

Discontinuous innovation in traditional industries

A model for innovation in the context of Nordic sustainable industry transitions



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Abstract

The climate crisis and the global effort to mitigate its effects require simultaneous innovation across energy systems, industry supply chains, and business models. This implies a particularly steep step-change for traditional industry sectors that rely on fossil fuels and heavily emitting processes, i.e. hard-to-abate industry sectors like steelmaking, mining, concrete, and petrochemicals. However, most existing innovation models for breakthrough transformations focus on user-driven market disruption rather than innovation settings where supply chains and physical infrastructure are at the centre, while the literature on sustainability transitions lacks a specific focus on innovation. As a result, there is no existing theoretical framework for comparative analysis of innovation processes, which could situate and guide the transition to sustainability in traditional industry settings.

This thesis argues that such analysis can be undertaken if hard-to-abate sustainability transitions are understood and theorised as instances of discontinuous innovation. The thesis proposes a new framework for categorising different modes for the strategic positioning of discontinuous innovation ventures and for analysing the roles and relationships of stakeholders shaping discontinuous innovation processes. The new framework is developed inductively from interlinked empirical case studies into pioneers in carbon-free steelmaking and hydrogen innovation in the Nordic region. The primary contribution of the thesis to the literature on innovation is to introduce a new theory perspective for analysing sustainability transitions – as processes of discontinuous innovation in traditional industries.

The thesis subsequently outlines how this new perspective helps clarify how innovation for sustainable industry transitions may be organised and shaped differently in different contexts. In the Nordic case context, this analysis suggests that successful discontinuous innovation surrounding sustainable industry transitions is driven not by any singular stakeholder or market disruption, but by system-level coordination between different ventures, by risk-sharing within the regional innovation system, and by the enabling impact of national innovation policies.

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Table of Contents

ABSTRACT	2
ACKNOWLEDGEMENTS	4
TABLE OF CONTENTS	5
LIST OF TABLES	8
LIST OF FIGURES	8
CHAPTER 1 – INTRODUCTION.....	9
CHAPTER 2 – LITERATURE REVIEW AND RESEARCH AGENDA	22
2.1 INTRODUCTION	22
2.2 EXISTING LITERATURE ON SUSTAINABILITY TRANSITION AND INNOVATION.....	27
2.2.1 <i>Sustainability transitions</i>	27
2.2.2 <i>Innovation</i>	30
2.3 OPEN QUESTIONS FROM THE LITERATURE	38
2.4 A RESEARCH AGENDA FOR THEORISING ON DISCONTINUOUS INNOVATION IN TRADITIONAL INDUSTRIES	45
2.5 DISCUSSION	47
2.5.1 <i>The shaping of innovation and market contexts over time</i>	49
2.5.2 <i>Institutional context and competitive advantage</i>	51
2.5.3 <i>Primary themes for the comparative empirical study of discontinuous innovation ventures</i>	54
2.6 CONCLUSION.....	58
CHAPTER 3 – RESEARCH METHODOLOGY	61
3.1 INTRODUCTION	61
3.2 PHILOSOPHICAL FOUNDATIONS FOR MORE NUANCED INNOVATION RESEARCH	62
3.3 RESEARCH DESIGN AND CASE SELECTION	65
3.3.1 <i>Steel decarbonisation ventures as case studies of large-scale discontinuous innovation</i>	68
3.3.2 <i>Hydrogen innovation processes as case studies of local-level innovation drivers</i>	71
3.3.3 <i>Energy innovation policy as a case study of state-industry innovation enablers</i>	74
3.4 RESEARCH PROCESS	77
3.4.1 <i>Data collection</i>	77
i. Archival data	79
ii. Core interviews.....	80
iii. Background interviews.....	82
iv. On-site observation and conference gatherings	84
v. Informal meeting notes and member-check emails	86
3.4.2 <i>Data analysis</i>	87
i. Within-case analysis	89
ii. Cross-case analysis.....	90
3.4.3 <i>Research ethics</i>	92
3.5 CONCLUSION.....	93
CHAPTER 4 – RESEARCH SETTING	95
4.1 INTRODUCTION	95
4.2 INDUSTRIAL HISTORY OF THE NORTHERN NORDIC REGIONS.....	98
4.2.1 <i>The northern Nordic regions – Extreme in conditions and rich in resources</i>	99
4.2.2 <i>Renewed sustainability momentum amidst a gradual decline</i>	104
4.3 NORTHERN SWEDEN	106
4.3.1 <i>From green energy to green systems – Northern Sweden and the sustainability transition</i>	108
4.4 NORTHERN FINLAND.....	111
4.4.1 <i>A window of opportunity to scale up – Northern Finland and the sustainability transition</i>	114

4.5 NORTHERN NORWAY	116
4.5.1 <i>Strategies for long-term survival – Northern Norway and the sustainability transition</i>	119
4.6 DISCUSSION – THEMES ARISING FROM THE DESCRIPTION OF THE RESEARCH SETTING	121
4.6.1 <i>The momentum for green steel and hydrogen</i>	121
4.6.2 <i>The unsolved tensions in local-level Nordic resilience</i>	123
4.6.3 <i>The 'Transition Belt' effect</i>	124
4.7 CONCLUSION.....	125
CHAPTER 5 – DETERMINANTS OF LARGE-SCALE DISCONTINUOUS INNOVATION VENTURES IN STEEL	128
5.1 INTRODUCTION	128
5.2 LITERATURE ON DISCONTINUOUS INNOVATION: LACK OF INSIGHT INTO VENTURES STRATEGIES FOR SUSTAINABILITY TRANSITION	133
5.3 METHODS AND RESEARCH SETTING – A DOUBLE CASE STUDY OF PIONEERING GREEN-STEEL INNOVATION	135
5.4 FINDINGS – COMPARATIVE ANALYSIS AS PART OF THE DOUBLE CASE STUDY	139
5.4.1 <i>HYBRIT – The incumbent model</i>	139
5.4.2 <i>H2 Green Steel – The start-up model</i>	140
5.4.3 <i>Comparison – Two different but complementary innovation strategies for green steel</i>	142
i. Initiative.....	144
ii. Research and development	147
iii. Collaboration.....	151
iv. Industrialisation	156
5.5 DISCUSSION	160
5.6 CONCLUSION.....	165
CHAPTER 6 – LOCAL-LEVEL DRIVERS OF DISCONTINUOUS INNOVATION IN HYDROGEN 167	
6.1 INTRODUCTION	167
6.2 LITERATURE ON REGIONAL INNOVATION SYSTEMS IN A NORDIC CONTEXT	171
6.3 METHODS AND RESEARCH SETTING – NORTHERN NORDIC REGIONS AND THE NASCENT HYDROGEN ECONOMY	174
6.4 FINDINGS – COMPARATIVE ANALYSIS AS PART OF THE MULTIPLE CASE STUDY.....	179
6.4.1 <i>The Network Model – Hydrogen Innovation in Vaasa, Finland</i>	179
6.4.2 <i>The Scale-up Model – Hydrogen Innovation in Luleå, Sweden</i>	182
6.4.3 <i>The Community Model – Hydrogen Innovation in Berlevåg, Norway</i>	185
6.4.4 <i>Comparison – Identifying three models for local-level drivers</i>	189
i. Early-stage venture coordination	190
ii. Research-intensive innovation.....	197
iii. Risk-sharing and investments.....	201
iv. Community engagement.....	208
6.5 DISCUSSION	214
6.6 CONCLUSION.....	219
CHAPTER 7 – STATE-INDUSTRY RELATIONS AS ENABLERS OF DISCONTINUOUS INNOVATION IN TRADITIONAL INDUSTRIES	222
7.1 INTRODUCTION	222
7.2 LITERATURE ON THE IMPACT OF STATE-LEVEL AGENCY AND INSTITUTIONS ON INNOVATION IN A NORDIC SETTING	226
7.3 METHODS AND RESEARCH SETTING – TRACING STATE-INDUSTRY RELATIONAL DYNAMICS FOR NORDIC DISCONTINUOUS INNOVATION IN STEEL AND HYDROGEN	230
7.4 FINDINGS – TRACING STATE-INDUSTRY RELATIONAL DYNAMICS AND THEIR IMPACT	235
7.4.1 <i>Coordination interactions</i>	237
i. Policy process: Ombudsman for societal transformation in Sweden	237
ii. Regulation process: Designated hydrogen TNO in Finland	241
7.4.2 <i>Capacity-building interactions</i>	244

i. Policy process: ‘Leading company initiatives’ in Finland.....	244
ii. Regulation process: Grid expansion in Norway	247
7.4.3 <i>Promotion interactions</i>	250
i. Policy process: Oil and gas electrification in Norway.....	250
ii. Regulation process: Transmission network buildout in Sweden	253
7.5 DISCUSSION – CROSS-CASE COMPARISON AND THEORY IMPLICATIONS.....	256
7.5.1. <i>Cross-case comparison</i>	256
i. Comparison across state roles.....	257
ii. Comparison across state-level actors.....	259
iii. Comparison across direct and indirect impact of state-industry relations	261
iv. Comparison across countries	263
7.5.2 <i>Theory implications</i>	268
i. Same institutions, different outcomes – the impact of material lock-ins	268
ii. Similar action, different impact – the systemic nature of sustainability transformations	269
iii. Same countries, different process stages – the impact of changing state roles over time.....	270
iv. Implications for the future of Nordic Varieties of Capitalism	272
7.6 CONCLUSION.....	280
CHAPTER 8 – DISCUSSION AND THEORY IMPLICATIONS FOR DISCONTINUOUS INNOVATION IN TRADITIONAL INDUSTRIES	282
8.1 INTRODUCTION	282
8.2 A NEW COMPARATIVE THEORY FRAMEWORK FOR ANALYSING DISCONTINUOUS INNOVATION VENTURES	284
8.2.1 <i>Material resource dependence brings variation between innovation settings</i>	284
8.2.2 <i>New comparative theory framework for viewing differences between innovative ventures</i>	289
8.2.3 <i>Applying the theory framework for analysis of discontinuous innovation ventures</i>	295
i. Coordination mode	296
ii. First-mover mode	298
iii. Disruption mode.....	299
iv. Paradigm mode.....	300
8.2.4 <i>Wider implications and literature contributions of the new theory framework</i>	301
8.3 A NEW PROCESS FRAMEWORK FOR DISCONTINUOUS INNOVATION	305
8.3.1 <i>Need for a process framework</i>	307
8.3.2 <i>New process models for discontinuous innovation ventures</i>	310
8.3.3 <i>Applying the process framework for analysis of discontinuous innovation ventures</i>	316
8.3.4 <i>Wider implications and literature contributions – The role of time and place for discontinuous innovation</i>	321
8.4 CONCLUSION.....	326
CHAPTER 9 – CONCLUSION	327
9.1 SUMMARY OF FINDINGS: REGIONAL COORDINATION AND RISK-SHARING AS CRUCIAL STAKEHOLDER ROLES IN NORDIC GREEN STEEL AND HYDROGEN INNOVATION.....	327
9.2 SUMMARY OF CONTRIBUTIONS: A NEW COMPARATIVE RESEARCH PERSPECTIVE ON DISCONTINUOUS INNOVATION	330
9.3 PRACTICAL CONTRIBUTIONS: INNOVATION FOR SUSTAINABILITY IN INDUSTRY, THE STATE, AND REGIONAL POLICY	333
9.4 LIMITATIONS: PIONEERING CASES IN SURPRISING SETTINGS	335
9.5 FUTURE RESEARCH AVENUES: UNDERSTANDING INNOVATION IN A TRANSITIONING WORLD	338
ABBREVIATIONS AND ACRONYMS	341
BIBLIOGRAPHY	342
APPENDIX: LIST OF INTERVIEWS.....	358

List of Tables

Table 3.1: Research agenda for empirical case studies.....	76
Table 3.2: Qualitative data sources (written).....	78
Table 3.3: On-site visits and conference observation	86
Table 5.1: Comparing the discontinuous innovation process of two green steel ventures....	143
Table 6.1: Three models for local-level drivers of discontinuous innovation	189
Table 7.1: Comparing state-industry innovation enablers	236
Table 7.2: Benchmarking case studies against Varieties of Capitalism ideal-types	275

List of Figures

Figure 4.1: Map of case study locations	100
Figure 5.1: Coding framework for the case studies in Chapter 5.....	138
Figure 5.2: Timeline of two green steel ventures	143
Figure 6.1: Coding framework for the case studies in Chapter 6.....	178
Figure 7.1: Coding framework for the case studies in Chapter 7.....	233
Figure 8.1: New comparative theory framework for discontinuous innovation ventures.....	294
Figure 8.2: Modes of discontinuous innovation in the steel sector.....	296
Figure 8.3: New process framework for discontinuous innovation ventures (axes only).....	308
Figure 8.4: Process models for Nordic green steel innovation ventures.....	311

Chapter 1 – Introduction

Faced with the global climate crisis, industry stakeholders are pressured to undertake their most overwhelming transformation since the first industrial revolution (UNEP, 2017). The urgency for a global transition to sustainability has become increasingly clear to civil society, industry, and policymakers. However, due to the subversive nature of the climate threat, innovation for sustainability involves a lot of uncertainty and risk. In many sectors, there is not yet a business case to incentivise a ‘race-to-the-top’ for innovating sustainable solutions and implementing them at pace (Garud and Gehman, 2012; Fagerberg, 2018; Lema, Fu and Rabellotti, 2020; Henderson, 2021). The sustainability transition, therefore, needs to be both coordinated at a system level and of a near-unprecedented scale.

The scale of the innovation required to bring the transition about implies a particularly steep step-change for traditional, resource-intensive industries such as steelmaking, manufacturing, and petrochemicals. For example, coal, oil and gas in 2022 accounted for 82% of the world’s energy supply (Energy Institute, 2024). On the one hand, these are some of the most heavily emitting sectors due to the energy and carbon intensity of their processes, but on the other hand, these traditional industries are ‘normally’ expected to develop through incremental innovation over several decades rather than through sudden breakthrough transformations (Lee and Malerba, 2017). The climate crisis thereby presents both policymakers and industry practitioners with the challenge of implementing some of the largest sustainability transformations in sectors where step-change transformations are the least well-understood.

Existing academic research is not well attuned to analyse these sustainable industry transitions in traditional industry sectors, particularly because the latter do not fit in with existing

assumptions in innovation literature about which sectors and contexts are conducive to disruptive, large-scale, or breakthrough innovation (Schot and Steinmueller, 2018). In recent years, literature on global innovation benchmarks has focused mainly on consumer-facing settings of industry and innovation, such as services and digital platforms. For example, Silicon Valley is by far the most commonly adopted benchmark of Christensen's (1997) influential work on *disruptive* innovation (Casper, 2007; King and Baatartogtokh, 2015; Kivimaa *et al.*, 2021; Weigelt, Lu and Verhaal, 2021; Ritala, Huotari and Kryzhanivska, 2022). However, in these benchmark innovation environments the mechanisms of innovation are different from industry settings where policy priorities like decarbonisation, rather than consumer trends, are incentivising innovation, and where complex resource and infrastructure dependencies are core strategic questions that determine a venture's success (McDowall, 2018; Henderson, 2021). The sectors undertaking the most profound decarbonisation processes are predominantly found in very different innovation settings than in Silicon Valley. Literature on innovation lacks comparative frameworks to explain why and how breakthrough innovation processes may work differently across or within different innovation settings (McDowall, 2018; Schot and Steinmueller, 2018; Breznitz, 2021). This implies that some of the most fundamental processes and ventures of sustainability-focused innovation are at risk of being under-theorised and misrepresented.

This thesis seeks to mitigate this knowledge gap and argues that mechanisms and enablers for innovation in sustainable industry transitions can be best understood as instances of *discontinuous* innovation. The construct of discontinuous or non-continuous innovation denotes innovation processes that build on new knowledge and seek to transform existing industry structures and epistemic regimes through a step-change (Utterback, 1996; Kaplan, 1999). In the case of sustainability transitions, innovation is targeted at shifting the existing

technologies and business models of fossil-fuel-driven supply chains, material flows, and infrastructures. This challenge is, on the one hand, inspired by climate policy incentives that are disruptive and external to the existing logic of the productive market economy, and on the other hand, path-dependent and heavily rooted in the material infrastructure and process-models of the existing industry system. Consequently, there is a strong case for widening research on discontinuous innovation to sustainability and decarbonisation contexts, where the tensions between new and old are particularly significant (Henderson, 2021).

Adopting the theory lens of discontinuous innovation, the principal research question for this thesis is framed as the following: *How are discontinuous innovation processes organised in traditional industry settings undergoing sustainability transitions?* The thesis examines this question through an empirical research project into pioneering innovation processes in the fields of steelmaking and hydrogen (steelmaking being one of the hardest-to-abate industry sectors). The study is inspired by the observation of large-scale innovation taking place in many small-town industry contexts that lack the resources of leading metropolitan start-up hubs but still manage to develop pioneering first-mover technologies and business solutions that are transforming entire industries and production processes. In particular, the thesis examines how ventures based in four rural industry towns in the Nordic countries are pioneering both technological and architectural innovations to accelerate the sustainability transition through green hydrogen and steel decarbonisation.

This study thereby combines elements of strategy and innovation studies to examine a set of case studies that, due to their location and industry, would otherwise mainly be approached from a perspective of regional development or sustainability studies (Garud and Gehman, 2012; Breznitz, 2021; Henderson, 2021). The empirical analysis and subsequent theory building are

anchored in innovation research on disruptive and discontinuous innovation as well as the development of clusters and innovation systems, and in strategy research on business models and the roles of start-ups and incumbents in driving innovation and industry change (Lundvall, 1992; Christensen, 1997; Kaplan, 1999; Santos and Eisenhardt, 2009; Gambardella and McGahan, 2010; Ansari and Krop, 2012). The primary theory lens of discontinuous innovation takes a *process* perspective of describing and analysing *inter-stakeholder relational dynamics* (i.e. roles and relationships) that are transforming system-wide industry operations, rather than a structural or technologically determinist perspective, which assumes a specific disruptor-incumbent market logic and holds that successful innovation can be determined only by *post hoc* analysis on a narrow set of indicators (Langley, 1999; Garud and Gehman, 2012; Garud, Tuertscher and Van De Ven, 2013; Henderson, 2021).

In addition, when linking the innovation processes of the case studies to their surrounding institutional context, part of the thesis also engages with literature on the political economy of innovation, including the role of the state and its economic institutions (Hall and Soskice, 2001; Acemoglu, Johnson and Robinson, 2005; Mazzucato, 2018; Thelen, 2019; Breznitz, 2021). Framing the question of sustainability-focused innovation throughout this thesis specifically as discontinuous innovation in traditional industries is relevant to many policymakers and agencies across the world that are looking to catch up and adapt their industries to fast-changing conditions, but who lack models for which business models and innovation strategies to apply when doing so (Lema, Fu and Rabelotti, 2020).

In many ways this thesis, therefore, resonates with broader contemporary calls in both academia and industry for analysing sustainability transitions with a *systems change* perspective (Savaget *et al.*, 2019; Henderson, 2021). However, research relating to systems

change takes on many different forms, with different implications and underlying assumptions. This thesis does not analyse change solely from the perspective of single companies, but neither is the level of observation placed at the macro level of sweeping trends in industry ecology. Thus the focus on relational dynamics at the inter-firm level (i.e. inter-organisational social processes between firms, governments, and other societal institutions, such as supplier relations, ecosystems, consortia, and informal partnerships). This follows the calls by Garud and Gehman (2012) for more relational research on innovation and sustainability topics, and also aligns with other research focusing on inter-stakeholder relations to determine innovation patterns (Garud and Gehman, 2012; Hall and Soskice, 2001). Specifically, this thesis examines how stakeholders in traditional industry settings develop the inter-stakeholder trust and commitment needed for managing the business risks of discontinuous ventures that do not align with established technologies and business models – the ‘innovator’s dilemma’ for discontinuous innovation (Utterback, 1996; Christensen, 1997; Kaplan, 1999).

The rationale for the inter-organisation level of observation is that discontinuous innovation is a collective endeavour that depends on a wide variety of stakeholders to succeed and that, therefore, is heavily shaped by what the inter-firm roles and relationships look like in a given innovation process (Kaplan, 1999). Moreover, a systems level of analysis with an inter-stakeholder level of observation is particularly important for studying the markedly cross-sectional and systemic nature of the transition to sustainability (Markard and Truffer, 2008; Riemer and Johnston, 2019; Henderson, 2021). On the one hand, both formal and informal institutions at the macro level shape the interactions of industry stakeholders and their joint incentives for innovation. On the other hand, the practice of innovative experimentation and new ventures is shaped by local networks and micro-processes. These factors come together at the meso-level (inter-stakeholder relational level) of analysis, where processes are driven

forward by the collective of interacting stakeholders that form an innovation system. Routines and processes are collectively negotiated among different stakeholders in the innovation system to create a social order that frames what type of research takes place, what type of companies and ideas get funded, etc. (Lundvall, 1992; OECD, 1997; Pisano, 2015). The innovation system context ultimately defines the success factors of discontinuous innovation processes. However, in the context of ‘hard-to-abate’ industry transformations (i.e. high-emitting traditional industry sectors like steel, concrete, or petrochemicals), what these success factors are mostly remains unclear.

The empirical focus of this thesis will be on case studies of pioneering sustainable industry transitions taking place in the Nordic regions of northern Sweden, Finland, and Norway. The Nordic countries are traditionally viewed to have a rigid socio-institutional setting, but they also consistently rank among the strongest innovation systems in the world (World Intellectual Property Organization., 2024). On the one hand, the industrial history of the Nordic region is often described as driven by slow-paced, incremental improvements to complex engineering and manufacturing processes (Hall and Soskice, 2001; Kristensen and Lilja, 2011). On the other hand, the success of Nordic urban highly-skilled, high-technological sectors is described as agile and entrepreneurial, featuring vibrant start-up ecosystems and active venture capital funding (Glimstedt and Zander, 2003; Bergholm and Bieler, 2013). This presents a paradox at the core of defining and studying innovation in the Nordic countries, giving rise to several competing narratives for what drives success.

The early success of Nordic traditional industry clusters in pioneering solutions for sustainability transition aligns with this uncertainty about defining Nordic innovation success: Sustainability innovation in a Nordic context leverages both world-leading venture capital and

start-up cultures, and long-established traditional industry networks with a high degree of trust, policy experimentation, and adaptation that have developed over many decades (Kristensen and Lilja, 2011). The continued strength of Nordic innovation systems is clear, but no systematic study has been undertaken in the contemporary Nordic industry context to map out different ways in which these pioneering ventures are concretely engaging with each other and navigating hard-to-abate sustainability transitions. The most recent examples of ambitious and transformative Nordic sustainability innovation projects include carbon-free steel production, hydrogen production and storage, as well as a range of other sectors, many of which are interlinked in wider energy and digital systems. This thesis focuses on case studies into near carbon-free, 'green' steel innovation as well as green hydrogen innovation. Among other cases, this thesis presents the first in-depth case study of the two most advanced green-steel innovation ventures to be found anywhere in the world.

The principal contribution of this thesis is to deepen our theoretical and empirical understanding of discontinuous innovation processes as they evolve in traditional industry settings, particularly during sustainability transitions. The thesis thereby presents a new theory perspective on innovation that helps us analyse innovation settings with more nuance to the specific context and enabling mechanisms of step-change transformations. Through inductive, grounded theorising based on iterations between theory-building and empirical observation, the section presents *a new comparative theory framework for analysing discontinuous innovation ventures* and elaborates on its applicability for further research. The new comparative framework presented and elaborated as part of the thesis will enable innovation research to understand discontinuous innovation processes and ventures in a range of different innovation contexts. This can be applied to guide policy, business strategy, and research in understanding why innovation may look different in different country and industry contexts,

how innovation processes are shaped by connections to firm strategy, local industry networks, and national institutions, and what implications this may have for the future success of technological innovations and industries under transformation.

The particular benefit of the new framework is that it is among the first to apply a lens of discontinuous or breakthrough innovation to traditional industry contexts of decarbonisation and sustainability transition, which are research settings that have so far been under-explored and under-theorised by innovation scholars (Kemp, Loorbach and Rotmans, 2007; Eisenhardt, Graebner and Sonenshein, 2016; George *et al.*, 2016; Fagerberg, 2018; Lema, Fu and Rabelotti, 2020). More concretely, the new theory framework clarifies some substantive differences between innovation ventures driving sustainability transitions in traditional industries and our common benchmarks for discontinuous innovation (most notably, the more narrow construct of disruptive innovation and its common application in benchmark cases such as Silicon Valley). The most notable among these differences is the level of engagement of an innovation process with system-level factors such as material infrastructure dependencies, which a singular actor cannot coordinate on their own. Different forms of system-level coordination and risk-sharing, particularly at the level of regional innovation systems, are found to be an essential driver of the cases included in this thesis, while the role of national policy and regulation comes across more as enabling than agenda-setting.

This thesis will proceed to undertake the described empirical analysis and theory development through the following steps. Chapter 2 summarises the literature on innovation and sustainability transitions, presents the construct of *discontinuous innovation* as a suitable theory lens for analysing sustainability transitions in traditional industry settings, and lays out a set of secondary research questions to frame an empirical research project into this topic. It is

emphasised that while sustainability transitions include many unique mechanisms, they are not categorically separated from other innovation activities in practice and, thus, should not be kept separate in theory development, either. The chapter therefore proposes to bring closer together the hitherto mostly separate fields of study of innovation and sustainability transitions by proposing a new theory perspective of *discontinuous innovation in traditional industries*. The discussion section of the chapter sets out a research agenda for analysing and comparing discontinuous innovation processes in traditional industry settings, emphasising the need to focus both on the dynamics and innovation strategies of innovative ventures themselves, as well as on the regional¹ and national level stakeholders they interact with. This agenda frames the focus for the subsequent empirical chapters and the inductive theory development undertaken based on the empirical case studies.

Having thus laid out the research agenda for analysing discontinuous innovation processes in traditional industry settings, Chapter 3 outlines the philosophical foundations, research design, case selection, and methodology for the empirical research process that is described in subsequent chapters. The inter-stakeholder relational dynamics that shape industry action are not comprehensively documented, especially when it comes to informal networks. The level of observation on inter-stakeholder relational dynamics, therefore, hinges on identifying formal, as well as informal and undocumented processes. As there is no existing analytical framework for researching discontinuous innovation in traditional industries, data analysis needs to aim at inductive theorising and formulating a new analytical framework. The research design for this thesis subsequently builds on combining different types of qualitative empirical observation: Inductive fieldwork observation, interviews, and document analysis conducted through a multiple case-study approach, following the guidelines of grounded theory building and the

¹ 'Regional' is defined throughout this thesis as sub-national level regions.

constant comparison method (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016). The chapter outlines each step of the research design for the thesis, from case selection to data collection, analysis, and inductive theory-building.

Following the introduction of the methodology and research design, Chapter 4 introduces the empirical setting for the thesis case studies: The traditional industry agglomerations located in the resource-rich north of Finland, Sweden, and Norway, and the globally significant momentum for sustainability-focused investment and innovation that has emerged in these northern Nordic regions in the past decade. The chapter provides a general overview of these recent industry developments, focusing on the ventures and localities at the centre of the three case studies to be analysed in the following chapters. This initial presentation of the research setting is particularly important given the research agenda for the thesis of analysing and theorising on discontinuous innovation that takes place beyond the standard innovation-benchmark clusters. Chapter 4 establishes that the research setting is markedly different from what most existing models expect to see from successful, innovation-enabling contexts.

Chapter 5 takes on the first of the sub-questions presented in the research agenda in Chapter 2 and analyses determinants of large-scale discontinuous innovation ventures. The chapter does this through a double process case study of the two most advanced carbon-free steel innovation ventures to be found anywhere in the world: The H2 Green Steel start-up, and the HYBRIT consortium of legacy industry incumbents. Both of these first-movers in sustainable steelmaking are emerging in the same region of Norrbotten in northern Sweden. The chapter compares how two markedly different business models for discontinuous green-steel innovation – a start-up and a consortium of incumbents – have played out and managed their

industry relations within the distinctive industrial context of northern Sweden. The double case study engages with strategy research on different business models and stakeholder roles in enabling innovation and nascent markets (Santos and Eisenhardt, 2009; Gambardella and McGahan, 2010; Garud, Tuertscher and Van De Ven, 2013; Christensen, Raynor and McDonald, 2015).

Having thus examined the role of pioneering ventures themselves, Chapter 6 maps out different models by which local industry networks can enable discontinuous innovation processes – even in seemingly surprising settings. The chapter does this through a comparative study of three Nordic case studies of ongoing discontinuous innovation processes for carbon-free hydrogen production and downstream applications: One in Finland, one in Sweden, and one in Norway. Based on the empirical analysis, the chapter presents and compares three models through which the regional innovation system drives discontinuous innovation to create commercially viable systems for carbon-free hydrogen production – with varying degrees of success in terms of investments and scaling. The chapter does not seek to present a ‘Nordic model’ or best-practice scenario. Instead, the general institutional context of the Nordic political-economy setting acts as a common backdrop and context for three distinct innovation settings, each with its own strengths and challenges in driving discontinuous innovation in traditional industries. The chapter engages with research on different types of stakeholder roles and relational dynamics within regional innovation systems (Cooke, 2004; Asheim and Coenen, 2005; Iammarino and McCann, 2006; Edquist, 2019; Breznitz, 2021).

Chapter 7 complements the empirical analysis with the perspective of national policy and regulation that enables the emergence and success of discontinuous innovation in traditional industries. The empirical focus is on Nordic policy and regulation processes that are shaping

the incentives, infrastructure, and societal capacity to undertake discontinuous innovation processes in traditional industries. The chapter particularly focuses on how discontinuity in the energy system is being promoted in Finland, Sweden, and Norway, respectively, by way of both policies and regulations (e.g. through the innovation policies of national grid authorities, regulatory agencies, and government policymakers). The empirical study identifies a set of case examples from the three countries and analyses how state-level actions enable these case examples. The case study engages with research on how state institutions and innovation policy may impact innovation and sustainability transitions (Reichardt *et al.*, 2016; UNEP, 2017; Mazzucato, 2018; Thelen, 2019; Lema, Fu and Rabellotti, 2020). More broadly, the chapter also discusses what the case studies imply for further research on comparative political economy in the Nordic countries (Hall and Soskice, 2001; Kristensen and Lilja, 2011).

Following the empirical part of the thesis, Chapter 8 brings together the empirical findings to examine how the analysis of ongoing discontinuous innovation processes around sustainable industry transitions contributes to our theoretical understanding of innovation and sustainability. The findings are related back to the presented theoretical agenda for discontinuous innovation in traditional industries. A proposal is subsequently made both for a *new comparative theory framework for analysing discontinuous innovation*, and, based on this, a *new process framework for analysing discontinuous innovation*. Both of the new theory frameworks are illustrated by applying them to the case studies of this thesis, after which the chapter outlines their broader application to benefit future research. In order to support policy and strategy for sustainable industry transitions, theory on innovation needs to be able to characterise, categorise, and analyse breakthrough innovation in settings that previous models would have overlooked. This is where the new theory development of this thesis makes its contribution to the innovation literature.

Finally, Chapter 9 offers a conclusion of the findings and main contributions of this thesis to the literature on innovation, discusses the main areas of future research based on the empirical case studies and proposed theory frameworks, and addresses general research limitations.

Chapter 2 – Literature Review and Research Agenda

2.1 Introduction

The previous chapter framed the challenge at the core of this thesis: The climate crisis prompts traditional industry stakeholders to undertake their most overwhelming transformation since the first industrial revolution (UNEP, 2017). There is a clear need across the global economy for undertaking and implementing large-scale innovation for step-change transformations, departing from the existing assumptions and dynamics of fossil-fuel-driven supply chains and infrastructures. Sustainability journeys can be markedly different in different industries and innovation settings and are particularly discontinuous in the most hard-to-abate sectors that have based their operations on fossil-fuel-driven processes for several decades (Garud and Gehman, 2012; Lee and Malerba, 2017; McDowall, 2018; Henderson, 2021). The climate crisis thereby presents both policymakers and industry practitioners with the challenge of shaping the future through discontinuous innovation processes that are not well understood in today's industry environment in general – and even less so in particularly hard-to-abate sectors such as steel.

On the one hand, existing literature on sustainability transitions has developed a set of models and frameworks to analyse specific developments such as industry decarbonisation, but this research has not included a designated focus on innovation (Markard, Raven and Truffer, 2012; McDowall, 2018; Schot and Steinmueller, 2018). This is important because, especially in traditional industry contexts, sustainability transitions are unlikely to develop completely separate from the sustaining, 'day-to-day' research and development activities in these industries. A specific research focus on examining and comparing innovation processes would help establish the links between sustainability-focused innovation and 'non-sustainability'

innovation. This is crucial for understanding how new ventures are financed and how partnerships or alliances are formed with other industry stakeholders or with policymakers. As it stands, existing ‘sustainability-only’ theory frameworks in the literature on sustainability transitions (for example, strategic niche management) are not bridging these different elements of innovation processes (Schot and Geels, 2008). This leads to limited understanding especially of hard-to-abate sustainability transitions where innovation is heavily dependent and conditioned on pre-existing industry processes.

On the other hand, existing literature on innovation is not well attuned to analysing innovation processes relating to sustainable industry transitions and how they may have different requirements than more familiar benchmark cases of innovation (McDowall, 2018). There has been a strong focus on researching and theorising a relatively narrow range of innovation environments, such as digital platforms and ecosystems where innovation is fuelled by competition for market share between rival technologies (for example, in FinTechs or consumer electronics) (Jacobides, Cennamo and Gawer, 2018; Thomas and Autio, 2020; Furr, Ozcan and Eisenhardt, 2022). This literature evolves hand in hand with our existing understanding of how innovation drives industry-level transformation through constructs such as disruptive innovation and creative destruction (Foster and Kaplan, 2001; Christensen, Raynor and McDonald, 2015). These existing perspectives in innovation studies portray industry transformations as fiercely competitive innovation processes, where entrants with new technologies seek to win over consumers and replace incumbents (Christensen, 1997; Ansari and Krop, 2012). But the rationale for step-change transformations in traditional industries, particularly in sustainability contexts, may often be rooted outside this mainstream innovation model of market-competition and incumbent overthrow. This is visible particularly in that goals such as carbon neutrality and preventing biodiversity loss are, in most sectors, only gradually

being converted to firm-level competition incentives in current-day markets (McDowall, 2018; Schot and Steinmueller, 2018; Savaget *et al.*, 2019).

Despite these clear signs of variation in driving innovation mechanisms across different contexts, there is no comprehensive comparative innovation theory framework to explain why breakthrough or discontinuous innovation processes may work differently across or within different industry sectors. Consequently, there is also no existing theoretical framework that applies general research on innovation with the aim to situate and compare the innovation processes underway in the transition to sustainability (Fagerberg, 2018): innovation that is, on the one hand, inspired by climate policy incentives that are external to the existing logic of the productive market economy, and on the other hand, path-dependent and heavily rooted in the material infrastructure and process models of the existing industry system.

This theory chapter sets out a proposal for a research agenda based on the questions left unanswered by current literature on innovation and sustainability. Firstly, the chapter emphasises that the needed analysis can best be undertaken through a broadening and deepening of the construct of *discontinuous innovation*. This construct is chosen as the starting point because it is specific enough to denote innovation activities that seek a step-change industry transformation but broad enough to encompass different potential strategies and industry settings driving such transformation, including sustainability contexts (Kaplan, 1999). The conceptual focus on discontinuous innovation is rooted in a need to examine how innovation processes are organised at times of significant transformation – such as the sustainability transition – where the business models and innovation strategies have not yet been settled (as they are in mature settings of continuous or sustaining innovation) (Geroski, 2003; Thompson, Purdy and Ventresca, 2018).

Secondly, this chapter observes that most contemporary innovation literature focuses on industry contexts that are rooted in social networks and end-user markets (such as the digital platform economy) (Casper, 2007; Breznitz, 2021). The proposal is therefore made for more focused empirical study and theory development based on research into innovation processes in *traditional industries* that are heavily dependent on existing infrastructure, energy systems, and material supply chains (rather than, for example, innovation in software or services). Traditional industry settings are not only under-researched but also facing some of the most hard-to-abate sustainability transitions, making their study particularly salient. While few industry sectors would fall completely into one specific category, making the conceptual distinction to focus on traditional industry settings helps us identify patterns in discontinuous innovation that may be particularly important in innovation contexts that are heavily dependent on material supply chains and physical infrastructure (McDowall, 2018).

Thirdly, moving down from the level of inter-industry comparison to the level of innovation processes, this chapter argues that a new theory framework is required for comparing and categorising innovation ventures based on their interactions with the surrounding actors of the industry and innovation system. The analytical lens of discontinuous innovation is applicable for shifting focus from endogenously analysing technological diffusion models of singular ventures, to a systemic focus on *relational dynamics (inter-stakeholder roles and relationships)*, which analyses and compares how different innovation processes are collectively organised and shaped (Garud and Gehman, 2012). This perspective is strengthened by existing inter-firm level research, in particular relating to regional and national innovation systems (Lundvall, 1992; Edquist, 1997; OECD, 1997; Cooke, 2004; Pisano, 2015). A new theory framework for comparative analysis of discontinuous innovation ventures based on

inter-stakeholder relational dynamics, as well as a process model based on this framework, are set out as the target and research agenda for this thesis. The empirical research agenda follows directly from this: Examining how sustainability-focused discontinuous innovation processes are organised in traditional industry sectors.

The discussion section outlines the wider rationale of these research aims. Firstly, to bridge the hitherto largely separate literature streams on innovation and sustainability transitions, and secondly, to increase comparative nuance in the literature on innovation by making it possible to pinpoint key drivers of discontinuous innovation processes (e.g. for sustainability transitions) in a way that cannot be captured with conventional taxonomies of innovation (such as product vs. process, radical vs. incremental, or sustaining vs. discontinuous). The new framework to be developed in this thesis, for which the current chapter sets the agenda, provides a foundation for comparing how different strategies to innovate in a specific industry sector may diverge from each other and how they may evolve over time. The focus of the theory development is important because settings of discontinuous innovation are, by definition, particularly changing and uncertain, as is the case in many contemporary contexts of industry transformation. The final part of the chapter sets out potential empirical applications of the outlined agenda to define a theory framework, serving as a rationale and theory anchorage for the empirical chapters and their respective research questions.

2.2 Existing literature on sustainability transition and innovation

This section briefly introduces existing literature applications on sustainability transitions and innovation, finding a mismatch and limited common understanding between them about how innovation processes unfold and are enabled in the context of sustainability transitions. To demonstrate the literature mismatch, the first sub-section briefly reviews how innovation is analysed in relevant literature on sustainability transitions.

2.2.1 Sustainability transitions

Social science and management scholars have developed a range of research analysing change processes surrounding sustainability transitions and climate adaptation (Coenen, Benneworth and Truffer, 2012; Markard, Raven and Truffer, 2012; Savaget *et al.*, 2019). These fields of research inquiry, ranging from environmental policy and sociotechnical systems research to sociological theorising of the way climate change demonstrates the tragedy of the commons, seek to describe distinctive dynamics of climate-change-induced social phenomena (Ansari, Wijen and Gray, 2013).

In research on innovation and technology, the transition to sustainability has been framed as a ‘green techno-economic paradigm’, which acts as a rule-shaping regime or framework for how the entry of sustainability as a societal priority comes to transform markets and industries (Freeman, 1992). Subsequent research builds on this view of the sustainability transition as an external and discontinuous disruption to existing technological systems and innovation processes (Kivimaa and Kern, 2016; Schot and Steinmueller, 2018; Lema, Fu and Rabellotti, 2020).

Lee and Malerba (2017) describe the nature of this paradigm shift induced by the sustainability transition in terms of a ‘green window of opportunity’, alluding to new opportunities to develop new products, processes, or business models to address sudden step-change transitions in sustainable supply chains, resources and technologies. The authors define these windows of opportunity as ‘discontinuities’ in sectoral systems of innovation. However, they do not offer a specific model for analysing how these discontinuities are leveraged by early-stage, pioneering ventures but rather focus on the role of catch-up cycles and latecomers in shaping the sector-wide trajectory of more mature-stage markets. Lema, Fu and Rabellotti (2020) describe how the green window of opportunity also provides promising opportunities for developing economies to leapfrog some of the step-changes in technology and infrastructure while advanced economies need to spend significant time and resources on changing their existing systems and infrastructures. The authors highlight three ways in which the sustainability transition differs from other industry change and latecomer catch-up processes: (a) a sustainability-driven innovation directionality features gradually emerging development pathways instead of a clear pathway for innovation and latecomer catch-up, (b) sustainability is developed as public goods and a social-value logic instead of purely market-driven mechanisms, and (c) sustainability contexts afford a greater level of policy intervention and directed development than other innovation contexts.

Some research on innovation for the sustainability transition has developed new theory frameworks that are specific to the context and characteristics of sustainability. One such sustainability-specific framework is provided by the research on strategic niche management and the Multi-Level Perspective (Kemp, Loorbach and Rotmans, 2007; Schot and Geels, 2008). This research describes innovation and breakthrough research for the sustainability transition as strategically shielded from market forces in innovation niches that only gradually transform

the prevailing technology regime. From the perspective of these research strands, the distinct nature of sustainability-related change processes needs to be understood through a purpose-built theory lens that is specific to the sustainability context (Fagerberg, 2018). Thereby they do not carry over implicit assumptions from general theory frameworks on innovation and industry change.

While the developing work on sustainability transitions brings important insights and a breadth of empirical knowledge, this literature has developed separately from the dedicated literature and theory on innovation. This may risk an overtly essentialist approach to the analysis of sustainability processes (Fagerberg, 2018). The shift to sustainability has distinct characteristics and non-market incentive structures that are more nuanced than any general model of technological change. Indeed, Schot and Steinmuller (2018) highlight that the transformative and unprecedented nature of the sustainability transition is so distinct from other innovation processes that it cannot be paralleled with other existing innovation framings. The authors point to studies labelling the sustainability transition as the ‘second deep transition’, shifting industrial mechanisms that have not been significantly altered since the first deep transition, i.e. the first industrialisation (Schot and Kanger, 2018).

However, viewed from the perspective of innovators and policymakers, sustainability transitions do not exist in a categorically different reality but are inherently connected to the day-to-day context of industrial development as well as to other ongoing transitions, not least to digitalisation. Familiar terminology and strategic innovation models are already widely used in sustainability contexts among practitioners, policymakers and analysts (Fagerberg, 2018; McDowall, 2018). Existing literature on sustainability transitions has not included a comprehensive analysis that would benchmark sustainability-linked innovation processes

against general taxonomies and theory frameworks from innovation literature (Adams *et al.*, 2016). Therefore, the next sub-section turns to review relevant innovation literature and, in particular, how it has been applied to date to analyse sustainability contexts.

2.2.2 Innovation

Innovation is the continuous process by which new ideas are developed and applied in practice for technological advancement and economic and societal benefit (Fagerberg, 2005). Scholars have developed several ways to categorise innovation, narrowing down the concept to analyse particular settings of innovative activity. The locus of innovation is, in general, conceived as either *product* or *process* innovation, depending on whether the focus of new ideas is on improving or re-inventing the qualities of an end-stage product itself or on improving the speed or resource-efficiency of the process by which a product is created (Schmookler, 2013). The intensity of innovation, i.e. the relative pace with which new innovations are developed and applied, is categorised as either *incremental* or *radical* (Utterback, 1996). In addition to this, a body of literature has developed to describe *service* innovation, where the main locus of innovation is on a service-based value proposition rather than a physical product (Gallouj and Savona, 2009; Furseth and Cuthbertson, 2016). Finally, *architectural* innovation describes innovations that reshape entire market segments or the industry architecture, i.e. the roles and relationships of stakeholders operating in a specific industry (Henderson and Clark, 1990; Garud, Tuertscher and Van De Ven, 2013).

While innovation, by definition, includes an element of novelty that seeks to challenge or improve on what existed before, the direction of travel for innovation processes can take different forms. Innovation that builds on new knowledge (and often on basic research) and that seeks to transform existing industry structures and epistemic regimes through a step-

change transformation is labelled as *non-continuous* or *discontinuous* innovation (Utterback, 1996; Kaplan, 1999). Discontinuous innovation is, in many ways, a similar construct to architectural innovation, but where the focus of architectural innovation is on the recombination of architectural components of an industry regime, discontinuous innovation encompasses both technological change and architectural change and puts centre-stage the process of the non-linear, step-change transformation: how the discontinuous innovation process is incentivised given its clear step away from existing processes, to which degree it builds on existing knowledge as a base while simultaneously overhauling the existing processes, and how a discontinuous venture interacts with day-to-day, continuous or ‘sustaining’ innovation processes, either through competition or non-market mechanisms. Kaplan (1999) defines four market-driven business strategies for discontinuous innovation: *radical cannibalism*, *competitive displacement*, *market invention*, and *industry genesis*. However, these strategies are connected to general examples rather than a theory framework that compares how discontinuous innovation develops in different industry sectors or innovation contexts.

