central in large-scale solar PV projects, which justified directing attention toward solar PV parks. Study IV further highlighted substantial firm heterogeneity, even among firms employing similar types of business models. These insights together motivated broadening Study III into a comparative case study in order to capture variation in collaborative arrangements and identify patterns that could support more transferable claims.

During the development of the thesis, it became clear that although technology diffusion had served as an overarching guiding problem, the empirical and theoretical focus gradually centred on business models. Following feedback from my opponent, Anna Bergek, at the final seminar, and in line with the systematic combing approach (Dubois & Gadde, 2002), the thesis was refined to emphasise the more specific problem of market formation. As the work progressed, the significance of understanding market formation challenges and firms' use of their business models became increasingly clear. This conceptual shift has direct implications for the thesis's claims. Because the empirical studies primarily examined how firms structure, adapt and mobilise their business models in response to changing market conditions, they offer insight into the mechanisms underpinning market formation rather than the outcomes of large-scale diffusion. Reframing the thesis around market formation therefore aligns the theoretical framing with the empirical evidence and strengthens the credibility of the conclusions.

To further strengthen the theoretical framing and contribution, and to reflect the broader analytical focus of Study I, the thesis was also expanded beyond the initial empirical focus on solar PV to encompass low-carbon technologies more generally. This shift was motivated by the recognition that several of the challenges and business model patterns identified across the studies are not unique to solar PV but correspond to dynamics observed across low-carbon technologies more broadly. Treating solar PV as an empirical lens rather than the sole analytical focus clarifies how the findings can be extended beyond a single technology, enabling the thesis to contribute to wider theoretical discussions on business models and sustainability transitions. Table 5 provides an overview of how the research aim and the individual studies evolved over the course of the research process.

Table 5. Evolution of research focus and studies.

	Research Project	**Research Proposal**	**Licentiate Thesis**	**Doctoral Thesis**
Aim	Understand how innovative business models can contribute to a large-scale diffusion of solar PV.	Contribute to an increased understanding of the role innovative business models have for large-scale diffusion of solar PV.	Increase the understanding of the role that business models play in large-scale diffusion of solar PV.	Explain the roles of business models market formation for low-carbon technology.
Studies	Literature review of solar PV business models and context-specific factors.	I. Literature review of sustainable business models and innovation strategies.	Retained.	Retained.
		II. Typology analysis of Swedish firms' solar PV business models.	Retained.	Retained.
	Interview study with key stakeholders in Sweden and abroad.	III. Single case study of actor collaboration around a solar PV business model.	Not yet initiated.	Expanded to a comparative case study of solar PV parks in Sweden.
		IV. Multiple case study of Swedish firms and the contextual factors influencing their solar PV business models.	Expanded to also include firm-internal factors.	Refocused on firm responses to environmental changes.

4.2. Research Design

In examining the roles of business models in market formation, I build on the notion that that both markets and business models are socially constructed phenomena (e.g., Chesbrough & Rosenbloom, 2002; Doganova & Eyquem-Renault, 2009; Ottosson et al., 2020). This view implies that they do not exist as objective structures "out there", but emerge as enacted realities shaped through actors' interpretations, interactions, and practices. As such, they are best studied through the interpretive accounts and observable activities of the actors who construct them, which aligns naturally with qualitative research approaches (Eisenhardt, 1989; Yin, 2014).

Guided by this logic, the thesis adopts a qualitative research design comprising four complementary studies, corresponding to the appended papers: a literature review of published firm-level cases (Study I), an empirical typology analysis of Swedish solar PV firms' business models (Study II), a comparative case study of actor networks surrounding solar PV parks in Sweden (Study III), and a multiple case study of Swedish solar PV firms (Study IV). Given the emergent stage of research on business models in sustainability transitions (Aagaard et al., 2021), this exploratory and interpretive approach is well suited to examining the actor-level underpinnings of market formation mechanisms, as it enables close analysis of how firms interpret and respond to evolving market conditions. While the research design does not allow all phases of market formation to be examined in full, its strength lies in capturing the nuances and decision-making processes that shape market formation as it unfolds.

To capture the multifaceted nature of market formation, the thesis employs multiple studies that each contribute a distinct analytical layer, together offering complementary perspectives that address the research questions. Study I provides a conceptual foundation by synthesising firm-level business model patterns and strategies in low-carbon technology contexts (RQ2). Study II maps business model patterns across the Swedish solar PV market, highlighting both sources of market formation challenges (RQ1) and the business model configurations firms use to address them (RQ2). Study III examines the interorganisational dynamics through which firms encounter market formation challenges (RQ1) and how they respond to these collectively through networked business models (RQ2). Study IV adds a temporal dimension by exploring how business models and market conditions co-evolve, illustrating how firms experience challenges over time (RQ1) and how they respond using their business models (RQ2). Together, these studies build a cumulative and multi-layered understanding of how business models influence market formation, using the Swedish solar PV context as the empirical setting. Table 6 summarises the design of the studies.

Table 6. Design of the studies.

Study	Data Sources	Data Analysis	Unit of Analysis	RQs
I	87 empirical cases from 25 articles published in academic journals (2010-2020).	Literature review involving thematic synthesis and typology development.	Published firm-level cases.	RQ2
II	Secondary data from 241 firm websites.	Typology analysis based on Richardson (2008) and roles, activities, and application as described in energy policy literature.	Firms.	RQ1-RQ2
III	Primary data from 14 interviews with multiple network participants across three solar PV parks. Secondary data from press releases, news articles, and IEA PVPS Swedish market reports (2020-2022).	Coding based on Gioia et al. (2013), within- and cross-case analysis.	Actor networks.	RQ1-RQ2
IV	Primary data from 20 interviews with founders, managers, industry experts. Secondary data from IEA PVPS Swedish market reports (2002-2023) and global trends reports (1992-2023), firm websites, press releases, news articles, social media pages, emails, register of companies, internal documents, and annual reports.	Systematic combining, timeline mapping, coding based on (Gioia et al., 2013), within- and cross-case analysis.	Firms.	RQ1-RQ2

4.3. Empirical Context: Downstream Firms in the Swedish Solar PV Market

This thesis focuses on downstream firms in the Swedish solar PV market. Because market formation assessments differ depending on how technologies, applications, and geographies are delineated (as illustrated by contrasting accounts of early solar PV in Section 2.3.2), careful consideration of boundary conditions is essential for analysing market formation. The selected empirical context reflects deliberate boundary choices, motivated by several reasons. First, solar PV is widely recognised as a commercially mature low-carbon technology for renewable electricity production that is readily available, increasingly cost-competitive, and broadly supported by the public (IEA, 2024b). Yet, as outlined in Section 2.3.2, it continues to face a range of market formation challenges that constrain its wider deployment. This combination makes solar PV analytically valuable, as it provides an empirical lens for investigating the shift between later market formation phases, which remains underexplored in existing research.

Second, although solar PV is developed and manufactured in highly globalised upstream value chains, markets for its deployment is primarily formed at national and sub-national levels, where policy frameworks, electricity system characteristics, and actor constellations differ substantially (IEA PVPS, 2025b). Sweden offers a particularly interesting context in this regard. Despite being a global frontrunner in the energy transition and having ambitious climate targets (World Economic Forum, 2024), solar PV has so far played a marginal role in Sweden's electricity production, accounting for less than one percent of total electricity production in 2023 (Swedish Energy Agency, 2023). The Swedish electricity system has long been dominated by centralised low carbon generation from hydropower and nuclear power (Swedish Energy Agency, 2023), which means that solar PV must compete with established and comparatively low cost alternatives. Nevertheless, as electricity demand continues to grow and Sweden strives to meet ambitious climate and energy goals, solar PV is expected to play an increasingly significant role in the country's future electricity mix (IEA, 2024c).

This context gives rise to specific patterns of market formation. Sweden's already high share of fossil-free electricity implies that solar PV deployment has not been driven by the same urgency or relative cost advantages that have propelled market formation in countries with greater fossil fuel dependence At the same time, rapid global cost declines have created a situation in which solar PV is technologically mature and cost-competitive, while the national market has remained comparatively underdeveloped (IEA PVPS, 2025b). As a result, the Swedish solar PV market has expanded rapidly within a relatively short time period, experiencing exponential growth over the past decade (Lindahl & Öhgren, 2025). As in many other European countries, this expansion has been driven primarily by investments in small-scale distributed solar PV applications, while large-scale centralised installations have remained relatively limited (Lindahl et al., 2022). However, unlike many European markets where growth has been stimulated by feed-in-tariff schemes (IEA PVPS, 2025b), the expansion of the Swedish market has been supported mainly through capital subsidy programs and energy tax reforms (Cardol et al., 2025).

Together, these dynamics make Sweden a particularly relevant context for studying market formation. The rapid growth of the Swedish solar PV market enables the observation of major developments within a relatively short time frame, while the coexistence of shared European characteristics and distinct national features provides a strong analytical foundation for theory development, with insights that may be transferable to other contexts with similar market characteristics.

Third, the choice to focus on firms in the downstream value chain was motivated by both the pronounced divide within the solar PV industry (IEA PVPS, 2025b), and the limited attention downstream firms have received in research on market formation. As highlighted in Section 2.3.1, the upstream segment of the solar PV value chain is highly consolidated and globalised, whereas the downstream segment is fragmented and strongly shaped by national and local conditions. While upstream firms primarily influence technological development and cost reductions, downstream firms are directly engaged in deployment-oriented activities such as project development, sales, installation, and operation (Figure 3). As such, downstream firms constitute primary actors in market formation at the national level. Despite this central role, research on market formation has predominantly focused on policymakers, technology developers, and early adopters (e.g., Dewald & Truffer, 2012; Jacobsson & Bergek, 2004; Ottosson et al., 2020), leaving the challenges and actions of downstream firms comparatively underexplored. By focusing on downstream firms, the thesis responds directly to this gap and aligns the empirical focus with the research questions.

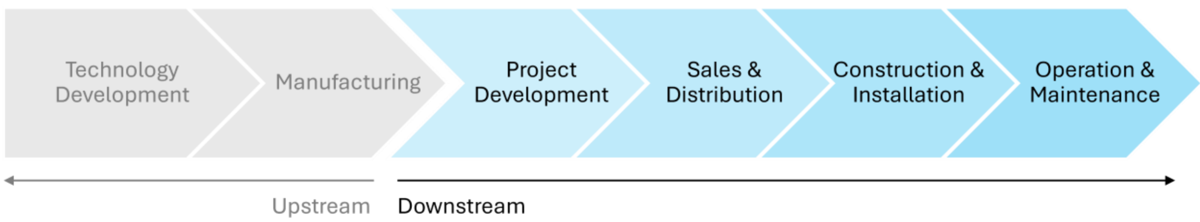

Figure 3. Selected focus of the solar PV value chain.

Within the downstream segment, the thesis places particular emphasis on firms without prior experience in electricity production. Since the liberalisation of the Swedish electricity market in 1996, a large number of such actors have entered the energy sector to produce renewable electricity and commercialise renewable energy technologies (Bergek, 2020; Bergek et al., 2013). This focus is motivated by evidence showing that incumbent energy utilities in Sweden often treat solar PV as an extension of existing portfolios and commonly outsource their solar PV activities to specialised new entrants (e.g., Altunay & Bergek, 2023), positioning these firms as central market actors. In addition, prior research shows that new entrants are more likely to pioneer novel types business models (Bohnsack et al., 2014), making them particularly relevant for capturing variation the business models that are being used. Foregrounding firms without an electricity production background therefore strengthens the alignment between the empirical focus and the aim of the thesis by concentrating on firms that are both empirically central to the solar PV market and likely to exhibit greater variation in business model use.

4.4. Study I: Literature Review

To build a comprehensive analytical foundation for understanding how firms use their business models to navigate market formation challenges, Study I adopts a broad perspective by examining the state-of-the-art on sustainable business models and the innovation strategies used to design and implement them. Specifically, the study reviews 87 empirical cases of business model innovation towards sustainable business models from 25 articles published in academic journals between 2010 and 2020. While this study design is constrained by reliance on secondary interpretations and the varying level of detail provided in the original case descriptions, it also enables the identification of robust patterns by drawing on a substantial and diverse body of empirical material across multiple contexts. A detailed account of the full methodological procedure is provided in Paper I.

The review followed a six-step process informed by Petticrew and Roberts (2008). First, we searched the Web of Science for research articles published between 2010 and 2020 that included the terms *sustainable business model* and *business model innovation* in the title, topic, or keywords (step 1), yielding 312 records. After screening titles and abstracts for these terms or closely related concepts (e.g., business model innovation for sustainability), 49 articles remained (step 2). A full-text review was then conducted, excluding articles that lacked empirical cases, interpreted sustainability solely as economic viability, or mentioned the key terms only superficially (step 3). This step resulted in a final sample of 25 articles describing 87 unique empirical cases.

Next, each author independently analysed the articles to identify recurring patterns related to the keywords, which were synthesised into two overarching themes through discussion and comparison (step 4): sustainable business model types and business model innovation strategies. During the review of sustainable business model literature, we observed variation in sustainability outcomes across business models, prompting us to examine whether similar patterns occurred in our empirical cases. We began by independently categorising the cases before refining the categories through discussion. I then categorised the remaining cases, and my co-author verified consistency (step 5). Cases lacking clear sustainability claims or sufficient detail were excluded. When cases exhibited overlapping characteristics, we assigned them to the category deemed most representative. In total, 72 cases across 19 articles were categorised based on patterns in sustainable business model outputs.

We then reviewed literature on business model innovation strategies to inform our analysis of how firms in the empirical cases had developed and implemented sustainable business models. We categorised the strategies used in the cases, remaining open to identifying new strategies beyond those described in the literature. Some cases lacked sufficient detail to determine the strategies used, either due to limited descriptions or a lack of focus on the business model innovation process. In total, we identified 59 cases across 19 articles that demonstrated business model innovation strategies toward sustainable business models.