Christensen’s (1997) influential work on *disruptive* innovation can be viewed as a specific form of discontinuous innovation. The step-change described in this case is the competition-driven substitution of existing products or entire market segments by alternative technologies and product solutions. The theory framework discusses industry disruption as the practical enactment of the ‘Innovator’s Dilemma’: On the one hand, economic actors are expected to compete in innovation and become experts in improving their own product, but on the other hand, this makes incumbent stakeholders more vulnerable to themselves becoming outcompeted by challengers who undertake discontinuous innovation to disrupt the existing markets with a completely new offering. In Christensen’s (1997) model the success of a

disruptor depends on whether enough resources can be mobilised towards the development and marketing of a disruptive value proposition to turn consumer interest away from the incumbent and bring the disruptor ‘from the fringes to the mainstream’ of the industry (Christensen, Raynor and McDonald, 2015). The model of disruptive innovation is actively referenced especially in strategy literature, when analysing consumer-facing innovation strategies in high-technological sectors and clusters (Carlo *et al.*, 2014; Kumaraswamy, Garud and Ansari, 2018; Ozalp, Cennamo and Gawer, 2018; Ritala, Huotari and Kryzhanivska, 2022). However, it was originally applied to cases such as the steel industry, describing how the development of efficient and modular (albeit lower-quality producing) ‘mini-mills’ outcompeted the large, integrated steel plants that had been the dominant organising model of the US steel industry (Christensen, 1997).

The framework and terminology of disruptive innovation are applied widely in business and policy settings that discuss sustainability: a framing of disruptive innovation becomes a powerful rhetorical tool for promoting an envisioned transition in industry and energy technologies as driven mostly by competition between firms (Schot and Steinmueller, 2018; Ritala, Huotari and Kryzhanivska, 2022). Kivimaa and Kern (2016) are among the few who apply the lens of disruption and creative destruction to their proposed approach of a disruption-oriented innovation policy mix. Others have focused on disruptive innovation as a lens to forecast financing processes and stranded assets for renewable energy (Green and Newman, 2017).

Meanwhile, McDowall (2018) emphasises that a direct application of Christensen’s (1997) theory of disruptive innovation may lead to a skewed image of what the sustainability transition entails. The author argues this to be due to narrow assumptions underlying the framework of

disruptive innovation: (a) The scale of the sustainability transition is not limited to underserved user groups, like in Christensen's theory, but is much more subversive, (b) Christensen's model of competition-driven disruptive innovation by start-ups is not the only path to industry disruption, and (c) the literature on disruptive innovation focuses on markets and underplays the role of public policy and regulation, which is significant in the case of the sustainability transition.

As Henderson (2021) stresses, the transition to sustainability will inescapably involve a system-wide transition towards low-carbon alternatives in energy, industry production, and transport and infrastructure systems. The nature of the industry architecture under transition in material-intensive sectors implies the need for dramatic shifts from fossil-fuel-based production to decarbonised alternatives. Consequently, the context of sustainability invites analysis of *discontinuous* innovation processes in many different sectors under transition.

However, existing academic studies of discontinuous innovation and industry disruption are more focused on the essence of technological change than on its instantiation in different innovation settings, and have thereby focused relatively little on analysing the innovation dynamics in sustainability contexts. More specifically, there is no comparative theory framework that discusses how different discontinuous innovation ventures are incentivised, initiated, and industrialised, nor how the capacity for different relational dynamics (i.e. inter-stakeholder roles and relationships) to promote discontinuous innovation may vary over time (Garud, Tuertscher and Van De Ven, 2013). For example, research on disruptive innovation is focused on competitive dynamics between market actors, not on comparing different innovation settings and strategies. Lee and Malerba (2017), as referenced earlier, do connect 'windows of opportunity' to 'discontinuities' in existing sectors, but focus more on latecomers

and catch-up to mature markets than on analysing strategies for discontinuous innovation. Our existing theory frameworks of innovation are also mostly focused on *post hoc* analysis of established innovation contexts rather than on *processes* (Garud and Klopp, 2023). This, by definition, makes it exceedingly difficult to theorise on discontinuous innovation in nascent and unsettled market spaces, such as the sustainability transition has created for many industry sectors (Kumaraswamy, Garud and Ansari, 2018).

Literature on innovation policy and *green industrial policy* does include a specific focus on sustainability transition settings and how state-level policy can best support them (UNEP, 2017; Fagerberg, 2018; Mazzucato, 2018). Based on the Maastricht Memorandum, Mazzucato (2018) outlines differences in how complex sustainability challenges ought to be tackled by ‘new mission-oriented innovation policies’ (MOIP) that are more flexible and changing compared to state-directed innovation policy in more mature sectors (Soete and Arundel, 1993). However, these frameworks are not meant as analytical tools to compare how these innovation processes evolve differently in different contexts.

The richest analysis to date of different innovation settings and relational dynamics can be found in the literature on *innovation systems*, which evolved during the latter part of the 20th century as a framework for discussing innovations as the outcome of macro-level features of industrialised societies (Lundvall, 1992; Nelson, 1993; Cooke, 2004). Pisano (2015:4) defines the innovation system as “*a coherent set of interdependent processes and structures that dictates how the company searches for novel problems and solutions, synthesizes ideas into a business concept and product designs, and selects which projects get funded*”. Innovation systems literature views innovation outcomes in a given territory as the complementary performance of the public sector, the private sector, and academic research institutions (the so-

called triple helix) (Etzkowitz and Leydesdorff, 2000). This level of analysis is supported by theory from population ecology and research is concentrated on high-level statistical analyses about firm entry and exit, growth and survival, and R&D spending rates in different countries and regions. Innovation systems thinking became and remains widely applied by policy organisations: the OECD was instrumental in refining the concept and in developing prescriptive research detailing the profiles of different countries and regions from an innovation systems perspective (OECD, 1997). In academia, the concept has been applied most actively by comparative political economists and economic geographers. The discussion about innovation systems is considered mature and there is no imminent momentum to refine it much further (Scaringella and Radziwon, 2018; Suominen, Seppänen and Dedehayir, 2019). However, the literature on innovation systems clearly continues to be one of the most influential sub-streams of academic research that inform public policy around innovation and regional and economic development (Edquist, 2019).

Literature in the tradition of innovation systems and other industry-wide innovation phenomena has developed different frameworks for categorising different innovation processes. The legacy literature builds on the Schumpeterian distinction between ‘Mark I’ or ‘widening’, and ‘Mark II’ or ‘deepening’ technological classes, depending on the characteristics of an industry’s core technology (Fagerberg, 2005). The characteristics of different innovation systems have, building on this, been accredited to the ways in which different industries usually innovate. On the one hand, industries transforming by radical change and dynamism through ‘widening’ the number and diversity of competing innovators in search of radical growth, and where new entrants and models significantly disrupt the established practices and balances of the industry, is a pattern of *creative destruction*. On the other hand, a concentrated and rigid industry, where the hierarchy of market actors rarely

changes and where the focus is instead on ‘deepening’ the existing knowledge base among established groups of innovators, is a pattern of *creative accumulation* (Malerba and Orsenigo, 1996). Political economy literature on different *Varieties of Capitalism* makes a similar distinction between different types of industries but focuses on institutions and industrial relations rather than technology as the differentiating factor. Hall and Soskice (2001) demonstrate how the socio-institutional context of an economy provides different advantages for different kinds of industries and innovation processes: liberal market economies such as the US and UK are more conducive to processes of radical innovation, whereas coordinated market economies like Germany and the Nordic countries provide a conducive environment for incremental innovation. Subsequent work on industry and innovation has elaborated on these frameworks with increasing nuance (Braunerhjelm and Feldman, 2006; Casper, 2007; Hancké, Rhodes and Thatcher, 2007; Breznitz and Ornston, 2013; Ornston, 2014; Thelen, 2019).

Existing comparative theory frameworks on different innovation settings and processes mostly discuss industry-level patterns rather than specific ventures or cases, and tend to focus on describing ‘business-as-usual’, i.e. continuous/sustaining innovation processes that are regularly taking place (whether the intensity of such continuous innovation is radical or incremental). Consequently, existing literature lacks analytical and comparative focus on how discontinuous, step-change innovation processes develop in different settings and over time. Discontinuous innovation is distinct from sustaining innovation in that the incentives and strategies for the discontinuous innovation process, by definition, go against the surrounding innovation context and against innovation pathways that may have been institutionalised and codified within a national or regional innovation system during several decades (Utterback, 1996). Comparative analysis of discontinuous innovation, therefore, requires not wider industry-level comparisons but more granular analysis at the level of the firm or venture and

its inter-stakeholder relational dynamics: how different discontinuous innovation processes positions themselves and develops in relation to the surrounding industry setting/innovation system (Garud, Tuertscher and Van De Ven, 2013).

In conclusion, this literature review section finds a clear lack of frameworks for analysing discontinuous innovation processes taking place in different settings, which is particularly visible in the disconnect between analyses on sustainability transitions and traditional innovation literature. On the one hand, literature dedicated to the analysis of sustainability transitions has not undertaken in-depth theory development linked to established innovation theory concepts. Much of the recent system-level literature on sustainability transitions views sustainability as a separate category of industrial change and thereby does not apply existing innovation or disruption theory to analyse it (Schot and Steinmueller, 2018). On the other hand, while literature on innovation has developed insightful theory frameworks, not least the literature on discontinuous innovation and adjacent constructs, these are not comparative at the process and venture level nor nuanced enough to be meaningfully adopted across different innovation contexts where sustainability transition is taking place. In particular, traditional industry settings are under-researched in discontinuous and disruptive innovation literature relative to many other industries and technologies, even though these innovation settings are also some of the most heavily polluting and hard-to-abate, and thus facing significant transformations to their operation due to the climate crisis. The latter industry contexts look very different from the ‘Silicon Valley model’ innovation settings that existing research and theory building has predominantly focused on instead (Casper, 2007; McDowall, 2018; Breznitz, 2021). The focus of existing innovation research has not been on describing the concrete differences in terms of how different stakeholders operate across innovation settings. This perpetuates the unhelpful knowledge divide between those who study sustainability

transitions as a phenomenon and those who theorise on processes and enablers for discontinuous innovation.

It follows from these literature observations that existing theory frameworks of innovation need to be complemented with a new framework, which categorises discontinuous innovation processes based on inter-stakeholder relational dynamics. This will enable the bridging of the observed knowledge divide by allowing for side-by-side comparisons of how different discontinuous innovation processes are organised and what enables them to succeed. These comparisons can be applied across different sectors and in both sustainability and ‘non-sustainability’ innovation contexts. Based on the preceding literature analysis, the next section will systematically frame the rationale of complementing existing literature with a new comparative theory framework developed through a research agenda of *discontinuous innovation in traditional industries*.

2.3 Open questions from the literature

The previous review section highlights that there are still several unknowns surrounding how discontinuous innovation is organised in different industry settings and that this gap in theory development is particularly relevant given the need to manage and support sustainability transitions. On the one hand, existing sustainability-transitions literature lacks a specific, substantive focus on the enablers and implications of discontinuous innovation in industry sectors transitioning to sustainability. On the other hand, existing theory on innovation fails to distinguish how the characteristics and context of sustainability-focused innovation relates to patterns of discontinuous innovation and technological change. The literature streams contributing to the analysis of sustainability transition and innovation are predominantly separated from each other (Schot and Steinmuller, 2018; Fagerberg, 2018). The literature

review thereby suggests that innovation processes in traditional industry settings, and more specifically for the sustainability transition, evolve in a way that is yet to be fully defined and understood. This section of the chapter outlines the key questions that remain unanswered in the existing literature.

The literature review unveils a fundamental disconnect in existing research, which makes it difficult to apply existing theory frameworks to the context of sustainability transitions. This disconnect stems from implicit assumptions underlying contemporary innovation research: that discontinuous innovation, where an industry transformation evolves through a clear step change, mainly emerges within dynamic start-up ecosystems that develop as fully detached from the existing industry dynamics and evolve through consumer-driven disruption of incumbent technologies (e.g. disruptive innovation in software or consumer electronics) (Ansari and Krop, 2012; Ozalp, Cennamo and Gawer, 2018; Ritala, Huotari and Kryzhanivska, 2022). Our current-day understanding of how to succeed in disrupting or overhauling an industry and building new market segments reflects a consumer-driven model based on out-competing incumbent stakeholders by scaling up either vertically organised start-up firms or digital platform-based innovation ecosystems. This type of radical entrepreneurial scale-up is best exemplified by high-technological, resource-rich and mature innovation environments like the current-day tech ecosystem of Silicon Valley (Saxenian, 2000; Casper, 2007; King and Baatartogtokh, 2015; McDowall, 2018; Breznitz, 2021).

However, this is only one of many kinds of industry environments where discontinuous innovation can occur. This is demonstrated by the extensive literature comparing innovation more generally, which does not develop specific comparative frameworks for discontinuous innovation processes but clearly underlines that innovation as a whole is a context-driven

process that looks different in different places and also over time (Breschi, Malerba and Orsenigo, 2000; Storper *et al.*, 2015; Edquist, 2019; Fu, 2020; Breznitz, 2021). Indeed, even research focused on the world's leading start-up ecosystems like Silicon Valley has emphasised that the current-day innovation mechanisms are not the same as the drivers that were prevalent during the nascent stages of these innovation systems (Saxenian, 2000; Mazzucato, 2011; Storper *et al.*, 2015). Based on this, we can formulate the following open question:

- *Q1. How do discontinuous innovation processes get organised differently in different industry settings and over time?*

The lack of diversity in innovation research is particularly pronounced in the case of *discontinuous innovation in traditional industry contexts*. On the one hand, the literature on discontinuous innovation and disruption highlights market-driven models where existing processes are overhauled and completely discarded. Nascent technologies and market-building efforts are thereby more detached from sustaining innovation processes in these 'Silicon Valley model' innovation contexts (Casper, 2007). This has been the starting point for existing research on industry disruption and formation of nascent market segments, as described above (Santos and Eisenhardt, 2009; Thompson, Purdy and Ventresca, 2018). On the other hand, traditional industry sectors, by definition, have a more networked and path-dependent trajectory that relies on physical infrastructure and resources, and where change tends to happen through repurposing rather than discarding the existing resources and process models (Pavitt, 1984; Jacobides, MacDuffie and Tae, 2016; Lee and Malerba, 2017). Existing literature has not explored in depth what the discontinuous innovation process looks like in these industry sectors: To what extent it is equally market-disruptive as in other sectors, and to what extent the resource dependencies of traditional industries give rise to unique elements that make step-

change, discontinuous innovation or nascent market formation processes look different in these industry settings compared to others (Pfeffer and Salancik, 2003). This motivates a more specific open question, which also forms the primary research question of this thesis:

- *Q2. (Main Research Question). How are discontinuous innovation processes organised in traditional industry settings undergoing sustainability transitions?*

In order to approach these emerging questions with more nuance, there are several sub-elements that may bring additional insight to the study of discontinuous innovation processes in different settings. Firstly, there is little existing research on different business models and strategies for discontinuous innovation that firms in a given industry setting may adopt and how these strategy decisions get shaped by the industry context through relational dynamics to other stakeholders (Garud, Tuertscher and Van De Ven, 2013). The general assumption in existing research is that rigid incumbents get outcompeted by dynamic start-ups (Ansari and Krop, 2012; Cozzolino, Verona and Rothaermel, 2018). However, the reality of discontinuous innovation may be more complicated, particularly in traditional industry settings where transformation requires large-scale ventures capable of simultaneously transforming multiple supply-chain elements. This makes the tensions between new and old technologies and value chains and the roles and relationships of stakeholders particularly pronounced in these settings. To reach a more nuanced understanding of how discontinuous innovation processes are organised it is, therefore, crucial to develop empirical research that analyses the *drivers of large-scale discontinuous innovation ventures in traditional industries*, for example, in terms of the roles and relationships of start-up and incumbent business models.

Secondly, beyond the analysis of venture business models and innovation strategy, a nuanced and comparative analysis of discontinuous innovation processes in different settings cannot be fully understood without insight into the relational dynamics of the locality/region in which these ventures develop. The headlines surrounding breakthrough innovation mostly focus on the main innovator, while relatively little attention is paid to how the local industry environment and regional innovation system of these ventures can fundamentally shape the pathways and success factors (Breznitz, 2021). There is, subsequently, a need to study *local-level enablers for discontinuous innovation*. Once again, this is particularly crucial for gaining a deeper understanding of discontinuous innovation in traditional industry settings, as these are inextricably linked to place-based capabilities and strategic resources as well as immovable physical infrastructures for their transformation processes (McDowall, 2018).

Thirdly, it is also important to gain a more in-depth understanding of how exactly policy, regulation, and the institutional context at the national level may shape discontinuous innovation processes based in a certain country and how this may shape the overall competitive advantage for discontinuous innovation. This line of inquiry complements the two previously described focus areas: While there are several aspects to map out and compare when it comes to processes at the level of ventures and their surrounding industry networks, analysis is also needed that compares ventures' relational dynamics with state-level agencies and institutional structures. On the one hand, this connects to a recent revival of research surrounding the role of the state as an active stakeholder in innovation and industrial policymaking, for example, through concepts such as 'mission-oriented innovation policy' (MOIP) or state 'directionality' for innovation (Edquist, 2019; Mazzucato, 2019; UNDP, 2017). On the other hand, beyond formal state-level policy and regulation, this also relates to examining the impact on discontinuous innovation of the surrounding socio-economic institutions, such as

complementarities of industry stakeholders with the national education system or labour market structures (Hall and Soskice, 2001; Kristensen and Lilja, 2011). As in the previous paragraphs, these questions relating to the national policy context are again particularly important for understanding discontinuous innovation in traditional industry settings, which are dependent on existing energy and infrastructure systems that are coordinated, regulated, and often owned by the state.

These areas frame three open sub-questions surrounding discontinuous innovation processes in traditional industry settings:

- *Q3. How do large-scale discontinuous innovation ventures in traditional industry settings balance between new and incumbent markets, technologies, and value chains?*
- *Q4. How and to what extent can local-level relational dynamics shape the strategy and success of discontinuous innovation processes in traditional industry settings?*
- *Q5. How do state-industry relational dynamics and institutional factors impact discontinuous innovation processes in traditional industry settings?*

The context of ongoing sustainable industry transitions highlights the need for comparative venture and process level research and theory building on discontinuous innovation in traditional industries. To be successful, the complex and systemic sustainable industry transition cannot be orchestrated by any one stakeholder acting on their own, nor can it be boiled down to a singular *moonshot mission* with a categorical determinant of completion, such as a successful space mission or effective vaccine (Mazzucato, 2018). This means that we cannot easily apply familiar frameworks for innovation strategy and policy that lay out linear processes of industrialisation, technology diffusion, industrial policy, and market-driven

overhaul of incumbents, when we seek to understand global processes of sustainable industry transition (McDowall, 2018; Henderson, 2021). As the market incentives and regulatory frameworks for sustainable and carbon-neutral technologies are only gradually emerging and display a lot of heterogeneity across industries and regions, we do not yet have clear and generalisable models of the pathways that industry stakeholders can take to navigate the transition or that governments can follow for successfully enabling it.

For example, as will be explored in the following chapters, many actors currently pioneering sustainability innovation in traditional industry settings are organised either as large-scale consortia or small-scale network partnerships in rural towns, where incentives for innovation are not based solely on Chandlerian-type competition but on collaborative innovation through long-term supplier relations and non-market alliance mechanisms (Kristensen and Lilja, 2011; Breznitz, 2021). The dominant innovation logic of a ‘Silicon Valley model’ of disruptive innovation does not emphasise system-level innovation drivers of collaboration and shared learning networks that may prove crucial for the wider sustainability transition but focuses on vertical scale-up and dichotomous competition between rival innovators (Casper, 2007; King and Baatartogtokh, 2015). Existing innovation theory has not developed a typology to categorise and compare different types of discontinuous innovation, through which sustainability-related innovation and its distinct innovation mechanisms could be more clearly described and compared across different industry settings.

2.4 A research agenda for theorising on discontinuous innovation in traditional industries

With the aim to better understand the innovation processes driving sustainability transitions as well as other settings of discontinuous industry change, this chapter sets out a research agenda for developing a comparative framework typology for discontinuous innovation ventures, building on the open questions highlighted as part of the above analysis and literature review. This research agenda can build on earlier research on innovation but needs to focus more specifically on distinguishing between different relational dynamics, i.e. the stakeholder roles and relationships, that enable discontinuous innovation to develop. The focus of the current theory discussion is specifically on *discontinuous innovation processes*, as these step-change transformations may be seen as evolutionary turning points during which the dominant innovation rationale for a sector is shaped through the actions and relationships between innovators and their surrounding industry context (Kaplan, 1999; Garud, Tuertscher and Van De Ven, 2013).

Reiterating the point made above that innovation processes look different *across different industries*, it is necessary to develop a theory framework that can help understand how discontinuous innovation processes are shaped by these differences. In particular, a useful comparative framework should be applicable to the understudied innovation realities faced by ventures in traditional industry settings where the overarching innovation context is still conditioned by material affordances and physical design elements. In these industry contexts, downstream applications and end-user markets are by no means insignificant factors, but their direct impact on the strategic decisions of ventures – and on shaping the nascent industry space that the discontinuous innovation process is promoting – may be less pronounced than the regulatory regime, supply of required resources, infrastructure networks, and other material

elements of the early-stage innovation process (McDowall, 2018). These factors of physical place and resources are linked closely to the bottlenecks and fossil fuel dependencies that make many traditional industries ‘hard to abate’ in terms of decarbonisation and sustainability transition, but these factors do not figure in our mainstream models of innovation (Henderson, 2021). A novel theory framework needs to account for these differences between industry contexts in a nuanced way.

Having emphasised the need for a comparative framework that can be applied in different industry contexts, the example of under-researched and highly relevant traditional industry settings also demonstrates the type of new research agenda that is necessary: Empirical process research to pinpoint what conditions may be used to differentiate individual ventures from each other *within different industries*, at the level of their inter-stakeholder relational dynamics. This proposed research agenda thereby departs from earlier taxonomy frameworks by not differentiating between different levels of component knowledge as a basis for categorising innovations (Seidel and O’Mahony, 2014). From a relational and systemic perspective of discontinuous innovation processes, the exact intensity of component skills involved will inevitably vary among different stakeholders, and some actors will focus more heavily on technological innovation while others are more concerned with innovation of organisational and institutional structures. Therefore, the choice is made to differentiate based on how discontinuous innovations are evolving in relation to their surrounding industry and innovation context (by way of analysing relational dynamics) instead of by trying to ‘box in’ ventures based on the specific skill base of individual innovators.

Based on the open questions set out in this chapter, and the emerging theme of differentiating discontinuous innovation ventures from each other based on their relational dynamics, an

empirical research agenda is set for this thesis: To undertake an inductive, empirical research project into *discontinuous innovation processes taking place in traditional-industry settings*, particularly within empirical settings of sustainability transition. This is to inform the theory development agenda of this thesis: To formulate a new comparative theory framework and related process model of discontinuous innovation, applicable across different industry settings but focusing on the strategic positioning of stakeholders within specific industry contexts.

Through the proposed research agenda, this thesis argues that discontinuous innovation for the sustainability transition can and should be analysed with the same terminology and theory development as any discontinuous innovation, but that this requires widened and deepened theory development on discontinuous innovation especially to gain a more nuanced perspective on traditional industry settings. It may not be useful to try to define a ‘sustainability-only’ mode of discontinuous innovation because coordinating a step-change sustainability transformation often implies operating flexibly across the divide between sustainability-focused and ‘other’ innovation (especially in infrastructure and resource-dependent traditional industry settings) (McDowall, 2018; Henderson, 2021).

2.5 Discussion

The theory framework under development in this thesis seeks to provide an opportunity to map out different ‘modes’ of discontinuous innovation and to compare them based on the inter-stakeholder relational dynamics that shape how different ventures develop and whether they succeed. However, as is immediately clear when considering the above-described interdependencies between different ventures, sectors, and ‘sustainability vs non-sustainability’ settings, the reality is not as simple as to be represented in categorical, black-and-white distinctions. To claim that certain cases or innovation stakeholders always revert to

one ideal-type model would be to present unhelpful generalisations about innovation processes as static and universally predictable. On the contrary, the purpose of the comparative framework under development will be to support a *process* view of discontinuous innovation (Langley, 1999; Garud, Tuertscher and Van De Ven, 2013).

This links back to the literature review, and in particular to the view of innovation processes and sustainability presented by Garud and Gehman (2012), who call for complementing the dominant *evolutionary* lens of innovation phenomena with a *process-based* and *relational* lens. These authors view the sustainability transition as shaped by situational actions (i.e. shaped by specific social situations) and relational dynamics, rather than as a pre-defined change agenda. This means that to determine whether a sustainability innovation process is disruptive, for example, we do not have to wait for a post hoc industry analysis as we can instead analyse in real time how the relational dynamics of the innovation process are organised in the present and envisioned for the future (Kumaraswamy, Garud and Ansari, 2018; Thompson, Purdy and Ventresca, 2018; Garud and Klopp, 2023).

This discussion section outlines potential sources of variation in the relational dynamics of discontinuous innovation processes. This complements the outlined research agenda to make possible a formulation of process models, to be outlined in chapter 8 based on a new theory framework.

2.5.1 The shaping of innovation and market contexts over time

As introduced by the open questions listed previously in this chapter, one crucial source of nuance and change in how discontinuous innovation processes are organised relates to the development of technologies and markets over time. The competitive environment and drivers of innovation are heavily influenced by the stage of maturity of a specific sector or technology (Geroski, 2003). In the very early stages of new technology development, there is not yet a clear market mechanism in place to provide clarity and predictive capabilities to entrepreneurs and investors (Thompson, Purdy and Ventresca, 2018). At a later stage and when a specific sector has developed institutions and incentive structures for the new technology, these existing structures shape the operating space of innovators in different ways, giving rise to specific roles and challenges for new entrants and incumbents (cf. Christensen, 1997; Utterback, 1996; Ansari and Krop, 2012). For example, Santos and Eisenhardt (2009) illustrate the ambiguity of operating in nascent market settings by presenting the *Claim-Demarcate-Control* framework, describing how the strategic aims of firms change as a market setting matures.

Analysis of the relational dynamics for discontinuous innovation in traditional industries is likely to show even greater variation over time and between process stages than existing research has brought to light. For example, in sustainability and decarbonisation contexts, researchers point to the novelty of environmental targets and industry benchmarks, combined with the difficulty of decoupling these targets from existing projects and infrastructures, as specific challenges that are different from the innovation challenges that nascent industry segments have ‘normally’ been assumed to face (Adams *et al.*, 2016; Savaget *et al.*, 2019; Lema, Fu and Rabellotti, 2020; Henderson, 2021). These contexts of uncertainty and variation make it particularly useful to benchmark empirical observation of innovation processes against comparative theory frameworks, such as the one under development in this thesis. This will

allow not only for answering the open questions at one moment in time but also for analysing how and why innovation processes ‘move between’ different innovation strategies, and how this may lead to different stakeholder roles and relationships than the ones expected by mainstream innovation theory.

For example, the empirical research to be outlined in the next chapters ought to find out whether and how ventures within a specific sector have undergone ‘movement’ between different strategies and stakeholder relations for pursuing discontinuous innovation. On the one hand, sustainability transition is generally expected to be a systemic process that spans across sectors and where a clear market-competition incentive has not yet emerged, suggesting that new entrants and incumbents may take on different innovation strategies than existing literature on discontinuous or disruptive innovation would assume (Savaget *et al.*, 2019; Henderson, 2021). On the other hand, many ‘climate tech’ start-up ventures also appear to be pursuing sustainability innovation with a strategy of competitive scale-up and market-driven growth (Henderson and Newell, 2010; Seba, 2014). The new theory framework under development needs to be able to account for this variation in innovation strategies across different venture stages.

These initial observations give some indication of how we may attempt to theorise a relational and process-based perspective of discontinuous innovation in traditional industry settings. While there may not be a universal roadmap for what mode of innovation is more likely to be prevalent at a specific stage of development of technologies and markets, we may look for patterns that help us understand or predict variation in innovation processes over time. However, outlining these processes requires in-depth empirical research on how discontinuous innovation processes develop over time and what the enablers are for these changes in

innovation strategy. In particular, targeted research needs to be carried out to observe early-stage, nascent developments and how these processes may differ from each other. As the open questions highlight in section 2.3 above, this ought to include both observation of firm-level processes and business models, as well as the enabling roles of different stakeholders (local industry stakeholders and state-level policymakers) in the early stages of innovation processes.

2.5.2 Institutional context and competitive advantage

Besides variation over time, another source of variation that has been introduced during the literature analysis and that may be explored further through empirical research is the impact of socio-institutional and industry context on how discontinuous innovation processes unfold. Even when competing innovators are developing innovations for very similar purposes, the structure of the innovation process may vary significantly depending on institutional enablers and industry traditions of the innovation system context – or indeed of the sector context, as has been suggested through the call for increased empirical focus on traditional industry settings (Lee and Malerba, 2017; Welter, Baker and Wirsching, 2019; Breznitz, 2021).

The structure and institutions of national and regional innovation systems have been studied from the perspective of political economy, emphasising how the role of government agencies and regulators, higher education and research institutions, labour market and wage bargaining systems, venture finance and industrial relations, etc. may shape which innovation processes emerge and how they develop (Lundvall, 1992; Asheim, 1996; Cooke, 2004; Iammarino and McCann, 2006; Breznitz, 2014; Pisano, 2015). Some of this scholarship has been linked to theory on Varieties of Capitalism, which originally differentiated between more competition-driven liberal market economies (LMEs) (UK, US) that were seen to enable a competitive advantage for radical innovation and entrepreneurship while more coordinated market

economies (CMEs) (Germany, Nordics) were seen to enable incremental innovation (Hall and Soskice, 2001; Casper, 2007; Hancké, Rhodes and Thatcher, 2007). While there has not been research dedicated specifically to cross-country comparisons of discontinuous innovation, some studies have commented on the readiness of different innovation system settings to foster and maintain disruptive transitions, for example, in connection to digitalisation (Glimstedt and Zander, 2003; Braunerhjelm and Feldman, 2006; Casper, 2007; Ornston, 2014; Thelen, 2019). Elsewhere, a growing literature focused on state-level industrial policy is underlining the active role of the state in shaping and improving its innovative capacity (Mazzucato, 2011, 2018; Edquist, 2019).

The inductive theory development work undertaken in this thesis can serve as a starting point for more detailed discussion and research on how either proactive industrial policy at the regional or state level, or the socio-institutional context in a region, country, or specific industry sector may impact how discontinuous innovation processes are shaped in traditional industry settings. For example, different regional or national contexts may well impact whether a specific discontinuous innovation setting involves a market-based competition incentive at the level of individual firms or whether innovation is supported through collaborative networks and more open exchange. In this vein, political economy literature on ‘innovation commons’ has outlined institutional settings under which, for example, a more system-driven innovation strategy may be enabled (Allen and Potts, 2016). In the case of many traditional industry sectors, the geographical, institutional, or regulatory context may be particularly decisive for how stakeholders operate, both in terms of enabling crucial infrastructure development, developing institutions on labour markets, and developing required training opportunities (Lee and Malerba, 2017). In some cases, governmental actors also directly enable industry development through state-owned enterprises and national or regional control of resources and

infrastructure networks. This may lead to the state context either deliberately or unknowingly enabling a specific type of discontinuous innovation through its policy actions.

Moreover, the institutional context may also shape whether innovation processes lead to destructive changes to the existing industry architecture. Regulation and existing industry traditions in terms of industrial relations (mergers, takeovers, availability of high-risk or long-term venture capital, collaborative research ventures, etc.) shape the way in which a discontinuous innovation process interacts with existing markets. Similarly, some coordinated-type or corporatist industry contexts have a very particular dynamic of entrepreneurship, where SMEs are networked with incumbent companies and often dependent on the latter for their business and resources (e.g. Fu, 2015; Kristensen and Lilja, 2011). In these settings, new entrants seek to develop through non-market collaboration structures rather than seeking to out-compete incumbents, and the regional context may experience virtually no creative destruction at all while still producing innovation and industry renewal (Braunerhjelm and Feldman, 2006).

These are some examples of how the institutional and policy context may be an active shaper of innovation outcomes. Both empirical study and new theory development on discontinuous innovation in traditional industry settings need to be able to identify and account for variation due to factors of innovation context. As brought up in the open questions of section 2.3, this requires covering a diverse set of perspectives beyond singular firms: Both regional and national industry stakeholders and policymakers.

2.5.3 Primary themes for the comparative empirical study of discontinuous innovation

ventures

As outlined above, a comparative theory framework for discontinuous innovation like the one to be developed in this thesis needs to address not only the identified open questions surrounding how discontinuous innovation processes are organised but also account for process variation across different settings and over time. Characterising the relational dynamics present in discontinuous innovation processes and outlining differences between them is particularly important for studying innovation processes for nascent transitions in traditional industry settings. However, gaining more extensive empirical insight into these processes also requires narrowing down the specific focus areas for further research. This final sub-section discusses the three identified open questions on different stakeholder perspectives (Q3, Q4 and Q5) and addresses how they may be studied empirically to enable new theory development. Three empirical studies are outlined with the ambition of pinpointing innovation-enabling relational dynamics present in ongoing discontinuous innovation processes surrounding sustainable industry transitions. The three studies will inform the formulation and analysis of case studies for the empirical section of this thesis.

Firstly, the previous sections have highlighted the diversity of innovation strategies, business models, and incentive structures potentially available to drive discontinuous innovation. The first identified sub-question (Q3) addresses the lack of research and theory development on how discontinuous innovation processes in traditional industries balance the ‘new and old’ when facing the challenge of coordinating their new technologies or business models across incumbent infrastructure and resource dependencies (a common feature facing traditional, hard-to-abate industry settings in particular): *How do large-scale discontinuous innovation ventures in traditional industry settings balance between new and incumbent markets,*

technologies, and value chains? A case study tackling this question, with a focus on large-scale ventures that target industrial-scale production, needs to observe different kinds of ventures operating within a relatively homogeneous institutional context in order to single out the crucial relational dynamics and strategies of different ventures rather than inadvertently capturing variation that is due to the institutional context. Researching and comparing both start-up ventures and incumbent firms would be useful for testing whether their innovation strategies follow the general assumptions in literature relating to start-ups and incumbents or whether their roles and relationships are more nuanced (Christensen, 1997; Hockerts and Wüstenhagen, 2010; Ansari and Krop, 2012). A process focus and longer timespan of data collection would also be useful for this research to allow for more nuanced insight into the case-study ventures: Not only what key relational dynamics they engaged with at one moment but also how these develop over time. These empirical questions are addressed in Chapter 5: *Determinants of large-scale discontinuous innovation ventures in steel*.

The second identified sub-question seeks to gain insight into the impact of relational dynamics at the level of local industry networks and regional innovation systems where discontinuous innovation ventures are embedded. This second empirical angle seeks to create a fuller image of the stakeholder groups that are involved in the promotion and execution of discontinuous innovation beyond a headline-making main innovator. The question is: *How and to what extent can local-level relational dynamics shape the strategy and success of discontinuous innovation processes in traditional industry settings?* (Q4) The question is particularly relevant for traditional industry sectors that are generally relatively highly networked and place-based in their operations but for which success ultimately depends on globalised markets and value chains. In the context of the sustainability transition, calls for increased local innovation partnerships have increased, but there is little consensus on a ‘winning model’ for such

partnerships on innovation processes over time (Savaget *et al.*, 2019; Weigelt, Lu and Verhaal, 2021). In order to shed new light on this, the institutional and regulatory context for different case studies ought to be relatively homogeneous, as should the specific industry context being analysed. Once again, a more long-term research perspective can shed new light on our existing accounts and assumptions about how innovation processes are shaped and altered during their development. These empirical questions are addressed in Chapter 6: *Local-level drivers of discontinuous innovation in hydrogen*.

The third identified sub-question focuses on understanding the impact of the national policy and regulatory context on discontinuous innovation processes: *How do state-industry relational dynamics and institutional factors impact discontinuous innovation processes in traditional industry settings? (Q5)* Prior research on the role of the state in innovation, as well as on innovation systems, has explored at length both the impact of specific policy decisions and of the general institutional environment on successful innovation (usually measured through high-level metrics such as patent volumes) (Hall and Soskice, 2001; Reichardt *et al.*, 2016; UNEP, 2017; Mazzucato, 2018; Thelen, 2019; Lema, Fu and Rabellotti, 2020). However, there has been less process-focused work looking specifically at relational dynamics, such as policies and interactions for the development of new infrastructure and their impact on specific discontinuous innovation processes. Once again, there has particularly been a lack of focus on traditional industry settings, even though innovation in these sectors is often highly dependent on state-level policies and infrastructure processes. In conducting empirical analysis on these issues, the institutional/regulatory contexts being studied should not be completely alien to each other – the more similarities they have, the more easily any observed finding can be ascribed to specific policy actions or institutional differences. At the same time, the industry and technology context in such a study should also remain constant so that the impact of

policies and institutions is kept in focus as the main level and variable of analysis. These empirical questions are addressed in Chapter 7: *State-level enablers for discontinuous innovation in energy-intensive industries*.

Simultaneous analysis of these complementary empirical research questions has the potential to provide a comprehensive overview of how discontinuous innovation processes may be organised in different ways, in different industry settings, and over time. With in-depth case study research building on the identified open questions, we are able to trace how discontinuous innovation processes may be shaped by relational dynamics aimed at either firm-level strategy, local-level industry networks, or national-level policies and institutions. This empirical data may then be applied for cross-case comparison and theory building, pinpointing exactly how the observed cases and their characteristics relate to each other and how this may be presented and analysed in new theory frameworks and process models. This will allow for more transferable conclusions and implications to emerge from specific case studies.

The empirical chapters of this thesis will address these questions by focusing specifically on case studies of pioneering steelmaking and hydrogen innovation taking place in the Nordic countries. By focusing on one region with relatively well-defined institutions and innovation systems, as well as focusing on innovation cases from a narrow set of technologies and industry sectors that are inter-related, many variables in the industrial and socio-institutional context can be kept constant in a way that allows for in-depth analysis and comparison of the key relational dynamics unfolding in different cases. The rationale and process behind the case selection are elaborated in Chapter 3.

2.6 Conclusion

This chapter started out by summarising the literature on sustainability transitions and innovation, finding that the climate crisis and subsequent sustainability transitions ongoing in traditional industry sectors are taking place within a knowledge gap that means sustainable industry transitions are not sufficiently understood or researched by either literature stream. To address this knowledge gap, the chapter presents the construct of *discontinuous innovation* as a suitable theory lens for analysing sustainability transitions in traditional industry settings (Kaplan, 1999; Henderson, 2021). Existing literature on discontinuous innovation (and adjacent constructs) and sustainability transitions has developed mostly as two separate literature streams, as sustainability scholars have emphasised the distinct characteristics of system-wide sustainability challenges (Schot and Steinmueller, 2018; Savaget *et al.*, 2019). The sustainability transition may indeed prove as transformative as suggested by its label as the ‘second deep transition’ (Schot and Kanger, 2018). However, at the current stage, it is difficult to make judgements about the endgame of the sustainability transition and to research it as a niche innovation phenomenon that is categorically separated from present-day industry and society (Garud and Gehman, 2012; Fagerberg, 2018). Far from being isolated, sustainability is placed increasingly centre-stage across industry strategies and policy goals, and sustainability-focused innovation work takes place in constant connection to other innovation and development processes.

This chapter has, therefore, argued for a more active research and theory focus to compare how discontinuous innovation processes are organised in different industry settings, and how they interact with incumbent technologies and industry structures. Existing literature on discontinuous innovation does not focus on comparing processes and strategies for discontinuous innovation across different contexts. Through a narrow focus on specific sectors

and benchmarks such as an ideal-type ‘Silicon Valley model’, an assumption has gradually formed in innovation research for what kinds of industry processes and stakeholder roles and relationships are conducive towards discontinuous innovation (viz. market-driven industry disruption akin to Christensen’s (1997) model). This has created a lack of both theoretical and empirical understanding of discontinuous innovation processes that are different – especially discontinuous shifts taking place in traditional industry settings.

Through these open questions in existing literature, this chapter has outlined a set of secondary research questions that frame an empirical research project on this topic. It is important to build and maintain a relational and process-focused approach to analysing these phenomena, as the relational dynamics between stakeholders are what ultimately shape the different trajectories that innovation processes may take (Garud and Gehman, 2012). For example, it is important to better understand the role played by a variety of stakeholders, both legacy incumbents and greenfield start-ups, by exploring the relational dynamics between these and finding out how they balance the dependence on the old with the urgency for the new (Hockerts and Wüstenhagen, 2010). Moreover, it is also important to understand how sustainability-innovation is embedded both in the macro-level climate agenda through national policies and global markets, and in micro-level networks of local industry knowledge, as both dimensions may decisively impact the strategies and success factors of discontinuous innovation processes.

With a relational and process-focused research agenda as proposed by this chapter, the research aim for this thesis is to develop a new theory framework and a new process model to help both researchers and practitioners characterise and compare how discontinuous innovation processes may take on different strategies within different industry contexts and over time. For the context of sustainability transitions, this theory development may be used to understand,

for example, how organising for long-term sustainability goals and existing policies may align or misalign with present-day industry settings, especially in industry settings where a systemic sustainability transition has not yet been fully proliferated.

In empirical terms, the study of discontinuous innovation in traditional industry settings may clearly be furthered by seizing the valuable opportunity to analyse in real time the various innovation processes that are currently underway to promote system-wide sustainability transitions. Where this chapter has set out the research questions that the empirical case studies will answer, the next chapter will outline the methodological steps that the empirical case studies will apply.

Chapter 3 – Research Methodology

3.1 Introduction

This chapter outlines the research design and methodology for the empirical research process that is described in subsequent chapters. The previous chapter has reviewed existing literature on innovation and sustainability transitions and developed a research agenda focused on two parts: Undertaking empirical research of discontinuous innovation processes in traditional industry settings, with an analytical lens of inter-actor relational dynamics, followed by an inductive theory development process to design a new theory framework for discontinuous innovation. The rationale for this research agenda is based on the need for more research that moderates the existing research biases favouring narrow and specific models of breakthrough or disruptive innovation, as these benchmark models may not be applicable for analysing discontinuous innovation in traditional industry settings. Subsequently, the research agenda calls for a research philosophy and design that can capture specific nuances in different organisational processes and industry contexts.

For example, the inter-stakeholder relational dynamics that shape innovation are not comprehensively documented by audits, progress reports or other formal documentation, as no singular stakeholder has administrative responsibility for keeping records of inter-firm activities, especially in informal networks (DeJordy *et al.*, 2020). Therefore, effective observation and analysis of these roles and relationships between innovation stakeholders need to be rooted in interpretive philosophical foundations and be carried out predominantly using a qualitative and inductive research methodology (Berger and Luckmann, 1967; Hallett and Ventresca, 2006; Garud, Tuertscher and Van De Ven, 2013). Moreover, as there is no existing analytical framework for researching discontinuous innovation in different industry settings,

data analysis needs to aim at inductive theory building to formulate a new analytical framework. To enable effective theory development, the data collection stage needs to capture a diverse range of inter-stakeholder relational dynamics in different discontinuous innovation settings. Therefore, the research design should build on combining different types of qualitative empirical observation: Inductive fieldwork observation, as well as interviews and document analysis conducted through a multiple case-study approach, following the guidelines of grounded theory building and the constant comparison method (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016).

The next section of this chapter will establish the philosophical assumptions at the core of the research questions and research agenda presented in Chapter 2. Based on this, the following section discusses the research design and case selection. The final section outlines the data collection and data analysis as well as research ethics, covering all three empirical sub-studies that will be presented in Chapters 5-7.

3.2 Philosophical foundations for more nuanced innovation research

Much of the existing literature on success factors for innovation and industry transformation takes on an evolutionary perspective built on markedly positivist philosophical foundations (Fagerberg, 2005; Markard and Truffer, 2008; Garud, Tuertscher and Van De Ven, 2013; Hoagland, Shultz and Timbie, 2018). The population-ecology-influenced macro debate around disruption and innovation systems is anchored into a narrow set of statistical benchmarks and assumptions about the nature of innovation that are seen as universally and unequivocally conducive to innovative output (often referencing Silicon Valley as the ideal type model) (Christensen, 1997; Kaplan, 1999; Geroski, 2003; Kumaraswamy, Garud and Ansari, 2018;

McDowall, 2018). Later micro-process-focused entrepreneurship scholarship, instead of illuminating the situational construction of the innovation process, seems to predominantly reinforce these key axioms in schematic ecosystem models without including almost any context perspective at all (Welter, Baker and Wirsching, 2019). In this way, the philosophical foundations in the innovation literature have mostly retained a positivist ontology and epistemology, with a focus on defining universal benchmarks and models for successful innovation.

However, as the previous chapter has highlighted, this received view has been questioned, especially by authors considering the transformative innovation processes brought on by the pressure for climate change mitigation and industry decarbonisation (Garud and Gehman, 2012; Savaget *et al.*, 2019; Henderson, 2021). These realisations subsequently also call into question the positivist philosophical perspective of previous literature and are anchored instead in an interpretive, social constructivist philosophy (Pinch and Bijker, 1987; Miller, 2005; Markard, Raven and Truffer, 2012; Savaget *et al.*, 2019). From the interpretive perspective that anchors literature streams such as socio-technical systems, the nature and success factors of innovation are constantly being shaped by the actions and interactions of stakeholders involved in a specific innovation setting. As these interactions are also viewed to shape and be shaped by the technological and material features of the system, these authors define unique features of specific sustainability transitions that separate them from ‘other’ innovation and organisational change (Schot and Steinmueller, 2018). This interpretive philosophical perspective, and its different approach vis-à-vis the benchmark models of ‘mainstream’ innovation literature, also partly explains the separation between literature streams on sustainability transitions and innovation that was presented in the literature overview in Chapter 2.

An interpretive lens is not only important for deepening research into sustainability-focused innovation but also for increasing our broader understanding of how innovation may work differently in different contexts. Given the wide variety of innovation system contexts studied by current-day researchers, and especially given that the pressure for sustainability transitions is particularly strong on sectors that are not usually at the centre of disruptive shifts, both theorists and practitioners of innovation need to become increasingly attuned to contextual variation and local embeddedness in innovation processes and practices. The context of sustainability transitions provides an urgent and clear rationale for doing so, but the need for more nuance and more constructivist, process-focused, and inductive research on innovation and industrial change is not limited to research on sustainability transitions (Garud, Tuertscher and Van De Ven, 2013; Eisenhardt, Graebner and Sonenshein, 2016; George *et al.*, 2016; Kumaraswamy, Garud and Ansari, 2018; Breznitz, 2021; Henderson, 2021).