4.5. Study II: Typology Analysis of Solar PV Business Models

Study II is a typology analysis of solar PV business models in Sweden based on secondary data from 241 firm websites. The study offers a comprehensive, empirically grounded mapping and analysis of business model configurations that have emerged in the Swedish solar PV market, anchoring the findings in observed accounts rather than theoretical assumptions. By drawing exclusively on website data, the study captures the communicated versions of firms' business models, while offering limited insight into their internal operational elements, particularly regarding cost structures and other commercially sensitive details. This limitation is, however, defensible given the thesis' focus on business models as mechanisms of market formation, where external communication plays a central role (e.g., Doganova & Eyquem-Renault, 2009). The use of website data also means that the study risks reflecting the business models of more visible, digitally active firms. However, this limitation is likely modest given Sweden's digital maturity, where over 90 percent of enterprises have internet access (Statistics Sweden, 2025). The methods used in Study II are summarised below; full details are reported in Paper II.

For the sampling, the study drew on unique access to a comprehensive database of Swedish solar PV firms, provided by my co-supervisor Johan Lindahl. This database is maintained within the International Energy Agency's Photovoltaic Power Systems Programme (IEA PVPS) (https://iea-pvps.org/), which annually reports on the technical, economic, environmental, and social developments in the Swedish solar PV market (e.g., Lindahl et al., 2021). During the time of investigation (2021), the database contained 741 organisations engaged in solar technologies in Sweden, listing firm names, websites, founding years, operational status, technology types, and business focus (e.g., manufacturing, research, sales, consulting, installation). From this, an initial sample of 351 firms were chosen for analysis based on their primary focus on downstream value chain activities (i.e., sales, consulting, and installation) (Frantzis et al., 2008; Schoettl & Lehmann-Ortega, 2011). To enable comparison, firms offering non-standard solutions, targeting only other solar firms, outsourcing their solar PV business, or lacking sufficient website information were excluded, resulting in a final sample of 241 firms.

From April to September 2021, secondary data was collected from firm websites, including information on target customer segments, offerings, activities, partnerships, and revenue structures following Richardson (2008). We also documented if the firms emphasised certain features of their business model (e.g., describing themselves as turnkey providers). Data was then analysed based on roles, activities, and applications in line with energy policy literature (for more detail, see Table 2 in Paper II). While roles such as property owners or electricity consumers were not always explicitly stated, they were inferred from descriptions of offerings and activities. Similarly, project size and application were approximated using market segments defined by Lindahl et al. (2021).

4.6. Study III: Comparative Case Study of Solar PV Parks

Study III employs a comparative case study design to examine the actor networks surrounding three solar PV parks in Sweden, exploring business models in settings where multiple actors collaborate to commercialise solar PV. This approach is well-suited for capturing the complexity of real-world contexts and enhances the robustness and transferability of findings through cross-case comparison (Eisenhardt & Graebner, 2007). Below is a summary of the methodological procedures; full details are provided in Paper III.

To identify relevant cases, we consulted the Swedish representative for IEA PVPS, who recommended five Swedish solar PV parks either under construction or completed since 2020. We assessed each park's development stage and involved actors through news articles and firm websites. Three parks were selected based on their similar multi-actor business models and advanced development stages, which indicated formalised networks. One park was put in operation in 2020, and the remaining two in 2023.

Primary data was collected between December 2022 and May 2023 through 14 semi-structured digital interviews with representatives from multiple firms involved in the development, construction, and operation of the solar PV parks. Initial contacts were facilitated by the Swedish IEA PVPS representative, and additional interviewees were recruited via snowball sampling to ensure inclusion of key participants in the networks. To capture diverse perspectives and reduce potential individual bias, we sought to interview representatives from all involved actors, although not all agreed to participate. Interview topics included organisational focus, motivations for involvement, actor roles, and interactions. Interviews lasted approximately 45 minutes each, were recorded, and subsequently transcribed. Secondary data in the form of press releases, news articles, and IEA PVPS market reports (2020–2022), was used to contextualise and triangulate the findings.

Data analysis followed a bottom-up approach inspired by Gioia et al. (2013). Interview transcripts and secondary data were coded into first-order concepts, second-order themes, and aggregated dimensions. Each case was first analysed individually, then compared across cases following Eisenhardt (1989). First-order concepts were empirically derived from the data and grouped into second-order themes informed by the industrial marketing and purchasing literature, which served as the study's theoretical framing. The themes were then synthesised into three aggregated dimensions aligned with the paper's research questions. I conducted the initial coding, which was reviewed by my co-author; final coding decisions were reached through discussion. The full coding structure is presented in Table 3, Paper III.

4.7. Study IV: Temporal Multiple Case Study

Study IV employs a multiple case study design to explore how seven firms have responded to developments on the Swedish solar PV market between 2009 and 2024 in relation to their business models. This period represents a particularly turbulent time in the Swedish solar PV market, with significant shifts in technology prices, customer demand, network structures, and institutional conditions following the introduction of a direct capital subsidy by the Swedish government in 2009 (Cardol et al., 2025; Lindahl & Öhgren, 2025). Paper IV provides a detailed account of the methodological approach, which is summarised below.

When selecting firms to study, we purposefully selected new entrants (i.e., firms without prior experience in electricity production) that had introduced novel business models to the Swedish solar PV market. Because such firms operate outside established industry practices, tensions between their business models and the surrounding market environment tend to become especially pronounced (Bidmon & Knab, 2018). This decision aligns with Flyvbjerg (2006, p 13) who argue that "[a]typical or extreme cases often reveal more information because they activate more actors and more basic mechanisms in the situation studied". Selecting strategically informative cases thus enable deeper insight into mechanisms behind the co-evolution between business models and their environment.

We assessed the novelty of firms' business models using accounts of innovative business models in IEA PVPS reports (e.g., IEA PVPS, 2021; Lindahl et al., 2021). For solar PV, novel business models diverge from conventional ones by introducing alternative ownership structures (e.g., third-party or community-shares models) and energy-service-based offerings (e.g., home or building energy management systems, aggregation of flexible energy resources). Based on the list of firms in the IEA PVPS database referenced in Study II, together with information from firm websites, we identified ten new entrants that met these criteria during 2021. We contacted the founders/managers of these firms and seven agreed to participate, forming the final sample. The founders and managers were specifically targeted due to being involved in strategic decision-making with regard to the business model. All selected firms were founded between 2012 and 2014.

Data was collected and analysed over five years (2020 to 2025) in three phases using systematic combining, an abductive approach that iteratively refines theory and empirical insights (Dubois & Gadde, 2002). The first phase explored exogenous changes and firm responses through eleven semi-structured digital interviews conducted between December 2020 and May 2021 with the selected firms' founders, managers and two industry experts. Interviews lasted one to two hours, were recorded, transcribed, and structured around topics including market developments, business model elements, and firm responses to exogenous changes. We also collected secondary data (e.g., websites, press releases, social media, news articles, annual reports) before and after interviews to enable follow-up questions and triangulation.

In this phase, we analysed the data in NVivo using a two-step process: within-case analysis followed by cross-case comparison. In the first step, we examined each case individually to identify business model changes using the framework by Cavalcante et al. (2011), and coded exogenous changes into first- and second-order themes inspired by Gioia et al. (2013). Both authors coded the data independently and reached consensus through discussion. We then repeated the process to identify responses that did not involve business model changes. This analysis led to the synthesis of four sources of environmental change and four types of firm responses, including non-responses. We also documented the motivations behind each response and validated our findings with secondary data.

The second phase mapped changes on the Swedish solar PV market between 2009 and 2024. In 2024, we compiled secondary data from two annual IEA PVPS report series: the *National Survey Report of PV Power Applications in Sweden* (2002-2023) and *Trends in PV Applications* (1992-2023). To capture recent developments, we conducted two expert interviews in 2025, which were recorded, transcribed, and focused on current trends in the Swedish and global solar PV markets. The data was compiled into two databases categorised by year and topic (e.g., installation rates, system costs, policies, regulations, business models). Interview excerpts were added to relevant categories. We then categorised all data according to the four identified sources of exogenous change and mapped key developments along a timeline (see Figure 1, Paper IV).

The third phase revisited firm responses though seven follow-up interviews with the founders and managers[4], conducted between December 2024 and March 2025. Each interview lasted about one hour, was recorded, transcribed, and built on topics from the first phase, with added questions about specific events identified in the second phase. We also collected updated secondary data (e.g., websites, social media, press releases) before and after the interviews. The data was coded into existing categories of exogenous change and firm responses, using a more top-down approach than in the first phase, while remaining open to new patterns. Finally, we mapped firm responses to exogenous changes along the timeline.

4.8. Methodological Reflections

Given the socially constructed nature of both markets and business models (e.g., Doganova & Eyquem-Renault, 2009; Ottosson et al., 2020), and the emergent stage of research on business models in sustainability transitions (Aagaard et al., 2021), a qualitative research approach offers a particularly strong fit for this thesis, as it enables close analysis of how actors interpret, enact, and respond to evolving market conditions. At the same time, as with any empirical inquiry, this approach also entails several methodological limitations that warrant careful reflection. Most notably, qualitative methods do not allow for statistical estimation of causal effects or precise measurement of the impact of business models on market formation. Their strength instead lies in generating rich, contextualised insights into how and why business models may influence market formation processes (Yin, 2014). This depth is particularly valuable for understanding mechanisms and firm strategies that underlie market formation mechanisms, insights that would be difficult to capture through quantitative methods.

Another key limitation of the chosen research design is that it examines market formation while it is still ongoing, which means that not all phases of the process can be observed in full. A historical design could have addressed this limitation but would have risked reconstructing motivations and decisions in light of outcomes that were not known to actors at the time (Mahoney, 2015). Although the research approach chosen for this study also relies on interviewees' recollections to some extent, these accounts are anchored in an ongoing process rather than a completed one and collected at different points in time. As such, it captures actors' evolving understandings, uncertainties, and decision rationales as they emerge, which limits retrospective rationalisation. Nevertheless, linking firm-level business model actions to system-level outcomes such as market formation is methodologically challenging and typically requires sustained longitudinal analysis, as these connections often only become visible as interactions accumulate and institutional patterns consolidate over time (Aagaard et al., 2021). In this regard, this thesis provides a foundation for future longitudinal research that can trace how these dynamics evolve and stabilise over time.

Reflecting on the methodological choices of this thesis highlights both strengths and limitations related to the trustworthiness of qualitative research (i.e., credibility, transferability, dependability, and confirmability) (Lincoln & Guba, 1985). Across the thesis, credibility has been strengthened through multiple forms of triangulation and cross-validation. The four studies draw on a variety of empirical materials (e.g., published empirical cases, multi-actor interviews, longitudinal interviews, and extensive secondary material such as firm websites and

[4] One firm declined due to closure.

IEA PVPS market reports), enabling insights to be corroborated from several angles. The temporal dimension integrated across the thesis also enhances credibility. Beyond the longitudinal interviews in Study IV, the research incorporates secondary data spanning two decades, which helps mitigate retrospective bias and supports more robust interpretation of firm responses.

The decision to focus on the Swedish solar PV market inevitably limits transferability, especially given the cross-country contextual differences (e.g., Strupeit & Palm, 2016). However, the research design also incorporates features that enhance transferability. Restricting the empirical setting to Sweden enabled a more detailed examination of how business models and market formation interact over time, which would have been difficult to obtain in a broader, cross-country design. This depth supports analytic generalisation to other contexts in which downstream firms face similar market formation challenges. Transferability is further strengthened through a replication logic across studies, for example by approaching market formation challenges from different empirical perspectives. Still, transferability remains constrained by the national focus and market characteristics specific to Sweden. Future comparative research is therefore invited to assess the extent to which these findings hold in other contexts.

Dependability is reinforced through clear documentation, methodological coherence, and transparent reporting of adaptations throughout the research process. In particular, the thesis provides an account of how its focus evolved in response to empirical insights and contextual developments. Importantly, these adjustments did not compromise methodological consistency; instead, they ensured closer alignment between empirical evidence, research questions, and theoretical framing.

Confirmability has been strengthened through collaboration with co-authors, which provided continuous opportunities for analytical challenge and cross-checking. Independent coding rounds, joint discussions of emerging themes, and iterative manuscript development helped reduce individual researcher bias and ensured that interpretations remained grounded in shared assessments of the data. The extensive use of secondary material also offers external reference points that reinforce and nuance interview-based interpretations.

Overall, despite its limitations, the thesis seeks to uphold research quality through methodological transparency, extensive triangulation, and analytical depth. It should be noted that the AI-based language tool Copilot was used for copyediting. However, all substantive analysis and interpretations remain my own.

5. Summary of Appended Papers

This chapter summarises the four papers included in the thesis. Each paper addresses one or more of the research questions, differs in publication status, and reflects varying levels of my contribution to the writing process (Table 7). Papers I, II, and IV were co-authored with my main supervisor, Ingrid Mignon, while Paper III was co-authored with my co-supervisor, Lisa Govik. Paper I draws on research on sustainable business models to explain how firms use business models to navigate market formation challenges. Paper II identifies firm-level market formation challenges and corresponding business model configurations in the Swedish solar PV market. Paper III adopts an interorganisational perspective, showing how firms navigate market formation challenges through networked business models for solar PV parks. Paper IV adds a temporal perspective by explaining how firms respond to evolving market formation challenges over time through their business models.

Table 7. Overview of appended papers.