Aligning with these calls for a more critical examination of the built-in assumptions in our current knowledge about innovation and sustainability transitions, the philosophical foundations adopted by this thesis are likewise anchored in an ontological position of social constructivism and interpretivism (Berger and Luckmann, 1967; Giddens, 1979; Pinch and Bijker, 1987; Heidegger, 1993; Hallett and Ventresca, 2006; Orlikowski and Scott, 2008). The societal structures governing key decisions on innovation and sustainability transitions are continuously shaped by the involved actors and the innovation system setting, which are changing across different times and venture stages and in different locations (Geroski, 2003; Pisano, 2015; DeJordy *et al.*, 2020). This philosophy, therefore, needs to be coupled with an epistemological commitment towards qualitative, inductive, and exploratory research that is focused on observing and comparing different instances of discontinuous innovation processes

(Eisenhardt, Graebner and Sonenshein, 2016). The ultimate aim of this research, as stated in the research agenda set out in Chapter 2, is to gain new insights that can be leveraged towards inductive theory development and the creation of new frameworks that can be used for similar research across other innovation contexts. This means that the epistemological position of the thesis, while interpretive in nature, also values comparisons between different settings as a way to distinguish and characterise innovation-driving stakeholder roles and relationships.

This does not mean that case studies are applied with a view to ‘cover’ all possible variation between different cases – in fact, given the small amount and narrow geographical spread of discontinuous innovation ventures for decarbonisation in many traditional industry sectors, it would not be possible to adopt a more positivist case-study approach (Yin, 1994; Blok and Pedersen, 2014; Eisenhardt, Graebner and Sonenshein, 2016). Instead, the trustworthiness of the research may be strengthened through a multiple case-study approach guided by careful theoretical sampling (Morse *et al.*, 2002; Bremner and Eisenhardt, 2022). The next section will outline the case selection and research methodology stemming from the research agenda and its philosophical foundations.

3.3 Research design and case selection

The guidelines for research design for this thesis follow directly from the research agenda and research questions proposed in Chapter 2 and the subsequent interpretive philosophical foundations highlighted in the previous section. The adopted analytical focus of the thesis is inter-stakeholder relational dynamics that shape discontinuous innovation processes in traditional industry settings. Given that these are shaped and instantiated in a socially-constructed reality by stakeholders in specific innovation system context, the outlined research agenda and research philosophy clearly call for a predominantly qualitative research design

that is able to capture subtle nuances and mechanisms of ongoing innovation processes (Guba and Lincoln, 1989; Flyvbjerg, 2006; Garud, Tuertscher and Van De Ven, 2013; Bansal and Song, 2017). As brought up in this chapter's introduction, the inter-stakeholder relational dynamics that shape industry action are not comprehensively documented by formal documentation (DeJordy *et al.*, 2020). There are also no existing benchmarks for innovation that collect data specifically on inter-stakeholder relational dynamics (stakeholder roles and relationships) that could be used for quantitative analysis across different innovation settings. Existing quantitative models, such as global indexes of capacity for research-intensive innovation and entrepreneurship, may be used as proxies to frame the broader picture of a specific innovation system used as a research setting, but these models cannot provide specific information about the roles and relationships of different stakeholders in a discontinuous innovation process. Consequently, effective observation and analysis of these roles and relationships between important stakeholders need to be carried out predominantly through a qualitative and inductive research methodology (Eisenhardt, Graebner and Sonenshein, 2016). The primary set of research methodologies for this thesis will be a combination of qualitative empirical observation methods: Inductive fieldwork observation, semi-structured interviews and document analysis, all combined through a framework of case study analysis (Flyvbjerg, 2006; Bremner and Eisenhardt, 2022).

Given the analytical focus is specifically on relational dynamics *between* different stakeholders, the qualitative analysis in this case needs to be built on *nested* case studies (DiBenigno and Kellogg, 2014; Bremner and Eisenhardt, 2022). Nested case studies involve the observation of more than one organisational entity, for example, a consortium of companies and other stakeholders, a business ecosystem focusing on a specific technology, or a regional innovation system centred around a specific location. The benefit of this approach is that data

can be collected from a wider variety of stakeholders to form a more nuanced image of the collective or system under observation and of how different stakeholders within it interact with each other. The latter point makes nested case studies particularly crucial for the current thesis, given its analytical focus on inter-stakeholder relational dynamics.

Moreover, given the research aim of inductive theory development and formulation of a new framework for *comparing* different innovation processes with each other, the qualitative analysis in this case also needs to be built on *multiple* case studies (Eisenhardt, Graebner and Sonenshein, 2016; Bremner and Eisenhardt, 2022). The multiple case-study approach increases the richness and overall trustworthiness of qualitative case-study research by allowing for comparison where some elements may stay similar across cases while the specific ventures and active stakeholders may be different. In the case of this thesis, multiple case studies can be applied for simultaneously following different ventures or partnerships undertaking discontinuous innovation in the same industry sector and in the same geographical area. As already mentioned, multiple case studies do not guarantee the universal transferability of the conducted case study research (Guba and Lincoln, 1989; Flyvbjerg, 2006). This is especially important to highlight in the current thesis, given that the nature of studying discontinuous innovation processes, by definition, involves observation and theory development based on pioneering ventures that may be the first of their kind in the world. However, a multiple case-study approach may be insightful, for example, for distinguishing what is characteristic about a specific innovation process based on how it compares to a related case. The multiple case-study approach is thus particularly helpful for gaining a crucial ‘big picture’ perspective that can be used for new theory development.

The research design for this thesis subsequently builds on combining different types of qualitative observation and data collection conducted through a *multiple nested case study* approach. This connects, in particular, to the guidelines of *grounded theory building* and the *constant comparison method* (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016). Through in-depth empirical case studies and data analysis of the features of the different cases, this thesis seeks to inductively observe and analyse key mechanisms in inter-stakeholder relational dynamics surrounding discontinuous innovation processes and apply this analysis to new theory development. The empirical analysis will also apply constant comparison through iterative rounds of observation and coding of the different case studies. In this way, the agenda for empirical research and theory development directly informs the research design of the thesis.

3.3.1 Steel decarbonisation ventures as case studies of large-scale discontinuous innovation

Having laid out the research design, the next step is to select suitable cases for empirical research. The case selection needs to inform each of the three sub-questions as laid out in the empirical agenda of Chapter 2 and be amenable to the above-described research design of multiple and nested case studies.

The first of the sub-questions brought up in the research agenda focuses specifically on the operation and interactions of innovative ventures themselves, and in particular, their strategies of balancing between transformative and step-change innovation and dependence on incumbent infrastructure networks and supply chains: *How do large-scale discontinuous innovation ventures in traditional industry settings balance between new and incumbent markets, technologies, and value chains?* As suggested in Chapter 2, a case study based on this question needs to analyse and compare multiple ventures that are operating in a similar industry

setting and with a similar technological focus. This is to single out the relational dynamics and strategies of different ventures rather than inadvertently capturing variation that is due to the institutional context.

Few sectors are as relevant and representative of the challenges addressed in the first sub-research question as the decarbonisation effort in the steel industry. Steelmaking accounts for approximately 7% of all the world's carbon dioxide emissions, alongside other forms of environmental impact (Rodríguez Diez *et al.*, 2023; OECD, 2024). The leading technological trajectory for transitioning to almost completely emission-free steelmaking combines elements that are familiar from pre-existing technologies but, in doing so, creates a new technology pathway that is almost completely untested at an industrial scale. In combination with an energy and hydrogen supply based fully on renewable energy, this pathway can bring down steelmaking emissions to near zero: 1) fossil-free iron-ore pelletisation using biofuels; 2) switching the use of coal and coke to hydrogen in iron-ore reduction; 3) replacing traditional blast furnaces with electric arc furnaces (EAF) (AFID, 2023; HYBRIT, 2024). This pathway combines and innovates on elements of the two main steelmaking processes in use today: The traditional Blast-Furnace Basic Oxygen Furnace (BF-BOF) route (the most common steelmaking route globally, which is also by far the most intensive in energy and carbon emissions) and the Direct-Reduction Electric Arc Furnace (DRI-EAF) route (which traditionally uses scrap metal and iron ore reduced using natural gas) (Rodríguez Diez *et al.*, 2023).

The sustainability transition in steelmaking is a representative example of the discontinuous innovation challenges faced by many hard-to-abate traditional industry sectors. Firstly, the nature of the steel industry as a resource-intensive, traditional industry sector often found in

non-metropolitan areas creates a contrast against sectors with a relatively faster industry clock speed (such as many parts of the tech industry) that we have become more used to describe in terms of discontinuous or disruptive innovation (Kivimaa and Kern, 2016; Hoagland, Shultz and Timbie, 2018; Ho and Chen, 2018; Kumaraswamy, Garud and Ansari, 2018; McDowall, 2018). Secondly, the steel industry has also undergone many other kinds of overhaul and innovation in recent years, thus demonstrating the closeness between sustainability and ‘non-sustainability’ innovation and the need for a theoretical framework that captures both (Fagerberg, 2018). Finally, the steel industry is a particularly suitable context for the current mission of expanding the reach of discontinuous innovation research to broader contexts since a market-driven transition in steelmaking technology was originally used as a case study for Christensen’s (1997) model of disruptive innovation.

Chapter 5 of this thesis, therefore, presents the first process case study of the two most advanced green steel innovation ventures to be found anywhere in the world: The H2 Green Steel start-up and the HYBRIT consortium of legacy industry incumbents. Both first-mover ventures are headquartered in the Swedish capital of Stockholm but have the bulk of their operations centred in the two adjacent towns of Luleå and Boden in the country’s northernmost county. Through a nested case study that examines both the two green steel ventures and their respective interactions with each other and their key partners in the innovation process, we can compare two ventures located in the same region and tackling the same issue, yet with different industry backgrounds and business models. This provides new insight into how different innovation processes balance the transformation process with their reliance on incumbent industry infrastructure and to what extent these processes conform to literature expectations about the distinct strategies of start-ups and incumbent firms.

3.3.2 Hydrogen innovation processes as case studies of local-level innovation drivers

The focus of the second sub-question concerns relational dynamics at the level of local industry networks and regional innovation systems where discontinuous innovation ventures are embedded: *How and to what extent can local-level relational dynamics shape the structure and success of discontinuous innovation processes in traditional industry settings?* An important prerequisite for case selection is again to identify case studies that are comparable both in their sector focus on discontinuous innovation and in some of their main features (such as geography or general societal structures). This provides an opportunity to compare how different local industry networks and innovation systems interact to enable innovative ventures. Moreover, a nested case study with a process focus can bring a more nuanced perspective of how local stakeholders interact at different parts of the innovation process.

One of the key areas in which regional and local industry networks and innovation systems have a particularly visible role is hydrogen innovation. The production and application of hydrogen produced from sustainable energy sources has emerged as one of the central technologies to achieve carbon neutrality across traditional industry sectors and energy systems. The primary technology emerging as the dominant design for hydrogen production is electrolysis, which splits water molecules into hydrogen and oxygen. As hydrogen can be produced both from renewable and fossil-fuel sources ('green' hydrogen, often compared to 'blue' hydrogen produced by vapo-reforming natural gas), it can act as a conduit for a smooth transition to a fully renewable energy system (Velazquez Abad and Dodds, 2020; AFID, 2024). The energy held in hydrogen can also be stored and, if converted to ammonia or another gas, transported long distances, which opens new opportunities for balancing an energy system based on uneven production sources (such as wind and solar). Hydrogen also has a range of other downstream applications that are useful for sustainability transformations in industry,

one of them being its aforementioned potential to substitute coal in the iron reduction stage of the steelmaking supply chain (OECD, 2022, 2024). However, the use of hydrogen in most of these applications has only been proven as viable under laboratory conditions and in small-scale tests. The concept of a ‘hydrogen economy’ or energy system relying heavily on hydrogen infrastructure is, therefore, clearly a context that requires decisive discontinuous innovation to progress (Velazquez Abad and Dodds, 2020; OECD, 2022). As one interviewee remarks: “*At the end of the day, hydrogen is still a very unstable and explosive substance to work with, so we do not know exactly how the innovation will play out... it takes constant research and high-risk projects to make large-scale ventures feasible*”.

Due to the features of hydrogen as being simultaneously important for industry decarbonisation and costly and difficult to produce and store, discontinuous innovation involving hydrogen-based technologies inherently invites system-level coordination among different stakeholders in the local industry network (Velazquez Abad and Dodds, 2020; OECD, 2022; AFID, 2024). Much like other network infrastructures in the energy sector, there is little commercial or environmental sense for stakeholders to build independent hydrogen value chains that are not shared among several sectors and downstream applications (McDowall, 2018). This inherently system-based logic of hydrogen technology makes ongoing hydrogen innovation ventures a suitable industry case for analysing and comparing different ways in which local industry stakeholders enable and initiate discontinuous innovation.

Regional innovation systems and local industry networks in the Nordic countries are pioneering innovative ventures in several traditional industry sectors – including hydrogen innovation – and demonstrate particularly well the uncertainty in the existing literature about the impact of local-level enablers and relational dynamics (Business Sweden, 2023; Nordic Energy

Research, 2024). On the one hand, Nordic industrial regions seem well-placed to succeed in sustainability transitions based on conditions that previous research has highlighted, such as the potential to leverage close-knit informal networks and knowledge transfer capabilities of long-established local and regional industry networks (Asheim and Coenen, 2005; Kristensen and Lilja, 2011; Giacometti and Teräs, 2019). On the other hand, the mechanisms by which such an advantage for discontinuous innovation may come about have not been studied or theorised in depth (Garud, Tuertscher and Van De Ven, 2013; Breznitz, 2021). In fact, some studies do not seem to accept that discontinuous innovation is likely to emerge in these more rural and coordinated type innovation settings in the first place (Ornston, 2014).

Chapter 6 of this thesis presents a multiple nested case study of three northern Nordic industry settings pioneering discontinuous hydrogen innovation: Vaasa in Finland, Luleå in Sweden, and Berlevåg in Norway. The three selected regions are relatively comparable in their general characteristics as well as in their status of being first-movers in industrial-scale hydrogen innovation. The three cases also have their general institutional environment in common as well as some aspects of their location: While different in their accessibility, urban population, and size of existing industry, all three cases are located in the northern parts of the Nordic region (two of them bordering the Gulf of Bothnia in the northern parts of the Baltic Sea, and the third bordering the Arctic Ocean). This setting implies some shared innovation challenges of being located far away from financial and political centres and in regions that are experiencing general population decline. But each of them has a distinct industry profile and can, therefore, be expected to have different inter-stakeholder relational dynamics enabling innovation. The case study in Chapter 6 aims not to create a comprehensive image of all possible local-level drivers of hydrogen innovation but to present diverse insights across three different hydrogen innovation cases and draw some overarching conclusions from comparing

them to each other. Including Luleå as a case region, where large-scale hydrogen innovation is connected particularly to green steel ventures, also opens an opportunity for complementarity in data collection across chapters 5 and 6.

3.3.3 Energy innovation policy as a case study of state-industry innovation enablers

Finally, the third sub-research question focuses on the impact of the national policy and regulatory context on discontinuous innovation processes: *How do the national policy-setting and institutional environment impact discontinuous innovation processes in traditional industry settings?* As presented by the research agenda, the empirical study of this question requires observation of both deliberate actions by national-level stakeholders in their relational dynamics as well as analysis of the effect of the overall institutional environment, and this observation benefits from being conducted in relatively stable and homogenous socio-institutional conditions. At the same time, the industry and technology context in such a study should also remain constant so that the impact of policies and regulations is kept in focus as the main level and variable of analysis.

The Nordic countries present a relevant case for observation as they consistently rank among the world's most innovative countries, with a high degree of skills in many material-intensive sectors such as forestry, heavy machinery, shipbuilding, chemical engineering, etc. (World Intellectual Property Organization., 2024). The role of Nordic policies, regulations, and socio-economic institutions has been widely recognised as an enabler of innovation, but as Chapter 4 will elaborate, the message is unclear as to exactly what types of innovation are enabled in particular (Ornston, 2014; Edquist, 2019; Thelen, 2019). The confusion in existing literature may be attributed to the lack of nuance in understanding the role of these industrial traditions in specifically supporting *discontinuous* innovation and change, which, by definition, involves

a lot of upheaval and where innovation policy decisions may thereby become more complex than normal (Henderson, 2021). Transformations like these have been the focus of attention much more strongly in some settings (like digital software innovation) than in others (like traditional industry sectors), risking a one-sided view of what discontinuous or disruptive transformation means in a Nordic industry context (Ornston, 2014, 2018).

The Nordic context presents a suitable set of country case studies due to the combination of its relative institutional heterogeneity with the presence of some clear differences in national policy between different countries. Recent decades of industry development have been relatively similar across the Nordic countries, but there have also been regional and national differences in terms of economic structure and strong sectors, as well as policy priorities (Fellman *et al.*, 2008; Kristensen and Lilja, 2011). This, in addition to the benefit of building nested case studies that incorporate the data collection for the other two sub-studies, makes the Nordic region a suitable setting for observing the impact of state policy and regulation on discontinuous innovation processes in traditional industry settings, as well as commenting in general terms on how this connects to the main features of the Nordic socio-institutional environment.

Chapter 7 will mirror the two previous ones in both setting and structure. In terms of setting, the empirical focus is on state-level enablers that are shaping the incentives and capacity of industries and societies to undertake large-scale discontinuous innovation processes in traditional industry settings in Finland, Sweden, and Norway, with a particular focus on the industries and regions examined in Chapters 5 and 6 (hence the selection of these three Nordic countries, all of which have seen significant decarbonisation investment in traditional industry settings especially in their northernmost regions). The study particularly focuses on how

discontinuity in the energy system is being promoted by way of incentivising policies and regulations (for example, through the innovation policies of national grid authorities). In terms of structure, the chapter aims to discern patterns by tracing the *state-industry relational dynamics* present in each country: between the regulatory/policy stakeholders and the ventures/local stakeholders whose activities the national actors seek to support. In this way, the focus of the multiple case study is on uncovering the enablers through which successful venture development is supported (or not supported) at the level of state-industry interaction in the three countries.

Based on the descriptions above, Table 3.1 below summarises the research design and case selection for each of the sub-research questions. Chapter 4 provides background on the empirical research setting.

Table 3.1: Research agenda for empirical case studies

Chapter	Research question	Case selection
<i>Chapter 5: Determinants of large-scale discontinuous innovation ventures in steel</i>	<i>Q3: How do large-scale discontinuous innovation ventures in traditional industry settings balance between new and incumbent markets, technologies, and value chains?</i>	<i>Two large-scale steel decarbonisation ventures in northern Sweden: H2 Green Steel (start-up) and HYBRIT (incumbent)</i>
<i>Chapter 6: Local-level drivers of discontinuous innovation in hydrogen</i>	<i>Q4: How and to what extent can local-level relational dynamics shape the structure and success of discontinuous innovation processes in traditional industry settings?</i>	<i>Three regional innovation systems with discontinuous hydrogen ventures: Vaasa (Finland), Luleå (Sweden) and Berlevåg (Norway)</i>
<i>Chapter 7: State-industry relations as enablers of discontinuous innovation in traditional industries</i>	<i>Q5: How do state-industry relational dynamics and institutional factors impact discontinuous innovation processes in traditional industry settings?</i>	<i>Case examples from state policy and regulation to support energy-intensive discontinuous innovation in steel and hydrogen in Sweden, Finland and Norway</i>

3.4 Research process

Having presented the research design and case selection for this thesis, this section will describe the research process, from data collection to data analysis, as well as research ethics. Given the nature of the three sub-studies as multiple nested case studies that are linked to each other, the research process will be described in parallel for each of the three empirical chapters. In instances where the research process differs between the three empirical chapters, this variation will be explicitly described.

3.4.1 Data collection

In line with the research agenda and methodology, the collection of data for this thesis combined desk-based literature review with a variety of qualitative data collection. This was in order to increase the nuance of the analysis and capture the relational dynamics between all relevant stakeholders in the innovation system and also beyond the ‘usual suspects’ of firms, policymakers and universities (Etzkowitz and Leydesdorff, 2000). In addition, given the process focus of the research agenda, the data collection took place over an extended period and made use of several sources for background material in order to include important antecedents of the case study innovation ventures. This was to allow for more nuanced insight into the case studies: Not only what key relational dynamics they engaged with at one moment but also how these have developed over time (Garud, Tuertscher and Van De Ven, 2013).

Empirical data collection was divided into the following data sources: (1) archival material, (2) core semi-structured interviews, (3) background interviews, (4) on-site observation of conference gatherings, and (5) informal meeting notes and emails to clarify and verify early findings. This variety of data sources allows for increased accuracy and analytical depth

through triangulation and peer confirmation (O’Mahony and Bechky, 2008). Figure 2 below summarises the written qualitative data sources.

Table 3.2: Qualitative data sources (written)

Data source	Details	Quantity
Archival material	<i>Corporate and public sector press releases, news media articles, (three main Nordic economic news sources, three regional papers, selected international stories), regional, national, Nordic and EU policy reports and documents.</i>	<ul style="list-style-type: none"> • 127 core press releases (258 in total) • 64 core media articles (361 in total) • 43 regional, national and international policy reports • 3 global news interviews • 2 popular books • 1 documentary
Core interviews	<i>Interviews with executives, directors, team managers, site personnel, and regional partners of stakeholders relevant to one or more of the empirical case studies (see Appendix for full list). Some interviews were used as core material in more than one case study, others as core material for one case study and background for others.</i>	<p>76 in total (Some overlaps across chapters):</p> <p>Chapter 5: 32 main interviews</p> <ul style="list-style-type: none"> • 16 venture executives, directors, managers and site personnel • 10 regional public, private and university partner representatives • 6 national public and private partner representatives <p>Chapter 6: 41 main interviews</p> <ul style="list-style-type: none"> • 21 project leaders and executives • 17 local and regional government and agencies • 13 local and regional industry and business associations <p>Chapter 7: 42 main interviews</p> <ul style="list-style-type: none"> • 15 national government and agencies • 13 regional partner executives in case examples • 14 industry partner executives in case examples
Background interviews	<i>Interviews with relevant stakeholders in the region and industry, collected during two earlier research periods (see Appendix for full list).</i>	<p>32 in total</p> <ul style="list-style-type: none"> • 14 in first background interview wave in the Vaasa area (2018) • 18 in second background interview wave in northern Sweden (2020)

i. Archival data

Archival data was gathered using a systematic download of corporate press releases and policy documents relating to each of the case studies: The two northern Swedish green steel ventures, three cases of regional hydrogen innovation in Vaasa, Luleå, and Berlevåg, and three cases of national policy and regulation relating to the energy transition in Finland, Sweden, and Norway. The timespan for all archival data collection ranged from the inception of the earliest ventures included in the case studies until the end of the data collection period (2016-2024). Corporate press releases were collected from the home page of relevant stakeholder and key partner (this included press releases by private companies, municipalities, state agencies, and county councils. A pre-selection was done whereby clearly less relevant press releases were left out from the outset). National and regional policy documents were collected from the document libraries of the relevant ministries, energy agencies, and county councils. For media articles, general online searches based on keywords for each case study were complemented with a targeted search and download from the three largest sources of economic and financial news in Sweden, Finland, and Norway, as well as three local papers in case study regions. Both media articles and press releases were categorised in ‘core source material’ and the rest, based on whether they contained three paragraphs or more (two for press releases) describing the central focus of study, i.e. roles and relationships of stakeholders in enabling innovation and scale-up of steel and hydrogen innovation ventures (for national-level enablers, the focus of relevance was wider and encompassed energy transition themes more broadly) (Bremner and Eisenhardt, 2022).

In addition to media articles and press releases, a documentary film and a set of popular books have been published recently concerning industry development in the north of the Nordic

countries. Transcribed excerpts from these were included as background archival sources on the same grounds and following the same procedure as the media articles.

ii. Core interviews

For the interview dataset, a total of 108 semi-structured interviews were gathered from different sources (see Appendix). Of these, 76 interviews were categorised as core interviews, as they were collected during the main research period in 2022-2024 and featured respondents who are directly involved with practices and decision-making around the roles and relationships of the main stakeholders of a case study. The core interviews for Chapter 5 on determinants for green steel innovation included respondents employed by either of the two green steel ventures or by a closely partnered stakeholder. For Chapter 6 on local-level drivers of hydrogen innovation, the core interviews included respondents employed by stakeholders directly in developing or supporting hydrogen ventures in one of the case study locations or by a closely partnered stakeholder. For Chapter 7 on national-level enablers, the core interviews included respondents with a role at a state-level stakeholder (such as a ministry or energy agency) or with another affiliation that gives direct insight into the policy and regulation process under observation.

The core interviews were gathered predominantly during two waves during the 24-month main fieldwork period from March 2022 to March 2024. This period represents, for most case-study innovation and policy processes, a stage of scale-up – moving from exploratory research, pilot projects and preparation to commercial industrialisation and full-scale implementation. Informants were selected through a combination of theoretical sampling and snowball sampling, with an aim to include a variety of views from different managerial levels (C-suite/top management, division or team lead/middle management) on the case study ventures and policy processes and in particular on any external engagement with partners and other

stakeholders (Heckathorn, 1997; Eisenhardt and Graebner, 2007). There was one gatekeeper individual for each case study region, who, in each case, was one of the first individuals interviewed and who had an overarching and long-term perspective on the specific case study. The gatekeeper individuals supported the identification of potential first-contact respondents at relevant stakeholders and provided support in making research introductions throughout the data collection stage. Follow-up interviews with these gatekeeper respondents also provided validity-check input during the data analysis stage (Guba and Lincoln, 1989; Seale, 1999).

All interviews followed a similar semi-structured interview guide. Interviews lasted between 45 and 90 minutes, and they were recorded and transcribed in the original language (Swedish, Norwegian, Finnish, or English). The interviews included the following main themes: The respondent's background in the region, sector, and with their current employer; the respondent's involvement in the innovation process under observation; their perspectives on the role and external relationships of the respondent's organisation; their perspectives on external partnerships and the role of other key stakeholders (with specific questions on relevant regional actors as well as state-level agencies); their outlook on future opportunities and challenges with relation to the innovation process under observation; and recommendations for further interview respondents with complementary and diverse perspectives. During the interviews, a variety of interview techniques were used in order to support data reliability (i.e. open-ended and nondirective questions, as well as more directed discussion relating to the respondent's reaction to a specific event or statement) (Eisenhardt and Graebner, 2007). For increased triangulation, formal interview data was complemented with field notes and materials from informal discussions, on-site field visits, as well as relevant conference events (more on these below) (O'Mahony and Bechky, 2008).

Due to the structure of the research agenda as nested case studies – nested both within the case studies themselves as well as across different chapters – the interview process provided opportunities for complementarity and data triangulation across and between different chapters. This complementarity often arose organically, as many respondents automatically brought up cases, topics, and stakeholders that informed the research process for one or several of the other case studies or stakeholder perspectives. After the initial interviews in each region, when this complementarity had become increasingly clear, the interview guide was iteratively complemented to include more specific questions about respondents’ perspectives on the other stakeholders and processes. All key stakeholders interviewed for the green steel case study in Chapter 5 were asked both about their connections to local-level stakeholders in Northern Sweden and to state-level stakeholders in Stockholm. Stakeholders interviewed for the local-level hydrogen drivers in Chapter 6 were also asked about their perspectives on state-level stakeholders. In the northern Swedish case, the complementarity was even greater given the co-location with the green steel ventures in Chapter 5 and the direct relevance of the green steel ventures for hydrogen innovation in the region. Among the stakeholders interviewed specifically for the policy cases in Chapter 7, many respondents also commented more specifically on the case studies included in the two other chapters. In this way, several interviews could serve as core interviews for more than one chapter, while the majority of interviews provided at least background information for more than one chapter.

iii. Background interviews

In addition to the core interview material, a set of background interviews provided the case studies with additional analytical depth and a more nuanced picture of the roles, relationships, and historical context surrounding the main innovation processes and ventures (O’Mahony and Bechky, 2008; Bremner and Eisenhardt, 2022). This deep context and understanding of each

case study is particularly important given the main mission of the research agenda, which is to understand how discontinuous innovation may evolve differently in different traditional industry settings (Garud and Gehman, 2012; Breznitz, 2021).

As described above, many core interviews for one case study provided valuable background information for other chapters and case studies. The iterative process of refining the interview framework included these more general insights as topics for the latter parts of the interview after discussing the respondent's main connection to the case study and innovation process. Given the close-knit industry networks of the case study regions, respondents connected to one specific venture or stakeholder frequently had experience and insight into other stakeholders and the region's recent development more broadly.

The role of informal networks in the case study regions is particularly strong in the context of Nordic societies and smaller industry towns. On the one hand, Nordic innovation systems and socio-economic institutions, by definition, include strong non-market mechanisms of collaboration and coordination based on a foundation of trust, openness, and social capital (Hall and Soskice, 2001; Kristensen and Lilja, 2011; Ornston, 2018). On the other hand, the small-town industry environment of the Chapter 5 and 6 case studies also strengthens these mechanisms, as the social and professional networks are close-knit: Many professionals and executives have multiple-decade-long careers serving several stakeholders in the region and sector, and thus have an outsider's perspective on the main ventures being observed but an insider's view on the regional and national landscape for energy and industry in transformation. Through their experience and personal networks, many of these individuals, therefore, have insight into the innovation processes under observation without currently being employed by the main stakeholders. The background interview data could highlight additional stakeholder

relations from a ‘bigger picture’ perspective that had not been discussed in the core interviews for the chapter and thereby guide the continued data collection and sampling of respondents.

Finally, the interview process was also complemented with 35 background interviews conducted by me during two earlier research projects in Finland’s Vaasa area and in northern Sweden, in spring 2018 and spring 2020, respectively. Both these research projects focused on innovation in the energy sector in these regions, and while the case studies are not the same as in this thesis, the interview material provides additional background as well as an extended timeframe for formal data collection. These background interviews followed a generally similar semi-structured pattern as in this thesis, and therefore, the overarching insights gained from them about the regions and their development are useful as a complement to the data collection of the main research period. As is reiterated in the research ethics section below, all interviewees for these background interviews from the previous projects at the time gave their consent for interview material to be used as background in future thesis research.

iv. On-site observation and conference gatherings

The main data collection period also included observation periods where I physically visited relevant locations for case studies and attended conference gatherings. Table 3.3 below lists these observation periods and conferences. The primary purpose of the site visits was to collect qualitative data in the form of printed resources, photographs, and field notes to guide the data collection and analysis and achieve a more nuanced picture of the sites: Which stakeholders are present and how are they present, how do the geographical characteristics of the site affect the interactions between stakeholders, and how does the perspective given by respondents in a local setting differ from the overarching perspective given by online and remote resources (DiBenigno and Kellogg, 2014). This data collection took place in the form of photographing

and noting down relevant elements during visits to specific venture locations and case study towns into a set of comprehensive field notes. The field notes were organised into sections and focused on stakeholder roles and relationships, timelines, and local perspectives of how respondents understood the physical or social environment of the site to affect the innovation process. The field notes were structured and revisited soon after the visit or conference had taken place, either in written format or as a log of speech recordings (Seale, 1999). These field notes, log recordings, and photographs were later incorporated as part of the qualitative data analysis.

In addition to data collection, the in-person visits were an important part of forming and maintaining research access and connections to new respondents. In many cases, an informal discussion during an on-site visit or conference was later followed up by a semi-structured interview over a conference call. This element of the research process – combining conference calls with informal in-person discussions – became particularly relevant due to the timeline of the main research period during the gradual reopening of in-person interactions following the COVID-19 pandemic. For all case studies, initial research access had to be agreed upon, and the data collection initiated remotely through a set of conference call interviews, while the first in-person visit took place later and thereby had the function of expanding access to new stakeholders and following up on previous interview discussions, rather than to serve as the first point of contact to the case study. The exception to this was the Northern Sparsely Populated Areas (NSPA) conference in northern Sweden, which had an early timeline in the winter of 2022 and served as an initial point of contact to the northern Swedish case, notably including site visits and planning meetings with a local gatekeeper respondent.

Table 3.3: On-site visits and conference observation

Data source	Details
Conference observation	<ul style="list-style-type: none"> • <i>Northern Sparsely Populated Areas conference, Skellefteå, Sweden, 2022</i> • <i>Swedish Railroad Forum, Luleå, Sweden, 2023</i> • <i>Wasa Future Festival industry conference, Vaasa, Finland, 2023</i> • <i>Västerbotten Week Conference, Stockholm, Sweden, 2024</i>
On-site research visits	<ul style="list-style-type: none"> • <i>Skellefteå, Sweden, 2022</i> • <i>Stockholm, Sweden, 2022</i> • <i>Helsinki, Finland, 2022</i> • <i>Luleå, Sweden, 2023</i> • <i>Boden, Sweden, 2023</i> • <i>Alta, Norway, 2023</i> • <i>Vadsø, Norway, 2023</i> • <i>Berlevåg, Norway, 2023</i> • <i>Stockholm, Sweden, 2023</i> • <i>Vaasa, Finland, 2023</i> • <i>Stockholm, Sweden, 2024</i> • <i>Boden, Sweden, 2024</i> • <i>Luleå, Sweden, 2024</i>

v. Informal meeting notes and member-check emails

After the main data collection period, when the data analysis stage was already ongoing, the qualitative dataset was complemented with a small number of semi-structured interviews with relevant respondents, but also with informal ‘member-check’ interaction to verify the emerging findings and inform theory development (Guba and Lincoln, 1989; Seale, 1999; Morse *et al.*, 2002). These were conducted as informal conference call discussions with gatekeeper respondents or in-person meetings during the latter site visits and conference gatherings. The structure for these discussions was different to the semi-structured interviews: The focus was more specifically on getting feedback for emerging findings from the respective case studies and clarifying remaining questions in the qualitative dataset. For most of these meetings, the emerging findings were shared either before the meeting in a written draft or during the meeting

through presentation slides. The feedback was noted in meeting notes, which were used in the iterative process of refining and finalising the empirical case study findings.

Finally, the informal member-check discussions with gatekeeper respondents were complemented by 'member-check' email correspondence to a wider group of interview respondents. These emails focused specifically on verifying the consent of the respondents to the use of specific quotes from their interview testimonials under their name in the final thesis chapters (see the research ethics section below). The use of the respondent's name was suggested only in cases where the respondent's title and occupation provided substantive additional relevance to the interview quote. Beyond attaining confirmation of respondent consent for using the named quotes, these member-check emails also acted as additional data as a platform for guiding and validating the emerging research findings and conclusions. The email correspondence was not analysed formally but incorporated as notes during the final stages of data analysis. The next sub-section will describe the data analysis process in detail.

3.4.2 Data analysis

The data analysis process started concurrently with the middle stages of data collection and proceeded through iterative rounds of interview coding and continued data collection as guided by emerging results (Hammersley and Atkinson, 1995; Corbin, 2014). Interview recordings were anonymised and then transcribed using an AI-based transcription software (Sonix.ai), after which the transcripts were uploaded into NVivo qualitative coding software and stored on an encrypted cloud data server. Each interview was transcribed and analysed in its original language to preserve the accuracy and nuance of the interview testimonials. The coding and categorisation of the transcript data was then executed in English to harmonise the findings.

The same process for qualitative coding was also carried out for a sub-selection of the core archival materials with particular relevance to at least one of the case studies.

In alignment with guidelines for structuring the data analysis for theory-building research based on multiple and nested case studies, data analysis began with a process of forming a timeline and chronological narrative of events based on archival material and interview testimonials (Bremner and Eisenhardt, 2022). This provided a helpful background timeframe to contextualise the information gathered during further interviews and data collection. The work on a chronological timeline was also refined further in a process of *temporal bracketing* to compare how different stages of the qualitative case studies have unfolded and how they relate to each other (Langley, 1999). An example of temporal bracketing and forming a timeline of chronological events is presented in Figure 5.2 for the case studies in Chapter 5.

In addition to collating events into chronological timelines, the early stages of data analysis included open coding of archival texts and interview testimonials to discern overarching themes, important events, and key processes that formed part of the innovation process of each case study and contributed to the inter-stakeholder relational dynamics through which these are enabled. These elements were given descriptive codes and were assigned codes for the case studies to which a specific passage was relevant. In addition, stakeholders and individuals mentioned in interview testimonials and archival materials were coded with specific tags, which were used to guide and plan out further sampling of respondents and stakeholders to include in the data collection.

During the next stage of data analysis, the descriptive codes and first-order concepts were used to form a set of second-order themes, and based on these, a set of third-order aggregate

dimensions, in alignment with the so-called ‘Gioia method’ of structuring qualitative data analysis to form new categorisations and theory insights (Corley and Gioia, 2004; Gioia, Corley and Hamilton, 2013). Figures 5.1, 6.1 and 7.1 illustrate this coding process in relation to the data analysis for each respective case study.

Using the categorisations and analytical models emerging from the different coding rounds, the latter-stage process of data collection and interviews became gradually more refined and focused on pinpointing the specific innovation enablers and stakeholder relationships that were emerging as the most consequential. This iterative process also informed the assessment of data ‘saturation’, and new data collection was concluded when it became clear that the dataset had covered the driving processes of each case study to the required level of detail (Saunders *et al.*, 2018). The following two sub-sections will describe the two latter-stage elements of the data analysis and how the analysis was subsequently linked to new theory development: Within-case analysis with the subsequent development of descriptive models and process models, and cross-case analysis with the subsequent development of a new comparative theory framework for discontinuous innovation ventures.

i. Within-case analysis

The next stage of data analysis, conducted inductively during and after the main interview period, was a process of within-case analysis for each of the respective cases nested in the three empirical studies based on the initial analysis of the empirical dataset (DiBenigno and Kellogg, 2014). The themes and categories from the initial data analysis were used to form descriptive ‘models’ of the main turning points, roles and relationships pertaining to each case study, and thereby to structure the empirical findings such as which enablers had been active in supporting each venture. For example, when the initial categorisations in early data analysis highlighted

early-stage risk-sharing as a central driver of a venture in Chapter 6, the within-case analysis stage sought to provide and present a more in-depth account of how this risk-sharing was organised within each separate case study. Tables 5.1, 6.1 and 7.1 illustrate the within-case empirical models that were developed using the emerging dimensions from the iterative coding rounds and later applied also for cross-case analysis.

Beyond describing the main elements, roles and relationships of the innovation case studies, the within-case analysis stage also initiated inductive theory development to form descriptive process models based on the case study research (Langley, 1999). The key elements of the different case studies emerging from the descriptive models were joined together with the chronological accounts of different events and main turning points, thus starting to piece together overarching accounts of how the discontinuous innovation processes have developed and at which stages different stakeholders have been enabling them. After conducting this process analysis separately for the different case studies, the different elements emerging in Chapters 5-7 were combined in fuller picture process models, where both the venture processes and the roles of local-level innovation drivers and state-level innovation enablers are taken into account. This theory development of a new process framework is described in Chapter 8 (section 8.3).

ii. Cross-case analysis

Having analysed each of the case ventures and processes separately, these were finally compared in a process of cross-case analysis to highlight similarities, differences, and other emerging observations in their innovation stages and process models. Focus when coding this final stage of data analysis was placed on identifying both similarities and differences between the different innovation processes: Both at the level of vision, strategy, and general discourse,

as well as at the more concrete level of what kind of strategic positioning and partnerships were undertaken at different process stages (Navis and Glynn, 2010; DiBenigno and Kellogg, 2014; Bremner and Eisenhardt, 2022). In these comparisons, observations included both what stakeholders had been covered by different kinds of strategic partnerships engaged in an innovation process and qualitative similarities and differences in what these partnerships entailed. The prevalence of key constructs or, for example, mentions of external partners in communications or interview transcripts, were also followed up iteratively both through desk-based analysis and in confirmatory ‘member-check’ interview discussions with gatekeeper individuals and other expert respondents (Seale, 1999).

The final data analysis stages also incorporated an element of theory development: Based on the emerging findings from comparing across cases, the latter analysis stages focused on formulating possible frameworks and categorisations along which these comparisons may be explained and discussed in more detail. For example, the differences between two green steel ventures in Chapter 5 were analysed in depth, gradually resulting in the finding that a flexible categorisation along the lines of policy-driven vs. market-driven incentive structure was the most useful for describing the roles and relationships of the two ventures and how they relate to each other. These categorisations in new theory development emerged inductively between rounds of final-stage data collection and data analysis, with different options being considered and member-check discussions being used for feedback in new iterations. Gradually, the model that emerged from this analysis is the one presented in Chapter 8 (section 8.2) on a new comparative theory framework of discontinuous innovation ventures.

3.4.3 Research ethics

The empirical research process obtained standard ethics approval prior to the start of formal data collection and in line with the University's regulations when conducting empirical research in social settings (CUREC). The research agenda does not focus on researching or interviewing minors or persons in a vulnerable position, nor do the research questions or subsequent interview framework focus on sensitive business information or ongoing transactions. For these reasons, the project could be carried out by applying the common standards of ethical research practice.

Prior to their interview, each respondent was provided with a written overview of the research project and its aims, of the main researcher and supervisors along with contact details, as well as of the ethics and data protection standards followed by the researcher. The main tenets of this information were repeated orally at the start of each interview, after which the respondents were asked to reconfirm their express consent to proceed with the interview and to make and store an audio recording for the purpose of transcription. It was made clear to respondents both in writing and verbally at the start of each interview that participation is voluntary and that consent for participation and further use of respondents' data can be withdrawn at any time without naming a reason. Respondents were also encouraged, both before and again after the interview, to name any specific element in their interview testimonial that they only shared off the record and did not want to be included in the formal dataset for analysis and publication. Consent for participation and data collection was given in writing in cases where this was practical and virtually in the remaining cases (with confirmation taking place both verbally and over email). The same policy for research ethics, data collection, and informed consent also applied to all background interviews from two earlier research projects (for these, the informed

consent expressly included a mention that the interview data could be stored and used for future publications that hailed from the original project).

The anonymisation practice was also explained before each interview. The cases and stakeholder names would not be anonymised as this was impractical due to the research context. However, every effort would be taken to maintain the anonymity of the respondent's identity in the final thesis and any publications. The only exception to this would be the use of interview quotes with the individual respondent's name and title, where this was particularly relevant for the research findings. In these cases, the respondent would be given a separate opportunity to review the proposed named quote over email and decide on their consent for using the quote prior to publication. These separate consent emails were sent out prior to the submission of the thesis, providing a reasonable timeframe for translated wording alteration requests or withdrawal requests.

3.5 Conclusion

This chapter has outlined the philosophical foundations, case selection, and research process for the empirical research conducted as part of the research project for this thesis. The aims of the research agenda of Chapter 2 are founded on an interpretive research philosophy, and this chapter has outlined how the nature of the research questions flowing from this philosophical foundation necessitates a qualitative and inductive research methodology based on multiple nested empirical case studies and grounded theory-building to formulate a new theory framework based on the findings of the empirical research. This has been followed by a description of the case selection and its rationale, as well as of the research process and research ethics. The empirical chapters (5-7) will revisit and link back to this methodological description with regard to their specific case studies.

Before moving to the empirical case study chapters, Chapter 4 will provide the backdrop and research setting for the case studies to be analysed. This context description will discuss both the geographical and socio-institutional environment, the industrial history, and the most recent developments surrounding sustainability transformations of traditional industry sectors in the northern parts of the Nordic countries.

Chapter 4 – Research setting

4.1 Introduction

Following the introduction in previous chapters of the theoretical foundations, research questions, and research design for the thesis, this chapter will provide an overview of the research setting for the empirical case studies. The research setting of this thesis is a set of traditional industry agglomerations located in the resource-rich north of Finland, Sweden, and Norway.

Understanding the broader characteristics and recent developments of the research setting is particularly crucial because of the overarching rationale of this thesis: To demonstrate and analyse innovation processes that look categorically different compared to our global benchmark models for discontinuous innovation but which are successfully innovating and scaling up first-of-a-kind transformations in some of the most complex innovation challenges of our time (in this case, in the case of sustainability transitions in traditional industry sectors). The first step towards doing this is to establish the characteristics of the case study setting and show that it is, indeed, substantively different from the benchmark ‘Silicon Valley model’ (Casper, 2007). This not only sets the scene for case study analysis but also pinpoints why developing new theory to understand discontinuous innovation across different contexts is crucially important.

In addition to the importance of describing the research setting as part of the rationale behind the thesis and its research agenda, this chapter also serves the more pragmatic purpose of clarifying the state of the art of regional and industrial development in the Nordic context and dispelling confusion that may otherwise arise from media accounts and existing literature. The

Nordic countries, and especially some of their northern regions, are currently demonstrating significant momentum for sustainability-focused investment and innovation, the scale of which is notable on a global scale (Ballard, 2023). However, against commonly presented views in media and industry reporting that this momentum for sustainability transition is something completely new and unexpected, this chapter emphasises that there are significant developments dating back more than a decade before most of the large-scale innovation ventures in the northern Nordic regions were initiated. The industry towns presented and analysed in this thesis are found in some of the most remote and extreme geographical conditions in Europe, but their recent momentum for sustainability-focused innovation is no coincidence. This chapter provides a general overview of these recent industry developments, focusing on the ventures and localities that are at the centre of the case studies that will be analysed in Chapters 5-7.