Paper	Title	Status	Authors' Contributions	RQs
I	Sustainable business models and innovation strategies to realize them: A review of 87 empirical cases.	Published in *Business Strategy and the Environment*, 2023.	Mignon, I*: Conceptualisation, data analysis, writing original and revised draft, review and editing, funding acquisition, supervision. Bankel, A: Data collection and analysis, writing original and revised draft, review and editing.	RQ2
II	Solar business models from a firm perspective – an empirical study of the Swedish market.	Published in *Energy Policy,* 2022.	Bankel, A.**: Data collection and analysis, writing original and revised draft, review and editing. Mignon, I.**: Conceptualisation, writing original and revised draft, review and editing, funding acquisition, supervision.	RQ1-RQ2
III	Networked business models on a nascent market for sustainable innovation.	Published in *Supply Chain Management: An International Journal,* 2025	Bankel, A.*: Conceptualisation, data collection and analysis, writing original and revised draft, review and editing. Govik, L.: Conceptualisation, writing original and revised draft, review and editing, supervision.	RQ1-RQ2
IV	How do new business models and their environment co-evolve? The importance of new entrant responses.	Under development for journal submission following two review rounds in *Long Range Planning*.	Bankel, A.*: Conceptualisation, data collection and analysis, writing original and revised draft, review and editing. Mignon, I.: Conceptualisation, writing original and revised draft, review and editing, funding acquisition, supervision.	RQ1-RQ2

* *First author.* ** *Equal contribution.*

5.1. Paper I

Paper I provides a conceptual foundation for understanding how business models can serve as devices for market formation by examining how firms use business models and business model innovation strategies to pursue sustainability-oriented objectives. The paper reviews 87 empirical firm-level cases drawn from 25 academic articles on sustainable business models and their corresponding business model innovation strategies. Motivated by the need to simplify existing typologies of sustainable business models, synthesise business model innovation strategies, and clarify their relationship, the paper identifies four reoccurring types of sustainable business models and outlines the four main innovation strategies firms use to develop and implement them.

The paper distinguishes between sustainable business models that imply improvements towards efficiency, are based on new ways of doing business, have a stronger orientation towards the environment or society, and are born sustainable. Business models that imply improvements towards efficiency aim to reduce environmental impact through resource efficiency, waste minimisation, or increased use of renewable resources. Models based on new ways of doing business involve shifts from selling products to offering services, sharing platforms, or circular economy practices. Business models with a stronger orientation towards the environment or society prioritise stakeholder collaboration, equitable value distribution, and social inclusion. Born-sustainable models are founded with sustainability as their core mission from the outset.

To develop and implement these models, firms employ strategies such as boundary spanning, experimentation, the use of practical tools and guidelines, and corporate management methods. These strategies are often used in combination, with boundary spanning and experimentation being the most common. Boundary spanning involves engaging external stakeholders through mechanisms like shared ownership, education, long-term agreements, partnerships, and platform sharing. Experimentation includes pilot projects, test groups, and iterative testing to enable learning and continuous adaptation of the business model. While not exclusive to sustainability, experimentation is a general strategy for business model innovation. Practical tools and guidelines assist firms in understanding and innovating their business models toward sustainability. Corporate management strategies, such as leading by example, employee involvement, and articulating a new vision, are crucial for implementing and sustaining these models.

Together, these findings offer an empirically grounded conceptual framework that links different types of sustainable business models to the strategies firms use to develop and implement them. The paper shows, for example, that boundary spanning strategies are more commonly associated with business models that have a stronger orientation towards the environment or society, whereas experimentation strategies are particularly prominent in the development of business models that are based on new ways of doing business. This framework informs the thesis's analysis of how firms use business models to navigate market formation challenges, by drawing on insights into how firms respond to broader societal and environmental challenges and how these responses translate into distinct business model configurations.

5.2. Paper II

Paper II contributes to the thesis by demonstrating how firms' business model choices are reflected in the current structure of the Swedish solar PV market, explaining why certain business models dominate while others remain marginal under prevailing market conditions. The paper specifically seeks to bridge the gap between how solar PV business models are conceptualised in energy policy research and how firms actually use business models to structure and communicate their offerings to customers. Energy policy research typically categorises business models based on actor roles, activities, and applications (e.g., host-owned, third party-owned, and community solar business models), an approach that often resembles deployment models rather than capturing firms' underlying value creation and value capture logics. In contrast, the paper shows that solar firms design and articulate their business models around how they create, deliver, and capture value for specific customer segments, reflecting firm capabilities and strategic positioning.

Based on an empirical analysis of 241 Swedish solar firms, the paper identifies six distinct business models: consulting services, technology provision, turnkey installation, leasing, engineering, procurement and construction (EPC), and power purchase agreements (PPA). This typology illustrates how firms build on their existing capabilities to position themselves along the solar PV value chain and tailor offerings to different customer needs and project scales. The analysis reveals a strong dominance of turnkey installation and technology provision models, while business models based on leasing, PPA and EPC are comparatively rare. Notably, none of the studied firms employ a community solar business model or explicitly target community groups, despite the prominence of this model in energy policy discourse.

By highlighting these patterns, the paper demonstrates that similar deployment models can conceal substantial differences in firm strategies and capabilities. For example, although leasing and PPA are both categorised under third-party ownership, they differ markedly in terms of target customers, capital intensity, and operational complexity. Furthermore, the paper shows that business models associated with large-scale solar PV deployment, such as EPC and PPA, remain rare in Sweden. This scarcity reflects not only the higher complexity and investment requirements of these models but also the influence of policy instruments that favour small-scale, adopter-owned systems. By offering direct capital subsidies for host-owned installations, Swedish policy has indirectly steered firms towards business models based on technology provision and turnkey installation. These differences have important implications for understanding the conditions under which firms pursue particular business models. In particular, the paper illustrates the critical role of policy frameworks in steering firms' business model choices and how this, in turn, contributes to uneven development across market segments, as firms concentrate on certain customer groups while leaving others under-served.

5.3. Paper III

Paper III adds an interorganisational perspective to the thesis by illustrating how firms navigate market formation challenges through business models that involve multiple actors. Using a comparative case study of the actor networks surrounding three solar PV parks in Sweden, the paper explores the drivers, challenges, and interactions that shape these networked business models. All three business models were structured around PPAs and involved constellations of public and private actors assuming roles such as developer, contractor, landowner, park owner, grid operator, electricity retailer, and offtaker.

The paper identifies a range of drivers for participating in the network, including transactional, relational, environmental and social motives. Since financial outcomes were uncertain, non-economic incentives became especially important. A major challenge was the underdeveloped and fragmented regulatory landscape, involving permitting processes that spanned multiple governance levels and an unclear regulatory treatment of solar PPAs. Yet the networked arrangement helped actors manage these regulatory risks and even influence regulatory development by pioneering financial setups that prompted institutional adaptation. Grid operators often had limited incentives to exceed their formal obligations, but when they were motivated to assume additional roles in the network, their engagement increased.

The paper highlights the dynamic nature of networked business models where actors' roles evolve over time, and new participants enter as others exit. Knowledge sharing enabled actors to build capabilities and expand their individual business models, but it also introduced competitive tensions as collaboration created conditions for opportunistic behaviour. To manage this tension, and to balance control over key resources with the flexibility required to respond to market developments, the networks combined transactional and relational governance mechanisms. Ultimately, the paper shows how firms use networked business models to mobilise distributed resources, structure activities and relationships, manage regulatory risk, and influence institutional development. Figure 4 illustrates the findings of Paper III through a framework of networked business models.

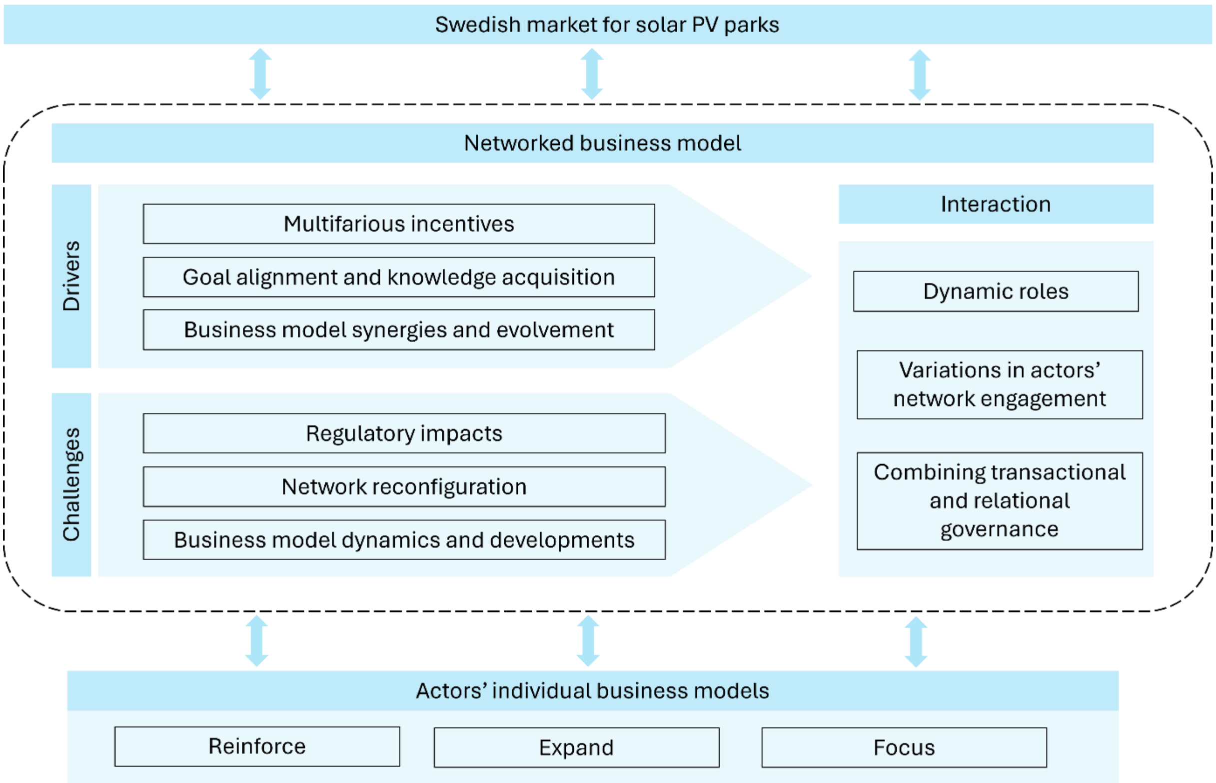

Figure 4. Framework of networked business models (adapted from Paper III).

5.4. Paper IV

Paper IV introduces a temporal dimension to the thesis by tracing how market formation challenges in the Swedish solar PV market have evolved over a 15-year period, and how seven firms with novel business models (e.g., alternative ownership or service-based models) have responded to these shifts. While the thesis focuses on market formation challenges, this paper adopts a broader lens by also highlighting opportunities. It identifies four main sources of exogenous change (technology, market, networks, and institutions), which correspond to the three dimensions of market formation emphasised in the thesis (technology, actors and networks, institutions). The paper further shows that the firms responded to these changes in four distinct ways: embracing, adapting, resisting, or persisting.

Embracing and adapting both involve modifying the firms' business models, whereas resisting focuses on shaping the external conditions surrounding those models, and persisting reflects a deliberate choice not to act. Embracing entails creating a new business model or adding elements to an existing one (e.g., offerings, partnerships, revenue streams). Adapting, by contrast, involves removing elements (e.g., offerings, target customer segments, activities) or even terminating the business model altogether. Resisting includes efforts to influence the broader market by building legitimacy through education, mobilising collective action, or shaping regulation through lobbying or legal action. Persisting was observed in only one case: a firm that had shifted from solar PV leasing to turnkey installation chose not to reintroduce leasing, even after demand for it increased. This decision was grounded in the firm's accumulated expertise in turnkey installations, illustrating how firm agency and capability lock-in can override market signals.

A key insight of the paper is that firms respond differently to the same exogenous changes. For example, while some firms lobbied the government to address grid congestion challenges, others treated these challenges as opportunities to expand their offerings in ways that bypassed the issue. These differences highlight the heterogeneity of firm responses, stemming from factors such as variations in internal capabilities and degrees of dependence on external stakeholders. Even when firms adopt the same type of response, the way it is expressed through the business models can differ. In response to high electricity prices, for instance, one firm expanded its offering, whereas another expanded its revenue streams, reflecting differences in strategy or learning processes. The effectiveness of resist responses also varied, particularly in relation to policy volatility. In some cases, efforts to influence institutions were successful, such as when several firms collectively pursued legal action in response to shifting interpretations of tax deductions and won. In other cases, attempts to shape the policy environment had limited or delayed effects. For example, efforts to accelerate the implementation of EU directives on energy balancing did not yield immediate change, prompting some firms to adjust their response by forming partnerships that enabled them to operate despite unresolved regulatory barriers.

Overall, the paper provides a deeper understanding of how business models evolve in response to market formation challenges over time, foregrounding firm heterogeneity and agency. It emphasises that firms not only adapt their business models to changing market conditions but also actively seek to shape those conditions in ways that support their business models.

6. Synthesis

This chapter synthesises the findings from the appended papers in order to answer the research questions of the thesis. Drawing on the integrative framework developed in Chapter 3, it first identifies and analyses the market formation challenges encountered by firms in the Swedish solar PV market, thereby addressing the first research question. The chapter then examines how firms navigated these challenges through their business models, addressing the second research question. Finally, by considering these findings together, the chapter points to the dynamic interplay between firms' business models and the market conditions in which they are embedded.

6.1. Firms' Market Formation Challenges (RQ1)

The appended papers demonstrate that firms in the Swedish solar PV market faced challenges related to both technology, actors and networks, and institutions. Compared with the phase-specific challenges outlined in Section 3.1, the identified challenges correspond to several, but not all, of the challenges associated with the bridging and mass-market phases. Technological challenges were relatively limited and primarily reflected mass-market characteristics, such as managing revenue risks stemming from fluctuating electricity prices and constraints related to grid access and other complementary assets. By contrast, challenges concerning actors and networks, as well as institutions were numerous and reflected a combination of bridging-market challenges (e.g., value-chain gaps, limited access to capital, and underdeveloped regulations) and mass-market challenges (e.g., heterogeneous adopter limitations, and policy volatility).

These findings are consistent with prior research showing that market formation challenges may persist even after a technology becomes cost-competitive (e.g., Hyysalo et al., 2022; Karneyeva & Wüstenhagen, 2017). At the same time, the results extend this literature by demonstrating that firms simultaneously face multiple phase-specific challenges across technological, actor and network, and institutional dimensions. Table 8 provides an overview of the identified challenges experienced by Swedish solar PV firms, which are further elaborated in the following subsections.

6.1.1. Technological Challenges

Firms in the solar PV market experienced relatively few technological challenges related to performance and cost, which are often emphasised in prior research on market formation (e.g., Andersson & Jacobsson, 2000). Instead, their main technological challenges arose from the inherent *characteristics of the focal technology* (e.g., high upfront investment requirements and strong embeddedness in the electricity system) and from limited alignment with *complementary assets* (e.g., electricity grid, batteries), rather than from insufficient technological development.

Table 8. Market formation challenges experienced by solar PV firms in Sweden.

	Challenges	Examples
Technology	Focal technology characteristics	High upfront cost of solar PV.
		Fluctuating electricity prices linked to the system-embeddedness of solar PV.
	Complementary asset links	Limited integration with electric vehicle chargers, batteries, heat pumps, and roofing services.
		Restricted and costly grid access due to congestion.
Actors & Networks	Value chain gaps	Limited capabilities for large-scale solar PV deployment among Swedish firms.
		Temporary gaps due to firm specialisation.
	Limited access to capital	Difficulties to attract financing for large-scale applications and new offerings (e.g., leasing).
	High competition	Quality risks from low-skill entrants.
		Opportunistic behaviour by new and incumbent firms. Intense competition resulting in firm exits.
	Incumbent resistance	Effective lobbying to delay ending the exclusive balancing-service mandate of energy utilities.
		Grid operators' reluctance to disclose information beyond minimum legal requirements.
	Adopter limitations	Limited installation skills among adopters.
		Unwillingness of adopters to change habits.
	Too weak network interactions	Difficulties in identifying key stakeholders for large-scale solar PV applications.
	Too strong network interactions	Industry associations' predominant focus on small scale solar PV deployment issues.
Institutions	Unfavourable policies	Limited vertical coordination for permit processes.
		Investment subsidy disadvantaging third-party ownership and large-scale solar PV application.
	Underdeveloped regulations	Regulatory uncertainty on financial setup for solar PV.
	Policy volatility	Unpredictable and short-notice policy changes.
	Limited legitimacy	Limited legitimacy for solar PV, but mostly for new business models used to commercialise it.

With regard to challenges linked to the *technological characteristics* of solar PV, Paper II shows that the high upfront investment cost of solar PV exposed adopters to financial risk, which firms needed to actively manage in order to stimulate adoption. Papers II, III and IV further identify challenges related to fluctuating electricity prices, reflecting the high system-embeddedness of solar PV and its dependence on electricity market conditions. These findings are consistent with previous research showing that, for mature low-carbon technologies, key challenges typically arise from capital intensity and exposure to market-based revenue uncertainty rather than from technological price-performance limitations (e.g., Iyer et al., 2015; Mignon & Bergek, 2016). At the same time, Paper III illustrates that the system-embeddedness of solar PV and the associated electricity price uncertainty constituted both a challenge and an opportunity for firms collaborating around solar PV parks. While revenue risks nearly prompted firms to exit the network, the same uncertainty incentivised offtakers (i.e. electricity buyers) to enter into long-term PPAs to hedge against price volatility, thereby enabling the deployment of solar PV parks.

Paper II, III and IV also highlight challenges with *complementary assets* (i.e., infrastructure, technologies, products, and services that need to be developed alongside the focal technology), particularly in terms of their limited connections to solar PV. For instance, Paper II shows that, although the benefits of solar PV were greatly enhanced in combination with electric vehicle chargers, solar PV batteries, heat pumps and roofing services, their mutual benefits were not always recognised among firms. Paper IV indicates that a potential explanation for this could be the relative high price for such complementary technologies. Paper III and Paper IV also show that limited and costly access to the electricity grid constituted a major challenge for firms as it significantly impacted the economic viability of their solar PV projects. For example, in Paper IV, grid congestion issues led to significant delays in connecting solar PV systems to the grid (thus postponing its ability to start generating revenues) or high costs for doing so, which made the projects unprofitable to pursue. These findings are in line with previous research on how misalignment with complementary assets can hamper market growth (e.g., Karneyeva & Wüstenhagen, 2017; Markard, 2020), and illustrate how such misalignments pose challenges for firms by eroding the economic potential of commercialising solar PV.

Many of the technological challenges emphasised in previous research, such as low price–performance ratios, technological immaturity, and uncertainty regarding competing designs (e.g., Andersson & Jacobsson, 2000; Markard, 2020) were not encountered by the studied firms. Instead, the findings point to the technological maturity and cost-competitiveness of solar PV, characteristics typical of the mass-market phase (Jacobsson & Bergek, 2004). As demonstrated in Paper IV, declining costs of solar PV and complementary technologies (e.g., electric vehicle chargers, batteries, and heat pumps) primarily stimulated firm entry into the Swedish market and encouraged the expansion of firms' offerings. Notably, none of the papers identified firm-level concerns about resource constraints or recycling needs for solar PV, despite the growing prominence of these mass-market issues in recent research (e.g., Atasu et al., 2021; Ertelt & Carlborg, 2024). Instead, firms continued to face constraints related to high upfront investment requirements, the strong system embeddedness of solar PV, and persistent misalignments with complementary assets.

6.1.2. Actor and Network Challenges

The appended papers highlight several market formation challenges related to supply- and demand-side actors and their networks. Supply-side issues involve *value chain gaps*, *limited access to capital*, *high competition*, and *incumbent resistance*. Demand-side challenges relate to *adopter limitations* in terms of resources and behaviours, while network challenges involve *too weak network interactions* as well as *too strong network interactions*.

In line with e.g., Hyysalo et al. (2022), Paper II and III point to challenges in the form of *value chain gaps* (i.e., the absence or insufficiency of actors, capabilities, and coordination mechanisms required to perform critical deployment-related activities). However, while these authors mainly emphasise the absence of actors and capabilities to deliver trustworthy, context-specific evaluation and coordination of technology suppliers, this thesis points to a broader lack of capabilities for large-scale deployment among firms in Sweden. As illustrated by Paper II, large-scale solar PV projects are not simply a matter of scaling up existing practices; rather, they introduce new layers of complexity that require firms to possess not only substantial financial resources, but also the skills to form and manage partnerships with a range of different actors, including financial institutions, municipalities, local communities, landowners, and grid operators. Paper III further reveals that the lack of such capabilities in Sweden means that firms often cannot rely on their current relationships when scaling up. Instead, they are compelled to seek out new collaborators, often from abroad, to fill critical skill and resource gaps. The scarcity of skilled actors also means that when key firms exit or shift focus, their roles cannot easily be replaced, leading to disruptions and delays in project implementation and ultimately market development. This finding challenges the assumption that specialisation always leads to efficiency (e.g., Jacobsson & Bergek, 2004), and instead shows how it can create temporary gaps in the value chain.

Another challenge closely linked to value chain gaps is *limited access to capital*. Paper II and IV highlight how firms struggle to raise funds for large-scale solar PV projects. This finding aligns with previous research, which has shown that the risk aversion of mainstream investors often makes it difficult to secure substantial capital for projects of that size (e.g., Karltorp, 2016; Mignon & Bergek, 2016). However, Paper II and IV also show that this challenge is not confined to large-scale projects but is equally critical for new business models such as solar PV leasing. The third-party ownership structure inherent in leasing arrangements introduces additional layers of risk, which makes it difficult to attract investors. As a result, even firms that manage to secure financing often become highly dependent on the preferences of their investors, since there are so few available.

High competition has also created significant challenges for firms. In line with Kangas et al. (2018), Paper III shows that the entry of firms with limited prior experience in solar PV deployment led to quality concerns, risking the credibility of more established actors. The paper also demonstrates how both opportunistic new entrants and incumbent firms (such as energy utilities) partnered with solar firms to learn how to implement large-scale solar PV projects on their own, offering key resources in exchange. While this knowledge transfer can benefit market formation by increasing the number of skilled actors (e.g., Jacobsson & Bergek, 2004), it also intensified fears of knowledge spillover among solar firms on the market. Paper IV further reveals that firms experienced intense competition as market growth plateaued following a temporary surge in demand driven by falling technology costs, ongoing public subsidies, and volatile electricity prices. The heightened competition for projects and customers made it increasingly difficult for firms to maintain profitability, resulting in widespread market exits and bankruptcies. This finding contrasts previous literature, which often associates such industry shakeouts with the establishment of a dominant design (e.g., Markard, 2020), as the Swedish solar PV market did not undergo significant technological shifts during this period.

Although Papers III and IV provide examples of established energy utilities collaborating with solar firms to promote solar PV, they also reveal challenges related to *incumbent resistance*. The most striking example, detailed in Paper IV, is how incumbent firms successfully lobbied to delay the implementation of an EU directive that would have allowed third-party actors to provide grid balancing services. As a result, energy utilities retained their exclusive legal mandate to offer these services until further investigations are completed, effectively preventing solar firms from leveraging their resources and expertise in this area. Furthermore, Paper III demonstrates that grid operators often acted as bottlenecks in the development of solar PV parks. By providing only the minimum information required by law, they made it difficult for solar firms to identify optimal connection points in the electricity grid. These behaviours align with previous research showing that incumbents may defend their existing position by lobbying or restricting access to critical infrastructure (Negro et al., 2012).

In relation to the demand-side, firms experienced significant challenges arising from *adopters' limited resources and behaviours*. Papers II and IV illustrate that adopters' limited technical skills, particularly in the residential segment, were perceived as a liability. Because electrical installations must be carried out by certified professionals, firms selling solar PV components directly to these customers had little control over installation quality, increasing the risk of unsafe systems and potential reputational damage. While previous research on innovation diffusion has highlighted limitations in adopter resources (e.g., Mignon & Bergek, 2016), it has primarily done so from an adopter perspective. This thesis extends this discussion by showing how these limitations also create challenges for firms targeting such adopters. Paper II and IV further illustrate issues related to adopter behaviours. In particular, adopters' administrative practices and preferences created obstacles for firms, as many adopters were unwilling or unable to modify existing arrangements to accommodate the technical and contractual requirements of solar PV. For example, Paper II describes how owners of apartment buildings were accustomed to measuring and billing electricity consumption individually for each flat. A shared solar PV system would require a joint contract, binding all residents under one agreement, which would complicate billing and limit individual choice. This observation aligns with Markard et al. (2020), who note that a majority of adopters may be reluctant to change their preferences for new technologies. However, these findings offer more detailed empirical evidence by clearly demonstrating how such inflexibility among adopters directly constrains firms' ability to implement and scale solar PV solutions.

Paper III and IV show that firms encountered challenges arising from both *too weak and too strong network interactions*. Regarding weak interactions, Paper III demonstrates that knowledge asymmetries and dispersed resources among market actors made it difficult for firms to identify landowners with suitable sites for solar PV parks and offtakers whose energy needs matched the planned electricity production. Such weak ties are characteristic of the nursing phase (Negro et al., 2012), and therefore a somewhat surprising observation given the maturity of solar PV. In contrast, Paper IV highlights challenges associated with overly strong network ties. Specifically, the Swedish solar industry association's strong focus on small-scale solar PV applications meant that issues relevant to large-scale projects received less attention in advocacy efforts. Consequently, there was less pressure on policymakers to address the needs of large-scale solar PV actors. This finding aligns with previous research showing that strong network connectivity can lead to strategic conformity (e.g., Jacobsson & Bergek, 2004), but it extends this understanding by providing empirical evidence on how such conformity can be problematic even after the emergence of a dominant design. Furthermore, it shows that strong ties can disadvantage certain actors in a network, such as those focused on large-scale applications, while benefitting others.

These findings show that firms faced distinct actor and network challenges depending on the market segments they targeted. Challenges associated with large-scale applications primarily reflected characteristics of the bridging phase, whereas challenges in small-scale applications aligned more closely with the mass-market phase. This is evident in the coexistence of intense competition and firm exits in small-scale segments, alongside limited access to capital and value chain gaps stemming from a lack of firms with the capabilities required for large-scale solar PV applications. This divergence is consistent with the argument put forward by Dewald and Truffer (2011) that market formation may develop differently across market segments.

6.1.3. *Institutional Challenges*

The papers show that firms in the Swedish solar PV market faced several challenges related to both formal institutions (e.g., policies, rules, and regulations) and informal ones (e.g., norms and values). Formal institutional challenges primarily concerned *unfavourable policies, underdeveloped regulations*, and *policy volatility*, whereas informal institutional challenges mainly related to *limited legitimacy*.

In terms of formal institutions, firms encountered *unfavourable policies*, with poor policy coordination (Markard et al., 2020) constituting a major obstacle. Paper III and IV reveal that firms struggled with complex permit processes for solar PV parks, having to navigate policies at three distinct levels that were poorly coordinated. Several firms also highlighted challenges related to technology-specific policies. However, contrary to what is commonly emphasised in earlier literature (e.g., Jacobsson & Bergek, 2004), the main obstacles were not the absence of technology-specific policies, but rather the presence of such policies that proved unfavourable to certain market actors. For instance, Paper II demonstrates that while the governmental investment subsidy for solar PV has stimulated market growth, it has also skewed development toward small-scale applications and adopter ownership setups. Consequently, firms focusing on large-scale projects or business models based on third-party ownership (such as leasing or PPA) have been significantly disadvantaged, facing a notable difference in competitiveness.

Furthermore, Paper III highlights challenges associated with *underdeveloped regulations*. In particular, firms faced legal uncertainties regarding the use of PPAs for solar PV deployment. This uncertainty meant that firms were not sure whether their chosen financial setups were legally permissible or if they might later be declared unlawful. Pursuing these business models therefore involved significant risks, including the possibility of having to make costly changes in the future or even being forced to terminate the business altogether. In contrast to previous literature, which has mainly emphasised the importance of developing technology-specific regulations (e.g., Markard, 2020), these findings underscore the need for regulatory frameworks that also enable diverse ways of commercialising the technology.