The first section of this chapter will provide a context overview based on existing research about the geographical and socio-institutional setting of the Nordic countries, especially in terms of the development of traditional industry sectors in the northern Nordic regions. The Nordic countries have always had a distinctive industry profile, which builds on a combination of relatively sparse population and harsh climate conditions, yet rich supplies of various natural resources. From a political economy perspective, the industrial guild-based communities that gradually organised into industrial production centres are still visible in the shape of current-day small and medium-sized Nordic industry towns and cities (Kristensen and Lilja, 2011). In addition to path-dependencies at the local level, these organisational forms have been carried forward in the shaping of several economic and societal institutional complementarities, which provide the incentive structures and operating procedures for the roles and relationships of different stakeholders (Asheim and Coenen, 2005; Iversen and Soskice, 2009). The context of

these industry complementarities is crucial for the analysis of innovation and industry transformation, particularly in traditional industry sectors and smaller industry towns where institutional changes driven by, for example, global financial markets have been less pervasive (Ornston, 2009). Therefore, the institutional and industry contexts across the northern and non-metropolitan parts of the Nordic countries can be viewed as relatively homogeneous, while there are, of course, also many elements of variation in cultural, social, and economic activity. The shared challenges and opportunities between the regions are recognised, among other aspects, in an active inter-regional dialogue and cooperation on innovation and industrial policy (OECD, 2017b).

Sections 2-4 of the chapter focus more specifically on the case study settings in northern Sweden, Finland, and Norway, respectively. After a brief historical background, the sections outline the most recent industry developments surrounding sustainability transitions in traditional industries. The regions in the north of the Nordic countries have several key features in common due to their geographical location and subsequent industrial and institutional developments. However, the three are also distinct in their industrial development due to various factors: Different industry capabilities, distinct local strategies, and political and economic governance from the respective capital cities. This thesis, by design, chooses to focus on localities with somewhat different sizes and profiles, seeking to present a richer image of the settings in which discontinuous green steel and hydrogen innovations are developing in the Nordic context.

The discussion section subsequently draws together the overarching themes that emerge from the overview of different elements of the sustainability and innovation context in the north of the Nordic countries. The significant current-day momentum for large-scale innovation

projects has emerged as a combination of traditional strengths in the region's industrial history and a new, more direct connection to global finance, industry, and policy processes. This gives rise to a variety of globally significant innovation hubs with the capacity to take on systemic sustainability transformations. However, both regional and national level factors give rise to boundary conditions that shape the innovation environment and, in some cases, risk curtailing the innovation momentum created in the north of the Nordic countries.

4.2 Industrial history of the northern Nordic regions

The Nordic countries (defined politically as Denmark, Iceland, Norway, Sweden, and Finland, but with a current focus on the latter three) are in research on political economy characterised as textbook examples of *coordinated market economies (CMEs)*, with features such as a strong tradition of consensus decision-making through close-knit informal networks and non-market coordination, relatively centralised labour market and wage bargaining mechanisms, a finance sector with active, long-term institutional investors and patient capital, and an extensive public system of R&D and higher education institutions that provide free education and training in highly specialised skills (Hall and Soskice, 2001; Campbell, Hall and Pedersen, 2006; Kristensen and Lilja, 2011; Thelen, 2019). On the one hand, the industrial history of the Nordic region is thereby often described as driven by a competitive advantage in developing slow-paced, incremental improvements to complex engineering and manufacturing processes (Hall and Soskice, 2001; Ornston, 2014). The Nordic region consistently ranks among the most innovative regions of the world, with a high degree of skills in many traditional industry sectors such as forestry, heavy machinery, shipbuilding, chemical engineering, etc. (World Intellectual Property Organization., 2024).

On the other hand, highly skilled, high-technological sectors centred on the metropolitan areas of the south of the Nordic countries are characterised as agile and entrepreneurial, featuring vibrant start-up and venture capital ecosystems (Glimstedt and Zander, 2003; Bergholm and Bieler, 2013). Some research, therefore, perceives the capacity for discontinuous innovation in the Nordic countries as limited specifically to these urban entrepreneurial clusters, concluding that high-technological sectors in the Nordic regional innovation systems have ‘liberalised’ through policy and deregulation brought on by disruptive ICT innovation (Breznitz and Ornston, 2013; Ornston, 2014; Thelen, 2019).

However, others find that the tendency to pioneer markedly discontinuous innovation that fundamentally disrupts existing market segments or invents entirely new ones is a recurring historical feature in Nordic rural industry towns (Lemola, 2003; Lindmark and Vikström, 2003; Fellman *et al.*, 2008; Jäntti and Vartiainen, 2009; Kristensen and Lilja, 2011). Even the metropolitan Nordic ICT corporations and innovation hubs emerged gradually from traditional industry towns and legacy firms, co-dependently with wider social welfare and education-systems developments (e.g. Ericsson and Nokia) (Rehn, 1996). Therefore, the industrial history of Nordic regions still clearly shapes Nordic innovation capacity and industry momentum in any sector, particularly in traditional industries that develop with continuous dependence on physical resources and infrastructure systems.

4.2.1 The northern Nordic regions – Extreme in conditions and rich in resources

The geographical focus of this thesis is on a set of industry agglomerations in the northern part of the Nordic countries (see Figure 4.1 below). Industry activity in these regions has a particularly strong connection to traditional industry sectors and has seen a significant recent increase in sustainability-focused investments and ventures (OECD, 2017b; Sörlin, 2023).

These northern regions (sometimes termed as the Nordic Arctic), situated on both sides of the Arctic Circle, are characterised by a cold, temperate climate, sparse population, and a wealth of natural resources (Teräs *et al.*, 2023). The Gulf Stream, which brings warmer seawater from the Atlantic up the Norwegian coast to the Bering Sea, is a crucial enabler of life and vegetation in the north of the Nordic regions, which, despite the extreme conditions, are significantly more habitable than other regions at a similar latitude (around a third of the world's population north of the 60th parallel are living in the Nordic countries). The Scandinavian mountain range cuts through the northern Nordic regions, giving rise to large rivers flowing in all three countries and a richness of minerals and precious metals. The map in Figure 4.1 above features the continental Nordic countries, showing the locations of the empirical case studies for this thesis as well as the capital cities for Sweden, Finland and Norway.

Figure 4.1: Map of case study locations



The northernmost regions of the Nordic countries are inhabited by the indigenous Sami peoples, the only officially recognised indigenous population of mainland Europe, whose traditional livelihoods, such as fishing and reindeer husbandry, have carried on to this day. Finnish, Swedish, and Norwegian peoples have likewise been inhabiting the northern regions for thousands of years, with much of the population agglomerated along riverbanks and in coastal villages and towns along the Bering Sea and the Bothnian Gulf (the northern part of the Baltic Sea).

When industrialisation first arrived in the Nordic countries, the northern regions' importance as a driver of industry for the southern regions and urban centres became clear (Sörlin, 2023). Efficient forestry, mining (iron, copper, gold, silver, zinc etc.), and hydropower industry grew rapidly, and towns and populations grew with them. Local industry facilities were often driven by a single owner, such as a state-driven mining company, or a local guild (Fellman *et al.*, 2008; Kristensen and Lilja, 2011). These economic institutions developed in alignment with political ones, creating structures for consensus decision-making and workers' unions (Iversen and Soskice, 2007). Indigenous rights were not safeguarded to the same extent as in recent decades, and Sami villages and reindeer pastures were often forced to move as new mines, towns, and railway lines were built (Koivurova *et al.*, 2015).

Through the 20th century, the northern Nordic regions gradually developed their distinctive industry profiles (Keskitalo, 2019). In Sweden, the strength of the mining and steelmaking industry in the north became and remained a pillar of the national export industry, which grew and expanded radically during the 20th century (Lindmark and Vikström, 2003; Fellman *et al.*, 2008; Sörlin, 2023). Urban populations grew along the northern coast of the Baltic Sea and in a few inland industry hubs: Kiruna and Gällivare for mining, and Boden for railway

connections and military garrisons. In Finland, alongside the crucial forestry sector, the state invested heavily in developing steel and heavy manufacturing industries (Rehn, 1996; Jäntti and Vartiainen, 2009). This focus was strengthened as war indemnities to the Soviet Union boosted the establishment of new industries after the Second World War. In order to maintain skill-intensive labour across the country, universities were strategically established in several larger towns and cities (Lindmark and Vikström, 2003). In Norway, with fjords and mountains inhibiting accessibility, small coastal communities have remained in place to a higher degree than in Finland and Sweden, with a strong focus on maritime industries such as fisheries and aquaculture (Fellman *et al.*, 2008; Grønning, Moen and Olsen, 2008; Kristensen and Lilja, 2011). By the second half of the 20th century, the petrochemical industry had become a national industry champion, which the state has used to shore up its public finances in a Sovereign Wealth Fund. As in Finland and Sweden, Norwegian skill-intensive industry production was strongest in southern urban centres rather than in the sparsely populated north, even if the strength of the Norwegian innovation system as a whole has been viewed as somewhat weaker than that of Finland and Sweden (Grønning, Moen and Olsen, 2008).

By the late 1900s, European trade and industry became more integrated, and the bank-based finance sector was liberalised, which grew the role of the stock market in the Nordic innovation systems. The earlier developmental role of the Nordic states evolved into a more arms-length role of indirect innovation support, which has been labelled as ‘creative corporatism’ (Ornston, 2009; Kristensen and Lilja, 2011). However, these changes still align specifically with a CME-type economic model, and the role of public-sector agencies as nodes for policy experimentation and non-market coordination was sustained. The Nordic states were among the first to develop designated National (and Regional) Innovation Systems strategies and ‘Centres of Expertise’ – various public innovation agencies for promoting different aspects of

innovation processes (especially early-stage venture support and funding) through private-public collaboration (OECD, 1997). During the 2000s, development in metropolitan areas and particularly digital-tech sectors have partly turned away from the CME-rooted corporatist institutions, with impacts such as a decline in centralised wage bargaining, an increase in short-term risk investments, and decreased public R&D spending, especially after the 2008 financial crisis (Bergholm and Bieler, 2013; Ornston, 2014; Nieminen, Loikkanen and Pelkonen, 2016).

However, while the Nordic economies, on the whole, have grown and developed into world-leading learning economies, these developments have not been mirrored to the same extent in the northern regions and have even brought about a sense of relative decline when compared to metropolitan growth regions and high-technology hubs in the south. Successive economic crises and global market fluctuations, as well as a migration trend from traditional industry regions to urban centres with a strong growth momentum, have led to a stage of demographic and economic decline across the northern Nordic regions (Ornston, 2018; Keskitalo, 2019; Sörlin, 2023). To be sure, strengthened innovation environments, increased access to investments, and overall stronger global trade have also positively impacted the northernmost regions and traditional industry clusters, which have remained key sectors in the Nordic export economies (OECD, 2017b; Teräs *et al.*, 2023). Digital transformation and increased infrastructure links have also significantly increased the development opportunities for rural and peripheral areas. However, as high-value-added sectors targeting highly skilled workers have taken centre stage for new ventures and investments, the regions where these sectors are represented relatively less have felt the increased pressure of losing recent graduates and skilled workers to areas with more diverse opportunities.

As a result, the previous decades in the northern Nordic regions are generally characterised as stagnant or steadily declining in industry opportunities and development when compared to the Nordic states as a whole (with some partial exceptions to this trend, such as the ICT innovation hub that Nokia and related ICT stakeholders established in Oulu in northern Finland) (Inkinen and Suorsa, 2010). The traditional industry stakeholders dominating the private sector in many northern Nordic areas have mostly managed to maintain their overall competitiveness, but this has mostly taken the form of incremental quality improvements rather than discontinuous transformations towards completely new technologies or processes.

4.2.2 Renewed sustainability momentum amidst a gradual decline

Against this trend of industry continuity, incremental innovation, and even stagnation, the increasing pressure on traditional industry sectors as caused by climate change and related sustainability challenges has set in motion a subversive, discontinuous, sustainability transition in the northern Nordic regions. The northern parts of the Nordic countries are directly affected by the global sustainability transition in several ways. On the one hand, these regions are no exception to the scientifically proven pattern that the adverse effects of the climate crisis are the most severe in vulnerable ecosystems and communities: The temperature increase and related climate impacts are already faster and more unsettling in the Arctic regions than in Europe overall (Rantanen *et al.*, 2022). On the other hand, seeing both the fragility of these ecosystems and the crucial role of traditional industry sectors in enabling a global sustainability transition, the past 15 years have seen pioneering action across the industries based in the area to seek out new solutions and break with carbon-intensive processes as quickly as possible. Traditional industry sectors are pressured to rapidly transition and decarbonise their processes or face increasing fines, carbon taxes, and regulatory impediments. In few other regions of the world has the focus on ‘cleantech’, ‘green tech’, and overall ‘regional resilience’ been adopted

so early across different sectors and stakeholders in society as it has in the northern Nordic regions (Giacometti and Teräs, 2019; Nordregio, 2024). The total investments into energy-intensive industry decarbonisation in the northern Nordic regions by 2023 is well over EUR 200 billion (Ballard, 2023; Finnish Ministry of Economic Affairs and Employment, 2023; Teräs *et al.*, 2023). While all the planned investments are unlikely to be implemented, the scale of the movement to discontinuous industry transition is indicative of a system-level shift being enabled at the local and regional levels to a degree that convinces both incumbent industry stakeholders, policymakers such as the European Commission, and global financial institutions to support the early-stage industry transitions in the northern Nordic regions.

This thesis delves deeper into the inter-stakeholder relational dynamics that are driving these innovation processes at the intersection of traditional industry and sustainability transition. While the innovation processes are unprecedented in both scale and scope and stand out as some of the largest investments and industry projects to take place in their respective regions (and the Nordics as a whole) for generations, they are also decisively place-based: The northern Nordic sustainability innovation wave is enabled by regional knowledge networks, close-knit informal networks to complement formal coordination, and a tradition of prioritising long-term resilience in regional development (Fellman *et al.*, 2008; Kristensen and Lilja, 2011; Ornston, 2018; Giacometti and Teräs, 2019). The following three sub-sections will outline the specific innovation context of each of the three countries' northernmost regions, thus setting the scene for the case studies analysed in the subsequent chapters of this thesis.

4.3 Northern Sweden

Sweden's two northernmost regions, Norrbotten and Västerbotten, are also its largest and most sparsely populated. Norrbotten, with a population of around 250,000, makes up approximately one-quarter of Sweden's land mass (Nordregio, 2024). Norrbotten stretches across the Arctic Circle to Sweden's northernmost point, and both of the two regions border the Bothnian Gulf and Finland to the east and the Scandinavian mountain range and Norway to the west. Most of the population and key industries are concentrated in the estuaries of large rivers running into the Bothnian Gulf, as well as at inland industry centres focused predominantly on mining and forestry. The majority of localities in the two northern Swedish regions have, in the past decades, suffered from the same adverse demographic developments as the other northern Nordic regions: out-migration of young people to larger cities, an unbalanced local economy and gender divide, and lacking personnel for healthcare, education, and social services (Giacometti and Teräs, 2019; Teräs *et al.*, 2023).

Nevertheless, both regions enjoy very high levels of employment. Local councils that have retained some municipal ownership of energy and industrial production have kept a particularly solid financial foundation. Key economic sectors with innovation capacity in recent years include ICT and data centres, cold-climate testing of cars and engineering equipment, forest and bioeconomy, high-technological processing industry, mining and mineral extraction processes and technology, renewable energy production, and space technology (Giacometti and Teräs, 2019). Many of these more research-intensive developments are understandably tied to the primary production and refining of natural resources: Approximately 20% of Sweden's total energy production comes from the two northernmost regions, which also account for 90% of all European iron ore production as well as a sizeable share of European extraction of other key minerals (Teräs *et al.*, 2023).

The case studies of Chapters 5-7 involve industry networks and innovation processes touching on several industry towns of northern Sweden, as these are in many ways interlinked into the same regional innovation system. The main focus, however, will be on the neighbouring towns of Luleå and Boden and the steelmaking and hydrogen innovation processes taking place within their industry networks.

Luleå (79,000 inhabitants) is located 700 kilometres north of Stockholm, just south of the Arctic Circle, and sits at the outflow of the Lule River into the Baltic Sea (Statistics Sweden, 2023). The town has a long industrial tradition enabled by the natural resources of the surrounding region. The Lule river has the second-highest waterflow of all Swedish rivers, accounting for the single largest share of hydropower production and 10% of Sweden's total energy production (Luleå Municipality, 2024). The port of Luleå has, for over 100 years, served as a key link for iron ore and steel shipments as iron ore and minerals hailing from Norrbotten's inland mines have been transported to Luleå on the strategically important 'Ore railway' (Swedish: Malmbanan). Luleå itself hosts one of the SSAB steel conglomerate's steel mills, which is one of the largest in Sweden, and from which excess energy is being utilised in a central heating system for the surrounding city. The steel mill is, however, only the fourth largest employer in the city, after the city administration, the county administration, and Luleå Technical University (LTU) – the only centre for engineering higher education and research in northern Sweden (Luleå Municipality, 2024). In this regard, the demographic and economic profile of Luleå resembles that of many mid-sized Nordic towns and cities, where public sector stakeholders and the education sector tend to be the largest employers in terms of personnel volume. Industry and entrepreneurship are also organised in a way that resembles many similar Nordic localities: The public sector is actively involved in coordinating new business

establishments and collaborative projects. Luleå used to have a private-sector-driven business development company – in recent years, however, this enabling role has shifted more strongly to the public sector. In terms of start-up activity and research focus, Luleå does not have a strong singular specialisation in the same way as the energy cluster formed around Vaasa in Finland (covered in the next sub-section).

A 30-minute drive upriver from Luleå sits Boden (28,000 inhabitants) which, since its establishment in the early 1900s as a railroad node along the Ore Railway, a military base, and a public administration hub, has grown concurrently with Luleå as its smaller sister town (Statistics Sweden, 2023). The gradual closing of many of the town's main employment centres in the second half of the 1900s was inevitably followed by a growing demographic imbalance and decreasing industry dynamism (Keskitalo, 2019). This is also noticeable in that the potential 'twin city' effect of Boden and Luleå has been left partly unsupported, and commuter traffic between the towns along the Ore Railway has been decreased to make way for goods transport. In sum, Luleå-Boden and its surrounding region fit the picture given by an incubator executive during an interview about the state of entrepreneurship across the north of Sweden: *“The truth is that for many years, not much happened in terms of new entrants, and most start-ups were somehow linked to the existing large industry players as suppliers or similar. We joke around saying we are the world's oldest start-up ecosystem – that our start-ups up here are over a hundred years old!”*

4.3.1 From green energy to green systems – Northern Sweden and the sustainability transition

The past 10-15 years have been a period of tangible momentum for large-scale innovation in northern Sweden. The pace of newly emerging and developing ventures has been particularly significant in the wake of the momentum created by the Paris Climate Agreement and the

European Green Deal pledges by the European Commission (European Commission, 2019). By 2023, more than EUR 100 billion in planned investments had been announced in the two northern Swedish regions for ventures relating to resource and energy-intensive industry production as part of sustainable industry transformations (Nordregio, 2024). The two northern Swedish regions, with a combined population of just over 500,000, are expected to require an immigration of over 100,000 people across different societal sectors to cover the scale-up required to the regional labour markets and societies, in addition to the labour force required by the planned industrial facilities themselves (Larsson, 2022).

However, while the public image and national conversation surrounding the growth momentum in Northern Sweden has been at its height since the latter years of the 2010s, the actual transition processes laying the groundwork for large-scale innovation are at least a decade older. At the core of this is the understanding by local industry and municipal directors that northern Sweden's endowment in clean resources will be an increasingly important competitive advantage amidst the deepening climate emergency. Moreover, Sweden's nationwide capacity to benefit from renewable energy production in the north is limited: the main electricity grid connection, transporting surplus energy from supply areas in the north to the growing energy demand of the south, does not have the required scale-up capacity to meet rising demand. Local and regional strategists realised this early: Through study visits and survey reports, an alternative long-term market was identified in the emergent sustainable-energy transformations and demand-hikes for a number of discontinuous industry developments, as driven by digitisation and energy-source decentralisation. For example, one energy-sector executive recounts that the system of turbines that generate power in the region's large rivers was physically rebuilt in order to provide the capacity profile needed by large-scale industry facilities.

The identification and groundwork for a broader transformation have been a regional trend of mutually complementing strengths and learning across sectors. An interview respondent employed at Luleå's municipal business development company recounts: *“This business of coordinating large-scale establishments is a network effort that’s taken a long time. In 2008-9, Google bought an old paper mill in Finland to use as a data centre and made a deal with a wind energy provider to power its operation and cooling functions. This was a wake-up call for us, and we started an internal process to prepare and market our existing facilities and resources to large IT companies”*. This strategy paid off – in 2011, Facebook announced the building of its first large-scale Nordic data centre in Luleå. Gradually, however, other sectors more closely linked to local skill-intensive industry took over the main focus. The respondent continues: *“Initially it was all about data centres. But over time, we understood that data centres are not the most innovative kind of establishments and do not really bring that much additional value and job opportunities to the region, so you want to look at other kinds of industry facilities to power with your surplus energy”*. Industry planning and marketing activities in northern Sweden shifted more strongly to resource-intensive, traditional industries. Despite challenges along the way, especially facing the Northvolt battery start-up and its global value chain, the momentum of new sustainable industry investments in the northern Swedish regions has held onto its unprecedented pace and scale (Milne, 2024).

Chapters 5-7 will provide case-study insights into some of the most significant of these recent developments in northern Sweden. Chapter 5 presents a double case study of the world's two first large-scale ventures to decarbonise steelmaking: The H2 Green Steel greenfield venture in Boden, and the HYBRIT consortium of incumbent decarbonisation with a focus on Luleå. Chapter 6 will delve deeper into the local-level enabling factors behind hydrogen innovation

ventures in Luleå and the surrounding area, the largest of which have a direct link to the green steelmaking ventures. Chapter 7 will consider these innovation processes from a national policy perspective, examining examples of how national-level stakeholders have interacted with the ongoing transformation processes in the northern parts of the country.

4.4 Northern Finland

Geographically and economically, the northern parts of Finland have faced similar industry development as the northern parts of Sweden (Lindmark and Vikström, 2003; Keskitalo, 2019). Lapland is the northernmost region of Finland and the European Union, bordered to the south by the regions of Kainuu and Ostrobothnia, and all three of these regions share a general industry and demographic profile focused on resource-intensive industries such as mining, forestry, chemical engineering, and metallurgy. Some towns have developed strong agglomerations in particular sectors, such as the ICT-innovation hub of Oulu in Ostrobothnia (Giacometti and Teräs, 2019; Teräs *et al.*, 2023). Many northern Finnish localities also depend on a strong tourism sector.

The case studies in this thesis focus on the area surrounding the town of Vaasa, which is the largest Nordic cluster agglomeration for energy sector innovation (Vasek, 2023). Vaasa is located on the Western coast of Finland, in the region of Ostrobothnia (while situated in the northern part of the Nordic countries, from a Finnish perspective, Vaasa is classified as Western rather than Northern). The port city of 70,000 inhabitants remains a strong regional centre of research and education, with 13,000 students spread across six universities, technical universities, and polytechnics (City of Vaasa, 2024; Statistics Finland, 2024). Vaasa is selected as a case-study area specifically given its unique combination of being situated in sub-Arctic

and relatively remote conditions from a European perspective but also maintaining one of the Nordic countries' most significant sector-specific innovation hubs in traditional industry sectors.

In terms of research and innovation, the Vaasa area is one of Finland's most entrepreneurial regions (especially when discounting the metropolitan centre of the Finnish capital of Helsinki). The energy innovation cluster accounts for one-quarter of Finland's energy sector and has 180 companies, many of which have been acquired as subsidiaries of global MNCs (Vasek, 2023). The several generations of energy sector research expertise maintain an environment of innovation and experimentation with an annual turnover of more than EUR 6 billion and the share of private R&D spending per capita in the Vaasa area is among the highest in Finland (Finnish Ministry of Economic Affairs and Employment, 2023; Vasek, 2023). Since over 80% of the cluster's output is exports the Vaasa region is also the most export-oriented in the country.

The governance and structuring of innovation activity and collaboration in the Vaasa cluster is described by interview respondents as a largely industry-driven network in which higher education institutions and regional and national government agencies act as platforms and enablers. Many of the firms in the energy cluster initially formed as spin-offs by employees of the town's legacy industry firms, Wärtsilä and Strömberg (later a subsidiary of ABB), or were supported by local investors employed at the two legacy firms or spin-offs from them, and a large incentive for innovation among new firms remains the supplier network around the large industry stakeholders in the town (Keskinen, 2017). Among the main platforms for innovation and collaboration in Vaasa are a private-sector-controlled business incubator (70% industry

ownership), a business development organisation run by the City of Vaasa, the Regional Council of Ostrobothnia, and other similar business associations.

Its consistent innovative capacity notwithstanding, the labour market and start-up development in Vaasa is relatively rigid. In recent years, some areas in the region have practically been at full employment, with an ageing demographic curve coupled with growth in regional industry and social sectors (Finnish Ministry of Economic Affairs and Employment, 2023). Interview respondents across the energy cluster describe a general aversion against a fail-fast mentality, stressing that bankruptcies are extremely rare and not considered a natural element of innovation activity. The statistics for firm entry and exit in Vaasa are relatively low among Finnish regions, even as Finland and the Nordic countries overall have followed a trend of ranking low on entrepreneurial dynamism and entry and exit figures (Braunerhjelm and Feldman, 2006; Ornston, 2018; Finnish Ministry of Economic Affairs and Employment, 2023).

However, these characteristics are not due to a lack of local entrepreneurialism but to a very specific and highly networked model of innovation that has developed within the Vaasa cluster and will be elaborated on in Chapter 6. This mechanism supports long-term commitments and non-market collaboration alongside market competition, dissuading a fail-fast entrepreneurial mentality while still encouraging flexibility and agility in innovative projects. This network model also seems relatively resistant to external industry influences: While some foreign acquisitions of Vaasa-based firms seem to have provoked changes in internal culture, this has not had a substantial impact on Vaasa's internal dynamic.

4.4.1 A window of opportunity to scale up – Northern Finland and the sustainability transition

Against this backdrop, the increased momentum for discontinuous change in traditional industry sectors, most recently in the context of decarbonisation, is not seen within the Vaasa cluster as uncomfortable or daunting. On the contrary, the crucial role of Vaasa's pre-existing advantage in energy sector innovation has been boosted even more, attracting unprecedented interest by external investors and industry start-ups to open new energy-intensive facilities in and around Vaasa (Finnish Ministry of Economic Affairs and Employment, 2023). One respondent explains: *"It feels like a continuation of the kind of innovation we have been trying to do here for a long time, but now of course with much more volume"*.

In the first years following the Paris Climate Agreement, Vaasa's capacity to attract the interest of large-scale innovation projects appeared to lose out to other Nordic industry towns. At the time, one regional industry coordinator described: *"It just seems we have to get much better at attracting these big investments, which are now going to Sweden. We did not have what it takes. But hopefully, this is still good for new similar projects in the future, maybe we can get the next one"*. Indeed, more than two years later, in 2023, a respondent comments: *"It is a long game, these investments, and you need to be sustainable in the resource availability. So I think our region is doing well, and we can offer incredibly stable and secure resources and an environment that can support fast growth"*.

Gradually the investment volume and frequency of new projects in and around Vaasa has been increasing, as the existing industry and innovation networks have succeeded in organising commercially viable pathways for large-scale ventures in different traditional industry sectors. As a result, there are now planned sustainable industry investments amounting to EUR 1.9

billion for the Vaasa energy cluster by 2030 (Vasek, 2023). This has taken place through coordination between several stakeholder groups, as there has been a requirement not only for suitable land for business purposes but also for connections to critical infrastructure and renewable energy capacity. Importantly, this has also included a partial reworking of the role of city and regional government in order to reduce administrative barriers to entry of new ventures in the town. While Vaasa's innovation capacity is predominantly industry-driven, the network has always been dependent on proactive enabling strategies from public administration. One Vaasa-based respondent summarises the strengthened role of local policy and governance: *“It appears as if the public administration bodies have gone into a more efficient mode of preparing and attracting these investments, and this is a new lesson learned over the past few years”*.

This trend of a gradual increase in momentum, after an initial experience of a slow start when compared to northern Sweden's large-scale discontinuous innovation ventures, is prevalent across the northern Finnish regions but particularly along the western industry towns (Vaasa, Kokkola, Oulu and Kemi, among others). This is partly connected to geopolitical concerns and realities of infrastructure and logistics networks, and partly to path-dependencies of scaling up based on existing industry networks and innovation hubs (Teräs *et al.*, 2023). The consistent growth of renewable energy production in the region has framed the potential for long-term momentum of scaling up new industry ventures. Chapters 6 and 7 will present case studies into some of these recent developments in more detail. Chapter 6 will focus on local-level enablers for hydrogen innovation ventures in the Vaasa area. Chapter 7 will add a national policy perspective, examining examples of how national-level stakeholders have interacted with the ongoing transformation processes in the northern and western parts of the country.

4.5 Northern Norway

Finnmark County is the northernmost region of Norway and mainland Europe. With 75,000 inhabitants, the vast majority of the region is uninhabited (much of the land area is only ever used as pasture by reindeer herders) (Finnmark County Council, 2024). To the southwest, the university city of Tromsø in Troms County is northern Norway's largest urban population (79,000 inhabitants) (Statistics Norway, 2024). In Finnmark, the largest town is Alta in the west of the county (21,000 inhabitants), while the county administration is in Vadsø (5,000 inhabitants) in the eastern part of the county, directly north of Finland and west of the Russian-Norwegian border (Finnmark County Council, 2024; Statistics Norway, 2024). Berlevåg, the 800-inhabitant fishing village at the centre of a hydrogen innovation case study in Chapter 6, is located on the northern coast of the mountainous Varanger peninsula, directly facing the Arctic Ocean.

Livelihoods and economic activity in northern Norway have traditionally been characterised by primary production. Being situated far to the north of the Arctic Circle, winters are long and harsh and conditions for agriculture close to impossible. Instead, local populations have made their livelihoods in fishing, forestry (in those parts of the region that have a tree cover), reindeer husbandry (particularly members of indigenous Sami communities), and natural resource extraction (OECD, 2017b; Teräs *et al.*, 2023). Distances between neighbouring villages can be dozens of miles long, and transport links are further hindered by uneven terrain with high mountains and narrow fjords traversing the landscape. Like in all rural parts of the Nordic countries, demographic development in northern Norway is tending towards an ageing population, and the emigration of young people in search of new opportunities presents a persistent threat to many communities where there has been a lack of new and diversified economic activity (Finnmark County Council, 2024). However, many small-village

communities have proven surprisingly resilient to these pressures, and communication links such as regular ferries and small-plane shuttles have allowed many communities to stay connected and reachable despite the extreme conditions.

In terms of research-intensive industry and innovation activity, Finnmark county is generally lagging behind most Norwegian and Nordic regions, and this is clearly connected to the conditions described above (OECD, 2017b; European Commission, 2023a). With the exception of wind energy production and the oil refinery in the coastal town of Hammerfest, there have been few large-scale industry investments in the region in recent years. The region's most active hub of entrepreneurial activity and knowledge exchange is the town of Alta, which hosts several business incubators as well as a satellite campus of the Tromsø-based UiT – the Arctic University of Norway – which is the northernmost university in the world (OECD, 2017b). However, there is little formal research-driven activity taking place, and the innovation environment is even weaker in other localities in the region. A business park manager in the county administration town of Vadsø describes supporting new entrepreneurship and innovation as a constant uphill struggle where one village's gain is easily seen as another's loss: *“It is just a long-running suspicion against open collaboration with those outside your immediate network. This probably comes from our history of being very remote, but also the realities of how small we are: If the next town over has a training scheme in a specific industry, it is completely impossible for us to also have one because there would not be enough people to either run or participate in those programmes. So any change or new business here is usually quite slow to grow”*.

The fishing village of Berlevåg, the focus for a Chapter 6 case study on hydrogen innovation, is in many ways a representative example of a significantly remote and closely-knit Arctic

community on the Finnmark coast. Reachable by land only by one road that scales and traverses a mountain pass, Berlevåg is regularly isolated by land transport from the rest of the region due to blizzards and storms. Despite the complete desolation of all dwellings by retreating German occupiers in World War 2 and a subsequent suggestion from the Norwegian government to evacuate the entire village to a new location, Berlevåg and its community have remained in place, and while the population is in a declining trend, the decline has been relatively gradual. In addition to the road link, Berlevåg is also served daily by passenger ferry and small-plane connections, building a crucial sense of reliable access for both citizens and businesses as described by a local energy sector professional: “*We often travel by those planes to get to larger towns like Alta or Tromsø – we call it ‘taking the bus’. Doing any business development here would feel pretty hopeless without them*”.

Fishing has remained Berlevåg’s main sector of employment, and gradual improvement to the harbour and wave breakers in the previous decades has increased the reliability of fisheries as a municipal income source, as well as the reliability of the business environment for a number of public services and community businesses (Berlevåg Municipality, 2024). Tourism is almost exclusively limited to nature tourism and birdwatching visitors in the summer months. Berlevåg municipality, along with the Varanger peninsula’s other municipalities, is co-owner of the regional energy company Varanger Kraft, the wind energy investments of which are providing the municipality with a steady source of external income and the opportunity to host a small number of engineering and mechanical work opportunities in the village. All in all, Berlevåg is viewed as an impressively resilient community set in extremely remote conditions (Teräs *et al.*, 2023). Research-based, formal innovation processes have generally been absent, but the village and its history feature a strong tradition of community-based social innovation

and the recombination of available resources to counter the significant challenges posed both by geographical conditions and population decline.

4.5.1 Strategies for long-term survival – Northern Norway and the sustainability transition

Economic activity across many industries in the Finnmark region has a long tradition of integrating environmental sustainability as a key pillar of the overarching concern for the long-term resilience and survival of Arctic communities (Teräs *et al.*, 2023). In the context of the momentum for decarbonisation and system-wide climate transition, this is apparent in how regional and municipal administrators generally find it straightforward to adopt new standards and models for innovation policy based on sustainability, such as the UN Sustainable Development Goal targets and EU innovation policy frameworks of Smart Specialisation. As one respondent describes: *“There is a general sense across this region that these sustainable development frameworks come with perspectives that our communities already have. Instead of adopting new concepts and changing everything, people generally want to keep on ‘doing it’”*. Both regional and municipal stakeholders are thus coordinated and ambitious in their policy action towards sustainability and decarbonisation, while many citizens feel that the transition will imply relatively little overhaul of their already sustainability-focused livelihoods.

However, in terms of translating the global policy momentum and local awareness to large-scale ventures for innovation and decarbonisation of resource-intensive industries and the energy system, northern Norway is facing challenges brought on by conflicting interests and lacking coordination. This is especially visible in two domains. The first is a set of challenges in the allocation and planning of carbon-free energy resources and grid connection capacity. In order to build up regional momentum for both the production and application of carbon-neutral

electricity, the existing plans and permits for new wind energy production and grid expansion would need to be amended at the national level, as Chapter 7 will explain in more detail. The second regional coordination challenge relates to safeguarding the rights and heritage of the indigenous Sami communities (Koivurova *et al.*, 2015). One regional administrator comments: *“It is clear that the Sami’s rights to use these lands need to be safeguarded. In the present conditions, this ambition is sometimes conflicting with plans for new sustainable industry projects”*. The most pertinent of these are conflicting land use interests between onshore industrial establishments and reindeer herding pastures, as the former can disturb the grazing reindeer and alter their movement patterns across large areas.

In Berlevåg village, the planning for decarbonised industry ventures and a future livelihood for the village has also faced these coordination challenges and initially managed to avoid conflicting interests or serious bottlenecks. In 2014, on a barren mountain top sitting just above Berlevåg, a wind farm with 100 MW capacity was constructed by the regional energy company Varanger Kraft. A local business administrator explains: *“There really is no better place in Norway for a wind park. The mountain is so far up north that there are no trees or structures, meaning they were able to install longer blades even though the park is onshore and not offshore. It is not a year-round reindeer pasture, and the wind is blowing basically all the time. This was the background rationale for commissioning the wind farm. With a 50% efficiency rate, it is one of the most efficient out of all wind farms in Europe – and bear in mind, this one is located on land”*. The wind farm has been a critical aspect of subsequent discontinuous innovation ventures in Berlevåg and provides its stakeholder municipalities with a continuous revenue source. Berlevåg’s subsequent first-mover position in research-intensive hydrogen innovation is both remarkable and surprising. However, Berlevåg has navigated a range of challenges throughout this process, which will be explored in Chapter 6. Chapter 7 will analyse

in more detail how the ongoing grid capacity challenges have led to conflicting interests between different innovation processes in northern Norway.

4.6 Discussion – Themes arising from the description of the research setting

The northern regions in Sweden, Finland, and Norway have many distinctive characteristics and trajectories that the previous paragraphs have introduced and that the upcoming empirical case-study chapters will analyse in more depth. This section picks up on common themes that arise from the description of the empirical and regional setting and that connect to the research questions for empirical case studies presented in Chapter 2.

4.6.1 The momentum for green steel and hydrogen

One of the clear signs emerging from the ongoing developments in the northern Nordic regions is their opportune positioning to undertake discontinuous innovation to decarbonise the supply chains in some of the hardest-to-abate traditional industry sectors – particularly steelmaking. As brought up in the case selection of Chapter 3, steel manufacturing accounts for approximately 7% of all the world’s carbon dioxide emissions, alongside an array of other environmental impacts (Rodríguez Diez *et al.*, 2023). In the Nordic countries – especially in the northern, more sparsely populated regions of Sweden (and partly in Finland and Norway) – a strong momentum has emerged to pioneer innovation for steel decarbonisation, combining a long tradition of steelmaking knowledge with the availability of renewable energy and other crucial resources. One respondent with involvement in the early-stage feasibility studies on green steel describes: “*It turned out that the north of Finland and Sweden are the best locations for this, given energy supply and opportunities to store hydrogen*”.

Chapter 5 will delve deeper into this development in order to answer the research question of how the inter-stakeholder relational dynamics are balancing the ‘old’ and the ‘new’ in steelmaking for large-scale green steel innovation. The two case studies to be discussed include the HYBRIT consortium of incumbents and the H2 Green Steel start-up, both of which are located in northern Sweden.

Chapter 6, in turn, builds on the analysis in Chapter 5 but with a particular focus on innovation in hydrogen. Within the context of the ongoing industry transition to sustainability, the production and application of hydrogen produced from renewable energy sources has emerged as one of the central technologies to achieve carbon neutrality in traditional industry sectors. Due to the features of green hydrogen as a promising opportunity for both industry decarbonisation and wider transformation of energy systems, but also as costly and difficult to produce and store, large-scale discontinuous innovation involving hydrogen-based technologies inherently invites system-level coordination of the local industry environment. Even in the case of large-scale electrolyzers being purpose-built for use by a single industry facility, any stakeholders with a technological framework involving hydrogen will benefit from the network effects of wider, systemic distribution and production of hydrogen in their surrounding industry environment (OECD, 2022). The Nordic context of highly networked regional industry clusters and innovation systems provides a backdrop and growing momentum for these system-level transitions driven by hydrogen innovation. However, the setting and drivers for these innovation processes work differently in different cases. Chapter 6 will analyse these drivers and differences by bringing in three Nordic regional settings that are pioneering in hydrogen innovation: Vaasa in Finland, Luleå in Sweden and Berlevåg in Norway.

4.6.2 The unsolved tensions in local-level Nordic resilience

The case studies included in this thesis all describe locations with relatively modest population sizes from a national or European perspective – whether in the context of mid-sized industry towns or very small and remote villages. The emergence of large-scale discontinuous innovation in these settings will take up a noticeable share of new regional industry capacity and impact the local communities and populations in a variety of ways, from jobs created/shifted and new migration patterns to growing pressures on administrative and social systems and political questions about resource allocation and citizens' rights (Larsson, 2022). However, the engagement and coordination between innovative ventures and different communities or citizen groups is not to be taken for granted, even in the Nordic countries with their reputable culture of trust and efficient governance. The true level of involvement or empowerment of local communities depends on what kind of relationships and interactions citizens have with the ongoing projects and their leadership, i.e. on whether there is a sense of citizen involvement in the regional innovation system (Edquist, 2019; Moodie, Salenius and Wøien Meijer, 2021).

This gives rise to possible tensions in new discontinuous innovation, particularly regarding the division of roles and responsibilities between different stakeholders. The scale and pace of the transition taking place in the north of the Nordic countries are without local precedent, which has led to increased calls for state-driven support and orchestration of resources (instead of leaving the bulk of the financial and organisational responsibility on regional-level stakeholders). Another crucial question is that of the relational dynamics and potential development imbalance between those localities that host large-scale innovation ventures and those that do not.

Chapters 6 and 7 of the thesis will analyse these tensions in inter-stakeholder relational dynamics from two different angles: Chapter 6 from the perspective of local industry communities and their innovation-driving role (specifically surrounding hydrogen innovation processes), and Chapter 7 from the perspective of state-driven policy engagement to enable large-scale innovation ventures and the localities hosting them.

4.6.3 The 'Transition Belt' effect

Finally, the overview of recent developments across the north of the Nordic countries suggests that boundary conditions to successful discontinuous innovation ventures give rise to a 'Transition Belt' in some parts of the northern Nordic context. Respondents explain this locally emerging concept as a perceived Goldilocks effect or 'sweet spot' in the conditions driving the agglomeration of discontinuous sustainability innovation: On the one hand, the demand for resources, in particular an affordable supply of green energy, implies that the bulk of successful projects in industrialising of large-scale innovation in these sectors are located in areas with particular resource advantages. In the Nordic context, especially the northern Nordic regions have a favourable position.

On the other hand, there are other boundary conditions that inhibit some large-scale ventures from being placed in too remote contexts, either. In the Nordic context, it is particularly the long distances and harsh conditions that get gradually more extreme to the north, also implying long distances to European supply-chain partners and hubs for knowledge-intensive innovation and highly skilled labour. To this can be added a number of additional factors: Firstly, the safeguarding of the rights of indigenous Sami populations (in particular in the high north of the northernmost counties) to protection and consultation of any industry ventures on their ancestral lands; secondly, geopolitical concerns such as orders from defence ministries to

maintain certain strategic zones without industry developments or e.g. windmills that may disturb radar observation (this is particularly in locations close to the Finnish eastern border with Russia, as well as in other strategic locations); and, thirdly, the physical capacity of energy infrastructure (which is limited especially in some parts of northern Sweden and Norway). These factors do not imply that there can be no ventures either in the very north or further south in the Nordic states. However, there does seem to be a momentum and agglomeration of activities at the southern edge of the northernmost Nordic regions, surrounding the Bothnian Arc, featuring towns like Kemi, Kokkola, Vaasa, Umea, Skellefteå, Luleå, Boden, and Mo i Rana.

However, these context factors do not specify the actual drivers of discontinuous innovation processes nor how different stakeholders shape them through their innovation strategy. The empirical chapters of the thesis will delve deeper into the questions of how successful large-scale ventures get organised and what boundary conditions impact this development. Chapter 6 will discuss regional and local stakeholders that are coordinating and navigating a range of challenges and resource dependencies for innovation, while Chapter 7 will discuss both the general Nordic institutional environment as well as policy and regulation processes that are playing a key role in state-level coordination.

4.7 Conclusion

Having outlined the general features and turning points of the Nordic industry and innovation context, with a particular focus on northern Nordic regions and their long-running focus on traditional industry sectors, this thesis will now turn to three sets of nested empirical case studies in the northern Nordic context that demonstrate particularly interesting cases of discontinuous innovation for the sustainability transition. The northern Nordic context is

extreme in several ways, especially in comparison to most industry regions in Europe. These areas have developed and hosted industry models and supply chains that have remained almost unchanged for several decades, and many observers from cities to the south are today generally sceptical of their northern regions' innovation capacity beyond general resource provision and incremental improvements to traditional processes (Sunden, 2023).

However, these observations generally overlook that the northern Nordic regions have undertaken conscious regional development and innovation efforts for over 10 years, whereby the potential afforded by prevailing conditions has been turned into a tangible competitive advantage for innovation. The context of the remote northern Nordic regions looks nothing like the 'usual suspect' benchmarks of discontinuous innovation, and especially not like Silicon Valley (Breznitz, 2021; Casper, 2007). Yet, pioneering discontinuous innovation is taking place in many domains. The research setting presented in this chapter explains how the competitive advantage in question has led, in particular, to growing momentum across the three countries for decarbonisation pathways in hard-to-abate traditional sectors like green steel and hydrogen. In fact, there are even signs of a 'Transition Belt' where sustainability transition ventures are agglomerating and strengthening each other.

Many of the main challenges surrounding innovation and scale-up are similar across the northern Nordic regions, covering themes like talent and capital attraction, resource coordination among competing interests, and safeguarding the rights of indigenous communities. But beyond these similarities, there are also clear signs of distinct strategies and frameworks, both locally and nationally, that the different regions have developed and adopted. Describing and analysing these similarities and differences will be the focus of within-case and cross-case analysis in the three empirical chapters. Overall, the regional industry resilience and

recent prowess in pioneering discontinuous innovation processes, which have emerged in some of the most hard-to-abate sectors and some of the most remote northern Nordic business environments, imply that these cases have a lot to teach a wider global audience interested in the theory and practice of innovation and sustainability in traditional industry sectors. In the next chapter, these lessons are discussed from the first out of three empirical perspectives, i.e. the perspective of Nordic large-scale ventures pioneering carbon-free steelmaking.

Chapter 5 – Determinants of Large-scale Discontinuous Innovation

Ventures in Steel

5.1 Introduction

The climate crisis and the global effort to mitigate its effects are having a profound impact on traditional industry sectors that rely on fossil fuels and emission-intensive processes (Garud and Gehman, 2012; Lee and Malerba, 2017). Dependence on existing processes and material resources creates a paradoxical challenge for the transition trajectories of these sectors: The transition to new, sustainable technologies and away from fossil fuels would need to be both as decisive and as seamless as possible in order to guarantee both environmental, social, and economic sustainability for business and society (Schot and Steinmueller, 2018; Bansal, 2019; Kivimaa *et al.*, 2021). The sustainable industry transition in traditional, hard-to-abate industry settings thus needs to involve large-scale innovation that drives simultaneous transition across energy systems, supply chains, and business models (Gambardella and McGahan, 2010; Garud and Gehman, 2012; McDowall, 2018).

However, there is a distinct lack of research on strategic pathways for industry ventures to innovate at a sufficient scale and pace to succeed in bringing about a systemic, ‘deep transition’ to sustainability (Schot and Kanger, 2018). Therefore, in the first of three nested case studies as outlined in the research agenda, this chapter adopts the perspective of analysing sustainability-focused traditional industry innovation as instances of discontinuous innovation as per Q3: *How do large-scale discontinuous innovation ventures in traditional industry settings balance between new and incumbent markets, technologies, and value chains?*

The previous chapters have emphasised that benchmark innovation settings like Silicon Valley are different from industry settings where policy priorities, rather than price-efficiency and customer trends, are incentivising innovation and where complex resource and infrastructure dependencies are core strategic questions that determine a venture's success (Casper, 2007; McDowall, 2018; Henderson, 2021). The respective roles of incumbent firms and new entrants, for example, may be markedly different across different innovation settings (Porter, 1989; Hockerts and Wüstenhagen, 2010; Kumaraswamy, Garud and Ansari, 2018; Breznitz, 2021; Weigelt, Lu and Verhaal, 2021). But this diversity has not been clearly reflected in theory models on innovation. Many of the most hard-to-abate traditional industry sectors are still today mostly understood as mature and slow-changing industries, and not as settings for discontinuous innovation and system-level transition (Henderson and Newell, 2010; Lee and Malerba, 2017; McDowall, 2018; Kivimaa *et al.*, 2021).

The steelmaking industry, which was a cornerstone case study in Christensen's (1997) original research on *disruptive* innovation, exemplifies particularly well the systemic challenges of discontinuous innovation for the sustainable industry transition. Steelmaking accounts for approximately 7% of all the world's carbon dioxide emissions, alongside an array of other environmental impacts (Rodríguez Diez *et al.*, 2023). The complexities of decarbonising the steel supply chain and the widespread supply shortages of renewable energy and resources required to scale up carbon-free steel production contribute to a lack of global direction for a sustainability transition in steelmaking. The leading trajectory for transitioning to near-zero emission steelmaking combines elements that are familiar from pre-existing technologies but, in doing so, creates a new technological pathway that is almost completely untested at scale (OECD, 2024). Crucially, any innovation process following this technological pathway depends on significant supplies of renewable energy to produce hydrogen as a substitute for

coal in iron-ore reduction (see Chapter 3). Both the political will to build up regulatory pressure on the steel sector and industry action in building up supply chains for ‘green’ steel (the ambition level for which is increasingly defined as reducing steelmaking emissions by at least 90%) were during the first years of the 2020s decidedly modest in most global steelmaking regions (Sunden, 2023; World Trade Organisation, 2023).

This chapter presents a double case study of the two most advanced green-steel innovation ventures to be found anywhere in the world: The H2 Green Steel start-up² and the HYBRIT consortium of legacy industry incumbents (OECD, 2024). Both first-movers are emerging in the same region of Northern Sweden – an area with a rich endowment in natural resources and a legacy tradition in iron ore mining, steelmaking, and renewable energy production (see Chapter 4). But the two ventures are very different in their respective business models (i.e. greenfield start-up vs. transitioning incumbent), and existing theory models would therefore expect their innovation strategies to be distinctive as well: H2 Green Steel should seek to overthrow incumbents’ market positions by faster, cheaper, and more sustainable alternatives to the traditional steel value-chain, and HYBRIT should seek to leverage its owners’ market position to keep out any new entrants to sustainable steel transitions (Christensen, 1997; Ansari and Krop, 2012). Interviews and observation for the qualitative case study were conducted over a two-year period in 2022-2024 when both green-steel ventures were undergoing their most fundamental scale-up stages of supply-chain formation, pilot production, and early industrialisation.

² In September 2024, H2 Green Steel was renamed as Stegra. As this thesis and its data collection focus on developments preceding the name change, the company will be referred to as H2 Green Steel.

The research design of this paper builds on an inductive double case-study approach, allowing for comparison across two different ventures undertaking a discontinuous innovation process in the same industry sector and in the same geographical area (DiBenigno and Kellogg, 2014; Bremner and Eisenhardt, 2022). Data analysis and temporal bracketing yield an understanding of the key stages of the two ventures, how they position themselves with key stakeholders and engage with the existing industry setting and crucial resource dependencies, and how well this conforms to expectations in existing literature about the roles and relationships of start-ups and incumbents during discontinuous industry transformation (Langley, 1999).

The findings show that instead of diverging and remaining distinct, the two green steel innovation strategies strengthen and complement each other and that their processes even converge at specific points during their scale-up. The initial impetus of the two ventures is rooted in different business models, and these differences have contributed to occasional tensions when navigating some of the resource dependencies involved in the innovation process, for example, relating to grid connections. However, the findings also demonstrate how the successful industrialisation of the two ventures became mutually reinforcing and even partially converged when it came to community engagement, regional infrastructure priorities, and building market legitimacy for carbon-free steelmaking. This is surprising given how existing literature perceives the contrasting roles and separate innovation dynamics of start-ups and incumbents (Hockerts and Wüstenhagen, 2010; Niesten, Pereira and Pinkse, 2023). Fundamentally, both green-steel ventures have adapted their innovation process to reduce risk by aligning the discontinuous innovation process with several existing elements of the steelmaking value chain rather than maintaining rigid internal integration and sticking to the expected playbook of a new entrant or incumbent. The complementarities between the two green-steel innovation strategies are found to have been particularly pronounced at the regional

level and at the scale-up stage, where the two ventures directly shaped each other's trajectories. In contrast, the two ventures were more distinct and more in keeping with the expected industry roles of new ventures and incumbents both at their initial launch and during the buildout of their full-scale industrialisation.

The case study thus demonstrates that innovation for sustainable industry transitions can be discontinuous in its technological trajectory but at the same time closely aligned with dependencies and processes of the existing industry architecture, rather than unequivocally *disrupting* them in Christensen's (1997) sense of the term. Moreover, ventures with competing and significantly different innovation strategies (in this case, a start-up and a consortium of incumbents) may develop mutual complementarities and even converge with each other's innovation strategies and market-building efforts. In this case study, these complementarities are prompted by a particularly path-dependent and material resource intensive innovation context (i.e. where several different resource dependencies are at the centre of strategic planning). These findings diverge from familiar models and perceived incumbent and start-up roles in existing innovation research, in particular from the market-disruptive innovation processes demonstrated in leading digital innovation benchmarks like a general 'Silicon Valley model' (Casper, 2007; King and Baatartogtokh, 2015; McDowall, 2018).

The discussion following the case study develops these findings further and emphasises how the findings can inform the structure of new theory development on discontinuous innovation to enable future analysis across different industry contexts. In particular, this chapter contributes by seeking to make the concept of discontinuous innovation a more nuanced analytical lens for understanding the innovation strategies of traditional industry ventures under sustainability transformation.

5.2 Literature on discontinuous innovation: Lack of insight into ventures strategies for sustainability transition

While innovation, by definition, includes an element of novelty that seeks to challenge or improve on what existed before, the ‘direction of travel’ for innovation processes can take on different forms. As presented in Chapter 2, innovation that builds on new knowledge and that seeks to transform existing industry structures and epistemic regimes through a step-change is called *non-continuous* or *discontinuous* innovation (Utterback, 1996; Kaplan, 1999). Discontinuous innovation is separate from the narrower but more widely used concept of *disruptive* innovation (Christensen, 1997). The step-change shift described in this narrower case is the competition-driven substitution of existing products or entire market segments by alternative technologies and product solutions (Christensen, Raynor and McDonald, 2015). Based on this and subsequent literature that discusses disruptive innovation and industry change, predominantly in the context of consumer-facing markets, we have become used to a narrow benchmark model of defining innovation success where start-ups, as new entrants, seek to overthrow incumbents with superior value propositions that take over their market share (Santos and Eisenhardt, 2009; Ansari and Krop, 2012; Christensen, Raynor and McDonald, 2015). Discontinuous innovation and scale-up of this kind are best exemplified by high-technological, resource-rich innovation environments like the start-up ecosystem of Silicon Valley (Saxenian, 2000; Casper, 2007; King and Baatartogtokh, 2015; McDowall, 2018; Breznitz, 2021). Incumbent stakeholders, in turn, are generally perceived as a source for continuous improvement rather than discontinuous change. At times of technological change and disruption – exploring the transition between the ‘old’ and the ‘new’ – academic research tends to explore the conditions of incumbent survival rather than incumbent-driven disruption (Porter, 1989; Ansari and Krop, 2012; Ansari, Garud and Kumaraswamy, 2016; Cozzolino, Verona and Rothaermel, 2018).

However, as found in Chapter 2 that outlines the research agenda, this dominant ‘Silicon Valley model’ represents only one of many kinds of industry settings where discontinuous innovation can occur. This disconnect – between mainstream concepts in innovation research and real-life innovation processes in different places – becomes particularly salient in the context of sustainability (Hockerts and Wüstenhagen, 2010; McDowall, 2018; Breznitz, 2021; Henderson, 2021). Consequently, the context of sustainability transitions invites a wider analysis of discontinuous innovation than has hitherto been undertaken and theorised (Garud and Klopp, 2023).

The lack of diversity in innovation research is particularly pronounced in the case of discontinuous innovation in hard-to-abate traditional industry sectors (such as steel, cement, and petrochemicals) that are intensive in physical infrastructure and resources, and where change tends to happen through repurposing rather than discarding the existing resources and process models that have been handed down and incrementally adapted for generations, since the first industrialisation (Kivimaa and Kern, 2016; McDowall, 2018). Existing literature has not explored in depth what discontinuous innovation looks like in these traditional industry settings: To what extent do resource dependencies give rise to unique elements that make discontinuous transitions between ‘old’ and ‘new’ look different in these industry settings compared to others? In particular, do discontinuous innovation processes in these contexts conform to literature assumptions about the roles of start-ups and incumbents? Comparative analysis of discontinuous innovation processes, therefore, requires not industry-level comparison but more granular analysis at the level of the firm or venture and its relational dynamics: how a discontinuous innovation venture positions itself and engages with the surrounding industry setting and resource dependencies (Garud and Gehman, 2012).

5.3 Methods and research setting – a double case study of pioneering green-steel innovation

As was presented in Chapter 3, the relational dynamics that shape industry action are not comprehensively covered in formal documentation, especially when it comes to informal networks. Moreover, as there is no existing analytical framework for researching discontinuous innovation in different industry settings, data analysis needs to aim at inductive theorising to formulate new theory development. The research design for this chapter subsequently builds on combining different types of qualitative empirical observation: Inductive fieldwork observation, as well as interviews and document analysis conducted through a multiple case-study approach, following the guidelines of grounded theory building and the constant comparison method (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016). The double case-study approach increases the richness and overall reliability of the research by allowing for comparison across two different ventures undertaking discontinuous innovation in the same industry sector and in the same geographical area.

In order to increase the empirical understanding of large-scale discontinuous innovation ventures in traditional industry settings, few sectors are as representative of these challenges as the steelmaking industry in its effort to decarbonise. As presented in the case selection in Chapter 3, steelmaking accounts for approximately 7% of all the world's carbon dioxide emissions, alongside an array of other environmental impacts (Rodríguez Diez *et al.*, 2023). The leading technological trajectory for transitioning to almost completely emission-free steelmaking combines elements that are familiar from pre-existing technologies, but in doing so creates a new pathway (almost completely untested at industrial scale) which, in combination with an energy and hydrogen supply based fully on renewable energy, can bring

down steelmaking emissions to near zero: 1) fossil-free iron-ore pelletisation using biofuels; 2) switching the use of coal and coke to hydrogen in the iron-ore reduction; 3) replacing traditional blast furnaces with electric arc furnaces (EAF) (HYBRIT, 2024; OECD, 2024).

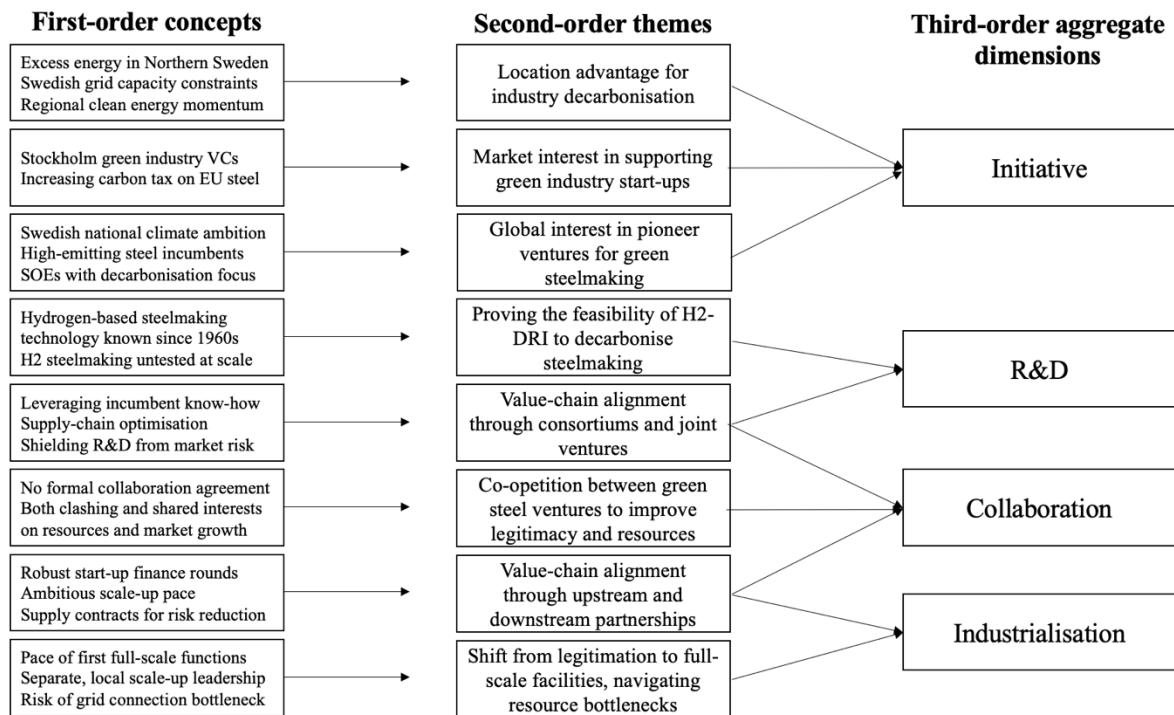
This chapter presents the first double case study of the two most advanced green-steel innovation ventures to be found anywhere in the world: The H2 Green Steel start-up and the HYBRIT consortium of legacy industry incumbents. Both first-mover ventures are headquartered in the Swedish capital of Stockholm but have the bulk of their operations centred in the two adjacent towns of Luleå and Boden in the country's northernmost region of Norrbotten (see Chapter 4). By using empirical research to compare these two ventures located in the same region and tackling the same technology pathway of steel decarbonisation, yet with different industry backgrounds and business models, we get new insight into different innovation processes seeking to transform steelmaking and to what extent these processes conform to literature expectations about the distinct innovation strategies of start-ups and incumbents.

Chapter 3 provides a comprehensive description of the case selection and research process, as well as the qualitative data sources used for this chapter. In alignment with guidelines for theory-building research based on multiple or nested case studies, data analysis began with a process of forming a chronological narrative of events based on archival materials (Bremner and Eisenhardt, 2021). This provided a helpful background timeframe to put into context the information that was later gathered during interviews. The work on a chronological timeline was also refined further through *temporal bracketing* to compare how different stages of the innovation process have unfolded for both of the two green-steel ventures and how they relate to each other (Langley, 1999). The next stage of data analysis, conducted inductively and

iteratively during and after the main interview periods, was within-case analysis, where each green-steel venture was analysed in relation to the main research question of how discontinuous innovation processes balanced the tension between the ‘old’ and the ‘new’ in terms of incumbent markets, technologies, and value chains. This followed a nested case-study approach, where the data was coded based on different elements that are part of the innovation process and where iterative coding rounds were used to derive patterns and themes in the data (Eisenhardt and Graebner, 2007; Gioia, Corley and Hamilton, 2013; DiBenigno and Kellogg, 2014).

Through the iterative coding rounds of interview data as well as the temporal bracketing of archival data, four innovation stages were most frequently brought up as particularly crucial for driving the green-steel innovation process forward: The *innovation initiative*, where the venture is first put together and funded for the start of formal operations; *research & development*, where existing knowledge of the steel industry is complemented by an emerging technology and process for near-zero emission steelmaking through expansive testing and research; *collaboration*, where green-steel ventures engage a set of formal and informal partnerships in order to scale up the entire steelmaking value chain rather than singular elements of it; and *industrialisation*, where test-scale facilities are expanded into full-scale commercial green-steel operations. In future coding rounds after identifying these four aggregate dimensions, both green-steel ventures were coded separately for each of these elements, with a particular focus on the actions, roles and stakeholder relationships that are viewed by respondents as particularly crucial for implementing each of them. Figure 5.1 below provides a summary of the coding process, with the four main innovation stages emerging from the analysis.

Figure 5.1: Coding framework for the case studies in Chapter 5



Having analysed each of the green-steel ventures separately, the two were then compared with each other in relation to their innovation process more broadly and at the four highlighted innovation stages more specifically. Focus when coding was placed on identifying both similarities and differences between the two ventures: Both at the level of strategic vision and general discourse, as well as at the more concrete level of what kind of strategic positioning and partnerships were undertaken at the different stages of the two processes (Navis and Glynn, 2010; DiBenigno and Kellogg, 2014; Bremner and Eisenhardt, 2022). In these comparisons, observations included both which actors had been covered by different kinds of strategic partnerships engaged by each venture, as well as the similarities and differences in what these partnerships entailed. The prevalence of key constructs or, for example, mentions of specific stakeholders in communications or interview transcripts were followed up both through desk-

based analysis and in confirmatory ‘member-check’ interview discussions with gatekeeper individuals and other expert respondents (Seale, 1999).

5.4 Findings – Comparative analysis as part of the double case study

This section of the chapter outlines the findings of the analysis and comparison undertaken in the double case study of two green-steel innovation ventures. The focus is on elaborating on the main features and strategic positioning of each of the ventures’ innovation processes at the four identified innovation stages and on summarising the findings of the comparison between them.

5.4.1 HYBRIT – The incumbent model

The first green-steel venture to emerge in northern Sweden was HYBRIT (short for Hydrogen Breakthrough Ironmaking Technology). HYBRIT Development AB was formed and announced in 2017 as a limited liability company with equal share ownership stakes for SSAB (steelmaker with some government ownership), LKAB (Swedish state-owned mining company) and Vattenfall (Swedish state-owned energy company). The rationale for the development company was the ambition to create a flexible yet proprietary R&D platform (protected from external competitors) that could research, test, and scale up the required technologies for green steel, using a combination of experience and resources for mining, steelmaking, and renewable energy in a Nordic setting that the parent companies could readily provide. The green-steel shift represented for the parent companies a transformational shift in operations – devolving operational control of the HYBRIT green-steel project onto the development company provided room to manoeuvre for both the HYBRIT-attached personnel and for ongoing projects and operations in the parent companies. The HYBRIT testing facilities are funded predominantly by the parent companies themselves, in addition to some public and

grant support funding from government agencies. For example, in 2022, the EU Innovation Fund supported the initiative with EUR 143 million (European Commission, 2022).

The HYBRIT project has extensively researched and tested all parts of the steelmaking supply chain. While the physics behind the technology is straightforward, none of the steps had previously been commercialised at an industrial scale. For hydrogen production and storage, HYBRIT's testing facility in Luleå has a 100 cubic-metre hydrogen storage capacity, with the full-scale facility being planned at 100,000 cubic metres or about 100 GWh of energy storage capacity. During the extensive tests that have run since 2018, HYBRIT has also successfully trialled the world's first fossil-free iron ore pellets, the world's first hydrogen-reduced iron sponge and, in August 2021, was subsequently able to produce the world's first batch of fully fossil-free steel. The executives of the HYBRIT project have, throughout the research period, remained optimistic that the timelines of testing and industrialisation have been fulfilled in accordance with expectations, whereby the focus shifts on constructing facilities and scaling production capacity in time to meet the emissions reduction deadlines set by national and European policymakers (HYBRIT, 2024).

5.4.2 H2 Green Steel – The start-up model

Industry incumbents were not the only ones to harness the strategic potential of northern Sweden for the sustainability transition. H2 Green Steel AB was launched in 2020 as a start-up company with the clear target to bring fully carbon-neutral, hydrogen-reduced steel to market in a commercially viable way. A suitable site was identified on the outskirts of the small town of Boden, along vital railroad and power grid infrastructure links and a half-hour journey upriver from the university town and transport hub of Luleå (where HYBRIT had located their testing facility for hydrogen storage and hydrogen-based direct reduction). The H2 Green Steel

(hereafter H2GS) initiative was met with enthusiasm by both regional and national authorities for its commitment to further speed up the ‘re-industrialisation’ of Northern Sweden with the first new steel mill to be built in Europe for over 50 years.

The business model of H2GS relies on a diverse group of early-stage investors (both institutional investors, industry conglomerates, venture capitalists, and financial institutions) rather than a smaller number of large shareholders, as well as on early and continuous efforts to negotiate off-take agreements with downstream industry companies. In this sense, the boundary between old and new technologies is being managed through novel financing mechanisms connecting existing industry stakeholders with a start-up business model. To meet investor targets, H2GS relies on fast-paced proofs of concept using mainly commercialised technologies (albeit that all existing applications are on a much smaller scale than the vision for the H2GS steel mill with its record-breaking 800MW hydrogen electrolyser). The technological basis is the same as for the HYBRIT project: Green hydrogen-reduced iron made into steel using an electric arc furnace. However, rather than optimising every stage in the existing steelmaking process from mining to end-stage steel as HYBRIT does, H2GS is focusing on rapid scale-up by recombining hydrogen electrolyser and EAF technologies and processes already available on the market. The H2GS model also targets efficiency gains and further emissions reduction from vertical integration and digitalisation (such as supporting design and operations with a ‘digital twin’ of the Boden steel mill).

By 2023, H2GS had already secured EUR 3.5 billion in combined debt financing and sold over half of the planned production of green steel. With resource supplier agreements, environmental permits, and site preparation all progressing as planned, H2GS announced in the summer of 2023 both the green light for breaking ground on the Boden site and the financial

close of its equity investment round of EUR 1.5 billion to fund the construction – the world’s first commercial investment decision into full-scale green steel production, and the largest private investment decision of any sector Europe in 2023 (Ballard, 2023; Bhat and Salazar, 2023; Pratty and Jaipuria, 2023).

5.4.3 Comparison – Two different but complementary innovation strategies for green steel

Figure 5.2 below presents the timeline of the innovation process of the two green steel ventures. As explained in the previous section, four prevalent innovation stages have been identified based on the case study analysis, and they have been highlighted in the timeline models through temporal bracketing (Langley, 1999). HYBRIT is described above the axis, H2GS below the axis, and separate temporal brackets for the two ventures are placed above and below the timeline.

Figure 5.3, subsequently, breaks down the innovation processes of the two ventures into the four innovation stages, on which the following paragraphs will then elaborate. Focus is both on the process and substance of how the two ventures have organised the balance between the old and new steelmaking technologies and, in particular, how the two ventures have been partially co-dependent on each other in mitigating the various resource and infrastructure dependencies facing them.

Figure 5.2: Timeline of two green steel ventures

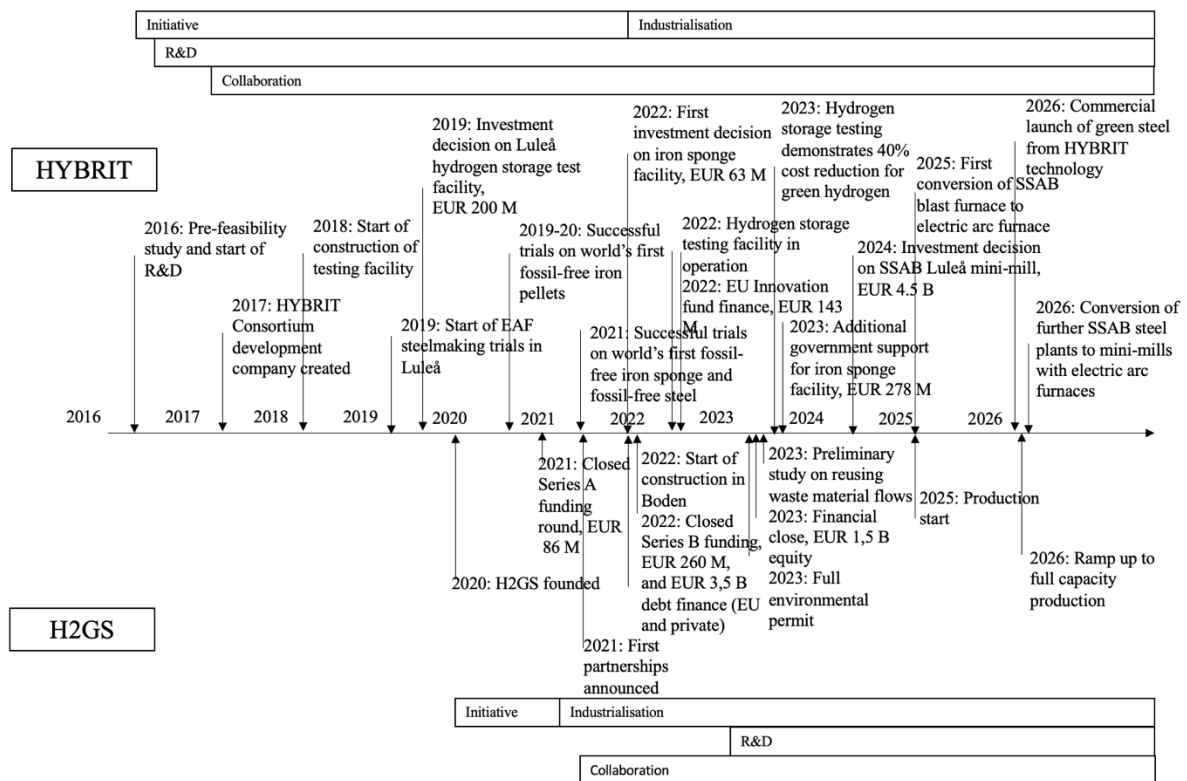


Table 5.1: Comparing the discontinuous innovation process of two green steel ventures

	H2 Green Steel (Start-up model)	HYBRIT (Incumbent model)
Initiative	Start-up with VC backing	Incumbent intrapreneurship
R&D	Outsourced to suppliers	Designated in-house R&D company
Collaboration	Modular supply-chain partnerships – decoupled local network governance	Equal-share consortium collaboration – decoupled local network governance
Industrialisation	Off-taker agreements and scaling to new markets	Operational control back from consortium to incumbents

i. Initiative

Both green steel ventures have been driven by entrepreneurial stakeholders, but the stakeholders in question were different, as was their operating incentive. Therefore, the initial approach and business model for the two ventures were different, and there was no discernible complementarity or co-dependence between them in the early stages.

The impetus for HYBRIT emerged from within the long-term strategy processes of incumbent Swedish industry companies, and both the internal processes and public identity of the HYBRIT initiative clearly reflect this incumbent-derived identity. As both LKAB and Vattenfall remain under ownership by the Swedish government, these incumbent companies and their driving stakeholders are viewing their decarbonisation not only from the perspective of long-term commercial advantage but also from long-term national interest. This perspective is similar for steelmaker SSAB as the third parent company, which, albeit not majority state-owned anymore, retains a position as a significant incumbent in Nordic traditional industries. Martin Pei, Chief Technology Officer of SSAB and initiator of the HYBRIT project, recounts: *“In the process of setting the Swedish national climate goals in 2015, which later led to the Swedish Climate Law, after discussions with various authorities and politicians, it became clear to us that SSAB’s 10% share of Sweden’s total emissions is a key issue and we needed to develop a solution”* (for coding detail, cf. the third box of first-order concepts in Figure 5.1 above). The incumbent-driven identity of the HYBRIT initiative has also, at times, faced pressures to navigate and decouple itself from public criticism periodically facing the parent companies, all three of which have their separate corporate cultures and reputations based on decades of industrial activity across Sweden and the Nordic countries.

In the case of H2GS, the initiative and corporate identity to drive a green-steel transition emerged with the mentality of an external player entering to disrupt a traditional industry sector. The financial and corporate partners of H2GS and its founders are closely connected with the incumbent industry in Sweden, Europe and beyond, across different sectors – this fits the general tradition in the Swedish political economy of active shareholder and board direction of industrial strategy (Thelen, 2019; Glimstedt and Zander, 2013; Hall and Soskice, 2001). However, the business model and strategic vision of H2GS are distinct from industry incumbents. H2GS is a start-up that raises capital for greenfield investments and orchestrates a wide network of partnerships to meet its output targets. Kajsa Ryttberg-Wallgren, Chief Growth Officer, summarises: *“Our business is to be sustainable, and to get paid for that by attracting private capital into a new kind of market in which we can deliver a return through CO2 emissions reductions”*.

The start-up identity is clearly visible in the flexibility with which H2GS builds partnerships that bridge across industry sectors. For example, the financing rounds of H2GS have included a mix of funders (including off-takers) that are not normally included in project finance for incumbent stakeholders (Ballard, 2023). The company’s Chief Technology Officer Maria Persson Gulda explains: *“With a funding set-up of 6.5Bn EUR, where 2Bn EUR comes from equity and a total of 4.5Bn EUR comes from debt, the risks and mitigations of the investments will obviously be in focus. Hence, securing a design, both the actual technical design of the plant, and business model design, that were bankable was absolutely crucial... e.g., choosing bankable (proven) technology, closing customer off-takes to show that you have sold out certain portions of your production, and getting both customers and suppliers involved already in the first investment, so that your strategic partners are across the whole value chain and are equally invested in your mission”*. This strategy for finance and industry legitimacy is also

naturally reflected in the brand image and communications of H2GS, which has an active presence in climate action forums and digital channels worldwide, akin to successful start-up enterprises in other (especially digital) sectors (Pratty and Jaipuria, 2023; Temple, 2023). This sentiment is a common denominator across the diverse profiles of H2GS hires, many of whom join the start-up with no prior experience working within steel or other traditional industry sectors.

In this way, the early-stage legitimization and scale-up efforts have been mostly separate from each other for the two green steel ventures, without significant clash or overlap, and largely in line with general literature expectations on the roles and actions of start-ups and incumbents (Christensen, 1997; Hockerts and Wüstenhagen, 2010; Ansari and Krop, 2012). The H2GS start-up has been actively engaging with existing steel markets as well as the finance sector to gain legitimacy and backing, while HYBRIT, as a mainly self-funded incumbent consortium, has been more inward-looking and planning out the stages of incumbent transformation. The two ventures relate to each other mainly in ways that uplift their own competitive advantage (HYBRIT emphasised their own strong R&D and industry background when compared to H2GS, and H2GS emphasised their agile and flexible growth strategy when compared to HYBRIT). An example is given by an external respondent based at a regional energy company, who observes that *“while the two are not very different in their end goals, they do talk about them differently – for H2GS, it’s almost like a tech company mode... The HYBRIT companies are clearly much more traditional and want to keep it that way”*.

ii. Research and development

As a direct consequence of their different founding incentives, the research and development strategies for green hydrogen and steelmaking differ decisively between the two green steel ventures. The HYBRIT initiative is structured as an applied yet highly research-intensive process, which undertakes a sequential workflow of research and testing as set out by the parent companies via the board of the consortium development company. This is also evident from the intellectual property regime in place at HYBRIT: The parent companies at HYBRIT are applying for patents to protect their green-steel innovations and standardise the green-steel process for their own and other stakeholders' benefit.

Most of the staff at the HYBRIT development company have roles related to R&D and testing, employed either by the development company itself or on secondment from one of the parent companies. An industry expert with several decades of industry experience describes the nature of R&D for green-steel innovation: *“To some extent this is a return from very granular incremental improvements to a mid-level testing of completely new processes, an approach that had been abandoned for a few decades in Swedish industry”*. Volker Schöllman, Director of Technology Development at HYBRIT, elaborates on the research process: *“In 2018 when we started, the rest of Europe wasn't talking about hydrogen-based direct reduction. It's a completely new process. Nobody has been doing hydrogen-based direct reduction on an industrial scale. The overall aim was really to prove on the pilot scale, on the semi-industrial scale, technical feasibility, and by that actually take away a lot of the risk to and take the next step”*.

Throughout the development of HYBRIT and especially in the early stages when a feasibility study was conducted, HYBRIT has had close connections to external research partners and

university departments in Stockholm and Luleå. HYBRIT has thus also focused on strengthening the R&D expertise around decarbonisation in the steelmaking value chain to support the development of parent companies for the long term. Both internal and external respondents agree that HYBRIT retains a different approach to sustainability transitions when compared to the start-up approach of H2GS. One respondent summarises: *“HYBRIT is really focusing on the transition of its owners, H2GS is more about bringing green steel to market as quickly as possible”*.

Indeed, the innovation strategy of H2GS builds on fast-paced scale-up to meet downstream targets rather than on robust early-stage efforts in original R&D. Instead of extensive in-house research and development projects, most of H2GS’s technological testing and innovation is carried out through partnerships with leading suppliers (such as US-based Midrex for DRI steelmaking and German ThyssenKrupp Nucera for electrolyzers). This strategy has also had clear impacts on technological pathways taken by H2GS, as one respondent recounts: *“There are technologies that we would like to use in our process, but that are not bankable yet, and so we have not put them in”*.

However, this early focus on more narrow operational targets ahead of, for example, supporting and undertaking breakthrough primary research, seems in the strategy of H2GS to be a question of sequencing, not of prioritisation. As specified by Maria Persson Gulda, CTO of H2GS: *“We don’t have a lab ourselves. We rely on our suppliers’ labs and pilot results for our chosen technologies, and we have secured strong performance guarantees in our contracts. We will, with time, start a lab for our product development but we start our production with well-known products on the market”*. In 2023, a deep-delving partnership was announced between H2GS and the Luleå Technical University for a research programme and testing facility that emulates

energy-intensive industry conditions and seeks to answer open questions about optimising the applications and system properties of green hydrogen. In this way, H2GS is gradually assuming a more traditional role of incumbent industry in Nordic regions – a role of pioneering new research facilities and training opportunities in collaboration with academia and the public sector (Asheim and Coenen, 2005; Braunerhjelm and Feldman, 2006; Kristensen and Lilja, 2011).

However different the two innovation strategies may seem at first glance, it becomes clear when comparing the timelines of strategic decisions and partnerships on R&D by the two green-steel ventures that there is an unplanned yet substantive complementarity between them (see Figure 5.2 above). HYBRIT and H2GS have concretely influenced each others' R&D decisions and trajectories. When interview respondents within and familiar with the strategy and business model of H2GS are asked about R&D, they consistently allude to the co-location and similar or slightly earlier timing of HYBRIT as a key factor that backs up H2GS through an indirect “proof of concept”. H2GS has been able to point to public information about HYBRIT's testing and research progress to enhance the legitimacy and validity of its own actions. Kajsa Ryttberg-Wallgren, H2GS Chief Growth Officer, concurs: “*What we do would be hard without the pilot that HYBRIT did, I mean they basically proved to the world that it works to reduce iron ore using hydrogen*”. Conversely, the presence and progress of H2GS has been similarly supportive to the HYBRIT initiative, not least in strategy discussions with parent companies about the future direction and viability of HYBRIT. As pointed out by one respondent: “*HYBRIT parent companies are also now opting for a mini-mill strategy like H2GS, and they are bringing their timetable forward significantly from the first vision*”. Indeed, in the spring of 2024, SSAB announced an investment decision of EUR 4.5 billion to transition the Luleå steelworks by way of constructing an electric arc furnace.

In this way, the R&D strategies of the two ventures are taking cues from each other in a way that was not envisioned or expected by either venture or by any external ecosystem orchestrator. The two ventures benefit from their mutual relation, both in terms of avoiding duplicating the same steps and partly in terms of emulating some strategic and timeframe decisions, thereby strengthening their own innovation strategy. This complementarity is proving instrumental for both ventures as a point of leverage when combining incumbent industry processes with new and discontinuous technologies. On the one hand, there is no official collaboration agreement between the two and much of the research information within the HYBRIT project, or as carried out under the orchestration of H2GS (predominantly through their supplier network), is proprietary. On the other hand, the mutual complementarities of the two initiatives are more coordinated and co-dependent than simply a market-driven legitimization phenomenon (i.e. clearly more co-dependent than the case of two grocery stores in the same neighbourhood increasing the business to both). During the early scale-up of the green-steel ventures through the R&D phase, the two co-located green-steel ventures have fallen into a complementarity pattern that structurally resembles the relationship between two partners in an innovation ecosystem (Jacobides, Cennamo and Gawer, 2018) – without there being any formal ecosystem arrangement in place. This complementarity has emerged gradually and was not foreseen by any stakeholder at the outset.

iii. Collaboration

The examination of two respective R&D pathways for green steel, and the finding of their being interconnected and complementary, bridges to a more general examination of how the two green-steel ventures approach inter-organisational collaboration and partnerships as part of their innovation strategy. This is especially crucial when it comes to navigating the complex resource dependencies facing the two Northern Swedish ventures.

No formal structure or memorandum of understanding exists between HYBRIT and H2GS that would set out a target and structure for collaboration. A senior project manager at HYBRIT summarises: *“This goes both for the industry in general and green steel initiatives in particular, we just don’t talk to each other as much as people or the media imagine we do”*. Other respondent testimonials corroborate this: Among executives, directors, and managers, relatively few are actively in touch with their counterparts in an official capacity or are keenly aware of what their counterparts do. Anne Graf, H2GS Head of Regional Affairs, comments: *“After all, [HYBRIT] do have a different timeframe than we do, whereas we are starting construction already.. but of course industry in the region is not huge and so we do end up in the same events and meetings quite a bit, especially for some common interests like the Luleå harbour expansion”*.

But neither are the two green-steel initiatives full-scale competitors – regardless of their overlapping resource interests in northern Sweden and potentially overlapping customer base of the end-product of near carbon-free steel. No interview respondent with ties to either steel initiative, nor any respondent familiar with their respective innovation processes, said they would agree to a characterisation of the two initiatives as competitors. H2GS CTO Maria Persson Gulda summarises: *“I don’t think that we are necessarily competitors (with HYBRIT)..”*

and if we would be in the future in terms of some parts of our portfolio and customers, is that a bad thing?... Many great Swedish based global companies have developed in strong competition (e.g., Scania and Volvo, Epiroc and Sandvik). Of course, there's a competition for talent, but in this case we need to move so many people up north in Sweden that we jointly have an interest in promoting the region for the very attractive place to live and work that it is".

This is not to say that the two green-steel ventures have identical strategies for partnerships and collaboration. For its external partnerships, the HYBRIT project has been able to capitalise on a 'double' collaboration strategy: The HYBRIT development company has collaborated extensively with research institutions, government agencies, and other stakeholders with crucial input at the research and development stage, whereas the parent companies have simultaneously been collaborating with a range of stakeholders, from labour unions and education institutions to resource suppliers and customer groups, in matters that revolve around the commercial industrialisation of their individual part in the transition process. A HYBRIT respondent summarises: *"When the parent companies look at their entire transition process there is a clear distinction between them, for example, two-thirds of all LKAB's iron ore operations are for other customers than SSAB. But those value chains will of course at the same time build on the jointly-developed technology"*.

The H2GS partnership model, in turn, is one of continuous orchestration of a large network of suppliers, investors, off-taker customers, and other stakeholders such as regional and national governance bodies and agencies. While the business model for the green steel value-chain itself is vertically integrated and follows a single-location mini-mill structure, the supplier network mobilised by H2GS extends from this core business model to form a consciously planned constellation of collaborators, centrally directed by H2GS. An H2GS respondent summarises:

“The reason we can run this fast is really the partnerships. We have called it a foundry model of sorts, basically having all the stakeholders that are important to make this journey happen investing in you, and having them across the value chain as being part of the same mission”.

At the level of global markets, H2GS operates in line with expectations placed upon it by markets and investors – a start-up entrant – with the power to leverage new business models to the industry, such as financing green steel innovation and scale-up with a broad mix of traditional investments and extensive off-take agreements.

In contrast, H2GS is choosing a more traditional Swedish industrial coordination approach at the local level, which in many ways appears surprising given the overall brand identity of H2GS as a global sustainability start-up rather than a legacy incumbent. Indeed, it is at the level of the regional innovation system in Northern Sweden (and with extensions to regulators and stakeholders in Stockholm and Brussels) where the collaboration practices of the two green-steel ventures display the most extensive commonalities. Both green-steel ventures seem to apply two-tiered relational dynamics, where the wider industry and supply chains are met with one collaboration strategy, and the regional industry environment is met with another. For the regional industry environment, both green-steel ventures seem to approach collaboration in relatively similar ways. Both H2GS (through its Boden office and commuting public affairs executives) and HYBRIT (through its Luleå and Gällivare test facilities, the local presence and networks of parent companies, and actively engaged public affairs executives) take an explicit ‘society-building’ role in the municipalities where they are based. One H2GS local outreach team leader explains: *“We have a showroom office in the middle of Boden, with the purpose of inviting locals in and informing them about our progress, whether it is to discuss job opportunities or what impact the building process will have on the nearest village. Generally, the local response is positive and inquisitive, even more positive than we expected”.* A regional

business development director confirms this: “*H2GS has been very proactive in their regional engagement, and I think this has also inspired the HYBRIT companies to seek new ways of coordination beyond their traditional channels*”. These similarities between the two are surprising as we may generally have expected quite different corporate identities and community engagement styles between new entrants and incumbents. Anne Graf, H2GS Head of Regional Affairs, describes: “*We even make jokes about how much we agree on: We need more trains, more electricity, larger ships, we are both here facing the same context... In theory, you could call us competitors for talent, but there has been an insight from the start that we need to attract more people to this region as a whole, because we are not just going to recruit from each other*”.

Neither initiative has claimed ownership of the entire development issue by creating their own proprietary regional networks that would rule some actors as insiders and some as outsiders. Instead, both initiatives have participated both in pre-existing coordination bodies as well as several more ad hoc and newly formed coordination bodies. For example, as the Mayor of Boden, Claes Normark, describes: “*We have been working closely together and actually structured the work with H2GS into four semi-permanent working groups, each with their own follow-ups and agenda items that concern both Boden and H2GS, from railways to the site to pre-schools for children of the hundreds of families who will move up here. They meet almost weekly at the moment. In one instance they even agreed to move the planned location of their entire steelworks by 85 metres in order to leave more distance to a local resident. This level of approachability is especially impressive considering the billion-euro scale of the venture*”.

Both green-steel ventures partake actively in these types of coordination processes in their respective locations, in several cases in a roundtable setting where both ventures are present

and exercise a high degree of transparency about each others' plans and requirements. In this way, the two green steel ventures are again shaping each other's trajectories by deepening the commitment to sustainable and coordinated regional industry growth. Larger than the challenge of mutual competition, the greatest challenges to the success of either initiative turned out to be those that are shared by both: Housing for new employees, talent attraction, energy and resource supply (particularly a timely connection to and expansion of the high-voltage grid), logistics and infrastructure (particularly the expansion of harbour and rail capacity), and growing public pressure by some commentators to abandon the energy-intensive projects altogether (Cf. Sunden, 2023; Larsson, 2022). Mikael Nordlander, Decarbonisation Director at Vattenfall and HYBRIT, elaborates: *"In terms of iron ore and renewable energy resources there is potential to cover all of the planned projects and more, even to completely transform steelmaking in Europe by moving more of the iron-ore reduction up here. The challenge is that for any single step forward in the scale-up, there many layers of conflicting interests here in the region, both in terms of permit processes, infrastructure bottlenecks, grid connectivity issues, lack of skilled workforce, safeguarding indigenous communities, military defence requirements, and so on"*. A regional council executive summarises the joint challenge ahead: *"The resources are basically all in place... it is more a question of actually making the transition work for all these industry companies together, and that requires us to keep in constant contact and to know what others are doing"*.

iv. Industrialisation

The scale-up stage through R&D and partnerships brought increased complementarity and similarity between the two green-steel ventures, as they both face similar resource dependencies and industry infrastructures to align with. In contrast, the shift to full-scale industrialisation seems to re-emphasise that the two have divergent innovation strategies from the outset, after a period of convergence during the scale-up phase. While clearly converging on many issues around local governance to scale up the green-steel innovation process, the broader perspective for operations, market strategies, and technology management remains as two distinct approaches – albeit not necessarily along the lines of traditional dichotomy into ‘old’ and ‘new’ industry, or incumbent and start-up.

The HYBRIT venture has remained narrowly focused on the transition pipeline of the parent companies’ operations. The change in focus toward full-scale industrialisation has developed as scheduled and planned from the perspective of the parent companies. From the perspective of the development company, however, the shift from a research-intensive mode to one focused on scale-up and industrial operations leaves the continued mandate and role of the HYBRIT development company unclear. Mikael Nordlander, Director of Decarbonisation at Vattenfall and early-stage strategist of the HYBRIT partnership, reflects: *“There has been a lot of discussion in the past few weeks about what the new structure and mandate will be like... From having been fully focused on industry disruption we are suddenly in a position where we need to divide between disruption and more incremental developments for the value chain... Some people have been asking why we couldn’t continue with the disruptive part and the large-scale ventures. But is it not in some ways a paradox for something to have to be disruptive all the time? HYBRIT is, after all, a technology development company for industry incumbents aiming to proceed with investments in this new technology”*.