Paper II and IV also emphasise the challenges firms face due to *policy volatility*. While previous research has highlighted risks associated with policy phase-outs, such as boom-bust market dynamics (e.g., Dewald & Truffer, 2011; Karneyeva & Wüstenhagen, 2017), this thesis provides a deeper understanding of how these dynamics affect firms operating in the market. In particular, Paper IV shows that the Swedish government's solar PV investment subsidy program underwent several changes since its introduction in 2009 (often with little advance notice) and was abruptly terminated in mid-2020 before a replacement program was established. This sudden change led to a complete market halt, as many potential adopters postponed their investments while awaiting a new support scheme, severely impacting the financial stability of firms on the market. As highlighted in Paper II, market growth had largely been driven by the investment subsidy program, making firms highly sensitive to such policy changes. Paper IV further illustrates the effects of policy volatility through the example of the green tax deduction that was introduced after the investment subsidy. The Swedish Tax Agency unexpectedly changed its interpretation of who was eligible for the deduction, ruling that owners with batteries used for grid balancing services were no longer entitled to the benefit. This decision significantly reduced the added value of adopting solar PV systems with complementary technologies, further complicating firms' ability to plan and invest.

In terms of informal institutions, the appended papers mainly highlight firm challenges related to *limited legitimacy*. Consistent with previous research (e.g., Markard et al., 2016), Paper IV point to some difficulties arising from the limited legitimacy of solar PV technology itself, requiring firms to actively persuade potential adopters and investors of its benefits and to reassure them that solar PV can be advantageous even in Sweden, where sunshine is comparatively limited. However, both Paper III and IV show that firms more frequently encountered challenges related to the limited legitimacy of the business models used to commercialise solar PV. For example, several firms struggled to convince stakeholders of the advantages of adopting new business models, such as leasing or PPAs, because these models lacked legitimacy in the Swedish context. This lack of acceptance made it harder for firms with such business models to attract customers and partners, ultimately constraining deployment of solar PV within the market segments they targeted.

Surprisingly, although scholars and policymakers have stressed the need for equitable access of solar PV (e.g., Sovacool et al., 2022), particularly through community ownership, Paper II demonstrate that this challenge was not acknowledged by firms on the Swedish solar PV market, as none of the 241 studied firms explicitly targeted community groups. This absence does not imply that equity challenges or community-owned solar PV initiatives are missing in Sweden (as evidenced by e.g., Bergek and Palm (2024)). Instead, it suggests that Swedish firms are either unaware of community groups as a potential user segment or do not perceive sufficient benefits in serving them, consistent with research showing that firms tend to prioritise segments that offer clear prospects for capturing economic returns (Teece & Linden, 2017).

6.2. Firms' Use of Business Models (RQ2)

The appended papers demonstrate that firms adopted five distinct business model approaches to navigate the challenges of the Swedish solar PV market: bundling, business scope change, holistic value framing, advocacy, and collaboration. These approaches reflect distinct ways in which firms mobilised their business models in response to challenges related to technology, actors and networks, and institutions. A single firm may use several approaches simultaneously, and the same approach may be observed across different business model types (e.g., turnkey, leasing, EPC, or PPA). As such, rather than representing specific business model types or configurations, the approaches denote patterned ways of using or enacting the business model in practice: (1) *bundling* refers to the integration of solar PV with complementary technologies, products, or services into offerings tailored to specific adopter groups; (2) *business scope change* involves the expansion or narrowing of business activities to increase value captured by the firm; (3) *holistic value framing* entails emphasising social, environmental, or relational value alongside economic benefits; (4) *advocacy* concerns using the business model as a reference point for promotional, legitimation, or lobbying activities; (5) *collaboration* involves coordination of resources and activities across organisational boundaries.

These approaches resonate with established insights on the performative roles of business models discussed in Section 3.3, particularly with regard to their value creating and boundary spanning functions. For example, bundling and business-scope change approaches are closely linked to firms' efforts to create and capture value from new technology (e.g., Chesbrough & Rosenbloom, 2002; Teece, 2010), whereas advocacy and collaboration primarily serve to enrol and coordinate key stakeholder and therefore align more closely with boundary spanning objectives (e.g., Doganova & Eyquem-Renault, 2009; Palo & Tähtinen, 2011). Table 9 summarises how these approaches were used to navigate challenges related to technology, actors and networks, and institutions, which are examined in more detail in the following subsections.

Table 9. Firms' business model approaches to market formation challenges.

	Challenges	**Approaches**	**Examples of Business Model Approaches**
Technology	Focal technology characteristics	Bundling Advocacy Holistic value framing	*Bundled* solar PV into third-party ownership models (e.g., leasing) removed high upfront costs for adopters. *Bundled* solar PV into PPAs removed offtakers' exposure to fluctuating electricity prices and served as basis for *advocacy* to enrol them. *Holistic value framing* to partners to offset revenue risks tied to fluctuating electricity prices.
Technology	Complementary asset links	Bundling Advocacy Collaboration	*Bundled* solar PV with electric vehicle chargers, batteries, heat pumps, and roofing services. *Collaborated* with grid operators, *advocated* for better grid access, or *bundled* solar PV with services that can address grid congestion issues.
Actors & Networks	Value chain gaps	Business scope change Collaboration	*Collaborated* with new and existing partners to address limited capabilities for large-scale solar PV projects. Firms addressed temporary gaps from firm specialisation by *expanding the scope of their business activities* and bringing in new firms to *collaborate*.
Actors & Networks	Limited access to capital	Business scope change Collaboration Holistic value framing	*Holistic value framing* to offset the financial risks of large-scale solar PV projects. For leasing, some firms used *collaborative* financial setups (crowdfunding) or *narrowed the scope of their business* to only target financially credible segments.
Actors & Networks	High competition	Bundling Business scope change Collaboration	Close *collaboration* with low-skill entrants who hold key resources to prevent quality issues. *Collaborated* despite opportunism by sharing knowledge selectively and limiting interactions. *Bundled* solar PV with complementary assets to create new revenue streams or *narrowed the business scope* to core activities to cut costs under intense competition.

Actors & Networks (continued)	Incumbent resistance	Advocacy Collaboration	Some firms *advocated* to end utilities' exclusive balancing-service mandate, while others chose to *collaborate* with them. Grid operators' reluctance to engage beyond legal duties was eased through *collaborations* that incentivised them to take on broader roles.
	Adopter limitations	Bundling Business scope change	*Bundled* solar PV into offerings tailored to different adopter needs and preferences. *Changed the business scope* to match adopter preferences and limited installation skills.
	Too weak network interactions	Collaboration	*Collaborated* with energy retailers to identifying offtakers for large-scale solar PV applications.
	Too strong network interactions	Advocacy Collaboration	Formed a solar PV park association to *collaboratively advocate* for large-scale solar PV issues overlooked by the industry association.
Institutions	Unfavourable policies	Business scope change Advocacy Collaboration	*Advocated* for better coordination of permit processes or *collaborated* closely to handle their complexity. *Changed business scope* to benefit from the subsidy or *advocated* for its removal.
	Underdeveloped regulations	Advocacy Collaboration	*Collaborated* to share regulatory risks of the new financial setup and *advocated* for its use by leading through example.
	Policy volatility	Business scope change Advocacy Collaboration	*Narrowed their business scope* towards less policy-reliant areas and *advocated* for policy stability through lobbying and *collaborative* legal action.
	Limited legitimacy	Advocacy Holistic value framing	*Advocated* for solar PV and new business models through demonstrations (e.g., pilot projects) and promotional activities. *Holistic value framing* to enrol key stakeholders.

6.2.1. Navigating Technological Challenges

In addressing challenges related to the technological characteristics of solar PV, particularly adopter risks tied to high upfront investment costs, firms *bundled* solar PV into a service-oriented offerings with recurring revenues. By removing the need for upfront capital and assuming the investment risk themselves, firms could lower barriers to adoption. As shown in Paper II, some firms used third-party ownership models such as leasing, where customers pay a fixed fee for solar PV system use, and PPAs, where customers purchase the electricity generated at an agreed rate. In both business models, solar PV is bundled into a service rather than sold as an asset. These business models have received considerable attention in previous literature due to their ability to reach underserved market segments (e.g., Drury et al., 2012; Strupeit & Palm, 2016).

Uncertainty related to fluctuating electricity prices constituted another major challenge, creating revenue risks for both firms and their key stakeholders. Rather than treating price volatility solely as a challenge, firms strategically reframed it as a value proposition. Papers II and III show how *bundling* and *advocacy* efforts were central to this reframing. By integrating solar PV into a broader service offering based on PPA, firms effectively hedged against electricity price volatility, turning uncertainty linked to the system-embeddedness of solar PV into a value proposition. Building on this foundation, firms then used advocacy to actively enrol offtakers into PPA-based arrangements, emphasising the benefits of long-term contracts with fixed electricity prices. For partners, firms instead used *holistic value framing* as a way to compensate for these revenue risks. Paper III demonstrates that by highlighting not only economic benefits but also social, environmental, and relational value, firms broadened the perceived payoff of participation, effectively strengthening partner commitment to the business model.

Weak linkages between solar PV and complementary assets were addressed through deliberate *bundling* approaches that expanded firms' offerings and enhanced value creation. Paper II shows that firms combined solar PV with complementary technologies and services, such as electric vehicle chargers, batteries, heat pumps, and roofing, to create more diversified and integrated offerings. Many firms leveraged their existing capabilities to exploit synergies between solar PV and their core businesses. Electricians and roofers, for instance, capitalised on their core competencies to enter the solar PV market. These patterns are consistent with research on firm strategies in market formation (e.g., Musiolik et al., 2020), which suggests that firms' actions are shaped more by the resources at their disposal than by specific market formation challenges.

Firms responded to costly and delayed grid connections is heterogenous ways, adopting three distinct business model approaches: collaboration, bundling, and advocacy. Paper III demonstrates how some firms pursued a *collaborative* business model approach, working with grid operators to secure better connection points. Yet these efforts were often constrained by operators' limited engagement beyond regulatory requirements. Paper IV illustrates that other firms reframed congestion as a strategic opportunity, *bundling* solar PV with grid-support services such as energy management and aggregation to create new value propositions. Paper IV further shows that a third group leveraged their business models as *advocacy* tools, pushing for stronger governmental oversight and increased investment in grid infrastructure. Together, these findings extend recent research on the heterogeneity of firm responses (e.g., Thomson et al., 2025) by offering broader empirical evidence of how firms navigate market formation challenges through markedly different business model approaches. Figure 5 provides an overview of the business model approaches used to navigate technological challenges.

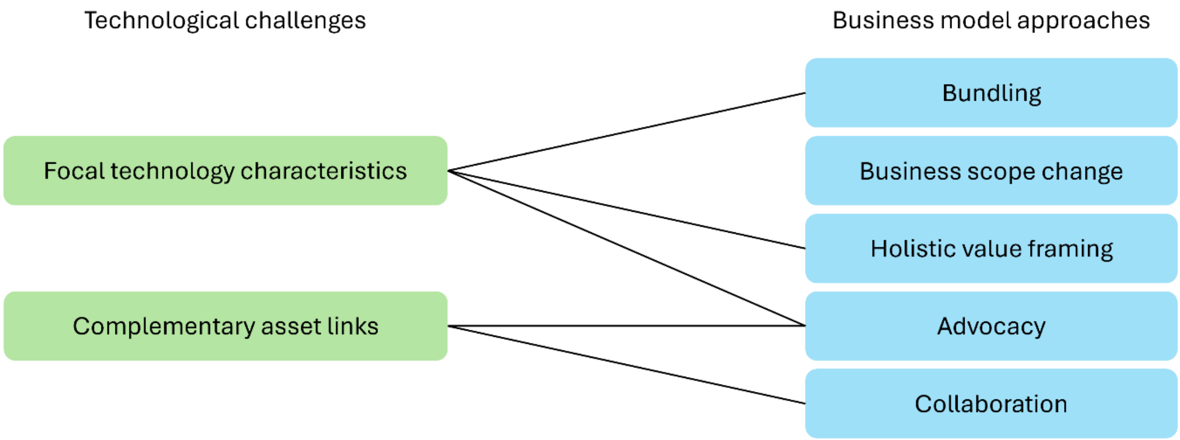

Figure 5. Business model approaches in response to technological challenges for market formation.

6.2.2. Navigating Actor and Network Challenges

Firms addressed value chain gaps stemming from insufficient capabilities for large-scale solar PV deployment in Sweden mainly through *collaborative* business model approaches with both new and existing partners. Paper III demonstrates that established relationships helped firms reduce uncertainty and coordinate activities more effectively, while new partnerships gave them access to critical resources and expertise that were missing in the Swedish market. It further shows how firms responded to temporary gaps caused by partner specialisation and network exit by *expanding the scope* of their own activities. This adaptive response transformed short-term challenges into opportunities for capability development, ultimately enabling more firms to build the competences required for large-scale solar PV deployment. Together, these findings complement existing studies on how actors can address persistent value chain gaps (e.g., Hyysalo et al., 2022) by showing how different business model approaches can bridge capability gaps.

Limited access to capital posed a major constraint for both large-scale solar PV projects and leasing models, prompting firms to adopt a range of business model approaches, including collaboration, holistic value framing, and business scope change. Paper III shows that, for large-scale projects, *collaborative* business model approaches helped firms mobilise sufficient capital, while *holistic value framing* that emphasised relational and environmental benefits was used to attract investors. Some investors were motivated by their own sustainability targets and relationship-building goals, which made them more willing to accept the financial risks associated with such projects. Paper II demonstrates that, for leasing models, firms also experimented with *collaborative* financial setups such as crowdfunding to reduce dependence on risk-averse institutional investors. Nevertheless, access to capital for leasing models remained highly conditional. Paper IV provides a striking example of how investor preferences prompted *business scope change*, as one firm abandoned residential adopters in its leasing model because investors favoured more financially credible market segments. To secure capital for scaling, the firm had to restrict its target market. This finding contrasts with prior research portraying leasing models as a mechanism for democratising access to solar PV among less affluent adopters (e.g., Drury et al., 2012), and instead highlights how investor-driven constraints can undermine the inclusive potential of such models.