This illustrates a further element of the multi-faceted innovation strategy that HYBRIT has adopted: Linking the breakthrough processes ‘back’ into alignment with the realities of the incumbent owners. The three parent companies all have far-reaching strategies for their futures, of which the HYBRIT collaboration has been one flexible and decoupled part – no one had expected the incumbents to merge completely or for the development company to take over operational control of their decarbonisation. But neither does a full scale-down of all HYBRIT activities seem to be an outcome that any stakeholder had planned for in the sense of a ‘return’ to continuous, day-to-day innovation and R&D. A world-leading level of tacit and codified knowledge for a process transition to green steel has been established within the development company’s domain, both in practice through its culture for exploration and learning, and legally because of the intellectual property arrangements now needing to be jointly managed by all three parent companies. The shift within the HYBRIT initiative thus seems to be one of bringing the remit of the highly discontinuous development company closer to the ‘day-to-day’ innovation and continuous improvement activities undertaken in the parent companies’ research departments, with a mandate to guarantee the stability, efficiency, and future development of the HYBRIT technologies on behalf of the parent companies.

For H2GS, in turn, the effort to ramp up learning and research intensity in-house is gradually starting to take shape, while operational control of the project is being transferred from the strategic leadership onto site-specific teams with the closest links to on-site project management and project execution partners. Mikael Lindström, H2GS Head of Public Affairs, summarises the developments: *“We are coming into very concrete steps now, like site processing, housing for new recruits, the actual construction of the electric arc furnace... the company also has a new Board where the new investors have their Board seats... so a bit of a*

change in structure as we come into this next phase". In short, the H2GS innovation strategy is going from the general to the specific and more diversified, while at HYBRIT, the specific breakthrough-research efforts that had been left to the specialised development company are being anchored back more strongly to the general level of strategy and innovation at the parent companies.

The industrial adaptation of the two green-steel initiatives of northern Sweden take different shapes, but as the previous section showed, they still clearly share a need to align their discontinuous innovation process with their region's industry system and especially with national-level infrastructure agencies in order to succeed in their full-scale industrialisation. This definitively shows that the formation of the nascent green-steel sector is far from a blank space or industry niche for disruptive entrepreneurial stakeholders to shape without constraints. Throughout the process stages of their innovation strategy, both ventures have been shaped both by the pre-existing industry realities that motivated their initiation and incentive structures, and by each other, in seeking to navigate the several interlinked bottlenecks and industry risks that the discontinuous green-steel innovation process implies. Neither venture has been able to do everything like a start-up or an incumbent is 'expected to' in existing theory benchmark models, but the two ventures have at the same time retained some key differences in their initial innovation strategy, including in the way they leverage their mutual complementarities.

For HYBRIT and its parent companies, the effective timeline and prioritisation for rolling out full-scale green-steel production and closing blast furnaces are aligned closely with national net-zero strategies of the Swedish government (as the geographical location of most of the incumbent facilities and majority owner of two parent companies), to some extent the Finnish

government, as well as the evolving (and increasingly ambitious) climate policy of the European Union. For H2GS, the EU emissions trading scheme (ETS) is a particularly crucial strategic pillar. The size of the ‘green premium’ on steel to be paid by H2GS off-takers and customers, and thereby the profitability and viability of the steel to be produced, is decided based on the timing and scale at which the EU seeks to curb and tax emissions of the steel industry. CTO Maria Persson Gulda outlines the strategic landscape facing the sector: *”It will become more and more expensive to produce steel in Europe... You need a lot of renewable green electricity at a low cost, which most European countries do not have. The Emissions Trading Scheme system has unfortunately worked in the opposite direction in the past, protecting the steel industry with full allowances that the steel industry could either use or sell. However, with CBAM, this will change starting 2025-26 when the steel industry starts to pay for its emissions, which will drastically change the landscape of the steel industry...”*. Both ventures are also shaped substantively by the timeline for regional infrastructure and resource capacity, the enablers for which will be revisited in Chapters 6 and 7. A multitude of determinants and stakeholders is shaping the dominant designs of green steelmaking, and while the Swedish ventures have many first-mover advantages, their long-term impact is yet to be determined.

5.5 Discussion

The previous sections of this chapter have outlined the formation, scale-up, and early industrialisation stages of the world's two first industrial-scale innovation ventures for decarbonising the steelmaking supply chain. This double case study was selected as a representative example of the discontinuous innovation challenges faced particularly by hard-to-abate traditional industry settings in light of the climate crisis: coordinating a large-scale effort to simultaneously shift in several parts of industrial value chains, bringing in new technologies to old and slow-changing processes (Garud and Gehman, 2012; McDowall, 2018; Henderson, 2021).

Beyond a general comparison between two strategies and processes of green-steel innovation, this double case study can also inform the wider research agenda for this thesis, of building theory for understanding different pathways of discontinuous innovation in traditional industry settings. Widening the empirical discussion to a theory framework to use in further research can both enrich our empirical understanding and bring more nuance to theory-building on how discontinuous innovation processes are organised. These nuances in innovation strategy are particularly important to understand in the context of sustainability transitions of traditional industry sectors that face complex infrastructure interdependencies and bottlenecks that definitively shape their strategic potential. As the case studies demonstrate, there is clearly more than one way to strategise decarbonisation pathways in traditional industry settings, and both incumbent companies and start-up ventures have a viable or even mutually complementing role to play.

Anchoring to the initial research question and the balance between 'new' and 'old', the two observed cases and their differences do exhibit certain parallels to existing literature

expectations of new entrant and incumbent behaviour in times of industry transformation (Christensen, 1997; Santos and Eisenhardt, 2009; Hockerts and Wüstenhagen, 2010; Ansari and Krop, 2012; Ansari, Garud and Kumaraswamy, 2016). But these parallels are only clear in some aspects of the two innovation strategies: There has not, for example, been a unilateral movement by the H2GS start-up to fully dominate its incumbent competitors in a nascent market segment, or by the HYBRIT incumbent consortium to freeze out or buy up new entrants. Neither are the two case studies conforming fully to expectations of how ‘old’ legacy industry stakeholders organise transformations: HYBRIT is following a traditional process familiar from the past industry experience of its owner-incumbents but takes on the discontinuous green steel transition through an adaptive and agile development company. H2GS, in turn, is combining elements of start-up strategy and finance from more digital-intensive and end-user-focused sectors with local-level relational dynamics more familiar to traditional industries than to tech start-ups. This suggests that success in coordinating large-scale innovation ventures in traditional industry settings like steel decarbonisation benefits from a heterogeneous innovation strategy that combines policy-driven and market-driven incentives – either through one diversified venture or through either direct or indirect complementarities across two or more ventures (Kivimaa *et al.*, 2021; Weigelt, Lu and Verhaal, 2021).

Based on the empirical case-study findings, we can theorise that the innovation process driving discontinuous shifts in traditional industry contexts such as steelmaking diverges from the general suggestions of existing literature and from empirical benchmarking against the current-day ‘Silicon Valley model’ innovation dynamics (Casper, 2007; Santos and Eisenhardt, 2009; Ansari and Krop, 2012; Kumaraswamy, Garud and Ansari, 2018). In the observed cases, albeit they are rightfully described as pioneers, there is no ‘disruptive innovation’ dynamic present in the innovation-economic (Clayton Christensen’s (1997)) sense of the term. The observed

discontinuous innovation processes are balancing the old with the new by coordinating strategies to align across the value chain and seek market-building complementarities among competitors. This drives not zero-sum competition and diversification to underserved user groups, but accumulation upon existing industry processes and research, funding, and governance partnerships to support the emergence of a completely new, near carbon-free steelmaking industry.

In other words, the green-steel ventures are not interacting with existing industry in an arms-length way where their own pioneering technologies are shaping a ‘clean slate’ of new industry – a process that many pioneering technologies in a ‘Silicon Valley model’ innovation setting have been shown to follow, described for example through the *Claim-Demarcate-Control* model (Santos and Eisenhardt, 2009). Instead, both green-steel ventures seem to be focusing in the first instance on demarcating the regulations and resource requirements of decarbonised steelmaking as a coordinated market-shaping effort, without overt strategies to claim or control it in a hierarchical way. The new discontinuous technologies and the pre-existing processes are being integrated with each other through complementarities and coordination. In the HYBRIT case, the business model is contained firmly within incumbent providers, and a temporary boundary is created wherein discontinuous breakthrough research is funded almost fully in-house and is carried out separately from day-to-day operations (this is in line with theory predictions of the sustainability-focused literature of *strategic niche management* (Schot and Kanger, 2018; Savaget *et al.*, 2019)). In the H2GS case, in contrast, the innovation process and the timeline for different steps have been integrated into, rather than shielded from, existing market dynamics. This demonstrates that ventures pursue discontinuous innovation in traditional industry settings with different tools and strategic pathways, not all of which align

with benchmark frameworks such as Claim-Demarcate-Control or *strategic niche management* for sustainability transitions (Schot and Geels, 2008; Santos and Eisenhardt, 2009).

An interesting comparison that further illuminates this theory discussion is to consider discontinuous innovation in other sectors and time periods. On the one hand, the two green-steel ventures have been shown as markedly different from the typical characterisation of the ‘Silicon Valley model’ in how they operate and coordinate their resources (Iammarino and McCann, 2006; Casper, 2007; Ansari and Krop, 2012; Carlo *et al.*, 2014). On the other hand, a truer comparison may be found in another time period. While some of the current-day elements of leading start-up hubs may have different innovation enablers than those mobilised for the two green-steel ventures, there may be closer parallels to be drawn to innovation in other sectors and nascent market settings. After all, current-day Silicon Valley is a mature innovation ecosystem that has been shaped by several decades of institutionalised processes, operating procedures, and local networks to incentivise a highly disruptive form of discontinuous innovation. In contrast, earlier discontinuous innovation processes in the same area of California, such as Xerox’s PARC innovation centre, seem to have more in common with green-steel innovation compared to later developments in Silicon Valley. The early examples of discontinuous innovation in Palo Alto were much less based on user-driven overhaul of incumbents than on consortium-driven research and support of breakthrough innovation by both incumbents and new entrants (Saxenian, 2000; Mazzucato, 2011; Storper *et al.*, 2015). Indeed, these earlier digital technologies were often decidedly linked to incumbent, material resources and infrastructure dependencies, much like the green-steel ventures have also been shown to be.

A final observation for deeper examination in the theory development chapter (Chapter 8) is the gradual formation in the case-study setting of mutual complementarities among the two discontinuous innovation ventures, linking together (at least temporarily) their different ‘modes’ of discontinuous innovation. The two Swedish green-steel ventures have, through their scale-up stage, been working as complementors in the nascent green-steel value chain, despite their differing business models and potentially overlapping customer base – and these complementarities and coordination efforts are the most pronounced at the level of regional industry networks. This observation brings further nuance to the theory discussion framing the research agenda of this thesis: Comparing different discontinuous innovation ventures and strategies with each other. Rather than finding that there is one preferable or categorically more efficient mode to support green-steel innovation, both are bringing valuable indirect input to each other through their differences. To put it boldly, neither green-steel venture in Northern Sweden would likely have developed as it did were it not for the existence of the other.

We can generalise this finding in the context of comparing discontinuous innovation processes more broadly: An innovation context in a nascent market setting, such as the sustainability transition in traditional industries, seems prone to benefit from simultaneous scale-up developments and exchanges covering more than one singular first-mover with one singular mode of discontinuous innovation. To some extent, this model of operating could be described through the literature on innovation ecosystems, which are broadly defined as non-hierarchical stakeholder networks collaborating through non-generic complementarities (Jacobides, Cennamo and Gawer, 2018). However, rather than extending a large-scale ecosystem partnership across all business areas, the case ventures in green steel have carefully developed such complementarities only in some parts of their relational dynamics and mainly during their scale-up period. Coordination efforts around these complementarities are also clearly contained

at the regional level in Northern Sweden. They are, therefore, not universal in either time or place.

5.6 Conclusion

This chapter has outlined and discussed case studies of large-scale discontinuous innovation ventures in traditional industry settings, seeking to identify and compare innovation strategies applied in the context of two pioneering ventures in carbon-free steelmaking. Answering the core question of how large-scale ventures in these settings organise the tensions between new and old industry, the chapter has identified and highlighted two distinct innovation processes, which diverge in many ways in their initial business models and subsequent trajectories but which nonetheless have been shaped by each other and developed mutual strategic complementarities that are being coordinated both directly and indirectly at the local and regional levels. Fundamentally, the two green steel innovation strategies have both adapted their process to align with several different parts of the steelmaking value chain rather than maintaining strong internal rigidity or seeking to overhaul the existing overarching structure of the legacy steel industry or the Northern Swedish regional innovation system.

Answering broader theory questions about how discontinuous innovation processes are organised over time and place, this chapter has emphasised that discontinuous innovation and market-building in the green steel context is ambitious and pioneering and may be based on both strongly policy-driven and market-driven incentive structures but is evidently systemic and resource-dependent in nature. It adapts to the existing industry conditions, coordinating and building on them while problem-solving to navigate a complex set of infrastructure and resource dependencies rather than seeking to disrupt the ‘old’ sector through comprehensive overhaul, creative destruction, or a ‘clean slate’. This is in contrast to what might have been

expected by prior research examining other contexts of discontinuous innovation, the roles of start-ups and incumbents, and the tensions of ‘new versus old’ during industry transformation (Christensen, 1997; Kaplan, 1999; Casper, 2007; Santos and Eisenhardt, 2009; Ansari and Krop, 2012; Kumaraswamy, Garud and Ansari, 2018). Green steel ventures in Sweden, whether choosing a start-up or incumbent pathway, diverge substantively from several global benchmark mechanisms to enable discontinuous innovation (and especially from the ‘Silicon Valley model’ of innovation).

These findings will be leveraged in Chapter 8 in the formulation of a new theory framework designed to enable similar analyses and cross-case comparisons to take place across a wide variety of discontinuous innovation settings, not least surrounding sustainable industry transitions. Updating the theories and concepts with which innovation and industry transformation are analysed is a crucial step in developing the technological and organisational solutions for sustainability transitions that the world direly needs.

The next chapter will pick up on a central element of innovation enablers already brought up throughout the green-steel case studies in this chapter: The role of the regional innovation system surrounding innovative ventures seeking to transform traditional industry settings.

Chapter 6 – Local-level Drivers of Discontinuous Innovation in Hydrogen

6.1 Introduction

The previous chapters have established that ongoing sustainable industry transitions transcend both geographical and sector boundaries (Schot and Kanger, 2018). For traditional industry sectors, the preceding case study into discontinuous green-steel innovation demonstrates how innovative ventures in these sectors are dependent on coordinating entire value chains, even among competitors, in order to scale up transformative technologies and products successfully (Lee and Malerba, 2017; McDowall, 2018). However, when it comes specifically to discontinuous innovation, ready-made structures for such alignment are rarely in place to span entire industries or national economies. One fundamental reason for this is the difficulty with disseminating knowledge and coordinating a specific innovation simultaneously across large and diversified networks of stakeholders (Savaget *et al.*, 2019). Another challenge stems from the volume of resources required to overhaul physical infrastructure and supply chains (McDowall, 2018).

This leads us to consider the role of *local and regional* dynamics as an enabler of innovation in traditional industry sectors (Savaget *et al.*, 2019). This chapter will examine this question in depth by comparing three parallel cases of hydrogen innovation being developed in Nordic regions. As set out in Chapter 2 when presenting the research agenda, the question that this multiple case study sets out to answer in particular is Q4: *‘How and to what extent can local-level relational dynamics shape the strategy and success of discontinuous innovation processes in traditional industry settings?’*.

The academic study of innovation, knowledge diffusion, and technological development has consistently included a dimension of regional agglomeration and innovation dynamics. The concept of *regional innovation systems* (RIS) was introduced shortly following the proliferation of the related concept of *national innovation systems* (NIS), building on the understanding that physical proximity and clustering play a key role in knowledge-intensive innovation and that successful innovation contexts are in many cases better understood as specific to a region or a town rather than an entire country (Porter, 1998; Cooke, 2004; Asheim and Gertler, 2006; Braunerhjelm and Feldman, 2006; Iammarino and McCann, 2006; Asheim, Boschma and Cooke, 2011). In more recent years, while the attention of many innovation scholars remains on macro-level industry phenomena and digital business ecosystems that span multiple countries, the attention toward local and regional innovation context has also consistently grown, with calls for more diversity and nuance in how different innovation contexts are understood (Edquist, 2019; Welter, Baker and Wirsching, 2019; Fu, 2020; Breznitz, 2021). The Nordic context is no exception to this trend of sustained academic interest in local and regional innovation dynamics (Asheim and Coenen, 2005; Kristensen and Lilja, 2011).

However, we have a limited understanding from existing literature of the role that these networks play in specifically enabling *discontinuous* innovation, which requires system-level coordination and involves high degrees of industry change. Existing research has outlined the impact on regional innovation system structures of macro-level phenomena such as trade liberalisation and multinational corporations (Mosley, 2000; Braunerhjelm and Feldman, 2006; Ornston, 2014; Thomas, Faccin and Asheim, 2021). However, we know less about the impact that stakeholders from within the regional innovation system can have on large-scale industry transformations, such as the discontinuous innovation processes surrounding sustainability

transitions (Fagerberg, 2018; McDowall, 2018). In the context of the sustainability transition, calls for increased local innovation partnerships have increased, but there is little consensus on what those such partnerships on innovation processes look like (Savaget *et al.*, 2019; Weigelt, Lu and Verhaal, 2021). Especially in more rural or peripheral areas, where traditional industries are often a cornerstone of the economy but which lack a metropolitan innovation cluster of the ‘Silicon Valley model’, the impact of regional-level processes is often overlooked, and the location of a venture only understood in terms of access to material attributes such as energy capacity or natural resources (Breznitz, 2021). The implication, when brought to its logical conclusion, would be that successful innovation looks the same regardless of where a venture is physically located and, by extension, that the agency of regional-level stakeholders makes little difference for transformative innovation.

Nordic traditional industry clusters that are pioneering discontinuous innovation – for example, the green-steel ventures explored in the previous chapter – demonstrate this uncertainty about the impact of regional innovation systems and their relational dynamics on discontinuous innovation. On the one hand, Nordic industrial regions seem well-placed to succeed in sustainability transitions based on conditions that previous research has highlighted, such as the potential to leverage close-knit informal networks and knowledge transfer capabilities of long-established local and regional industry networks (Kristensen and Lilja, 2011). On the other hand, the mechanisms by which such an advantage for discontinuous innovation may come about have not been studied or theorised in depth, and some studies do not seem to accept that discontinuous innovation is likely to emerge in the first place in coordinated market economy (CME) type regional innovation systems that have not conformed to become market-disruption driven technology clusters (Ornston, 2014).

Building on the theory lens of relational dynamics within regional innovation systems as presented in Chapter 2, as well as the empirical research agenda of innovation for sustainable industry transitions taking place across Nordic regions, this chapter sets out to map out mechanisms through which local-level networks and stakeholders are enabling and impacting discontinuous innovation ventures – even in seemingly surprising contexts. The chapter does this through comparison between three Nordic case studies of innovation for green hydrogen production and applications: One in Finland, one in Sweden, and one in Norway. All three cases feature some of the most advanced green hydrogen innovation ventures in their respective countries (see Chapter 4). Based on the empirical analysis, the chapter presents and compares three empirical models through which the local innovation context is found to enable discontinuous innovation processes to create commercially viable systems for carbon-free hydrogen production – with varying degrees of success in terms of investments and scale-up. The chapter does not present one singular ‘Nordic model’ or best-practice scenario. Instead, the general institutional context of the Nordic political-economy setting acts as a common backdrop and context for three distinct traditional industry settings, each with its own features and challenges in enabling discontinuous innovation for the sustainability transition.

The chapter finds that ventures for discontinuous innovation in hydrogen are developing in markedly different ways across the three cases even though their general institutional setting, technological focus, and commercial ambitions of creating a strong ‘hydrogen economy’ are similar. Moreover, these differences in regional innovation trajectories can be traced not only to differences in resources or the structure of formal institutions in place but also to differences in local-level actions that have a concrete effect on what kind of ventures take off and succeed in a given setting. The findings demonstrate how the three models have developed complementarities and lock-in effects between different parts of the regional innovation system

(for example, between the research community and regional governance) and that the agency of local-level stakeholders has been the biggest driver of these complementarities.

This chapter thereby contributes with an analysis of inter-stakeholder relational dynamics that explains how actors in the regional innovation system shape discontinuous innovation processes in traditional industry settings. Resources such as energy provision, material resources, and reliable infrastructure are found to be crucial for venture success. However, this chapter presents a perspective where these factors are not static resources but situational ones, all shaped by the way that the local innovation stakeholders operate together (Garud, Tuertscher and Van De Ven, 2013; Thompson, Purdy and Ventresca, 2018; DeJordy *et al.*, 2020). In this way, this chapter aligns with calls for more nuance to understand how innovation takes place in contexts that diverge from what existing research might expect (Fu, 2020; Bretznitz, 2021). The specific theory contribution of this chapter is to bring the analysis of local-level inter-stakeholder dynamics into the study of what drives discontinuous innovation in traditional industry settings.

6.2 Literature on regional innovation systems in a Nordic context

As presented in Chapter 2, the literature on *innovation systems* evolved during the latter part of the 20th century as a framework for discussing innovations as outcomes of macro-level features of industrialised societies (Lundvall, 1992; Nelson, 1993; Edquist, 1997). The concept of Regional Innovation Systems (RIS) forms a subset of this literature, which still describes relatively macro-level structures and economic phenomena, but views industry and innovation processes as inherently formed around regional clusters and agglomerations rather than nation-wide systems (Cooke, 2004; Asheim and Gertler, 2006). Different authors have sought to develop taxonomies of these structures: For example, between a ‘grassroots RIS’ model

without much formal orchestration, a ‘networked RIS’ model with a higher level of coordination (e.g. around university-driven research platforms), or a ‘dirigiste RIS’ with a high level of state-driven coordination (Cooke, 2004; Asheim and Coenen, 2005).

However, we have a limited understanding from existing literature of the role that these networks play in specifically enabling *discontinuous* innovation that requires system-level coordination and that involves high degrees of industry change. The real impact of regional innovation systems on the shape and success of innovation processes remains ill-understood, as has been emphasised by increasing calls for studying the role and impact of context for innovation outcomes (Fu, 2020; Breznitz, 2021). This lack of insight is particularly clear when studying the impact of the regional context on discontinuous and breakthrough innovation that involves a lot of industry change, and particularly in regional contexts where, from a ‘Silicon Valley model’ perspective, we would not expect a great deal of discontinuous innovation in the first place (Christensen, 1997; Kaplan, 1999; Casper, 2007; Lee and Malerba, 2017; McDowall, 2018).

The Nordic context of regional innovation systems demonstrate this blind spot in innovation literature. The industrial history of the Nordic countries is often described as driven by slow-paced, incremental improvements to complex engineering and manufacturing processes, and framed by a relatively rigid institutional setting driven by highly coordinated industrial relations (Hall and Soskice, 2001; Fellman *et al.*, 2008; Ornston, 2009). These features are not conventionally viewed as conducive to discontinuous innovation from the perspective of a ‘Silicon Valley model’ (Casper, 2007). But at the same time, Nordic regions also consistently rank among the most innovative regions of the world (European Commission, 2023a). Some research explains this apparent paradox by framing the Nordic capacity for discontinuous

change as limited specifically to urban entrepreneurial clusters in the southern Nordic regions, concluding that high-technological sectors in the Nordic regional innovation systems have ‘liberalised’ through policy and deregulation brought on by disruptive ICT innovation (Ornston, 2014; Thelen, 2019). However, others find that the tendency to pioneer markedly discontinuous and breakthrough innovation that fundamentally disrupts existing market segments or invents entirely new ones is a recurring historical feature in Nordic rural industry towns, not only in large, globalised cities (Lemola, 2003; Lindmark and Vikström, 2003; Fellman *et al.*, 2008; Jäntti and Vartiainen, 2009; Kristensen and Lilja, 2011). Even the metropolitan Nordic ICT corporations and innovation hubs emerged gradually out of traditional industry towns and legacy firms, co-dependently with wider social welfare and education-systems developments (e.g. Ericsson and Nokia).

In other words, while existing literature gives clues to the enabling conditions of the Nordic industrial tradition, it has not specified process models that would explain the roles and relationships of regional stakeholders in shaping these innovation trajectories. There are clearly peculiarities about some Nordic industry environments that give rise to competitive advantage – elements identified in existing literature include patient capital, a high level of labour market coordination, a high level of trust and closely-knit social networks, etc. (Kristensen and Lilja, 2011) But the specific role of local-level stakeholders in shaping these elements so that discontinuous innovation ventures can benefit from them, and the boundary conditions for their success, are less well understood. Therefore, it is necessary to examine and outline local-level innovation drivers more closely and from a process perspective that zooms in on inter-stakeholder relational dynamics (Garud, Tuertscher and Van De Ven, 2013; DeJordy *et al.*, 2020). This research focus is particularly relevant within the context of the ongoing momentum for sustainability innovation in traditional industry settings, which has brought some Nordic

localities a historical increase in innovation and industry investment activity while other localities have not benefited in the same way (see Chapter 4).

6.3 Methods and research setting – Northern Nordic regions and the nascent hydrogen economy

As was presented in Chapter 3, the relational dynamics that shape industry action are not easy to research only using formal documentation, especially in the case of informal networks. This is particularly consequential when analysing local-level networks that are often shaped heavily by informal and undocumented processes that are intertwined with professional networks. Moreover, as there is no existing analytical framework for researching discontinuous innovation in different industry settings, data analysis needs to aim at inductive theorising to formulate new theory development. As for each of the empirical chapters, the research design for this chapter, therefore, builds on combining different types of qualitative empirical observation: Inductive fieldwork observation, as well as interviews and document analysis conducted through a multiple case-study approach, following the guidelines of grounded theory building and the constant comparison method (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016). In this chapter, the multiple case-study approach increases the richness and overall reliability of the research by allowing for comparison across similar kinds of innovation ventures being developed in the same part of the world (the Nordic region) but across three different regional innovation system settings.

The northern regions of the Nordic countries are characterised by abundant natural resources in terms of minerals and potential for renewable energy production. As presented in Chapter 4, this geographical and social context gives rise to a unique setting for industrial activity and

innovation processes, where long distances and harsh climate conditions bring both challenges and opportunities. While these opportunities and profits are not evenly spread across different localities and the local population, some towns and municipalities have managed to grow and retain their economic and industrial capabilities as centres for innovation, training and research. University towns such as Vaasa, Oulu and Luleå along the Bothnian coast are surprisingly intensive in higher education and research-based innovation, especially in a European comparison and especially considering the challenging demographic conditions in these regions overall (Teräs *et al.*, 2023). In the years following the Paris Climate Agreement and the European Green Deal, which framed a renewed momentum in investments towards industry decarbonisation, the northern regions of the Nordic countries have received very large amounts of inward industry investment in energy-intensive sectors (Liljas, 2022).

However, the mechanisms remain unclear as to how some relatively small-scale industry localities of the northern Nordic regions manage to successfully attract and initiate large-scale investments and ventures in sustainability innovation, while development in other regions and localities remains more modest despite sharing similar geographical and socio-institutional characteristics. Increasing the understanding of how local-level stakeholders shape and drive the innovation environment will be crucial for building on this investment momentum and for improving the chances of successful discontinuous sustainability transformations – both in the Nordic context and beyond.

In order to increase the empirical understanding of local-level drivers of discontinuous innovation in traditional industry settings, the innovation processes surrounding renewable hydrogen production and the ‘hydrogen economy’ present an appropriate case study especially given the dependence of hydrogen innovation on on-site energy capacity and infrastructure

networks. As presented in Chapter 3, the production and application of hydrogen produced from sustainable energy sources has emerged as one of the central technologies to achieve carbon neutrality and industry decarbonisation. Due to the features of hydrogen as being simultaneously important for industry decarbonisation and costly and difficult to produce and store, discontinuous innovation involving hydrogen-based technologies inherently invites system-level coordination among different stakeholders in the local industry network (Velazquez Abad and Dodds, 2020; OECD, 2022). Even in the case of some large-scale electrolysers being purpose-built for use by a single industry facility (such as in the case of the H2GS start-up studied in the previous chapter), any stakeholders with a technological framework involving hydrogen will benefit from the network effects of wider, systemic distribution and production of hydrogen in their surrounding industry environment (OECD, 2022). This inherently network-based feature of hydrogen technology makes hydrogen innovation processes in Nordic regions a suitable case context for analysing and comparing different ways in which local industry stakeholders drive and initiate discontinuous innovation.

This chapter presents a multiple, nested case study of three northern Nordic industry regions pioneering hydrogen innovation: Vaasa in Finland, Luleå in Sweden, and Berlevåg in Norway. The three selected regions are relatively comparable in their general characteristics as well as in their status of being first-movers in industrial-scale hydrogen innovation, but each of them has a distinct industry profile and can, therefore, be expected to have different inter-stakeholder relational dynamics enabling innovation (Nordic Energy Research, 2024). The aim of the multiple nested case study is not to create a comprehensive image of all possible local-level enablers of hydrogen innovation but to present diverse insights across three pioneering regional innovation systems and draw some overarching conclusions from comparing them to each other. Including Luleå as a case region, where large-scale hydrogen applications are connected

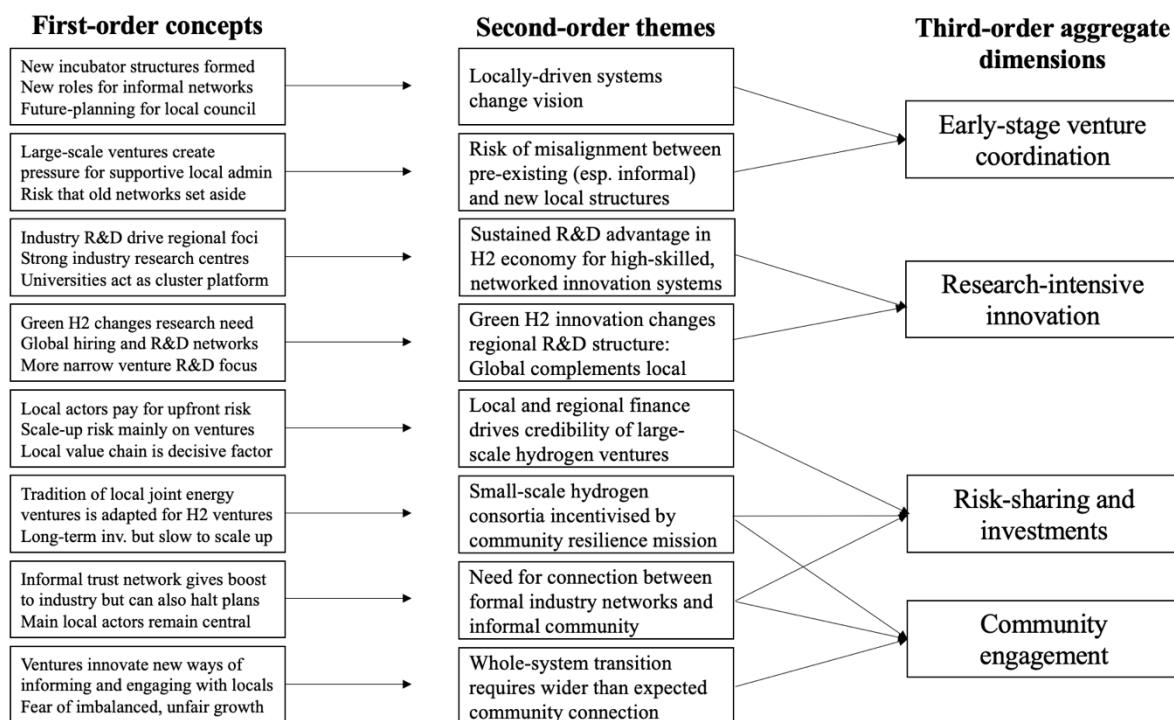
in particular to green steel ventures, also gives the opportunity for complementarity in data collection across chapters 5 and 6.

Chapter 3 provides a comprehensive description of the case selection and research process, as well as the qualitative data sources used for this chapter. In alignment with guidelines for theory-building research based on multiple or nested case studies, data analysis began with a process of forming a chronological narrative of events based on archival materials (Bremner and Eisenhardt, 2022). This provided a helpful background timeframe to put into context the information that was later gathered during interviews. The work on a chronological timeline was also refined further through *temporal bracketing* to compare how different stages of the innovation process have unfolded for the different regional innovation systems (Langley, 1999). The next stage of data analysis, conducted inductively and iteratively during and after the main interview periods, was within-case analysis, where each of the three localities was analysed in relation to the main research question of which stakeholders and actions had shaped or driven the hydrogen innovation processes.

Four elements of active local-level innovation support stood out in the interview data as particularly relevant for driving discontinuous innovation in hydrogen. These drivers emerged through iterative coding rounds as aggregate dimensions that connected to the process events and actions described by different stakeholders (Eisenhardt and Graebner, 2007; Gioia, Corley and Hamilton, 2013). Firstly, *early-stage venture coordination* was found to engage local-level stakeholders in different ways and provide a crucial role for local-level industry or public service officials in mediating and orchestrating early-stage ventures. Secondly, local-level stakeholders provide support for *research-intensive innovation*, where nascent innovation processes may rely partly on public or shared capacity for their research and R&D. Thirdly,

local-level stakeholders have played various roles in driving *risk-sharing and investments* in order to support the early scale-up of new ventures, and these roles have often gone unnoticed by the public view of large-scale ventures. Fourthly, practices of local-level *community engagement* by nascent innovation ventures are proving crucial for the long-term resilience and success of operations, but engagement strategies are unfolding differently in different cases. Figure 6.1 below provides a summary of the coding process, with the four main local-level drivers emerging from the analysis.

Figure 6.1: Coding framework for the case studies in Chapter 6



Having analysed each of the case studies in their own right, the three were then compared in relation to their regional innovation systems more broadly, and the four highlighted innovation drivers more specifically. Focus when coding was placed on identifying both similarities and differences between the three: Both at the level of capabilities, historical context, and general innovation profile, as well as at the more concrete level of what kind of strategic actions and

partnerships were undertaken by stakeholders in each case (Bremner and Eisenhardt, 2022; DiBenigno and Kellogg, 2014). The prevalence of key constructs or, for example, mentions of external partners in communications or interview transcripts, were followed up both through desk-based analysis and in confirmatory ‘member-check’ interview discussions with gatekeeper individuals and other expert respondents (Seale, 1999).

6.4 Findings – Comparative analysis as part of the multiple case study

The following sub-sections will present the three case studies included in this chapter before moving to comparing and analysing their innovation models in more depth based on the emergent empirical framework for local-level drivers of discontinuous innovation.

6.4.1 The Network Model – Hydrogen Innovation in Vaasa, Finland

The city of Vaasa on the Western coast of Finland is the largest energy-sector agglomeration in the Nordic countries. In the first years following the Paris Climate Agreement in 2015, Vaasa’s capacity to attract the interest of large-scale innovation projects appeared to lose out to other Nordic industrial towns, as elaborated in Chapter 4. However, gradually the investment volume and frequency of new projects in and around Vaasa have been increasing. While many investments involve foreign capital, the driving momentum for industry transitions comes from local stakeholders in the region. This has taken place through coordination between several stakeholder groups, as there has been a requirement not only for suitable land for business purposes but also for connections to critical infrastructure and renewable energy capacity. Importantly, this has also included a partial reworking of the role of city and regional government in order to reduce administrative barriers to entry of new ventures in the town.

It is from this momentum for collaborative projects that reimagine energy systems that the Vaasa energy cluster and its surrounding industry areas on the Western Finnish coast have become Finland's most active hub for the scale-up of hydrogen-based ventures, research, and infrastructure projects (Nordic Energy Research, 2024). These projects experiment with energy system solutions that seek to reshape industrial supply chains and increase energy flexibility, and they, therefore, clearly demonstrate discontinuous energy innovation. While many ventures, on their own, do not match the scale of some other hydrogen innovation, the profile of the projects in the Vaasa region is to leverage holistic connections across several sectors and applications in the energy system (Nordic Energy Research, 2024). Vaasa-based industry and research stakeholders have initiated several projects to develop hydrogen-based applications for powering industry – for example, hydrogen-driven engines for shipbuilding. The majority of these are not hypothetical or temporary test projects but concrete steps to implement needs analyses and decarbonisation plans of the industry companies involved. They are also rooted in a clear realisation amidst local industry that lowered incentives for additional energy production may inhibit the successful industrialisation of new ventures unless there is an increase in coordination and energy-system innovation. As summarised by one energy-sector executive in the Vaasa area: *“The question during the recent investment boom into these regions has been whether there is enough renewable energy to supply all the new ventures that are being planned. But actually, now we actually need the demand in terms of concrete investment decisions, as the steady build-up of energy supply has been so successful”*.

Among the hydrogen-focused large-scale ventures in Vaasa, one of the most significant is the **Power-to-X-to-Power** project – a consortium effort to build a hydrogen facility for balancing the electricity grid and energy market prices using hydrogen storage linked to offshore wind farms (City of Vaasa, 2021). The project was initiated as part of the Sustainable Technology

Hub platform, where a collaboration formed among four key stakeholders: The Wärtsilä marine and energy industry conglomerate, the Vaasa energy utility company, EPV (a regional energy company specialised in consortium projects), and the City of Vaasa. Kenneth Widell, General Manager of Research Coordination and Funding at Wärtsilä explains: *“We all more or less knew each other from before and, as so many times for us with these collaboration projects, it all started from a discussion on the problems we are facing in our businesses and how we could work together within the cluster to solve that”*.

Another interviewed executive from one of the project partners describes the rationale for the project: *“The idea is that our energy grid and electricity market is currently very unbalanced due to the increase in offshore wind: Production capacity fluctuates a lot with wind speeds, and so does the general energy price and energy supply on the Finnish market. The point with this project is to produce and store hydrogen in our facility, so we can store the wind energy when supply is high and prices are low, and re-convert it to electricity and sell it when supply is low and prices are high”*. In other words, the viability of the project depends on the wider development of the energy sector and existing infrastructure but includes a driving rationale of discontinuous innovation: Creating added value in the energy system through a new way of combining energy technologies for electricity and green hydrogen.

The project is the first of its kind in Finland and has quickly become an integrated and consciously calculated piece in the execution of a systemic transition and decarbonisation of Vaasa’s industry, rather than an independent start-up project for which the success and failure can be decoupled from the local and regional context. The Power-to-X-to-Power initiative thereby demonstrates what is labelled in Table 6.1 as Vaasa’s *network model*, i.e. the approach taken by actors in the Vaasa energy cluster to collaboratively develop new solutions and

innovations for discontinuous innovation such as decarbonisation through hydrogen (there are also clear parallels to the ‘Networked RIS’ model of Cooke (2004)). The rationale of the Power-to-X-to-Power initiative is built into the collaborative consortium that initiated it: The project will not succeed without coordinated investment and development work by all involved stakeholders. At the same time, the project is bold and innovative both in scale and application and involves public and private stakeholders sharing in the risk-reduction effort by making sure the finished hydrogen facility will have commercially viable use.

6.4.2 The Scale-up Model – Hydrogen Innovation in Luleå, Sweden

Innovation processes in Northern Sweden often involve several of the localities introduced in Chapter 4, as these are interconnected in the regional innovation system. The main focus for the present analysis, however, will be on the city of Luleå and the hydrogen-related innovation processes taking place within its industry network.

While the very early-stage processes of initiating and negotiating new ventures appear as a highly networked process in the Luleå innovation environment – similar to the Vaasa case study in Finland – the collaboration and coordination processes in Luleå’s case were initially organised more around the needs of specific large-scale industry ventures. Luleå thereby displays a pattern of bolstering the success of large-scale ventures for discontinuous industry innovation through local-level coordination, following what Table 6.1 labels as a *scale-up model*. While several stakeholders are involved in developing a discontinuous venture, it remains at the core a specific project focused on a specific sector rather than a bottom-up collective strategy direction. In many cases, the scale-up project is also a multinational industry venture rather than, for example, a fully local start-up initiative.

Hydrogen-focused projects demonstrate this *scale-up model* of innovation-driving processes adopted in Luleå and its surrounding area (Nordic Energy Research, 2024). The clearest example of in-house focused hydrogen innovation and scale-up development is the **HYBRIT hydrogen storage and testing facility** part of the wider green-steel project (described in Chapter 5), which was opened in Luleå in 2021. HYBRIT is a consortium of three incumbent companies, but at the regional level in Luleå, its business model relies relatively little on the wider regional innovation system beyond its three national-level owners. An interviewee from the HYBRIT development company explains the R&D process surrounding the hydrogen facility: *“Our facility does many different kinds of testing, but at least so far it has been closely linked to direction from the HYBRIT parent companies in terms of what projects and tests we run. There are no external stakeholders using the facility”*. In other words, while the Luleå-based hydrogen facility is closely linked to the research and industry capacity of the surrounding city and region and has been developed with the support of relevant regional and national authorities and other stakeholders, the hydrogen project itself is an in-house research enterprise separate from other ventures. It is also distinctly separate from the H2 Green Steel venture in neighbouring Boden.

A similar pattern is discernible in other planned hydrogen facilities and pipelines in the Luleå area, all focusing primarily on their in-house value chain. One Luleå city official explains: *“As there are no consolidated hydrogen pipeline plans yet, companies are looking at building their own separate pipelines and supply”*. As found in Chapter 5, this does not mean that there are no network effects or complementarities between projects, nor that these innovation projects are detached from the local economy or its key stakeholders in terms of general collaboration and dialogue. But there is relatively little formal exchange through shared learning and skills

and cross-sector planning in and out of the largest hydrogen innovation projects and facilities in northern Sweden (Nordic Energy Research, 2024).

However, with a growing focus on hydrogen-related energy transition trends in the region, there has also been a movement towards more collaborative and public initiatives and research projects – not necessarily to commercialise hydrogen-based energy solutions with a fully network-driven strategic approach, but to create a critical mass of skills and knowledge in the region that supports the scale-up of individual ventures. The clearest example of this is the **Centre for Hydrogen Energy Systems Sweden (CH2ESS)**, which is a cross-sectoral research centre at the Luleå Technical University that was started in 2021 to increase skills and research about applications, production, and storage of hydrogen in the energy system. In terms of hydrogen testing, the centre is expanding the existing testing facility LTU Green Fuels to include a substantive hydrogen facility. CH2ESS is also operational across different locations in Northern Sweden where hydrogen-based solutions are being developed, demonstrating the role of this university centre as a joint learning and networking platform. CH2ESS is, in fact, a key driver of collaborative initiatives and events for the entire Swedish hydrogen economy, which currently has a leading momentum in the country's northernmost regions (Nordic Energy Research, 2024). Cecilia Wallmark, Director of the centre, comments: *“It is very positive that within only a few years from establishing our hydrogen research and knowledge centre, even the national agencies start contacting us for expert opinions. And in March 2022 when I first set the meeting schedule for our steering committee, which also includes energy companies and large-scale industry ventures, I was expecting to have maybe quarterly meetings, but they said that since so much is happening around hydrogen and industry in the region, they wanted to meet 1-4 times per month”*.

Luleå-based innovation around the hydrogen economy thus demonstrates a combination of active regional stakeholder engagement with relatively less active national-level stakeholder engagement: The skills development, infrastructure planning, and incentivising of new market segments are developing more strongly at the regional level, while national-level policy dialogue is held predominantly for general planning of energy supply capacity as well as national support of research operations. This is echoed by several stakeholders calling for a public-sector vision for the sustainability transition and in the final report by Peter Larsson, the government's ombudsman for societal transitions in northern Sweden (Larsson, 2022). The role of national-level policy and regulation will be further developed in Chapter 7. Nonetheless, the regional drivers of Luleå's hydrogen innovation developments can mostly be connected either to research-driven initiatives or to large-scale industrial applications. There are actors across all parts of the hydrogen value chain, but an 'ecosystem' or 'networked RIS' type network collaboration model with cross-cutting directionality has not yet emerged (Cooke, 2004; Nordic Energy Research, 2024).

6.4.3 The Community Model – Hydrogen Innovation in Berlevåg, Norway

As described in Chapter 4, the northernmost region of Norway (Finnmark) faces many challenges of enabling and supporting industry transition ventures, ranging from grid capacity issues and a general lack of research-driven innovation capability to potential clashes with reindeer herding and Sami indigenous community rights. In spite of this, many regional and local authorities have taken concrete steps to support a growing hydrogen economy, and several of the most advanced hydrogen innovation projects in the country are located in northern Norway (Business Sweden, 2023; Teräs *et al.*, 2023). The fishing village of Berlevåg can be viewed as one of the most advanced first-movers, especially when accounting for the small size and extreme remoteness of the village (Nordic Energy Research, 2024).

Kjell Richardson, Business Developer at Berlevåg Municipality, describes the initial steps: “*What we noticed very early on was the great wind power potential but also the weak grid capacity situation, so we decided to start thinking off-grid*”. Berlevåg was envisioned as a suitable site for wind-powered green hydrogen production at a large scale, to be used at local refuelling terminals for transport or for downstream industry applications. A project consortium was put together, led by the municipally owned energy company Varanger Kraft, and the resulting **Haelous project**, which ran from 2018 through 2023, saw the construction by consortium partners from Norway, France, Spain, Italy, and Canada of an electrolyser for hydrogen production at a prepared site in Berlevåg harbour (European Commission, 2023b; Haelous, 2024). The site became operational in early 2022 and carries out assigned tests for research purposes. Both the way the facility was built (the first time a 2,5 MW PEM electrolyser with a single cell stack has been constructed) and the tests that have been carried out for research on, among other aspects, remote operation of hydrogen production as well as wind-hydrogen integration in the energy system, demonstrate that the process is a clear case of discontinuous and research-intensive innovation (European Commission, 2023b).