Firms responded to increasing competition in the Swedish solar PV market through three distinct business model approaches: collaboration, bundling, and business-scope change. For solar PV parks, quality concerns associated with inexperienced new entrants pushed firms toward *collaborative* approaches. As Paper III demonstrates, networked business models enabled close interaction and knowledge, helping partners prevent quality failures that could damage their collective reputation. Yet these collaborations were marked by tension, as both incumbents and new entrants engaged in opportunistic behaviour, seeking access to missing capabilities while simultaneously limiting interaction to protect their own competitive advantages. Paper I further shows that such collaborative approaches were especially prevalent among incumbent firms pursuing sustainability initiatives. These firms offered partners access to substantial resources while carefully managing the risk that collaboration could evolve into competition as the market matured, a dynamic well documented in prior research (e.g., Altunay

& Bergek, 2023; Planko et al., 2016). By contrast, Paper IV illustrates how intensified competition following slowed market growth in small-scale segments prompted firms to either *bundle* solar PV with complementary technologies and services, or *narrow their scope* to focus on core activities, with some firms exiting the market altogether. These divergent business model responses underscore the heterogeneity of firm behaviour (e.g., Thomson, Chatthong et al. 2025) and highlight how different strategic logics can lead to markedly different business model approaches in the face of the same market formation challenges.

With regard to incumbent resistance, firms responded either through a collaborative approach, seeking to align interests with incumbents, or through an advocacy approach, aiming to reshape the regulatory context in which incumbents hold power. Paper I demonstrates how firms often use a *collaborative* business model approach to engage incumbents. Paper III further illustrates that the engagement of incumbents (i.e., grid operators) in *collaborative* business models for solar PV parks often remained limited to legal obligations, but that such resistance was overcome when incumbents occupied multiple roles within the network. In such arrangements, role multiplicity created intrinsic incentives to contribute beyond compliance, underscoring the importance of strategic fit for engaging incumbents in solar PV business models in line with e.g., Altunay et al. (2021). Paper IV shows examples of both *collaboration* and *advocacy* approaches in response to incumbent lobbying that delayed the implementation of an EU directive allowing third parties to provide grid-balancing services. Some firms pursued advocacy by lobbying the Swedish government to accelerate regulatory change, while others combined advocacy with collaboration by partnering with incumbent energy utilities to build knowledge of grid-balancing services and position themselves competitively ahead of regulatory reform. Together, these findings align with research on collective strategies in market formation that highlights collaboration with incumbents as a way to circumvent restrictive regulations (Kangas et al., 2021), while extending this literature by showing how such strategies are operationalised through distinct business model approaches.

In response to adopter limitations, firms either bundled solar PV with complementary assets to better match adopter needs or changed their business scope to accommodate adopter constraints over time. Paper II illustrates how *bundling* was used to tailor offerings to specific adopter groups, including hassle-free turnkey solutions addressing residential adopters' lack of installation skills, impartial consultancy offerings to meet municipalities' need for neutrality in investment decisions, and arrangements combining solar PV with individual billing mechanisms to accommodate administrative constraints of apartment building owners. These examples reveal a much finer-grained market segmentation than suggested by prior research (e.g., Burger & Luke, 2017), with firms actively tailoring offerings to adopter-specific constraints rather than treating adopters as homogeneous. Paper IV further demonstrates how firms responded to shifts in adopter characteristics by *changing their business scope* in terms of targeted adopter segments and business model configuration. Consistent with Rogers (2003), as the market expanded beyond early adopters, firms increasingly encountered adopters with lower installation skills and a stronger preference for simple solutions, leading one firm to stop selling solar PV components to residential adopters altogether. Another firm shifted from leasing to turnkey installation in response to early adopters' strong preference for technology ownership. Notably, when interest in leasing later increased (e.g., due to high interest rates) the firm chose not to revert to its original model, having developed significant capabilities in turnkey installation. This example illustrates the path-dependent nature of business model evolution (e.g., Bohnsack et al., 2014), showing how responses to shifting adopter characteristics can reconfigure both firms' market focus and organisational capabilities in ways that shape their long-term trajectories.

To address challenges arising from network interactions, firms relied on collaborative and advocacy-based business model approaches. When network interactions were too weak, firms primarily adopted collaborative approaches; when they were too strong, firms turned mainly to advocacy, sometimes in collaboration with others. Paper III illustrates how weak interactions made it difficult for solar PV park developers to identify suitable offtakers whose consumption profiles matched planned production. They addressed this challenge by *collaborating* with electricity retailers in networked business models, leveraging retailers' access to offtakers to strengthen network ties. Conversely, Paper IV illustrates how overly strong network interactions fostered strategic conformity, as the Swedish solar industry association's predominant focus on small-scale solar PV marginalised the interests of firms targeting the large-scale segment. In response, some large-scale firms engaged in *collective advocacy* by forming a dedicated solar PV park association aligned with their specific needs, while others pursued individual *advocacy* through independent lobbying. Together, these responses demonstrate that business model approaches can be pursued both independently and in combination, aligning with research on individual and collective strategies for shaping market formation (e.g., Lee et al., 2018). Yet, while prior work stresses the importance of collective action to influence regulation (e.g., Bergek et al., 2008), these findings show that collective action may also be effective for developing specific market segments when strong network interactions in adjacent segments risk overpowering the development of others. Figure 6 provides an overview of the business model approaches used to navigate market formation challenges associated with actors and networks.

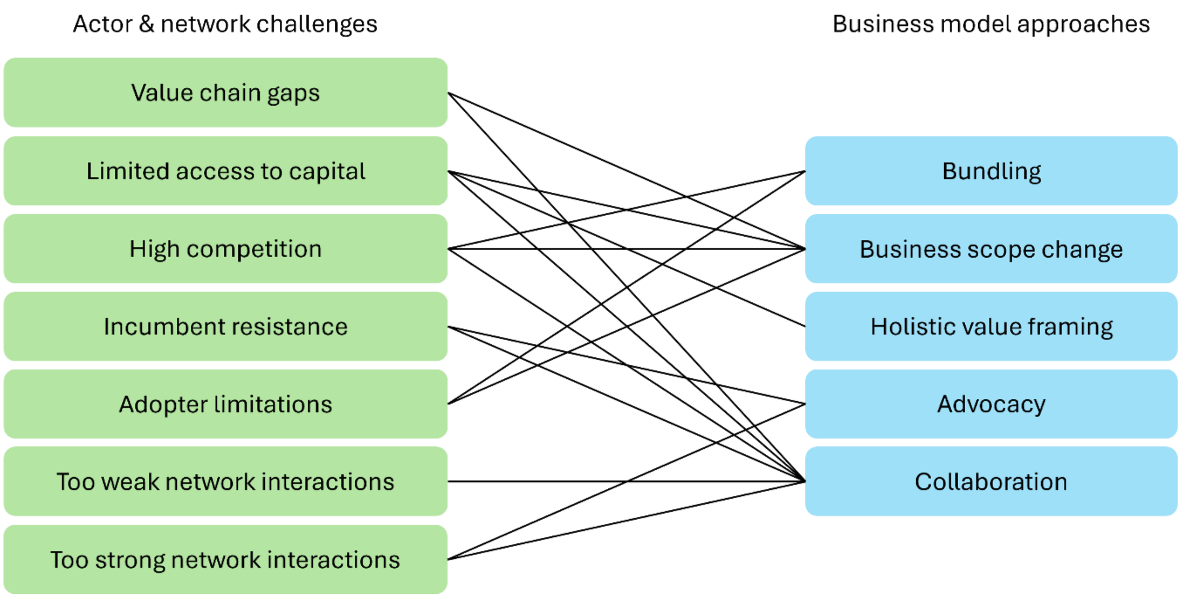

Figure 6. Business model approaches in response to actor and network challenges for market formation.

6.2.3. Navigating Institutional Challenges

Firms navigated unfavourable policies through three business model approaches: business scope change, advocacy, and collaboration. Consistent with research on business models for sociotechnical transitions (e.g., Huijben et al., 2016; Wesseling et al., 2020), these approaches reflect both conformity to and attempts to transform institutional constraints. Business scope change and collaboration primarily served conforming purposes, whereas advocacy was used as a transformative approach. Importantly, firms often employed different approaches to address the same policy-related challenge. For example, Paper III shows how firms responded to limited policy coordination among municipal, county council, and county board authorities in permit processes through *collaboration.* In these arrangements, one firm typically assumed responsibility for coordinating the resources and activities of network partners in order to mitigate bottlenecks in permitting. In contrast, Paper IV illustrates how firms *advocated* for greater alignment in permit processes to enable business models oriented towards large-scale solar PV applications. Similar patterns were observed in response to Swedish policies favouring small-scale applications and adopter ownership. Paper II demonstrates that many firms adapted their business models to these incentives by *changing their business scope,* for instance by offering turnkey installation of solar PV systems. Conversely, Paper IV highlights how firms offering solar PV leasing models challenged the same policy framework through *advocacy*, arguing that the investment subsidy created artificial demand and disadvantaged alternative models (such as leasing).

In response to underdeveloped regulations, firms employed business model approaches that combined collaboration with advocacy. Paper III shows how firms navigated regulatory uncertainties surrounding the financial arrangements of solar PPAs by *collaborating* in networked business models. This collaborative approach enabled the distribution of regulatory risks among network participants, making it possible to realise the construction of solar PV parks despite regulatory ambiguity. At the same time, the enactment of these business models functioned as a form of *advocacy*: by demonstrating the practical viability of solar PPAs, firms sent signals to policymakers and created pressure for regulatory clarification. This finding echoes Lee et al. (2018), showing that firms' business-oriented pursuits can generate spillover effects on overall market conditions beyond their immediate strategic intent.

With regard to challenges stemming from policy volatility, the findings show that firms responded through business model approaches involving business scope changes, advocacy, and collaboration. Paper IV illustrates how one firm responded to the sudden termination of the direct capital subsidy for solar PV by *narrowing its business scope*, closing certain units to concentrate resources on core activities that were less exposed to policy volatility. In contrast, other firms adopted an *advocacy*-oriented approach, actively lobbying for greater policy stability. When a sudden reinterpretation of tax-based incentive rules severely undermined business models combining solar PV with batteries and grid-support services, firms responded through *collaborative advocacy*, coordinating legal action that ultimately led to the reinstatement of the original tax interpretation. This outcome highlights not only firm resilience in the face of policy but also the role of collaboration in enhancing firms' capacity to address institutional challenges, as noted in previous research on market formation (e.g., Planko et al., 2016).

The findings point to advocacy and holistic value framing as central business model approaches for addressing limited legitimacy of solar PV and the business models used for its deployment in Sweden. With regard to legitimacy of the technology itself, Paper IV shows how firms engaged in *advocacy* through promotional activities such as educating potential adopters about the benefits of solar PV or constructing a solar PV park to demonstrate its suitability in Sweden. This finding aligns with previous research on strategies for shaping market formation (e.g., Planko et al., 2017), while also illustrating how efforts to build legitimacy for the technology simultaneously served to promote firms' own business models. Paper I further demonstrates how firms *advocated* new business models through experimentation, such as pilot projects and user tests, as well as through corporate management strategies aimed at demonstrating the model's value to both external and internal stakeholders. Across both Paper I and Paper III, these advocacy efforts were closely intertwined with *holistic value framing*, in which firms emphasised social, environmental, and relational values alongside transactional ones. For example, Paper III illustrates how the enrolment of key stakeholders into networked business models was premised not only on economic benefits but also on shared social and environmental commitments, underscoring how legitimacy-building can be enacted through business model approaches that frame value more broadly than immediate financial returns. Figure 7 provides an overview of the business model approaches used to navigate institutional challenges.

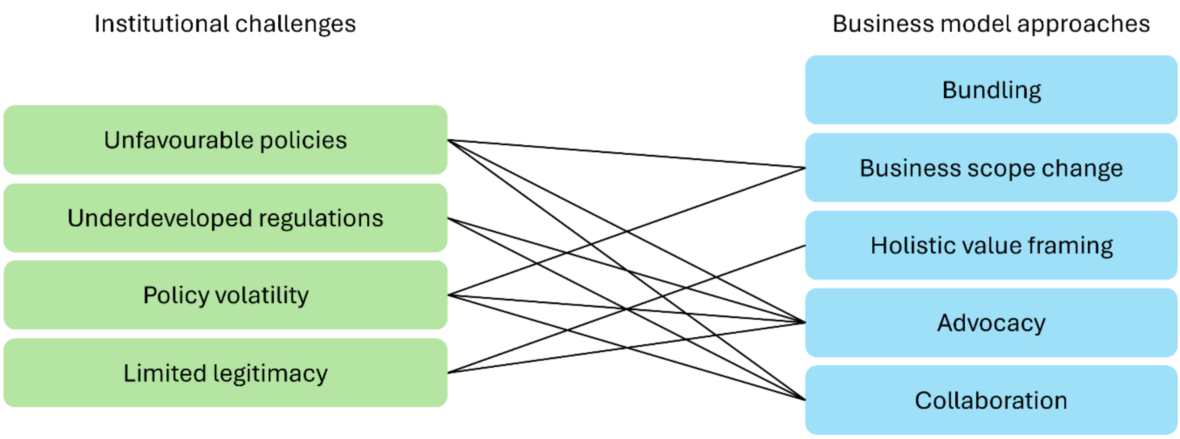

Figure 7. Business model approaches in response to institutional challenges for market formation.

6.3. Interplay between Business Models and the Market

The ways in which firms navigated market formation challenges through different business model approaches points to a mutual influence between firms' business models and the market. On the one hand, the observed challenges illustrate how market conditions constrain and channel firms' business model choices. On the other hand, the ways in which firms respond to these challenges through different business model approaches suggest that they also influence market conditions.

Market conditions constrain business model choices by making certain models more or less difficult for firms to pursue. For instance, Paper IV shows that challenges such as limited access to capital and low legitimacy were specifically associated with solar PV leasing models. Conversely, Paper II highlights how the investment subsidy significantly increased demand for small-scale adopter-owned solar PV systems in Sweden, making it favourable for firms to pursue business models tailored to this demand, such as turnkey models. This finding aligns with previous research emphasising how contextual conditions influence the prevalence of particular business models in a market, reflecting that business models are shaped by the socio-technical systems in which they are embedded (e.g., Engelken et al., 2016; Strupeit & Palm, 2016).