The way in which the Berlevåg-based stakeholders are approaching innovative business activities for their area is labelled in Table 6.1 as a *community model* – one where the momentum for developing new projects is almost exclusively driven by a small number of entrepreneurial individuals representing the municipality, the local energy company, and other community stakeholders. Top-down management or initiation of projects from regional and national hubs is limited, meaning a parallel can be drawn to a ‘grassroots RIS’ type structure (Cooke, 2004; Asheim and Coenen, 2005). Research-intensive, formal innovation processes are generally absent in Berlevåg, but the village and its history feature a strong tradition of community-based problem-solving and recombination of available resources to counter the

significant challenges posed by both geographical and demographical factors. In other words, Berlevåg is demonstrating continuous informal processes of social innovation and business model innovation, and this capacity acts as a backbone of its resilience. As one respondent comments when interviewed in the Finnmark region's administrative hub of Vadsø: *“That place really is as remote as you could possibly imagine. But somehow, the tiny place of like 800 people are managing to survive and not disappear altogether, and keep coming up with new improvements and projects for the future”*.

Fundamentally, the rationale and scale-up capacity of the hydrogen facility in Berlevåg after the end of the research project and the buy-out of external partners by the Varanger Kraft energy company has several potential avenues: plans include fuelling stations for hydrogen-driven transport, a local industry park for downstream developers based on the further derivative of *green ammonia* (the production of which can be fuelled by green hydrogen), and a memorandum of understanding for energy products from Berlevåg to serve Svalbard, the Norwegian island chain in the High Arctic Ocean. However, several significant challenges remain, which are categorically impeding a smooth scale-up and industrialisation of the Berlevåg hydrogen project. The most urgent of these is the lack of any secure downstream industrial value chain that could serve to off-take the initial output of green hydrogen. One respondent from the project team emphasises the geographical realities: *“From our calculations, the limit for the distance that we could make it commercially viable to transport our hydrogen is about 300 kilometres – in that distance, from here, you cannot make it anywhere where there is currently a regional hydrogen economy under development”*. The vision of 'power-to-hydrogen-to-ammonia' based in Berlevåg is not completely straightforward, either: In addition to the significant market uncertainty still surrounding large-scale investments into ammonia, Berlevåg also features a local scale-up uncertainty in that slow

electricity grid capacity buildout is stalling a much-needed and already planned expansion of wind power. The challenges currently faced by the project shine a light on key elements that first-mover discontinuous innovation processes crucially require to be successful.

From a local perspective, what is ultimately at stake is the survival of the village as an inhabited and dynamic community, and this motivation drives the Berlevåg hydrogen venture's distinctive innovation strategy. The stakeholders surrounding the hydrogen project are fully aligned in their assessment that the continuing commitment to the project and the resulting financial risks to the community – some of which are mitigated with external research and consortium partners and state-derived funding – are worth taking. Success in creating a renewed economic profile for the village is vital, and doing so based on a very competitive wind energy supply seems the obvious choice. Exactly what shape this innovation and economic development takes, and whether the wait for a commercialised hydrogen cluster in Berlevåg is extended by another five, ten or more years, is ultimately of secondary concern for the community, as long as a future is in sight for the long term.

6.4.4 Comparison – Identifying three models for local-level drivers

Table 6.1: Three models for local-level drivers of discontinuous innovation

	Network model Vaasa, FI	Scale-up model Luleå, SE	Community model Berlevåg, NO
Early-stage venture coordination	<i>Continuous multi-sector network process</i>	<i>Multi-sector, ad hoc structures to support new ventures</i>	<i>Predominantly municipality driven</i>
Research-intensive innovation	<i>Determined by network-wide agenda and incumbents</i>	<i>Determined by venture-specific agenda and incumbents</i>	<i>Outsourced to external network</i>
Risk-sharing and investments	<i>Incumbent network resources, external venture finance</i>	<i>Municipal and incumbent resources, external venture finance</i>	<i>Municipal resources, some external research project finance</i>
Community engagement	<i>Driven by consortium projects with help of local associations</i>	<i>Driven by individual ventures (frequently based off-site) and local associations</i>	<i>Driven by key individuals on-site</i>

The previous empirical sections have described and analysed three regional case studies of how discontinuous innovation projects are initiated in traditional industries in general and for developing green hydrogen value chains in particular. The aim of this multiple case study is neither to establish a fully comprehensive overview of all hydrogen innovation activity in the Nordic countries nor to compare three cases that are fully equivalent to each other in terms of size, timing, or technical features. Instead, the aim is to present three distinct cases that, while sharing several general geographical and institutional similarities, have different approaches to discontinuous hydrogen innovation. These differences substantively shape the type of ventures and business models that have proliferated within each region. This section of the chapter aims to compare the key elements of the three empirical models and to draw wider conclusions about

the impact of local-level drivers of discontinuous innovation processes in traditional industry settings.

Table 6.1 above summarises the discussion in the subsequent paragraphs: Four main drivers stand out in the empirical analysis as focal areas around which local and regional inter-stakeholder communication and coordination are particularly active. These drivers have been identified in the volume and frequency with which respondents across different stakeholder types bring up different elements of local and regional innovation in their interview answers (see the coding process in Figure 6.1). This section will discuss each of the four drivers in turn in order to compare the relational dynamics taking place across the three cases and their subsequent impact on discontinuous innovation processes.

i. Early-stage venture coordination

One of the most crucial shapers of the hydrogen innovation process and differences between the three regional cases is the locus of coordinating new ventures and strategic directions for innovation. This is not surprising from the perspective of existing research on clustering and industry agglomeration but has yet to be studied in depth when it comes to drivers of sustainability transitions or other cases of discontinuous innovation. Innovation and entrepreneurship have traditionally been boosted in centres of business activity in a specific industry or field due to the network effects in market development and knowledge sharing that increased proximity and agglomeration can provide (Porter, 1998; Saxenian, 2000; Feldman, 2001; Iammarino and McCann, 2006). However, over time, research on the organisation of networks, ecosystems, and innovation systems has also made clear that exchanges and innovation processes at the local level do not unfold by automation but are shaped by active coordination and orchestration processes by different stakeholders (Asheim and Coenen, 2005;

Nambisan and Sawhney, 2011; Thompson, Purdy and Ventresca, 2018; DeJordy *et al.*, 2020). The impact and effectiveness of the local conditions and resources on which new ventures build their innovation strategy are shaped by the concrete practice of coordinating new venture growth at the regional industry level.

Based on the observed cases, this focus on early-stage coordination seems to hold true also for discontinuous innovation processes in traditional industry settings. In fact, the level at which local-level agency has shaped the three present case studies suggests that the networked nature of hard-to-abate industry transformation and decarbonisation – and in particular, the infrastructure dependence of green hydrogen innovation – affords an even greater role and impact for both formal and informal industry coordination processes when compared to other innovation settings. As pointed out by Mathias Lindström, Director of the Kvarken Council cross-regional association in the Finnish case of Vaasa: *“To succeed with the transformations, the actors in the region has started to view all these energy issues more as an interlinked whole, so the customer does not need to buy these renewable and smart energy solutions piece by piece”* (for coding detail, cf. the first box of first-order concepts in Figure 6.1 above). Especially in the Vaasa and Luleå innovation networks, this kind of system-driven coordination of resources, competencies, and knowledge-sharing platforms is already taking place, as can be seen in the variety of collaborative green hydrogen and energy-system initiatives being established. In Vaasa especially, the energy-sector cluster has operated already for several years with a networked governance model where private-sector consortiums, business development companies, public-sector project initiatives, and other partnership models run many key projects creating innovation opportunities in the town (Vasek, 2023; Nordic Energy Research, 2024).

On the one hand, these models have been relatively slow in aligning with higher-order (e.g. EU-initiated) innovation policy frameworks. There is no single entity administering or gatekeeping the network processes and project negotiations in a *dirigiste* way, and the different platforms that exist for this purpose largely see each other as complements rather than competitors for control. On the other hand, the formal collaboration structures and regional strategic agendas build on the strong interpersonal and informal networks that exist in the local environment, serving as a cornerstone for communication, trust-building, and knowledge transfer. As one interviewee in the Vaasa area summarises: “*The door is very much open to anyone, and we do see each other regularly, if not at a networking event then at village hockey practice*”. The emergence in 2021 of the Power-to-X-to-Power hydrogen project in Vaasa exemplifies how these formal and informal networks co-depend and align with each other over time, as one project partner representative explains: “*When we found out about this opportunity to apply for a grant for the project, I needed to negotiate with potential partners, and I already knew the relevant people quite well, especially through our work together on Wärtsilä’s Sustainable Transition Hub. So it felt like a very natural meeting to set up*”. There is a great deal of discontinuous innovation unfolding in Vaasa, and despite step-changes in infrastructure provision, the energy mix, the required engineering skills, and available funding, the town’s underlying coordination model for innovation has not undergone a significant overhaul.

In the Luleå area, there is a very similar dynamic in place consisting of wide-reaching social networks in the local industry, where respondents confirm that “*everyone sort of knows each other, especially those having stayed here for a longer part of their careers. If someone quits one job they usually turn up in another capacity somewhere else in the same network*”. However, these informal networks do not always align with the formal collaboration mechanisms in place – especially as many of Luleå’s innovative ventures are driven partly by

external, multinational, and remote-working stakeholders. This has given rise to a more *ad hoc* approach in setting up formal coordination between stakeholders. These ad-hoc networks, such as the high-level group for green transition ('AGON') spearheaded by the County Governor, are strengthened by pre-existing informal networks. But they also demonstrate a lot of reshaping and rethinking of the decision-making platforms that existed before, and they are not directly shaped by a singular long-term vision for the local industry network, or consolidated by a central orchestrator such as Luleå's business development office.

One respondent summarises the changing dynamic: "*The reason why I started this working group is that we really did not talk about these specific issues at all before in our town or region*". Another respondent continues: "*There are different groups, and in the ones I am in, I meet new people all the time. It is all moving quite quickly and different people have control over different parts of the process*". Robert Eriksson, Land Development Director at Luleå Municipality, emphasises: "*So much is happening at all levels and we have never worked together across industry and municipality this much before, we have been the more silent enabler, so it has been a big difference and a journey for us... we have built a steering committee and many working groups with these big industry players that meet every week, working on coordination and risk mitigation*". And Lotta Finstorp, the County Governor for Norrbotten, summarises with regard to the network she leads: "*The two most recent Swedish governments have both taken great interest in how we work in the new county working group. From my perspective, it is really an extraordinary revitalisation in the county... And it is of course how we should always work: Sit around the table, bring up potential conflicts or problems, and solve them*".

These new collaborative initiatives are constantly emerging and evolving in northern Sweden, and interview respondents emphasise that there is an overarching commitment towards making the most out of the green transition for all venture sizes, including local SMEs. The Mayor of Luleå, Carina Sammeli, comments: *“These large industries are also only half the story. We have about three times as many companies established now compared to two years ago. Three times as many permitting requests and land enquiries. And this is despite that we are currently in an economic downturn”*. However, the growth momentum is clearly spearheaded by large-scale discontinuous ventures and many existing collaboration processes are predominantly angled to support their success, scale-up, and significant resource dependencies – from coordinating industrial energy supply and demand to supporting the long-term skills provision to Luleå’s and Boden’s hydrogen facilities by way of collaborative place-marketing as well as local reskilling. Cecilia Wallmark, Director of the CH2ESS hydrogen research centre, comments: *“You will have heard we need over 100,000 people in the region, and at the university we are quite actively involved in the work to attract people to the region, at the same time as the issue of course concerns not only the hydrogen sector. We also work actively on our structures for skills development and engage at knowledge sharing events in the different municipalities”*.

The partial gap between new ventures and pre-existing local industry networks on the one hand, and the newly-emerging formal working groups to support large-scale ventures on the other hand, has the combined effect that informal local industry networks in northern Sweden do not orchestrate strategy and coordination for new discontinuous innovation ventures to the same extent as in the Vaasa case in Finland. These coordination mechanisms also emerge in complementarity with the actions of industry stakeholders, particularly on two fronts: Firstly, industry business models, as many of the town’s leading ventures focus on in-house R&D

departments, vertical integration in supply chain and operations management, and reliance on extra-regional teams for business development and strategic leadership. Secondly, financing structures: Most new ventures are closely linked to the finance sector and industry headquarters in Stockholm, which gives rise to a prioritisation of fast growth and commercialisation for export rather than collaborative value-creation or risk-sharing at the regional level. As one respondent remarks: *“The first priority is to make sure the investors understand this region is the safest option for delivering returns on time”*.

In the case of Finnmark in northern Norway, the relative absence of dedicated hubs or networks for innovation implies a much narrower set of industry coordination dynamics than in the two other cases further south. Matthias Kock, Special Advisor for the northern regions at the Norwegian Research Council, comments: *“Up here it is unfortunately a bit like a Sisyphus task when you want to set up a network for coordination – it is really hard to make it continuous”*. In other words, formal and informal coordination processes are not aligning to a significant enough degree to create dynamic innovation-coordinating mechanisms at the local level (except for in very specific cases and sectors, such as the start-up environment of the town of Alta). Instead, the connections between different stakeholders and new ventures are driven by individual industry entrepreneurs, many of whom are either employed by or connected to municipal-level administration or to larger locally-anchored firms that have a long time horizon for new ventures.

A good example of this dynamic is the Berlevåg hydrogen project, for which industry coordination has fallen to only a handful of community-driven individuals at Berlevåg Municipality and the Varanger Kraft energy company. In time, the hydrogen venture is likely to lead to some new coordination mechanisms, for example, for any hydrogen transport

infrastructure being built or for the planned industry park. Kjell Richardson, Business Developer at Berlevåg Municipality, comments: “*While these regional corporations may not have that much in common now, the idea with the business park is that they can plan their value chain together*”. Similarly to the Luleå case, therefore, large-scale innovation ventures are leading to a rethinking and realignment of formal coordinating capacities and stakeholders – albeit in this case, such capacity would be new to the local community.

To summarise, there are similarities across the three patterns of early-stage venture coordination: All of them represent some elements of ‘networked’ and ‘grassroots’ forms of regional innovation system, where formal and informal coordination mechanisms complement each other (Cooke, 2004; Asheim and Coenen, 2005). This is taking place for knowledge diffusion but also for other aspects of the innovation process, from search to testing and finance, that elsewhere would be governed by competitive markets rather than non-market coordination. This is in line with the characteristic features of Nordic industrial communities and business models (Jäntti and Vartiainen, 2009; Kristensen and Lilja, 2011; Ornston, 2018). However, there are clear differences in how these complementarities between formal and informal networks are taking place in practice in the three cases, and how they impact the early-stage trajectory of new discontinuous innovation. In particular, differences hail from the extent to which new ventures have aligned with whatever coordination platforms (both formal and informal) were pre-existing in each case-study region. This has led to different trajectories in the way ventures and research projects for green hydrogen are currently being pursued, from a wide-network orchestrated consortium approach in Vaasa to more free-standing projects in Luleå and Berlevåg.

ii. Research-intensive innovation

The second discontinuous innovation driver that arises from the three case studies is the way in which research-intensive innovation is organised in each regional innovation system. The important role of both primary and applied research facilities in the competitiveness of regional innovation systems has been well-documented. However, the focus of this academic research has most frequently been on high-technological sectors and very research and capital-intensive university locations (Saxenian, 2000; Glimstedt and Zander, 2003; Breznitz, 2014; Storper *et al.*, 2015). Even in small-town locations, research capacity ought to be recognised as a cornerstone of industry and innovation (Fu, 2020; Breznitz, 2021). This is particularly relevant for the Nordic economies, whose capacity for innovation in sparsely populated regions has been recognised for a long time and keeps making scholars perplexed (Asheim and Coenen, 2005; Fellman *et al.*, 2008; Kristensen and Lilja, 2011; OECD, 2017b; Ornston, 2018; Giacometti and Teräs, 2019). The characteristics and pathways for organising research-intensive activity in these conditions remain under-researched, especially in the context of traditional industries (McDowall, 2018).

The three case studies demonstrate three complementary but also distinct sides of this story, showing that research-intensive processes are not identical across the Nordic region. On the face of it, the Vaasa and Luleå cases are structured in similar ways: To support in-house R&D by industry stakeholders, there are public universities with attractive research profiles hosted in both Vaasa and Luleå (both are mid-sized industry towns), which boosts innovation activity not only in the towns themselves but for the surrounding region. However, the approaches and roles of these research facilities are not identical between the two. In Vaasa, the existing research laboratories and test centres are closely supported by local industry networks and play a role in defining the future direction and technology foundation for the local energy-sector

skills cluster. A research director and centre manager in Vaasa explains: *“It is not like all the value-creation comes through here, but a lot of the critical connections made for new value chains require this more concerted research project approach”*.

In Luleå, the impetus for research programmes is more strongly anchored in supporting the skills and knowledge development of specific industry in-house projects. Professor Karl Andersson, Dean at Luleå Technical University, comments: *“The way in which we drive research and innovation in close collaboration with stakeholders is quite unique I think. We have the highest share of industry funding of all Swedish universities, over 20% of our total research expenses, so this is a testament to how we stay relevant to them”*. Luleå Mayor Carina Sammeli concurs: *“LTU is one of Sweden’s most practical-research oriented universities, a big amount of the research is funded by the large industries in the region to make sure the mine is strong, the agencies have staff, and that everything works even though it is remote”*.

This difference in approach can be partly linked to the volume of large-scale investments being developed in the Luleå area over a short period. The significant investment momentum into the Norrbotten region has put pressure on Luleå Technical University and other research stakeholders to make sure the recent large-scale ventures are as value-generating as possible for local research communities. Indeed, a large part of the research-intensive work surrounding the technologies being promoted by the large-scale ventures in northern Sweden is being done elsewhere, at R&D facilities and institutions in industry clusters further south or overseas. The H2 Green Steel start-up relies strongly not only on the skilled labour and research capacity of external clusters but also outsources much of the research-intensive activities of its hydrogen-based business model to upstream partners and suppliers, as discussed in the previous chapter and confirmed by CTO Maria Persson Gulda: *“The production steps and chosen technologies*

we deal with, there is simply very few European experts, so we are hiring a truly global team with more than 50 nationalities across all regions beyond Europe e.g., North America, South America, Middle East, and Asia". H2 Green Steel has, at later development stages, been focusing more on research, including supporting public research in northern Sweden, but this aim was only possible to include after specific scaling and progress criteria had been met vis-à-vis investors. The HYBRIT green steel project is participating in research-intensive projects in northern Sweden, but predominantly chooses an in-house research model for its own development.

Consequently, only a relatively narrow set of research-intensive transition ventures have so far been added to the northern Swedish innovation system, and the growth so far is driven by a relatively narrow set of skilled experts working on very large-scale in-house research projects. In other words, the research intensity is not pooled among different networks and different-sized hydrogen ventures in the same way as in the Vaasa case. Instead, the several research-intensive testbeds and projects created in northern Sweden in the wake of the current industry momentum are primarily acting to strengthen the significant scale-up momentum that the large-scale hydrogen innovation ventures have initiated.

The Norwegian case of Berlevåg village brings, once again, an extreme-case model that helps put the two Vaasa and Luleå cases into perspective. Berlevåg has no strong tradition of local research-intensive, formal innovation processes, and the same can be said for much of the rest of Finnmark county (Teräs *et al.*, 2023). This was known by the initiators of the hydrogen project and applicants for the initial grant for a hydrogen research project to receive EU Horizon funding. However, the primary aim was not to establish a project for which the skill-intensive labour force would need to be provided either from existing Berlevåg inhabitants or

by those who decided to move to the remote fishing village. Instead, a large majority of all research as part of the Berlevåg project has been carried out remotely, with strong links to knowledge-intensive innovation systems with hydrogen expertise in Italy and Canada, among others (European Commission, 2023b; Haelous, 2024). Similarly, for the planned next steps of innovation surrounding green ammonia, the Berlevåg venture would be relying on larger-scale research efforts by industrial partners, including some based in Vaasa at the Wärtsilä maritime propulsion conglomerate. If the planned Berlevåg industry park does develop in the envisioned way, a permanent facility may be founded for undertaking research-based innovation activity. But this is also likely to remain at a modest scale from a broader Nordic perspective.

The setting of the Berlevåg innovation case demonstrates how the organisation of large-scale discontinuous innovation in traditional industries is strengthened and dependent on research-driven innovation, but that this does not unequivocally have to mean that a given locality hosts formal research-intensive processes that are identical to larger industry clusters and university towns. The innovation processes taking place in Berlevåg, while also clearly discontinuous for the general industry as well as the local community (the Berlevåg venture managed to set up a commercial hydrogen facility earlier than any of the other stakeholders in this chapter), are clearly informal and practice-based at the local level while the formal expertise is largely outsourced. Matthias Kock, Special Advisor for the northern regions at the Norwegian Research Council, recounts: *“There is clearly so much innovation going on in these coastal communities, but it is not really recognised because it is not all scientific research but more based on tacit knowledge, experimentation and recombination of new methods and projects”*. In other words, the informal processes and networks have not been meeting the formal elements of the innovation system and aligning fully with its vision. Matthias Kock continues: *“One example of this was when a public entity was applying for scientific funding – they were denied*

with the motivation of being ‘too remote’, too far away from scientific ecosystems... But when you think about it, that is sort of the definition of periphery. So in this sense, a lot of innovation in the periphery is being overlooked here”.

The three cases show that research-intensive processes are not only front and centre in discontinuous innovation processes in general but also central for innovation in traditional, energy-intensive sectors in particular. That being said, the organisation of these ventures may start off as small-scale tests or grant-funded projects that need to commercialise and scale up to remain feasible. This chapter observes three distinct pathways through which actors in northern Finland, Sweden, and Norway have been seeking to drive research-intensive activities surrounding sustainable hydrogen innovation. The differentiating factor is the sequencing of research activities (whether local-level research intensity precedes or follows from the injection of external advice and expertise), as well as to what extent any formal innovation processes and institutes that are put in place are connected to pre-existing and informal local innovation networks. This finding aligns with research in other parts of the world, which emphasises the role played by local communities and tacit learning processes for sustained advantage in research and development (Fu, 2020; Breznitz, 2021). In the long run, the inclusion of more diverse and dynamic research environments also anchored in the local community – even if only narrowly for some components or business cases – seems to promise more balance and resilience for a venture than purely ad-hoc or project-based structures.

iii. Risk-sharing and investments

The local-level driver that displays the most similarity across all three case studies is the engagement of regional innovation system stakeholders with sharing innovation risks and up-front investments. A fundamental feature of discontinuous innovation processes is their

inherent uncertainty vis-à-vis established business models or market segments (Kaplan, 1999; Garud, Tuertscher and Van De Ven, 2013). The trajectory of a discontinuous innovation process takes shape before new market niches are formed, before dominant designs emerge, and before the financial sector or public policymakers have the necessary tools to evaluate ventures tied to newly emerging business models and technologies (Geroski, 2003). This mechanism is particularly pronounced in traditional industry settings with a high dependence on resources and infrastructure, as is the case for green hydrogen and other sustainability innovation (McDowall, 2018; Savaget *et al.*, 2019). It is still too early to say for sure what the hydrogen economy is going to look like or how fast it will grow in different industry sectors. However, the more different stakeholders are held back by this uncertainty, the less chance there is of coordinating the system-level innovation that is needed to make the hydrogen economy take off in the first place (Business Sweden, 2023).

In this situation, an up-front commitment by local stakeholders (either public, private, or both) can be a strong signal that local innovation stakeholders are committed to doing what it takes to support the successful scale-up of a new venture. This kind of risk-sharing to signal strategic commitment emerges from the research dataset as one of the strongest characteristic features of Nordic traditional industry settings supporting new discontinuous ventures. For example, as one respondent recounts one of the early large-scale commercial investments in northern Sweden: *“We would for sure not have been selected as the location for this venture if the company would not have believed 100% that this town and region will do whatever it takes to make this a success”*.

The risk-sharing mechanism takes different shapes in the three regional innovation systems. But the rules of the game are similar throughout. This can be discerned in patterns of how

hydrogen ventures are being formed and developing, as described by one respondent with expertise in several Nordic energy markets: *”It seems like all these hydrogen ventures across the Nordics are either very large ventures, with enormous capacity and resource commitments made at once, or very small projects. There does not really seem to be the capacity and resources for projects in the middle, to make those profitable”*.

The risk-sharing mechanism in the Vaasa area is based on long-established industrial culture and routines, which have been adapted to the ongoing sustainability transition and to projects such as the Power-to-X-to-Power venture described above. This partly explains the relatively later stage at which the sustainable industry transition momentum developed in the Vaasa area compared to northern Sweden. The bulk of the available resources and capital in Vaasa and the networks and structured settings to debate and make decisions are connected to the pre-existing industry consortia and networks described in Chapter 4. Regional private-sector-driven consortia and business associations hold most of the agenda-setting power in terms of local investments and risk-sharing projects (these agenda-setting stakeholders also include angel investors and entrepreneurs who have spun out ventures from the traditional Vaasa-based companies and have then returned to support the Vaasa cluster with funding). More recently, the city council has also become more actively supportive of new large-scale ventures, as one public-sector respondent describes: *“There has been a realisation here that in order to really attract new energy opportunities, everything should already at least to some extent have been planned and rolled out beforehand, such as site preparation – and paid for by the municipality”*.

These networked risk-sharing practices are based on institutionalised traditions during the last few decades, whereby successful companies in Vaasa have become accustomed to supporting

and staking younger ventures. However, there is an even longer legacy and business model for this risk-sharing approach in the Finnish post-war industrial build-up, where many companies in the traditional resource-intensive industries would come together with ownership stakes in a collective so-called ‘*Mankala company*’ that made large investments on behalf of the smaller stakeholders that could not have afforded it on their own (Lumijärvi and Ollikainen, 2011). Niko Paaso, Vice President at the Ostrobothnia-based EPV energy company, which operates with the Mankala principle, explains: “*We propose to our owners new energy production investments that we deem as profitable. Each owner then decides whether to partake. With this business model our owners can broaden their production portfolio beyond what they could have invested in themselves. Operating like this is particularly helpful for opportunities to join large-scale energy supply projects that are very capital intensive*”. Nonetheless, this model is not always the most compatible with step-change transition across all parts of the energy system, and several Vaasa-based interviewees describe a relative lack of formal commitment and investment in demand-side sustainable industry projects, which have not followed the same collaborative principle as supply-side energy production.

In northern Sweden, in turn, industry risk-taking is supported by a strong connection to the global finance hub of Stockholm, where many of the northern regions’ main industry incumbents are headquartered. This close link to the largest financial hub in northern Europe is a clear benefit to the northern Swedish large-scale discontinuous projects for industry decarbonisation – this is visible in how efficiently the fundraising and scale-up efforts for these ventures have developed overall (Ballard, 2023). In addition, some local public administrations, as well as private or quasi-private companies (such as energy utilities) gain a steady source of local income from energy and resource production, and this has put many stakeholders in and around Luleå in a good position to support new ventures. But despite this

strong positioning for industry finance, the task in the Luleå area remains largely the same as in Vaasa: For the local community to share the risk and give prospective ventures and external investors a guarantee of long-term local commitment towards the full scale-up of new ventures. Johan Sjökvist, the Inward Investment Director of the municipality-owned Luleå Business Region, recounts: *"We have to do a great many things without really having guarantees for them: A new harbour, railways, different sorts of terminals, and of course the industry will be part of paying for it, but it is still around 10-15 billion Swedish kronor that are needed up front that we need to find solutions for. At the same time, we need to do this in a way that the companies and their investors are happy with"*.

Localities in northern Sweden that demonstrate these risk-sharing strategies particularly strongly include, among others, the energy utility Skellefteå Kraft, which is investing its own capital into several projects around the energy transition and the hydrogen economy; the municipality of Luleå with its large-scale harbour improvement project that is crucial for all large-scale ventures in the area; as well as the municipality of Boden that undertakes a continuous process of site preparation for the H2GS steel mill and green hydrogen facility (such as the construction of power lines and a rail link to the site, all funded by the municipality). Carina Sammeli, Mayor of Luleå, describes: "We are working more collaboratively beyond Luleå as well and that takes more trust and example from the political leadership in working together. Of course officials in Luleå will always know Luleå best. But there are many things, like the railways, that are not a Luleå or Boden question: Either we succeed in overcoming these challenges for both of our industries, or then neither one succeeds and we have a problem".

In the case of Berlevåg in northern Norway, the Varanger Kraft energy utility (co-owned by municipalities in the area) as well as Berlevåg municipality itself have made continuous investments into the innovation capacity of the fishing village – not least within the wind farm and hydrogen projects. These investments demonstrated the commitment of the local stakeholders enough that the national grid administrator granted concession for building the wind farm, and the European Commission granted Horizon project funding for the hydrogen research project (European Commission, 2023b). These projects, in turn, have become crucial leverage to demonstrate the viability of the village in implementing its strategic vision of an ammonia facility and industry park. A public administrator in Berlevåg recounts: *“We have staked everything on these projects, it is about our village’s future. It is of course straining our municipal finances, the building of these facilities as well as a renewed school building, leisure centre etc., but if we survive here as a community, it will all have been worth it”*.

However, the *community model* of Berlevåg’s hydrogen innovation is based almost exclusively on local and regional investments and commitments – not a combination of local and global resources as is the case both in Luleå and Vaasa. This complementarity mechanism for venture investments is simply missing, and consequently, there is no commitment mechanism for scale-up and market building across the hydrogen value chain. This partly explains the standstill in the scale-up of the hydrogen project: While in the Swedish and Finnish hydrogen cases, both supply and demand-based ventures are being developed simultaneously, the Berlevåg project to date encompasses only supply-side considerations, with negotiations for a downstream value chain still at an early stage. Lacking energy grid capacity and the project's remote location exacerbate this innovation challenge.

The commitment by public administrative bodies and local industry stakeholders is not always enough to convince national-level agencies and policy-makers, international industry partners, or the financial sector of the viability of discontinuous innovation in traditional industries. The described case-study regions feature dynamic examples of large-scale ventures and hydrogen innovation but have also faced setbacks, for example, in terms of withdrawn plans and denied grants, investments, and partnerships. A report in autumn 2023 by the Stockholm-based Scandinavian Policy Institute sharply criticises the investment wave into northern Swedish regions and the allocation of clean energy resources to industrial development for green steel and hydrogen (Sunden, 2023). The report argues that the technologies in question are not yet dominant and that the risk of staking so much on singular ventures is too large for the national economy. Elsewhere, a Luxembourg-based administrator at the European Investment Fund discusses the analysis they had conducted in 2022 that led to a decision to deny a dedicated fund-of-funds investment mechanisms to support regional innovation in the northern Nordic regions, despite the substantial investments and large-scale ventures present in the area: “*We just did not manage to see enough of a financial commitment by capital institutions to support these regions with targeted funds*”. Indeed, the motivation by the EIF in 2022 describes that only 2 out of 27 surveyed venture capital institutions in the Nordic countries would have joined an EIF-driven investment fund on the terms presented (European Investment Fund, 2022). The remoteness and the lack of certain key resources, including a mature local tradition of venture capital on market terms, are inhibiting some external stakeholders from committing funds to new ventures in the case-study regions.

Especially given that the global ‘clean tech’ investment environment remains challenging, and criticisms of more peripherally located ventures’ viability are regularly voiced, it is clear that the local-level risk-sharing commitments made across all three case studies are a fundamental

condition for the successful emergence and industrialisation of Nordic hydrogen innovation projects (as well as other ventures described in previous chapters). At the outset, local-level drivers of upfront risk-sharing and investment have ensured that there is some discontinuous hydrogen innovation to begin with, even if only in small-scale testing. Later on in the process, the observed ventures are experimenting with different ways to complement local and global support, with the aim of lowering the business risks enough to get to the scale-up and market-building stage in their innovation process. One respondent tellingly describes a large-scale venture in their municipality and the process of supporting its establishment: *”Of course it is still in the air whether the venture will go ahead and all international investment will be in place. But the way the process has been supported locally has ensured that regardless of what happens, some sort of energy-intensive facility will definitely be built here – the site and infrastructure are all ready, the energy is available, and the local industry conditions are flexible and reliable, meaning a lot of the initial risk has already been taken care of. If this venture is not the one for us, then the next one may be”*. The location in question is in Northern Sweden, but it might well describe the risk-sharing process of any of the three case studies.

iv. Community engagement

The case studies included in this chapter all describe locations with relatively modest population sizes from a national or European perspective – whether in the context of the mid-sized industry towns of Vaasa and Luleå or the remote fishing village of Berlevåg. These contexts imply that the emergence of large-scale discontinuous ventures will take up a sizable share of local development capacity and impact the local communities and populations in a variety of ways, from jobs created/shifted and new migration patterns to new pressure on administrative and social systems, to questions about resource allocation and citizens’ rights.

However, the seamless engagement and coordination between ongoing innovative ventures and different communities or citizen groups is not a given. The true level of involvement or empowerment of local communities depends on the kind of relations that citizens have with the ongoing ventures and their leadership and on whether there is a general sense of citizen involvement in the regional innovation system (Edquist, 2019; Moodie, Salenius and Wøien Meijer, 2021). The specific impact and role of these ‘softer skills’ of community engagement in the regional innovation system is not well understood in current literature (Borras and Edquist, 2019; Edquist, 2019; Fu, 2020; Breznitz, 2021). Based on the case studies, the level and character of local community engagement for sustainability innovation has become a central concern both in industry and public policymaking. Stakeholders recognise that their community relations can mean the difference between successful scale-up and venture failure (in the short term due to permitting delays and lawsuits, in the long term because of lacking local-level resilience in terms of skilled workers and societal functions). The values of environmental sustainability and community resilience are also generally seen by Nordic stakeholders as closely interlinked (Giacometti and Teräs, 2019; Teräs *et al.*, 2023).

The capacity and strategy for community engagement take different forms across the case studies. In the Finnish Vaasa area, the ‘distance’ between citizens and innovative energy-sector ventures has traditionally been short, and the last few years seem not to have altered this considerably. Most of the pre-existing and new ventures in the area are initiated and/or staffed by local citizens working for stakeholders of the regional innovation system. The role of both local start-ups and larger industry stakeholders as a sense of pride in the town’s and region’s identity is significant, and the parts of local communities not actively involved in the innovation processes are still closely in touch with them in many ways. As Vaasa-based Mathias Lindström, Director of the Kvarken Council cross-regional association, points out: “*You can*

basically see a lot of these networks and their key figures just around town, at events and festivals, at local outdoor hockey practice in the winter, you name it”. Vaasa-based companies are also actively seeking to embed their activities in the daily lives of citizens, even including information campaigns about the energy sector and sustainability in local school and pre-school activities.

However, few of the active projects in Vaasa are inherently customer or citizen-facing, meaning that while citizen groups are included in public consultations and general processes to strengthen the innovation capacity of the region, there are not always natural points of connection between, for example, industry-facing hydrogen projects and a particular part of the local community. This is visible in the relative lack of value-chain level activity in Vaasa’s hydrogen economy: Both supply and demand are included in high-level strategies, but mainly energy supply-side projects have hitherto made it to the industrial-level scale-up stage. The best recent example of energy-sector innovation that successfully engaged local communities is the Aurora Botnia ferry that, since 2021, runs between Vaasa and Umeå in northern Sweden. The rationale and innovation process involved the town’s long-term community interests (e.g. commuting to Sweden for work) to a large degree, which facilitated the coordination between different sectors and companies to invest in the ferry as a showroom for the energy solutions developed in the regional innovation system (Kvarken Council, 2021).

The many forums for high-level exchange between community groups and industry initiatives are also present in northern Sweden, displaying many similarities to the Finnish communities surrounding the Vaasa regional innovation system. One local respondent summarises: *“Citizens have always been involved here to a large extent, some say that there are even too many consultation processes and citizen forums for different projects”*. With the rapid scale-

up of discontinuous innovation projects surrounding sustainability transitions, respondents explain that there has been a diversification in the level and nature of community engagement between different projects, with some ventures being seen as more accessible and inclusive than others. The H2 Green Steel venture and its linked hydrogen project, for example, has been actively engaging with different parts of their local community and through different channels: A local office on the high street in Boden for citizens to gain information, a tour of citizen discussions with those living in the immediate vicinity of the steel mill project (leading to the outcome of physically moving the site further away from dwellings), a set of outreach campaigns for internships and other youth opportunities, etc. Likewise, the HYBRIT project, and more specifically its incumbent parent companies, have been increasingly active in citizen and local community dialogue (although the different parent companies also face challenges in community engagement, especially further north where they operate close to indigenous Sami communities and their reindeer pastures). One respondent summarises: *“The steel company SSAB has always had a strong and good relation to the local unions in Luleå, and it appears like the transition is no different, where they are pledging to minimise impacts on local jobs from their green steel initiative”*. On the whole, the community impact, both challenges and opportunities, are actively discussed at different forums in and around Luleå, and there is a general sense in the area that there is ownership from both local industry and citizens.

The continuation of community engagement in the Swedish case appears heavily dependent on the extent to which the large-scale ventures keep up their engagement actions through the industrialisation stage. One local respondent summarises: *“Of course there are always sceptics, who have seen earlier failed industry projects and do not want to get their hopes up this time. But now the feelings up here are so clearly different, and the dynamism coming from the new jobs, newly opening transport links, and so on, can really be felt in the local atmosphere”*. The

response across all stakeholder groups in Luleå's regional innovation system is that so far the maturing of the industry transition ventures has not led to a decline in the level of community engagement. At the same time, many point to the risk that this engagement will be too focused on the immediate surroundings of industry ventures, leading to a sense of 'multi-speed' regional development where some local communities are benefiting and actively involved while others are left behind. Maria Jalvemo, Program Manager at the Swedish Grid Transmission Authority, comments: *"In my experience the surrounding municipalities, especially the inland ones, are quite different from the coastal towns, and there is already now a sense of "jealousy" or a feeling of being left out of the loop with the industry transition. Many of these may not have any hydrogen or other large new projects yet, but in some instances we still need to pass through them with new power infrastructure"*. In other words, the risk of alienating neighbouring communities appears stronger the further a community is from the large-scale sustainability ventures, as the *ad hoc* nature of local coordination and community engagement also reshapes ties between different localities.

In the Norwegian case of Berlevåg, instead of a larger-scale community engagement platform driven by individual ventures or by consortium or network organisations, the active process of community engagement rests fully with the local individuals in charge of the project in question (most recently, the green hydrogen and ammonia projects). This includes administrators and executives from Berlevåg municipality as well as the municipality-co-owned Varanger Kraft energy utility. A local respondent summarises: *"In general, everyone here knows the projects and the people involved, and of course they are cheering on it and are interested, even though it might not right now have a tangible effect on their own lives. Many understand that it is about the future of our community, and they treat all of us project team members like a part of the village"*. This does not mean that all locals are fully convinced of the hydrogen project's

successful future development or are personally involved in it. But in comparison with many other localities (both in Norway and elsewhere) where new energy-sector ventures are regularly stalled or denied due to local community scepticism, Berlevåg's community-driven project has evaded such concerns for potential conflict.

For the Berlevåg project, one of the most crucial community engagement issues has been with the local Sami community further to the south on the Varanger peninsula, and negotiations surrounding reindeer pastures in the areas for planned wind farms. However, these have so far been managed through close communication, both formally and informally, where the Sami community has a seat at the planning table and has had a real impact in shaping the project, rather than only an *ex-post* consultative role. Respondents describe, for example, altering the exact location of wind farm extension plans after a request from the community in charge of the reindeer pasture area.

Overall, the case studies show that meaningful community engagement is an embedded and consequential building block of the ongoing sustainability transitions in traditional industries. Given the discontinuous and initially industry-facing nature of hydrogen projects, the impact on citizens' lives is not always self-evident. But this does not mean that community acceptance and engagement have no role. Through an increased sense of ownership, the informal networks and tacit learning and competence-building processes of local communities work in favour of discontinuous innovation projects rather than against them, as has been shown through the observed outreach processes in all three case studies. The key tensions relating to increased community engagement involve, in the short term, mitigating the risk of deterred investment or scale-up due to conflicts during permitting and consultation rounds, as well as enhancing the holistic 'society building' where sustainable scale-up relies not only on industrial jobs but

on opportunities and welfare networks for spouses and families. Anne Graf, Head of Regional Affairs at H2 Green Steel, summarises this perspective: “*More broadly, there is for example a shortage of nurses, so we all have to work together on these wider society-building challenges*”. In the longer term, ventures without working channels for community engagement risk becoming fully detached from the local society and its development, bringing back tensions that had initially appeared resolved. The different case-study settings have also demonstrated how ventures can face very different citizen connections and provoke different experiences among local inhabitants at different times. The element of community engagement is, therefore, clearly dependent on continuous consensus-building and networking processes rather than on one-time efforts.

6.5 Discussion

This chapter set out to examine how local-level drivers in the regional innovation system shape discontinuous innovation processes in traditional industry settings. Through empirical observation and interviews, four drivers and three regional models have been outlined for how local-level relational dynamics in regional innovation systems shape discontinuous innovation processes in the context of hydrogen innovation in northern Nordic regions. This section discusses the main implications of local-level drivers of discontinuous innovation in traditional industries for theory development on the impact of place-based and regional dynamics for successful innovation (DeJordy *et al.*, 2020; Fu, 2020; Breznitz, 2021).

The local-level innovation dynamics explored in the case studies display some similarities with the *networked* and *grassroots* types of regional innovation systems as theorised by Cooke (2004), among others, in an effort to describe how collaborative network structures of close yet flexible relationships between stakeholders can create a competitive advantage for innovation.

Similarly, the cases display some elements that align with concepts of *open innovation*, as many of the collaborative ventures described in the case studies focus on learning processes spanning dynamically across firm boundaries, even in cases when the primary R&D effort would be carried out in-house (Chesbrough, 2003). However, none of the three models described in this chapter align fully with these existing structural models of regional or early-stage innovation and industry development (Cooke, 2004; Iammarino and McCann, 2006). Moreover, none of the three regional models represents a purely technology-driven view of innovation or industry processes, where markets form based on the characteristics of new technologies, nor of a ‘start-up ecosystem’ where entrepreneurs and their single ventures shape entire markets (Geroski, 2003; Jacobides, Cennamo and Gawer, 2018).

Instead, all three case studies point to a situational and co-constructive process, where a network of local stakeholders shapes the innovation strategies of large-scale ventures and projects, moderated but not dictated by technological or structural dependencies such as government policy or pre-existing local industry profile (Thompson, Purdy and Ventresca, 2018; DeJordy *et al.*, 2020; Breznitz, 2021). This informs the choice to label the mechanisms between the models in this chapter as local-level innovation *drivers*, implying an active and consequential role. The different challenges of undertaking discontinuous innovation in traditional industry sectors (see Chapter 2) become very real and tangible at the level of local communities and industry networks, as industry systems have finite resources and limited infrastructure capacity to make up for any bottlenecks with trade and transport. The case studies demonstrate how regional stakeholders have often supported ventures through either *ad hoc* or pre-planned, and both formal and informal relational dynamics to mitigate and overcome these dependencies at the local level.

The key difference to the assumptions of most structure-focused theory models is that the stakeholder relationships observed by these process-focused case studies are forming and engaging situationally and informally (i.e. as shaped by specific social situations) (Hallett and Ventresca, 2006). These innovation system settings have been shaped over time and continue to do so, actively changing the realities and incentive structures for the ventures they help initiate. In all three case studies, the local processes build on a combination of formal and informal commitments, beyond structural ecosystem partnerships. When it comes to routine and incremental innovation, it is logical that the existing industry structure either does or does not provide a conducive environment (e.g. Cooke, 2004; Saxenian, 2000, etc.). However, the case studies show that success and failure in *discontinuous* innovation are not decided by the existence or type of local-level structures, but are more uncertain and sensitive to the ways these are adopted and combined in shaping specific ventures at a specific point in time. The pre-existing structure of the regional innovation system becomes an affordance that the process to support hydrogen innovation (or any other venture) can build on and reshape, to create place-based advantage for discontinuous innovation.

The structural features of a regional innovation system are not new or undocumented in Nordic settings. The institutional complementarities of close social network ties and long investment horizons with a specialised training and education sector, as well as legislation that allows for close inter-firm collaboration, has been examined and modelled in many Nordic industry settings (e.g. Kristensen and Lilja, 2011). However, what is new is observing and analysing these types of innovation networks in the specific context of enabling discontinuous innovation. Traditional industry settings are not usually considered very transformative, so the local context of traditional industry clusters may not have been expected to be very significant to firm-level

outcomes of successful breakthrough and discontinuous innovation – at any rate not in a positive or innovation-driving sense (Ornston, 2014).

The complexity and scale of changes surrounding sustainability transitions in these settings show a different and much more active side to local innovation-driving mechanisms than prior literature would have predicted. The emerging picture is one where even the most remote or unassuming Nordic traditional industry settings can host, shape, and incentivise discontinuous innovation processes. Whether they end up doing so is dependent on situational processes and entrepreneurial agency by local-level stakeholders in both the public and private sector, not by deterministic structural pillars of the regional innovation systems themselves (which are roughly the same across the Nordic region and do not always produce successful innovation outcomes). This explains why the models undertaken in the three Nordic case studies have distinct individual features and pathways although they share many characteristics in terms of geography, culture, industry, and resources. This nuance can be observed and theorised only when taking a process (rather than structure) perspective (Garud, Tuertscher and Van De Ven, 2013).