Market conditions also channel firms' business model choices, as firms respond to market formation challenges through business model approaches involving different forms of adaptation. This channelling reflects how socio-technical boundaries shape the opportunities and constraints firms face when developing and enacting their business models, as emphasised by e.g., Wesseling et al. (2020). For example, Paper III illustrates how limited capabilities for large-scale solar PV projects in Sweden led firms to develop collaborative business models to mobilise the resources and skills needed to deploy solar PV parks. Similarly, Paper IV shows how business model approaches such as bundling and business scope change involve altering the value proposition, key activities, or revenue structure. In contrast, approaches like advocacy or holistic value framing do not entail business model adaptations but instead aim to influence external stakeholders and institutions.

The appended papers further suggest that firms can shape market conditions through their use of business models. These effects do not necessarily arise from firms' deliberate attempts to shape the market, but rather from unintended consequences of business model approaches aimed at influencing the firm, its customers, or the business network. As firms mobilise their business models for value creation and boundary spanning, as discussed in Section 3.3., they simultaneously contribute to the development of market conditions. This finding is consistent with Lee et al. (2018), who argue that market formation may be inadvertently stimulated through firm-centric actions.

Consistent with business models' value creation function (e.g., Chesbrough & Rosenbloom, 2002; Teece, 2010), business model approaches such as bundling and business scope change aim primarily to influence the focal firm and its customers by adjusting offerings, activities, or capabilities to better align with adopter preferences, enter new market segments, or strengthen competitive positions. For instance, Paper II shows how firms bundled solar PV into different offerings to respond to limited installation skills among residential adopters, municipalities' need for impartial advice, and billing-specific requirements of apartment building owners. While each offering addressed a distinct market segment, together they linked technological possibilities with heterogeneous adopter preferences, which is an important mechanism highlighted in market formation research (e.g., Boon et al., 2022; Dewald & Truffer, 2012). Similarly, Paper III shows how firms broadened their scope to build new capabilities, while Paper IV demonstrates how firms outsourced activities under competitive pressure. Although these changes primarily help firms maintain or improve their competitive position, widespread use of similar approaches can influence the industry's division of labour and capability base. This insight resonates with research emphasising the role of value chain specialisation and capability development in market formation (e.g., Dewald & Truffer, 2012; Jacobsson & Bergek, 2004).

Business model approaches such as holistic value framing and collaboration instead target the business network by enrolling firms with key resources, facilitating knowledge sharing, and coordinating distributed assets, aligning with business models' boundary spanning function. Paper III, for example, illustrates how holistic value framing helped mobilise actors with critical resources (e.g., grid operators, landowners, financiers, contractors) for large-scale solar PV projects. By foregrounding not only economic but also social and environmental value, this business model approach contributes to market formation by constructing the narrative through qualifying desirable traits of the technology, which has been highlighted as an important prerequisite for mobilising resources (Ottosson et al., 2020). These findings align with research that highlights the importance of inter-firm coordination, resource mobilisation, and collective action for market formation (e.g., Jacobsson & Bergek, 2004; Musiolik et al., 2020; Planko et al., 2016). However, while Paper III demonstrates that some firms managed to mobilise distributed resources, Paper II shows that such collaborative approaches remained limited in Sweden. This observation suggests that their overall market impact was limited, potentially because other firms struggled to replicate them due to limited capabilities and regulatory obstacles.

Although less common, some firms also pursued business model approaches aimed directly at influencing the market, particularly through advocacy (e.g., lobbying) targeted at formal institutions. Consistent with previous research on firm strategies for shaping market formation (e.g., Planko et al., 2017), these efforts were undertaken both individually and collectively. This pattern is illustrated in Paper IV by, on the one hand, the attempts of solar PV leasing firms to individually lobby for the removal of the investment subsidy and, on the other hand, the formation of a solar PV park association to collectively lobby for issues relevant for large-scale solar PV projects. While institutional change is often considered central to market formation, firms' ability to steer institutional outcomes is limited (e.g., Boon et al., 2022; Ottosson et al., 2020). Paper IV reflects this pattern by showing that, despite repeated calls for policy stability, firms' efforts did not produce more predictable policy outcomes, as exemplified by the six-month gap in support schemes. Business model approaches targeting the market therefore involve significant risk, as substantial efforts may still fail to produce favourable results.

To manage such risks, the appended papers highlight the importance of collective advocacy. Paper IV shows how firms collectively addressed the sudden reinterpretation of tax-based incentive rules by pooling resources to take legal action, reducing individual exposure and increasing leverage. This approach enabled them to reverse the decision and thereby stabilise institutional conditions for both adopters and providers. Paper III provides a complementary example in which firms collaborated to implement a new financial setup despite regulatory ambiguity, spreading risk and establishing practical precedents that pressured regulators to clarify and adapt the rules. These examples align with research on market formation emphasising that collective lobbying and promotion allow firms to spread risks and strengthen their influence when attempting to shape markets (e.g., Planko et al., 2016).

In sum, the findings underscore that firms play a pivotal role in market formation. Although market conditions constrain and channel their business model choices, firms actively respond through business model approaches that, taken together, can reshape value chains, mobilise distributed resources, and occasionally induce institutional change.

7. Discussion

This chapter addresses the overarching aim of the thesis by proposing that business models constitute devices that firms can use to shape market formation. To develop this argument, the chapter starts by discussing how market formation phases can be seen to overlap. It then proceeds to explain the ways in which business models serve as devices for market formation, foregrounding firm agency as a central mechanism behind business models' influence on market formation.

7.1. Overlapping Market Formation Phases

The first main finding of the thesis is that the bridging and mass-market phases of market formation are not discrete, sequential stages; rather, they overlap in practice. This finding challenges the dominant narrative in the literature, which tends to conceptualise market formation as a linear progression through clearly delineated nursing, bridging, and mass-market phases (e.g., Jacobsson & Bergek, 2004). More recent scholarship has questioned this linearity, emphasising that the underlying processes of market formation do not follow a natural or predetermined order (e.g., Boon et al., 2022). Yet even within this more dynamic view, scholars continue to treat the phases themselves as analytically separate and sequential at the aggregate level, implying a gradual establishment of markets (e.g., Dewald & Truffer, 2011). In line with recent findings (e.g., Hyysalo et al., 2022), this thesis nuances this understanding by showing that the characteristics associated with bridging and mass-market phases can coexist for extended periods, even after a technology has become cost-competitive.

The results illustrate this overlap between market formation phases, where technological issues commonly associated with the bridging phase, such as underdeveloped infrastructure and limited integration with complementary technologies (e.g., Bergek et al., 2008; Markard et al., 2020), persisted in the Swedish solar PV market even after the technology had become cost-competitive, a hallmark of the mass-market phase. Similarly, the findings show how incumbent behaviour displayed characteristics of both bridging and mass-market phases simultaneously. As commonly observed during the bridging phase (Negro et al., 2012), incumbent energy utilities continued to resist solar PV by lobbying and restricting access to infrastructure. At the same time, they also began to embrace the technology by collaborating with solar firms, a pattern more typical of mass-market conditions (Saleh, 2025).

One potential explanation for why these overlapping dynamics emerged is that different market segments matured at different speeds. While prior research acknowledges that market segment developments can differ and influence one another, it has largely emphasised synergies between them (e.g., Dewald & Truffer, 2011). The thesis instead points towards competitive dynamics, where certain market segments appear to expand at the expense of others. These dynamics are illustrated by how solar firms (re)directed their attention towards market segments that were more legitimate, policy-supported, and lower-risk. For example, the thesis demonstrates how the Swedish investment subsidy incentivised firms to pursue business models centred on adopter ownership of solar PV, such as turnkey installation, thereby accelerating growth in those segments. Conversely, firms offering solar PV leasing models withdrew from targeting residential adopters to align with the preferences of risk-averse investors which would enable them to scale their businesses in other segments.

This allocation of attention and resources means that challenges in underserved segments (e.g., less affluent residential adopters unable to afford the high upfront costs of solar PV) were not actively addressed. As a result, characteristics typical of the bridging phase persisted in these segments, even as others advanced toward mass-market conditions. Notably, the findings show that while the legitimacy of solar PV increased among Swedish market actors, new business models (e.g., leasing) continued to face low legitimacy, further entrenching these disparities.

Another potential explanation for the co-existence of bridging and mass-market phase traits can be linked to the heterogeneity and agency of firms. Since firms differ in their resources, motivations, and strategic orientations, it influences how they interpret and respond to market signals (e.g., Thomson et al., 2025). For instance, the findings show that energy utilities who identified strategic benefits, such as the potential to develop new capabilities and strengthen their position in large-scale electricity production, were proactive in embracing solar PV. In contrast, energy utilities that participated only because of legal requirements remained resistant. This pattern aligns with research highlighting the importance of strategic fit for incumbent firms to engage with solar PV (e.g., Altunay et al., 2021) and suggest that when such alignment becomes apparent, they are more likely to display mass-market behaviours.

This finding also deepens the understanding of why the prevalence of specific types of solar PV business models varies across countries. While earlier studies have attributed these differences to the broad notion of contextual conditions (e.g., Engelken et al., 2016; Strupeit & Palm, 2016), this thesis specifically links such conditions to market formation. This finding aligns with research on the spatial patterns of market formation, which demonstrates how technological, institutional, financial, and user-related factors create divergent market trajectories across regions and countries (e.g., Dewald & Truffer, 2012). At the same time, the thesis extends this work by foregrounding the role of firm agency. An illustrative example is the firm that chose not to return to a leasing model even when demand for leasing later increased, because it had developed strong capabilities in turnkey installation. This example underscores that the prevalence of particular business model types is not simply a reflection of the national context, but also the result of firms' strategic responses to market developments.

Overall, the results indicate that challenges in the shift between bridging and mass-market phases rarely stem from the focal technology itself, but rather from the slow development and misalignment of other components within the technological innovation system. One explanation is that solar PV, like many low-carbon technologies (e.g., Hyysalo et al., 2022), is deeply embedded in existing sociotechnical structures and therefore requires substantial adjustments in social, infrastructural, and institutional arrangements, which takes time (Grübler, 1991).

Another explanation relates to the boundary conditions of the technological innovation system under study, particularly its geographical and sectoral scope (Bergek et al., 2015). This thesis examines firms in the downstream segment of the Swedish solar PV value chain, a small subset of both the global solar PV industry and the broader Swedish energy sector. Regarding the geographical scope, a clear distinction can be observed between the upstream and downstream solar PV value chain. Technology development and cost reductions have largely been driven by upstream actors responding to global demand (IEA PVPS, 2025a), while market formation occurs primarily at national and regional levels, where solar PV represents only one of many elements of a technological innovation system that must be developed to increase technology deployment (Dewald & Truffer, 2012). Within the Swedish energy sector, solar PV also competes with several mature low-carbon technologies (e.g., hydropower, nuclear, and wind turbines)(Lindahl & Öhgren, 2025). Given this strong set of alternatives, the perceived urgency to accelerate solar PV deployment has likely been lower in Sweden than in countries with fewer established options. As a result, efforts to stimulate domestic market formation may have remained limited in comparison, contributing to a growing mismatch between the rapid global maturation of solar PV technology and the comparatively slow development of national system elements.

Taken together, these insights suggest that market formation should not be conceptualised as a linear progression through clearly delineated phases. Instead, phases may coexist and overlap as market segments mature at different rates and as heterogeneous firms respond differently to emerging threats and opportunities. This finding calls for a more dynamic and multilayered understanding of market formation, even at the aggregate level, since the simultaneous presence of phase-specific issues can send conflicting signals to policymakers and other market actors. Such ambiguity complicates the interpretation of market conditions and the design of effective interventions. For instance, the achievement of cost-competitiveness in solar PV (a typical indicator of mass-market maturity) may prompt policymakers to prematurely withdraw support, under the assumption that the market is now self-sustaining (e.g., Karneyeva & Wüstenhagen, 2017). However, if bridging-phase challenges such as infrastructural bottlenecks, regulatory misalignments, or limited legitimacy persist in certain segments, this withdrawal can undermine further technology deployment and stall market development (e.g., Dewald & Truffer, 2011). Conversely, continued support based solely on the persistence of bridging-phase issues may lead to inefficient allocation of resources in segments that are already competitive.

The need for a more nuanced conceptualisation of market formation is further strengthened by the existence of significant intra-phase variations. For instance, the results highlight how, within less than five years, the Swedish solar PV market experienced both rapid firm entry (early bridging phase) and high exit rates (late bridging phase). Unlike previous research, which often links such exit patterns to the emergence of a dominant design (e.g., Markard, 2020), the technological development of solar PV remained stable during this period. Instead, volatile demand driven by falling solar PV costs, continued public subsidies, and electricity price fluctuations, followed by a market growth plateau and intense competition triggered such firm entry/exit patterns. This pattern suggests that turbulence within the bridging phase can stem from broader innovation system dynamics rather than technological developments alone (cf. Andersson & Jacobsson, 2000), reinforcing the argument that market formation is more complex than the linear model implies.

7.2. Business Models as Market Formation Devices

The second main finding of this thesis is that firms play a significant role in market formation through the ways they use their business models, which can shape the market either intentionally or unintentionally. This finding underscores that market formation is shaped by firms, while business models represent the devices through which firms exercise that influence. Framing business models as devices thus clarifies that business models do not possess agency in and of themselves. Instead, they represent tools that firms deploy and modify in pursuit of strategic goals. This distinction is crucial as it shifts analytical attention away from the configuration of business model archetypes to the purposive actions of firms using business models.

Recognising firms as agents of market formation is important because it highlights that the influence of business models ultimately depends on the choices firms make in using them. This emphasis contrasts with dominant strands of prior research on business models for low-carbon technology deployment (e.g., Burger & Luke, 2017; Strupeit & Palm, 2016), which typically focus on classifying or comparing business model archetypes or configurations. By emphasising the structural features of business models, these studies implicitly assume that these models possess inherent capacities to drive technology deployment, regardless of who uses them or how. In contrast, conceptualising business models as devices emphasises that their influence only emerges through firm agency.

Foregrounding firm agency further underscores the need to account for firm heterogeneity when analysing business models and market formation (e.g., Lee et al., 2018; Thomson et al., 2025). The thesis shows that firms respond in different ways, even to the same market formation challenge, which reflect how differences in firm logics, capabilities, and motives may shape the influence of business models on market formation. Using the leasing model as an example, previous research has shown that when firms are incentivised to target underserved market segments, leasing can reduce barriers to adoption (e.g., Drury et al., 2012). However, when incentives instead steer firms toward more profitable or lower-risk segments, as in the Swedish solar PV market, the same model can reproduce existing inequalities. These patterns underscore the limitations of designing policy around the structural features of business model archetypes alone. Without accounting for firm agency as well as the market conditions in which firms operate, policies may inadvertently promote business models that exclude precisely the adopter groups they are expected to include, thereby undermining their own equity and technology deployment objectives.

The thesis also shows that many of the business model approaches firms use to navigate market formation challenges primarily target the firm, its customers and business network, which inadvertently influence market formation if scaled across multiple firms. While previous research acknowledges that firm-centric pursuits can shape market formation through unintended spillover effects (e.g., Lee et al., 2018), the focus has mainly been on firms' intentional market shaping strategies (e.g., Planko et al., 2017; Werner et al., 2022). By foregrounding the inadvertent influence of business model approaches targeted at the firm and network-level, the thesis shifts the analytical lens from asking *which* strategies or business models firms use to shape market formation to asking *how* and *why* such approaches accumulate across the market.

Addressing these questions require attention to the strategic intent guiding firm action, as well as the mechanisms that enable such actions to scale. In terms of strategic intent, the business model literature offer some insights, as viewing business models as devices for value creation (e.g., Teece, 2010) or boundary spanning (e.g., Doganova & Eyquem-Renault, 2009) implies that they are used to achieve a specific purpose or perform a particular function. These performative roles are also reflected in the differences between business model approaches targeting the firm and network level in the thesis. With regard to scaling mechanisms, transitions scholars have introduced a range of typologies in recent years (for an overview, see Robinson et al., 2025), although many of these focus on early scaling of, for example, experiments or pilot projects, which fails to account for the wide range of heterogeneous firms which are typically present in more mature market phases. As highlighted by Aagaard et al. (2021), time also constitutes an important aspect to consider in order to understand how the scope of business model influence grows over time. This insight opens up for future research to examine more closely the mechanisms through which business model accumulation unfolds or stalls, and how firm heterogeneity conditions these dynamics.

The thesis shows that firms also engage in deliberate market shaping, using their business models as a basis for advocacy (e.g., lobbying). However, while such attempts can have significant impact on the market trajectory, as illustrated by firms' collective influence on the legal interpretation of the green tax deduction, firms generally have limited control over such market outcomes. The results show that collective action is an important way in which firms can increase their influence, which underscores findings in previous research on market formation (e.g., Lee et al., 2018; Musiolik et al., 2020; Planko et al., 2016).

Overall, this thesis advances the understanding of business models as devices through which firms shape market formation, highlighting that the influence of business models is contingent rather than inherent, thereby placing firm agency at the centre of analytical attention. By examining downstream firms in the shift between bridging and mass-market phases, the thesis fills an important conceptual and empirical gap. Extant research on market formation (e.g., Jacobsson & Bergek, 2004; Ottosson et al., 2020) has predominantly focused on upstream firms (e.g., technology developers) who are central in early development phases, whereas technology diffusion research (e.g., Mignon & Bergek, 2016; Rogers, 2003) has largely centred on adopters in later phases. The findings in this thesis show that downstream firms play an important role in shaping market formation in the shift between bridging and mass-market phases by using their business models as devices to e.g., bundle low-carbon technologies with complementary assets, enrol key partners, and advocate for institutional change. This insight demonstrates that downstream firms do not merely serve as middlemen that distribute technologies developed elsewhere, they shape market formation through the use of their business models.

8. Conclusions

This thesis set out to explain the roles of business models in market formation for low-carbon technologies, with a particular focus on the challenges that firms face (RQ1) and how they navigate these challenges through their business models (RQ2). Drawing on a literature review and three qualitative empirical studies of downstream firms in the Swedish solar PV market, the thesis shows that firms face market formation challenges related to technology, actors and networks, and institutions. These challenges correspond to some, but not all, of those typically associated with both bridging and mass-market phases.

The thesis further demonstrates that firms navigate these challenges in different ways through five distinct business model approaches: (1) *bundling* the focal technology with complementary technologies, products, and services to create differentiated customer offerings, (2) *business scope changes* to increase the value they capture, (3) *holistic value framing* to persuade potential customers and partners of the benefits of the model, (4) using the business model as a baseline for *advocacy,* including promotional, legitimation, and lobbying activities, and (5) *collaboration* with other firms to access and coordinate distributed resources.

Based on these insights, the thesis highlights substantial overlaps between the bridging and mass-market phases, challenging the dominant view of market formation as a linear progression through clearly delineated phases. It further conceptualises business models as devices that firms use to shape market formation, whether deliberately or as an unintended consequence of their firm- or network-centric pursuits. In doing so, the thesis shifts attention away from business model configurations and the implicit assumption that they possess inherent qualities to facilitate low-carbon technology deployment, emphasising instead that their influence arises only through the agency of firms.

9. Implications for Research and Practice

The findings of this thesis give rise to several theoretical contributions as well as implications for future research, policy, and managerial practice. This chapter first outlines how the thesis advances the current understanding of market formation for low-carbon technology, thereby laying a foundation for future research. It then considers how the findings can inform policy design aimed at accelerating the deployment of low-carbon technologies. Finally, the chapter highlights managerial implications, offering guidance for firms seeking to navigate the complexities of markets for low-carbon technologies.

9.1. Theoretical Contributions and Implications for Future Research

The thesis offers several contributions to the understanding of market formation for low-carbon technologies, particularly regarding the roles of downstream firms and their business models. When considered together with the thesis' limitations, these insights open up new avenues for future research.

First, the thesis contributes to research on market formation by providing extensive empirical evidence that the bridging and mass-market phases overlap rather than unfold sequentially, as traditionally assumed (e.g., Andersson & Jacobsson, 2000; Jacobsson & Bergek, 2004). This finding contributes to a growing shift in innovation system and sustainability transitions research towards a more dynamic and multi-layered processual understanding of market formation (e.g., Boon et al., 2022; Hyysalo et al., 2022). In particular, the thesis underscores that technological maturation (e.g., dominant design, cost-competitiveness) does not imply that other system elements (e.g., infrastructure, firm capabilities, institutions) have matured simultaneously. Since the empirical scope is limited to the Swedish solar PV market, future research should examine other low-carbon technologies and geographical settings to assess whether similar overlaps occur. It would also be valuable to explore markets providing other types of public goods (e.g., defence, food, healthcare) to investigate whether comparable patterns arise in sectors with different technological, institutional, and actor-related characteristics.

Building on this insight, the thesis supports previous research showing that market segments mature unevenly (e.g., Dewald & Truffer, 2011), and therefore may display patterns of different market formation phases simultaneously. However, contrary to the synergistic dynamics predominantly emphasised in earlier work, the thesis indicates that some segments advance at the expense of others. These dynamics occur as firms direct their attention and resources toward addressing challenges in more attractive segments, while leaving challenges associated with underserved segments unaddressed. Such selective focus is often enacted through different business model approaches (e.g., bundling the technology into tailored offerings or advocating for changing specific regulations), which can reinforce disparities between segments. These dynamics point to patterns of reinforcing feedback loops between market developments and firms' business model approaches, potentially producing path-dependent outcomes. Future research should examine whether and how such reinforcing mechanisms emerge, interact, and potentially lock markets into suboptimal development trajectories. For instance, studies could investigate how firms' business models and market segments co-evolve. Methodologically, such focus calls for longitudinal and comparative designs capable of tracing business model approaches and market segment development over time.

Second, the thesis contributes to research on market formation by showing how downstream firms use their business models as devices that intentionally or unintentionally shape market conditions. By focusing on firms in the downstream value chain, the thesis addresses an important conceptual and empirical gap, as prior research on market formation and innovation diffusion has predominantly centred on upstream firms in early phases or adopters in later ones (e.g., Mignon & Bergek, 2016; Ottosson et al., 2020). The synthesis identifies five business model approaches through which downstream firms navigate and influence market formation challenges in the bridging and mass-market phases. These findings demonstrate that downstream firms are not merely distributors of low-carbon technology but significantly shape how such markets are formed through their business models.

While this thesis focuses on downstream firms, it is reasonable to expect that firms in the upstream value chain and in earlier phases of market formation also use their business models as devices. However, their business model approaches might differ in terms of purpose and impact, reflecting, for instance, the more globalised target markets for upstream firms as seen for solar PV, or the distinct market formation challenges characterising the nursing phase. These limitations provide fruitful avenues for future research to test and refine the business model approaches identified here. Additionally, the thesis relies on a qualitative design with a limited and context-specific sample, which constrains the transferability of the findings. Future research could therefore employ quantitative designs to examine whether the identified patterns hold across broader and more diverse contexts.

9.2. Policy Implications

The findings of the thesis have several implications for policy design aimed at accelerating the deployment of technologically mature low-carbon technologies such as solar PV. The thesis shows that market formation phases do not unfold in a linear, sequential manner but instead overlap. This finding has two important implications for policy design. First, it indicates that relying solely on technological cost-competitiveness as a signal for phasing out support is insufficient, as other crucial system elements (e.g., infrastructure, firm capabilities, and institutional arrangements) may remain underdeveloped and continue to constrain technology deployment. Second, the overlapping nature of market formation phases means that different market segments encounter distinct challenges, suggesting that uniform policy approaches are unlikely to be effective across an entire market.

To address these issues, policy portfolios should be layered and tailored to the needs of specific market segments. This approach involves complementing technology-focused instruments with measures that address other bottlenecks (e.g., capability-building programs, targeted infrastructure investments). In practice, this requires a gradual shift in policy emphasis from technology development to broader system-oriented interventions as different market segments mature. Such an approach demands that policymakers develop strong diagnostic capacity and analytical tools to monitor market development across segments. Continuous assessment is essential to determine where additional intervention is needed, where existing support schemes should be adjusted, and where phase-out is appropriate.

The thesis also demonstrates that business models serve as devices through which firms intentionally or unintentionally shape market formation for low-carbon technologies. This finding implies that policymakers should recognise business models as important complements to traditional policy instruments. Understanding how firms use their business models helps explain why some market segments expand rapidly while others remain underserved. In particular, previous research highlights that business models based on third-party ownership have significant potential to address issues of equitable access, resource efficiency, and end-of-life recovery. Yet the findings show that the conditions on the Swedish solar PV market have discouraged the use of such models.

To broaden market participation and support growth across segments, policymakers should consider creating more favourable conditions for firms to adopt alternative business models, including those based on third-party ownership. This support could involve clarifying regulatory ambiguities around financial arrangements, offering risk-sharing mechanisms that reduce firms' and investors' financial exposure, supporting business model experimentation through pilot programs or temporary incentives targeting underserved adopter groups (e.g., low-income households or tenants), or strengthening structured dialogue with firms through industry associations or dedicated consultation forums to identify barriers for using such models.

At the same time, the findings caution against designing policy instruments that target specific business model types. Because firms exercise considerable agency in adapting their business models to national market conditions, the same model can serve very different segments in different contexts. For instance, while leasing models have facilitated adoption among less affluent segments in other countries (Drury et al., 2012), this thesis shows that in Sweden they were limited to more financially robust adopters due to investor risk aversion. Policies should therefore concentrate on shaping the surrounding market conditions, such as stimulating demand in specific market segments or removing institutional impediments, rather than promoting any particular business model type.

These insights align with research on responsible scaling (e.g., Lukkien et al., 2025; Pfotenhauer et al., 2022; Robinson et al., 2025), which calls for more inclusive, democratic, and context-sensitive approaches to technology deployment. Recognising that firms shape market formation through their business models enables policymakers to design interventions that influence firm behaviour in ways that can accelerate low-carbon technology deployment while supporting socially equitable and environmentally responsible outcomes. It should, however, be noted that these implications are derived from the specific context of the Swedish solar PV market, which is characterised by heterogeneous firms and an open market structure. As such, they may not apply in markets with monopolistic structures or limited firm heterogeneity. Further comparative research is needed to examine whether similar dynamics occur for other low-carbon technologies and in other national contexts.

9.3. Managerial Implications

The findings of the thesis offer several managerial implications, particularly for firms operating in the downstream value chain of low-carbon technologies. The results demonstrate that market formation does not progress through linear, sequential phases. Instead, phases overlap substantially as different market segments mature at varying speeds, facing distinct challenges. This insight implies that managers should systematically analyse the specific segments they currently serve, or intend to enter, to identify which market formation challenges are most salient (e.g., policy volatility, capability gaps). Such diagnostic work enables firms to allocate resources toward the issues that matter most for their segment rather than relying on generic assumptions about overall market maturity. It also allows firms to anticipate upcoming challenges before they fully materialise. For example, the scarcity of capabilities for large-scale solar PV installation in Sweden suggests that early investments in workforce development, technical training, and project management capacity can position firms ahead of competitors as this segment expands.

The thesis further shows that business models are not only devices for value creation but can also be leveraged to shape market trajectories. Firms can use their business models as reference points for lobbying and institutional engagement, particularly when their offerings address overlooked market formation challenges such as equitable technology access, resource efficiency, or circularity. To strengthen their legitimacy and policy influence, managers should therefore articulate how their business models contribute to broader societal values in addition to considering their commercial viability.

Finally, the findings highlight the importance of collective action. Industry associations, collaborative business models, and coordinated lobbying efforts can significantly amplify firms' market shaping influence. This insight implies that managers should actively seek opportunities to collaborate with peers, suppliers, and customers, especially in markets for low-carbon technologies where individual firms often lack the power or resources to address market formation challenges alone. To paraphrase Planko et al. (2016), through collective action firms can create a larger market for their technology than they could by acting individually.

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