One of the fundamental drivers of success seems to be local-level processes that help combine the benefits and resources available from local and global industry networks – whether it comes to research activities, early-stage risk-sharing, scale-up investments, or building up regional supply chains. For example, many hydrogen innovation ventures developing in the north of the Nordic countries have made important use of their host locations' initiative of risk-sharing at the early stages of a venture while at the same time making sure that downstream off-takers in external markets are available to support the scale-up stage of the venture. Missing either of these dimensions may well be fateful for an innovative venture, as can, for the time being, be

observed in the Berlevåg hydrogen innovation venture that has not yet secured an external supply chain, or in the many prospective yet ultimately unsuccessful ventures that were interested in setting up operations in the case-study regions without forming a substantive community presence in the informal networks of the regional innovation system. Given that innovation in green hydrogen and similar discontinuous innovation niches cannot rely on a well-established global market at the stage when the ventures are emerging, this context-building as a combination of global and local operations acts as a non-market coordination mechanism that mitigates the venture's initial business and investment risks until a competitive market is formed.

In these ways, both the structural backdrop of the regional innovation system and deliberative situational processes of local-level agency are leaving their mark on the evolution of discontinuous innovation ventures. However, the deliberative situational processes ultimately shape what the role of the local-level drivers will be – for example, whether the research and risk-sharing environment will revolve more strongly around individual large-scale ventures or community-driven consortia.

In all three cases described in this chapter, the regional and local networks and alignment processes represent early-stage industry developments at a time before strongly consolidated market mechanisms have formed (in this case for green hydrogen) and a fossil-fuel phase-out across Europe is still waiting to happen. These innovation stages describe situations of discontinuous, step-change upheaval of markets and routines both at the local and global levels. Therefore, the innovation drivers discussed in the chapter are not necessarily comparable to continuous innovation dynamics in mature industry settings where the path dependency of a specific regional innovation system, i.e., the structures and resources in place, may be much

more consequential. Further research is also needed to benchmark and compare the drivers and models of this chapter vis-à-vis discontinuous innovation in more disruptive and fast-scaling contexts, such as high-technological clusters operating along a ‘Silicon Valley model’ (Casper, 2007). Based on existing research frameworks, these latter innovation contexts can also be expected to rely strongly on a connection of formal and informal networks like the identified Nordic models, but we can also expect that Silicon Valley type ecosystems would focus much more strongly on driving competitive markets for the supply of capital and resources rather than non-market coordination and supply chain alignment (Henderson and Newell, 2010; Seba, 2014; Storper *et al.*, 2015; Breznitz, 2021). The process modelling in Chapter 8 will return to the question of future research to complement the present findings.

6.6 Conclusion

This chapter has discussed the role of local-level processes and stakeholder networks as drivers of discontinuous innovation in traditional industry settings. It has outlined three empirical models based on three case studies into discontinuous hydrogen innovation ventures in Nordic regional innovation systems. The main finding of this analysis is that active inter-stakeholder relational processes act as a driver for what type of ventures get introduced and supported in a specific place and, consequently, for how well ventures can translate their regional innovation system into a competitive advantage for discontinuous innovation. While many existing studies focus on the structure of a local or regional industry environment as something that becomes shaped by large corporations and overarching market forces, or that unequivocally decides the fate of a venture based on structural and material affordances, this chapter takes a process lens that shows the enabling mechanisms of agency, coordination, and experimentation that different stakeholders are taking (Garud, Tuertscher and Van De Ven, 2013; DeJordy *et al.*, 2020). This explains the observed difference between regional models and venture

characteristics for discontinuous hydrogen innovation in three Nordic case studies, despite their many institutional and structural similarities. The role and boundary conditions of local-level stakeholders driving discontinuous innovation are situational: They are rooted in the physical resources and existing industry structures in a regional innovation system, but the tangible actions taken to support a venture are better viewed as a social process where local stakeholders combine, reshape, and experiment with pre-existing structures. The process view is particularly relevant when it comes to *discontinuous* innovation ventures, such as those targeting a hydrogen-enabled energy system, as these innovation settings require existing processes and mechanisms to be realigned and closely coordinated to provide the needed support for new ventures. The best chances of success arise when local stakeholders take action to connect and complement formal and national/international interests with informal local-level networks and risk-sharing collaboration, both in the private and public sectors.

Returning to the overarching aims of the thesis and its research agenda, this chapter has demonstrated that discontinuous innovation processes in traditional industry settings can be substantially shaped by the agency of local-level stakeholders, such as regional energy companies, municipalities and county councils, universities, and local industry. These stakeholders can have a driving and defining role in incentivising innovation, not only a background role that remains static or only adapts to external pressures (Thompson, Purdy and Ventresca, 2018; Fu, 2020; Breznitz, 2021). With a deeper understanding of the different roles and driving mechanisms of local-level stakeholders, we see that the location and success factors of new industry innovation depend on more than top-down strategising by industry or the state to maximise resources and material affordances.

The impact of local-level stakeholders is undoubtedly variable between countries, industries, and types of innovation. This chapter has focused specifically on discontinuous innovation in traditional industry settings in a northern Nordic context. These can be hypothesised to rely more heavily on non-market coordination, supply chain alignment and risk-sharing mechanisms than do either metropolitan ‘Silicon Valley model’ ecosystems with a strongly market-driven innovation setting or traditional industry innovation settings in other parts of the world where the impact and agency of local-level stakeholders may be more limited than in the Nordic regions (Christensen, 1997; Casper, 2007; Henderson and Newell, 2010; Ornston, 2018; Giacometti and Teräs, 2019; Thelen, 2019). Even between different Nordic cases of discontinuous sustainability innovation in traditional industry settings and more rural and remote clusters, this chapter has identified differences in the capacity and operating licence of local-level innovation drivers. Many of these differences can be attributed to state-level policies and regulatory agencies. Having now conducted empirical analyses into discontinuous steel and hydrogen innovation from a perspective of both ventures and their regional and local drivers, the next chapter brings the third piece of the research agenda: An examination of the role of the state, state-level agencies, and the national socio-institutional environment for enabling discontinuous innovation processes in traditional industry settings.

Chapter 7 – State-Industry Relations as Enablers of Discontinuous Innovation in Traditional Industries

7.1 Introduction

The previous empirical chapters have focused on the contextual nature of innovation for sustainable industry transitions: the importance of alignment across specific value-chain stakeholders, as well as the active role of local and regional stakeholders in shaping what type of ventures are advantaged in a specific field or region. However, while the regional industry context stands out as crucial for coordinating different drivers of success, the enabling role of the national policy and regulatory context is also consistently brought up by interviewees across the different case studies. The nature of the innovation processes under observation – sustainability-focused discontinuous innovation to transform existing industry infrastructure and value chains – further emphasises this connection between innovative ventures and the national policy and regulatory context. Therefore, this chapter complements the analysis of discontinuous innovation in traditional industry settings by approaching the topic from a perspective of public policy and political economy: how policy programmes and regulatory frameworks within different socio-institutional settings impact innovation processes.

This field of research, which examines the effect of policies and institutions on different phenomena in the political economy, has frequently been applied to studying innovation. On the one hand, there is existing research on the impact on innovation of a specific country's socio-institutional environment. Varieties of Capitalism (VoC) research demonstrates differences in how the relational dynamics between different stakeholders in the political economy have shaped each other over time to create specific competitive advantage conditions for innovation (Hall and Soskice, 2001; Casper, 2007; Hancké, Rhodes and Thatcher, 2007).

For example, coordinated market economies (CMEs, the Nordic countries counted among them) are characterised by more patient investors and more active non-market coordination mechanisms than some other countries, thereby creating an advantage for incremental (but not for radical) innovation. Other authors have contributed with additional layers of nuance, holding that specific regions and sectors have specific relational dynamics that support other variants of these advantages (Thelen 2019; Ornston, 2014).

On the other hand, literature on innovation policy examines impact of direct policy interventions by national governments and agencies, arguing that this directs and shapes which type of innovations gain an advantage in a given country (Mazzucato, 2011; UNEP, 2017; Fagerberg, 2018; Edquist, 2019). Recent additions to this literature call for increased focus on innovation *directionality* and mission-oriented innovation policies (MOIP), which have the capacity to combine different industry sectors and stakeholders under specific innovation missions (Mazzucato, 2018). However, the drivers of discontinuous innovation in the case of traditional industry transformations are different from many of those that existing literature has studied (as discussed earlier in Chapter 2). The sustainability transition cannot be distilled into a singular development direction or market disruption, as would be the case for innovation taking place in many other sectors. Therefore, the impact of the policy and regulatory environment on this innovation can be expected to be different, too. For example, the complex intersectionality between different aspects of the sustainability transition renders it exceedingly difficult to distil entire transformations into a single innovation-policy programme (Henderson and Clark, 1990; Fagerberg, 2018; Mazzucato, 2018; United Nations, 2023).

This chapter sets out to examine Q5 of the research agenda from Chapter 2: *How do state-industry relational dynamics and institutional factors impact discontinuous innovation*

processes in traditional industry settings? The chapter mirrors the two previous ones both in setting and structure. In terms of setting, the empirical focus is on national-level processes that are shaping the business incentives and societal capacity to undertake discontinuous innovation processes in traditional industry settings in Finland, Sweden, and Norway. Case examples are brought especially from the industries and regions examined in Chapters 5 and 6: how discontinuity in the energy system (especially in electrification and hydrogen) and industry decarbonisation (especially in green steelmaking) are being promoted by way of both incentivising policies and regulations (e.g. through the innovation policies of national grid authorities), and how this relates to the more general institutional environment (e.g. land use regulations and innovation capacity in the education system). In terms of structure, the chapter aims to discern enabling patterns by tracing the *state-industry relational dynamics* present in each country: between the regulatory/policy stakeholders and the ventures/local stakeholders whose activities the national actors seek to support. In this way, the focus is on uncovering the enablers through which successful venture development is supported (or not supported) at the level of national innovation policy and regulation.

One finding emerges above all through the multiple case study of three national innovation contexts: National innovation policy and regulation affect not only specific innovation ventures and their success but have system-level effects that may be both positive and negative for the overall success of sustainability transitions in the entire country. The way in which deliberate policies or regulatory action impacts emerging ventures has to do with the specific situational innovation context (i.e. tied to specific social situations). In some cases, the direct implications of national-level interventions complement and strengthen the innovation environment as a whole. In other cases, however, direct state intervention in favour of one venture, sector, or region has neutral or even detrimental effects on other ventures as an indirect side-effect. In

other words, policies and regulations have an effect beyond their immediate beneficiaries or target sectors: The surrounding innovation context can be enabled or inhibited by direct policies and regulatory actions, with widespread indirect effects on the innovation and success capacity of industry and sustainability transitions. The relatively high similarity in socio-institutional context across the three observed Nordic countries allows us to pinpoint specific examples where these enablers are interacting with discontinuous innovation processes.

The multiple case study thereby contributes to research on the impact of public policy and the state on discontinuous innovation and, more specifically, to recent literature on the impact of institutions and industrial policy on sustainability transitions (Reichardt *et al.*, 2016; UNEP, 2017; Fagerberg, 2018; Mazzucato, 2018; Thelen, 2019; Lema, Fu and Rabellotti, 2020). The contribution is a nuanced account of how a combination of direct and indirect mechanisms affects national competitive advantage for sustainable industry transitions. The role of the state in discontinuous sustainability transitions in industry decarbonisation contexts is crucial but relies equally on both direct efforts and on indirect reshaping of the wider institutional landscape for a sustainable economy. The theory assumption at the core of this contribution is that competitive advantage in a political economy is situational, not static – it arises through the relational dynamics between stakeholders and can vary across specific ventures and over time. Moreover, the state is far from the only consequential stakeholder. As explored in previous chapters, many initiatives are being coordinated and driven at the level of regional clusters and global commercial markets, and the state's role in these cases can be characterised as *enabling* (even as some ventures are state-owned). The discussion section also finds that the general tenets of the Nordic CME-type institutional setting are largely in place in the context of the regions and cases of this thesis, but that the innovation challenges and ventures surrounding sustainability transitions are recombining or *blending* the traditional Nordic

institutional complementarities with other mechanisms prevalent in global finance and industrial relations.

The Nordic case studies demonstrate how relatively similar institutional environments and policy interventions have already led to tangibly different innovation outcomes simply due to small variances in the combination of enabling factors. Even in the world-leading innovation systems of the Nordic states, there has not been a simple answer to the question of state intervention to drive innovation for sustainable industry transitions (Giacometti and Jessen, 2024). The complexity of ongoing industry transitions demonstrates challenges and uncertainties that policymakers may only be able to mitigate through situational flexibility and continuous policy experimentation.

While the majority of the chapter analyses deliberate state-level policy and regulation processes, the discussion section concludes by also connecting this analysis to potential theory implications about the impact of the wider Nordic socio-institutional setting on these processes (Hall and Soskice, 2001; Kristensen and Lilja, 2011).

7.2 Literature on the impact of state-level agency and institutions on innovation in a Nordic setting

As presented in Chapter 4, the Nordic countries are in political economy research traditionally characterised as having a relatively rigid socio-institutional setting. The Nordic countries are examples of *coordinated market economies (CMEs)*, with features such as a strong tradition of consensus decision-making through close-knit informal networks and non-market coordination, relatively centralised labour market and wage bargaining mechanisms, a finance sector with active, long-term institutional investors and ‘patient capital’, and an extensive

public system of R&D and higher education institutions that provide free education and training in highly specialised skills (Hall and Soskice, 2001; Campbell, Hall and Pedersen, 2006; Kristensen and Lilja, 2011; Thelen, 2019). As Chapter 4 summarises, there is scholarly debate over what kind of innovation processes are best placed to take advantage of the Nordic institutional environment: The countries consistently rank among the most innovative in the world, with a high degree of skills in many traditional industry sectors such as forestry, heavy machinery, shipbuilding and chemical engineering, but also in several high-technological sectors and the digital economy (World Intellectual Property Organization., 2024). The original framework of Varieties of Capitalism literature argues that the Nordic setting creates an advantage for incremental (but not for radical) innovation, while other authors have contributed with additional layers of nuance, holding that specific regions and sectors have characteristics that support other variants of these advantages (Hall and Soskice, 2001; Thelen 2019; Ornston, 2014).

The confusion in existing literature may be attributed to the lack of nuance in understanding the role of these industrial traditions in specifically supporting *discontinuous* innovation and change, which, by definition, involves a lot of upheaval and where innovation policy decisions may thereby become more complex than normal (Henderson, 2021). Transformations like these have been the focus of attention much more strongly in some settings (like digital software innovation) than in others (like traditional industry sectors), risking a one-sided view of what discontinuous or disruptive transformation means in a Nordic industry context (Ornston, 2014, 2018).

More recent literature on firm-level processes and practices connected to Nordic institutions and regulation gives some clues as to what the driving mechanism for Nordic discontinuous

innovation might be. In a volume edited by Kristensen and Lilja (2011), the authors uncover ways in which the institutional and regulatory framework has, in some settings, led to specific forms of collective and flexible policy experimentation and increased risk-taking. Different chapters in the volume demonstrate settings under which the business risks of sometimes markedly transformative projects were absorbed by the firm and its local business network – and also settings under which such advantages did not materialise in the same way. This research, while not specifically focused on discontinuous change processes, does provide useful insights into how experimentation for change and innovation has, under certain conditions, successfully leveraged the socio-institutional setting of the Nordic countries.

Another source of research debate surrounds the role and impact of Nordic governments in enabling these developments through innovation policy and regulation (Rehn, 1996; Jäntti and Vartiainen, 2009; Edquist, 2019; Thelen, 2019). These countries were among the first in the world to substantively apply the concept of National Innovation Systems (NIS) and to devise integrated innovation strategies to support research and development across the national economy (OECD, 1997; Alaja and Sorsa, 2021). In many cases, the foundations for innovation activity were laid already during the previous decades, through long periods of consensus-driven government (often led by social democratic parties) that founded universities and national research institutes, built up an export-supporting infrastructure, and provided crucial coordination and stability in times of trade liberalisation and regulatory reform (Fellman *et al.*, 2008; Jäntti and Vartiainen, 2009).

These trends have been relatively similar across the Nordic countries but with some regional and national differences in terms of economic structure and strong sectors. The most significant national prioritisation was Norway's state-led effort to build up a strong petrochemical industry

in the latter half of the 20th century, wherein both the investments and the profits have, to a large extent, been coordinated by the state (Grønning, Moen and Olsen, 2008). In Finland and Sweden, there has been no equally dominating single sector, although different stages innovation and exports have been concentrated more heavily on some industries (such as ICT and heavy manufacturing) (Ornston, 2018). Therefore, the Nordic states' track record on innovation policy in recent decades is a strong but predominantly arms-length state-industry relationship: Rather than outright dirigiste industrial policy, the direction of travel for the Nordic innovation systems has been led through coordinated discussion between government and industry (as well as government-owned industry). The Swedish case of the leadership provided by the Wallenberg investment empire and other incumbent industry stakeholders is a clear example of this model (Thelen, 2019). In the Finnish case, Breznitz and Ornston (2013) align with Kristinsen and Lilja (2011) in pointing to a strong capacity for policy experimentation among state-level agencies, albeit they argue that success in Finnish ICT innovation in more recent years has altered these structures and diminished this dynamic capacity of state agencies.

Recent additions to political economy literature call for increased focus on innovation *directionality* and mission-oriented innovation policies (MOIP) through deliberate and direct strategic policymaking by the state (see especially Mazzucato, 2011, 2018). This increased interest in the role and leadership of the state has developed hand in hand with calls for a strengthened innovation policy response to address the climate crisis and other grand challenges (UNEP, 2017; Fagerberg, 2018; Henderson, 2021). In the Nordic context, recent literature has found that Nordic states are taking on MOIP-type innovation policy roles and mission leadership but in different ways, and that pre-existing policy frameworks and processes have not been replaced (Edquist, 2019; Giacometti and Jessen, 2024). For example, Giacometti

and Jessen (2024) find that the Swedish state has been active in adopting some top-down innovation ‘mission’ policy structures in line with its general strengths in national innovation policies, while the Finnish state has emphasised balancing new strategic policy frameworks and state directionality with bottom-up ecosystem growth.

In the context of this thesis and its research agenda, it is important to contribute to this evolving theory discussion about the role of the state in innovation and sustainability, by analysing the nature of the Nordic states’ (and state-level agencies’) involvement in discontinuous innovation ventures focused on sustainability transitions in traditional industry settings. The focus of this chapter is not on providing a general or comprehensive analysis of innovation policy frameworks and trajectories in Sweden, Finland, and Norway, nor on equal-term comparisons between them. Instead, this chapter leverages the empirical case studies into discontinuous green steel and hydrogen innovation processes, seeking to identify and analyse the nature and impact of particularly relevant and consequential state-industry relational dynamics within these contemporary cases. These cases of state-industry innovation enablers as they play out ‘in real life’ can then be compared to existing literature expectations about the role of the state in innovation and sustainability in general, and the role of Nordic national-level stakeholders and institutional settings in particular.

7.3 Methods and research setting – Tracing state-industry relational dynamics for Nordic discontinuous innovation in steel and hydrogen

This chapter builds on this existing research by focusing specifically on what discontinuous innovation processes rely on (or get impeded by) in their state-industry relations and socio-institutional surroundings in three Nordic countries facing traditional-industry sustainability transitions: Finland, Sweden, and Norway. Departing from the literature assumptions of

discontinuous breakthrough innovation only taking place in digital markets and metropolitan start-up ecosystems, but also departing from general-level political economy research that does not focus specifically on discontinuous change, this chapter brings a fresh angle in focusing specifically on the role of policy and regulation in enabling discontinuous innovation in traditional industry settings (in this case sustainability transformations).

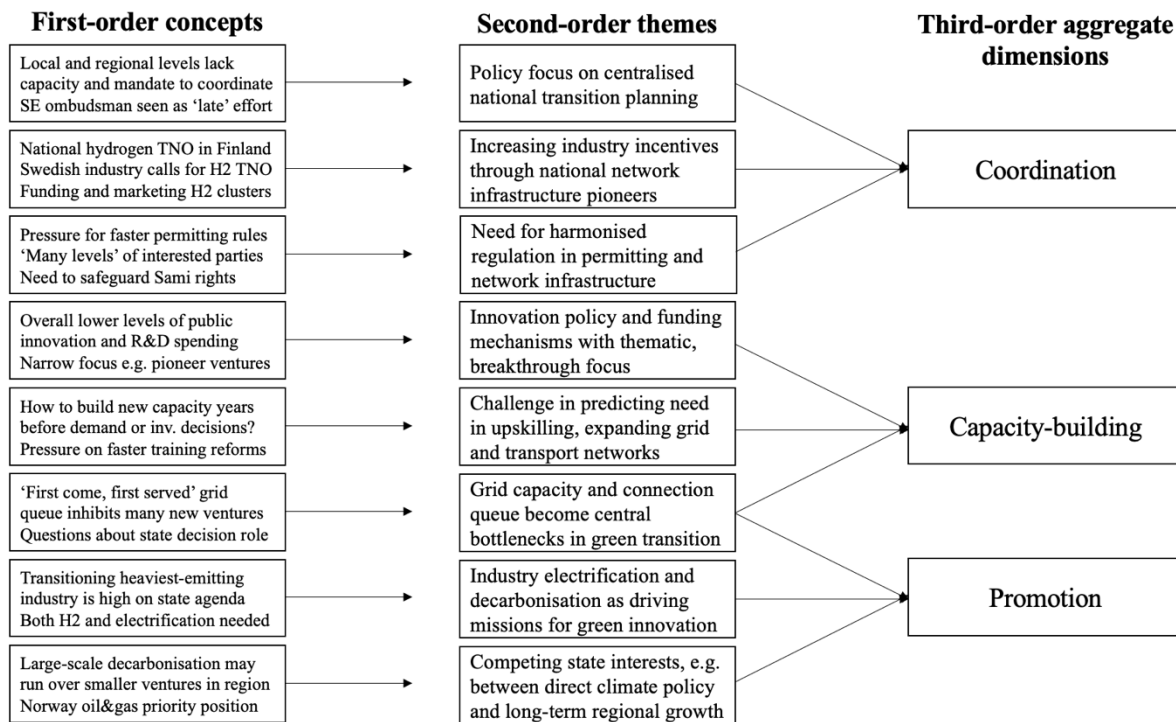
In order to mitigate biases and assumptions in existing literature and be able to follow state-industry interactions as they unfold, the impact of policy and regulation on industry innovation is observed predominantly through qualitative analysis (please refer to Chapter 3 for a comprehensive description of the case selection and research process, as well as the qualitative data sources used for this chapter). The chapter takes a perspective of state-industry relational dynamics where the processes of innovative ventures are studied in particular with two focus areas: Relational dynamics between innovative ventures and public policy (such as government ministries and innovation agencies) and relational dynamics between innovative ventures and regulation (such as infrastructure agencies and grid administrators) (Garud, Tuertscher and Van De Ven, 2013; Fagerberg, 2018). In this way, the chapter takes a pluralist view where impact is situational and enabled by a heterogeneous state and public sector. This is a broader perspective than recent literature on mission-oriented innovation policies, which accounts for the role of different agencies but fundamentally views innovation and industrial policy efforts as driven by deliberate and singular state-directed policy directionality (Mazzucato, 2018).

As has been elaborated in Chapter 3, the structure for further analysis and comparison of state-industry relational dynamics was developed inductively through iterative rounds of coding and grounded theory-building (Hammersley and Atkinson, 1995; Langley, 1999; Kellogg, 2011; Corbin, 2014; Eisenhardt, Graebner and Sonenshein, 2016; Bremner and Eisenhardt, 2021).

Given the importance accredited to the role of the state in innovation literature, each respondent across each case study was asked specifically about the nature of their interactions and exchanges with state-level actors and their assessment of the impact of these exchanges on innovative ventures. Each respondent representing a state-level stakeholder was similarly asked about their exchanges directly with innovative ventures and with other stakeholders in the innovation system, as well as about the specific process steps, background, and (their view of a) possible impact of these state-industry relational dynamics and of the state's role more broadly.

One specific part of the iterative coding rounds revolved around categorising the processes and interactions described by interview respondents as accurately as possible. For analysing state-industry relational dynamics, this meant identifying and categorising all prevalent exchanges between industry and state-level actors, not only in terms of the *ex-post* impact they may have had but from a process perspective, in terms of the nature and description of the interaction. This led to a compilation of second-order categories summarising the state-industry relational dynamics described in the empirical dataset (either in interviews or secondary materials). In turn, the second-order themes were analysed and compiled to form three dominant third-order aggregate dimensions, which together represent the main forms of engagement between state-level actors and industry throughout the empirical case studies. Figure 7.1 below summarises the analysis that leads to the categorisation of the empirical coding material into three main types of state-industry relations (Eisenhardt and Graebner, 2007; Gioia, Corley and Hamilton, 2013).

Figure 7.1: Coding framework for the case studies in Chapter 7



The aggregate innovation enablers emerging from this inductive analysis are the following: *Coordination*, where state-level actors take on the task of managing relations between industry and other stakeholders in order to enable and push forward innovative projects; *Capacity-building*, where state-level actors strengthen the innovative capabilities of industry and other stakeholders, and *Promotion*, where state-level actors substantively advocate and enhance industry ventures, almost at the level of full-scale 'missions' or 'national champions' (Mazzucato, 2018). These three types of innovation-enabling state-industry interactions are primarily chosen as they emerge from inductive data-driven analysis of how state-industry relations are described throughout the case studies. The three types are not necessarily all-encompassing, but they were chosen as the most comprehensive and discreet categorisation available based on the data. In addition, the features included in this categorisation are corroborated by general theory on state-industry interactions and relational dynamics in

political economy literature (Acemoglu, Johnson and Robinson, 2005; Block, Keller and Evans, 2016; Thelen, 2019).

Having thus categorised from a process perspective the different types of state-industry relational dynamics present in the dataset, we return to the question of reliably connecting discernible processes and interactions with signs of *impact* on innovation outcomes for case-study ventures. At this stage, the analysis of the present chapter becomes re-connected to the empirical analysis conducted in the two previous empirical chapters: Chapter 5 on firm-level innovation determinants and Chapter 6 on local-level innovation drivers. As is clear from the analysis undertaken in both of these chapters, state-industry interactions have an impact on these processes. This connection has also been elaborated in theory terms in the research agenda in Chapter 2. The state's role in innovation policy can be one of *direct* impact on the development and viability of an innovative venture, such as through direct funding of that venture as an innovation-policy priority (e.g. Mazzucato, 2011, 2018). However, the impact may also be *indirect* from the perspective of an individual firm or venture, such as when the state contributes to a learning-intensive economy through public research and education policies (Lundvall, 1992; Cooke, 2004). It can also be expected that the actual ex-post impact of state-level actions may not be identical to the ex-ante envisioned direct or indirect impact. This uncertainty and difficulty with discerning impact are emphasised particularly in contemporary research on complex sustainability transitions (Garud and Gehman, 2012; UNEP, 2017; Henderson, 2021; United Nations, 2023).

Therefore, the analysis of state-industry relational dynamics in this chapter proceeds with tracing and analysing, to the extent that it is discernible, both direct and indirect effects of described policy and regulation interactions in order to get a fuller picture of the role of the

state-level stakeholders in each case. In doing so, the analysis connects to the process elements already modelled and described in the two previous empirical chapters: four venture-level innovation determinants, and four local-level innovation drivers. In the previous chapters, these elements were identified and described from the perspective of how the observed innovation processes were developing, and how different stakeholders were shaping them through their inter-stakeholder relational dynamics. In this chapter, however, the focus is more narrowly on specific state-industry interactions, and the mechanisms identified in Chapters 5 and 6 are brought back to more efficiently observe signs of direct and indirect impact of state-industry interactions within the specific context of the empirical case studies included in this thesis. All interview accounts of state-related interactions were included in the initial analysis, after which the coding passages relating to specific case examples were analysed against the backdrop of the two impact categorisations brought in from Chapters 5 and 6.

7.4 Findings – Tracing state-industry relational dynamics and their impact

Table 7.2 below presents the summary of this analysis of direct and indirect impact of state-industry relational dynamics on sustainability-focused discontinuous innovation. The first column distinguishes between the three identified types of state-industry relational dynamics and presents representative examples of each as described in the case study dataset. While all of the six case examples involve several different state-level stakeholders, a distinction is drawn based on whether a specific case is predominantly a policy interaction or an effort undertaken by regulatory-type agencies. The second and third columns of the table subsequently trace each of the six cases in terms of how respondents (from all involved sectors and stakeholders) describe the impact of the relational processes. In column 2, the focus is on the direct impact on innovative ventures themselves, and the case descriptions have been connected to venture-level innovation determinants presented in Chapter 5. In Column 3, the

focus is on the indirect impact on local innovation networks and regional innovation systems that support industry transformations, and the case descriptions have been connected to local-level innovation drivers presented in Chapter 6.

Table 7.1: Comparing state-industry innovation enablers

<u>State-industry relational dynamics</u> (Coordination, Capacity-building, and Promotion as three identified types of enabling interactions)	<u>Direct impact on venture determinants</u> Initiative, R&D, Collaboration, Industrialisation (see Ch. 5)	<u>Indirect impact on local-level drivers</u> Early-stage venture coordination, Research-intensive innovation, risk-taking and investments, community engagement (see Ch. 6)
<p><u>Coordination interactions</u> Policy process: <i>Ombudsman for societal transformation in northern Sweden</i></p> <p>Regulation process: <i>Designated hydrogen TNO in Finland</i></p>	<p><i>Ombudsman: Ex-post strengthening of collaboration and industrialisation.</i></p> <p><i>Hydrogen TNO: Ex-ante boost to initiative and collaboration</i></p>	<p><i>Ombudsman: Enables venture coordination, lacks mechanism for risk-sharing and investments and community engagement.</i></p> <p><i>Hydrogen TNO: Enables risk-sharing and investments, centralises coordination.</i></p>
<p><u>Capacity-building interactions</u> Policy process: <i>'Leading companies' in Finland</i></p> <p>Regulation process: <i>Grid expansion in Norway</i></p>	<p><i>Leading companies: Enhances collaboration and R&D</i></p> <p><i>Grid expansion: Directs industry decarbonisation</i></p>	<p><i>Leading companies: Enables research and coordination, centralises risk-sharing and investments, lacks mechanism for community engagement.</i></p> <p><i>Grid expansion: Centralises coordination, divided impact on risk-sharing and investments.</i></p>
<p><u>Promotion interactions</u> Policy process: <i>Oil and gas electrification in Norway</i></p> <p>Regulation process: <i>Transmission network buildout in Sweden</i></p>	<p><i>Electrification: Enhances all venture determinants</i></p> <p><i>Transmission buildout: Directs industry decarbonisation</i></p>	<p><i>Electrification: Centralises coordination, lacks mechanism for community engagement.</i></p> <p><i>Transmission buildout: Centralises coordination, divided impact on risk-sharing and investments.</i></p>

Analysing and proving policy impact is notoriously difficult and uncertain. The present analysis aims neither to capture everything that the Nordic states do to support innovation, nor to cover all possible impacts and consequences of the mentioned policy actions, but to describe and compare particularly relevant examples from the case-study material. In this way, the table gives a more in-depth comparison between six instances of state-industry relational dynamics as they unfold in the innovation system. The following paragraphs of this section will present each of the representative cases in turn before moving to analyse and compare their characteristics in the subsequent discussion section.

7.4.1 Coordination interactions

i. Policy process: Ombudsman for societal transformation in Sweden

As has been established in previous chapters, the pace and scale of industry transformation through discontinuous innovation in northern Sweden has been the strongest out of all the Nordic regions. Due especially to a unique combination of resource availability, innovation and R&D capacity, and links to global capital markets, the Northern Swedish towns and regions have managed to attract and enable several billion-euro ventures that pioneer new business models and value chains for decarbonisation.

Through this development, the impetus for the HYBRIT green-steel venture (see Chapter 5) is a partial exception to the generally arms-length role of the state in these developments due to the ownership stake of the Swedish government in each of the three consortium companies (Vattenfall in energy and LKAB in mining are majority state-owned while SSAB in steelmaking retains a minority government ownership). There are also several active state-driven research institutions, such as the national-level RISE research agency. The Swedish state

has, in recent years, been active in experimenting and pioneering new top-down and mission-oriented policy frameworks for transformative innovation, such as the Strategic Innovation Programmes (SIPs) and the National Innovation Council (NIC) (Edquist, 2019; Grillitsch *et al.*, 2019; Giacometti and Jessen, 2024). At a general framework level, the state's role and discourse on innovation for sustainability transitions is thus quite active (Algers, 2024).

But overall, the initial relations between the pioneering sustainable industry ventures and the state and its different agencies are described as relatively arms-length (See chapter 6). Most of the ventures are fully commercial and privately owned, and rather than coordinating available resources in advance with various agencies, state-level stakeholders are generally seen to join the process of building and coordinating the new, decarbonised industry value chains only later in the process. For example, Robert Eriksson, Land Development Director at Luleå Municipality and with a background at the national railway agency, recounts: *“Right now I have weekly meetings of different kinds with state agencies. But it does take time to align with their planning and strategies, so there should be more space to move forward with temporary actions in the meantime”* (for coding detail, cf. the first box of first-order concepts in Figure 7.1 above). Klara Helstad, Head of the Sustainable Industry Unit at the Swedish Energy Agency, also comments: *“At the end of the day, companies need to decide for themselves, how to budget and whether to ask for state support. Many of them are driven completely without state intervention. A lot of our capacity to enable them depends on the complexity of the project”*.

Across the interviewed regional-level stakeholders, many view that more active state-level resources and leadership are needed and may have enabled faster and more flexible growth for innovative ventures. Karin Ahnqvist, HR Director at Umeå Municipality and with a

background in industry, comments: *“What nobody seems to have thought about is that the last time these towns were changing this quickly, during the first industrialisation, the regional level of governance hardly existed at all. So the state was responsible and active. Currently, the regions are left with tasks they have never been fully prepared for”*.

A singular policy action to create more flexibility and state-level response has been the creation of a specific office for coordinating the innovation and transition processes: The national Ombudsman and coordinator for industry transitions in Northern Sweden (Swedish: Samordnare – coordinator/ombudsman). The first of these, the experienced civil service executive Peter Larsson, was first appointed by the government in 2020 with the initial mandate of compiling a report on the ongoing ventures and transitions as well as make recommendations for their future support. Peter Larsson describes this role during a research interview in 2022, still within his active term: *“During the recession of the 1990s we developed successful models for transitioning from failing industries to booming ones. But we have no pre-existing model for how to support climate transitions within specific industries, where you suddenly need vast amounts of renewable resources and tens of thousands of skilled workers”*.

Larsson’s report was published in 2022 and included several calls for the government and agencies to take a more active coordinating role (Larsson, 2022). Partly in response to these calls and partly as a continuation of Larsson’s role as a network and resource coordinator, the Swedish government set up in 2024 a new Office for Accelerating the Green Transition, which is designed to oversee and connect the mandates of different agencies involved in the sustainable industry transition and the innovation processes driving it (Government Offices of Sweden, 2024). There is no directly connected change to funding programmes or existing

innovation policy, but the new office takes on the role of general coordination between stakeholders and state support.

The reaction from other involved stakeholders and government agencies on this coordinating role of Peter Larsson and his successors is constructive but also honest about elements where the actions have had limited influence. The positive impact of the coordinating efforts has been, in particular, in enhancing the communication and coordination capacity between the pioneering innovative ventures on the one hand, and the key governmental stakeholders on the other hand. A respondent at the national transmission grid administrator comments: *“Of course we have already been in contact before, but this has really helped clarify the communication links, to ministries, to companies, to be able to cut the process times and be clear on who is in need of what and even to already know that person. It’s very relationship based problem solving”*.

Other respondents point out that what is generally lacking is connecting these higher-level executive networks more closely with local communities in the region – both including communities directly affected by large-scale discontinuous ventures and communities outside of the immediate vicinity of the new green industry facilities. John Moodie, Senior Research Fellow at the Nordic Council of Ministers in Stockholm, comments: *“We are seeing a tendency where national government directs towards economic and technical dimensions of the transition, whereas the social impacts risk becoming a little bit sidelined”*. And Lotta Finstorp, the County Governor of Norrbotten, concurs: *“It is historical what’s happening here and there really is not a premade model. This is why the government appointed an ombudsman for the two northern counties. The problem is that there is a support structure and different options at government level when a municipality loses jobs. But there is no structure for areas that are in*

quick expansion, even though it is very expensive for a society to grow quickly... You need new schools, preschools, elderly care, infrastructure, roads to new industry sites... with all those expenses it becomes almost impossible for small municipalities. And it seems the government essentially tells the municipalities that it will be payback time when the growth has happened and new taxpayers have moved in. But that is really like comparing apples and oranges, the model does not work”.

To summarise, the Swedish state and its various agencies have had a gradually strengthening (albeit generally *ex-post*) role, which has sought to meet the unprecedented challenges created by fast-growing innovative ventures through increased and more efficient coordination between stakeholders and resources. However, the task has faced several complexities in harmonising different interests and needs, and the state’s response is still viewed, especially by some local-level stakeholders, to require more tools for substantive and timely innovation support, both for specific ventures’ needs and for wider regional development.

ii. Regulation process: Designated hydrogen TNO in Finland

The proliferation of sustainably produced hydrogen gas (and its several downstream derivatives) as a part of transitioning to a fossil-free energy system has been driven by very different types of ventures and projects in different parts of the world (see Chapter 6). In the public sector, there have been various degrees of policy response, ranging from the relatively conservative to the very ambitious (such as governments devising and implementing national hydrogen strategies with several different elements for promoting hydrogen-focused business and research) (OECD, 2022; AFID, 2024). In addition, countries such as Finland have taken specific regulatory steps already at the pre-market stage of coordinating hydrogen innovation. Finland’s action has been to designate a Hydrogen Transmission Network Operator (HTNO),

a TNO with the express mandate of building up transmission networks and pipelines for hydrogen gas to incentivise new hydrogen-driven businesses (the abbreviation TSO, for Transmission System Operator, is also used). The regulatory decision is particularly important in the Finnish energy context, as there is no pre-existing nationwide transmission infrastructure for natural gas that could be modified for hydrogen transmission. The Finnish hydrogen TNO, founded in 2019, is called Gasgrid, and is under the authority of the National Ministry of Employment and the Economy (Gasgrid Finland, 2024).

An executive at Gasgrid explains the agency's mandate in more detail: "*We are not literally building hydrogen pipelines just like that. Rather, we have a number of regional pipeline projects where we are coordinating different actors to trial viable hydrogen networks over time, as a proof of concept for larger infrastructure networks and functioning hydrogen markets*". Rather than outright funding or venture promotion, the assignment of Gasgrid as a national TNO has predominantly a coordinator's role and relation to the energy sector. What this coordination does amount to, however, is an increased confidence in new hydrogen investments and a sense of market-building already at a very early stage of including the 'hydrogen economy' as part of the wider energy system. The Gasgrid executive continues: "*For example, along the Western Finnish coast, our presence has incentivised several new companies, helping them to get funding. We are also in touch with incumbent players, who can start to develop their hydrogen strategies as part of a wider momentum rather than on their own*". Indeed, one respondent based within the Vaasa regional energy cluster summarises: "*Hydrogen is fundamentally a network resource, which needs pipelines and a large area coordinating its energy use. So the state becomes very important in this*". For the Vaasa area and Western Finland, the active commitment by the national Gasgrid administrator company to initiate hydrogen network projects such as the *Nordic Hydrogen Route* is confirmed by

several interviewees to have increased the regional industry commitment that hydrogen-driven applications are worth researching and investing in (Business Sweden, 2023).

The coordinating effect of the national hydrogen TNO is also being felt across the border in Northern Sweden. As an energy company executive comments: *”While Sweden has no hydrogen TNO of our own, we energy companies take on a larger responsibility of coordinating different projects. But at the same time, it helps that Gasgrid in Finland comes with such momentum, for example, through our joint project to create a pipeline that connects Finnish and Swedish hydrogen markets”*. Björn Santana Arvidsson, Deputy Managing Director of the Swedish energy company Nordion Energi, also comments: *“We believe Sweden is need of a designated HTNO in order to fully benefit from the current momentum and not fall behind in the development. We have let the government know that we stand ready to take on that role. Nordion Energi has the knowledge, experience, large-scale projects as well as being on the Board of a European organisation for HTNOs”*.

Indeed, the comparison to Sweden illuminates the effects of the Finnish decision to designate Gasgrid as a hydrogen TNO and as a separate agency. On the one hand, there is an undeniable advantage in increasing investor confidence and thus improving the risk landscape for new ventures and research projects surrounding hydrogen-driven energy systems and cross-sector value chains. On the other hand, as an indirect impact, the decisions and regulations pertaining to hydrogen ventures become much more centralised in a setting where one actor is the designated hydrogen TNO than in one where several energy companies share the role of coordinating new ventures with governmental (or state-assigned) stakeholders.

7.4.2 Capacity-building interactions

i. Policy process: 'Leading company initiatives' in Finland

The innovation policy of the Finnish government in recent decades has rested on strategically building innovative capacity across key industries rather than overtly 'picking winners' (Jäntti and Vartiainen, 2009; Breznitz and Ornston, 2013). In recent years, the 'developmental state' innovation policy momentum has been a bit less pronounced: for example, government ownership share of previously state-owned companies has been reduced, and the companies still under state ownership follow strict competition and state aid guidelines within national legislation and as mandated by membership in the EU. Nonetheless, Finland's capacity-building innovation policies, ranging from relatively high public R&D expenditure targets and active involvement of labour market coordination in supporting export-industry development to a long-term research and training strategy in key industry towns across the country, have resulted in one of the most renowned and successful National Innovation Systems (Jäntti and Vartiainen, 2009; Kristensen and Lilja, 2011; Ornston, 2014; Alaja and Sorsa, 2021; Giacometti and Jessen, 2024). Except for Nokia, there have been few 'boom-and-bust' innovation stories, and instead the expertise and innovative capacity is spread out across a wide network of businesses and both private and public stakeholders. However, in recent years, both the coordinated, programmatic NIS model of the government and the relative size of public R&D spending has been lower, and there has been general confusion in literature over the directionality of Finnish innovation policy (Alaja and Sorsa, 2021; Giacometti and Jessen, 2024).

In the case of state-industry relations in the Vaasa cluster, as described in Chapter 6, the state's overarching role in the development of the region's innovative capacity is viewed as relatively

arms-length, mirroring the findings in the northern Swedish case described above. A Vaasa-based industry executive summarises: “*Of course the state is important, for example, many key decisions such as what university facilities to place here can be attributable to the state, and these have of course been crucial. But lately our innovation projects cannot be said to be driven very strongly from Helsinki. It is almost that they come here on field visits to figure out exactly how we are doing so well up here with our own resources, they cannot seem to understand how we work*”. In other words, many innovation-enabling activities of the Vaasa innovation networks are locally coordinated. This is confirmed by research findings that the regional level has not traditionally been in focus in Finnish innovation policy, although regional and national innovation policy efforts have subsequently co-evolved over time (Sotarauta and Kautonen, 2007; Giacometti and Jessen, 2024). EU funding has also played an important role in many projects, and these have been applied for and granted “*by skipping a level and going directly to Brussels*”.

However, at the R&D and early venture stage, recent policy actions have increased the focus on building the capacity of clusters and ecosystems, including strategically supporting ‘Leading companies’ and flagship projects (*Finnish: Kärkihanke*) that are deemed particularly promising and important for the national economy in the long-term (Giacometti and Jessen, 2024). This policy direction still does not constitute outright *dirigisme*, especially as the state support is concentrated at the seed and growth funding stage. However, especially in comparison to the earlier arms-length tradition in Finnish innovation support for regional clusters, these recent policy programmes stand out as a partial turn in innovation policy priorities towards stronger capacity-building involvement by policymakers and state agencies. Rather than outright mission-oriented innovation policies (MOIP), the turn in Finnish policymaking has been towards strengthened support of regional ecosystems (*ibid.*).

One of the main programmes implementing this vision in Finnish innovation policy is that of the *Veturi* (Finnish for locomotive) projects. The national innovation agency, Business Finland, is the administrator for seed and research funds, which private stakeholders can apply for under a designated fund that grants support for ventures at the forefront of promising new sectors and technologies (Business Finland, 2024). The Power-to-X-to-Power project presented in Chapter 6 is one of the first ventures granted funding under the scheme, in 2021, which acted to reassure both consortium participants and external partners of the viability and importance of the project for the Vaasa cluster and the Finnish energy system at large. As an energy company executive part of the consortium for that project explains: *“Each of us involved stakeholders, we knew each other from before, but if it were not for that funding from the state we would not have embarked on this project”*. Another respondent continues: *“The state has not usually been a very active player in our operations, but in this case the legitimacy of the Veturi fund has brought in a lot of stability and trust in the project”*.

In sum, the Finnish turn towards ‘Leading company’ type innovation policies – as a complement to other innovation policy measures – works foremost as a capacity-building measure, while the collaboration mechanisms for stakeholders using the funds were pre-existing at the local level. At the same time, the funds are also indirectly centralising the risk-taking and investment activity in lieu of other stakeholders in local and regional innovation systems, thus increasing the state’s role over time, also in domains where it had previously held a less active role. Indeed, several respondents familiar with the recent energy-intensive innovation ventures in the case of Vaasa as presented in Chapter 6 emphasise that several state-driven policies (including both the Veturi fund and the Gasgrid hydrogen TNO) have contributed to shifting the previous dynamic or predominantly regional-driven innovation in Vaasa to increasing capacity-building and active coordination also from the national level of

administration (OECD, 2022; Giacometti and Jessen, 2024). As the Vaasa region has lacked some of the time and resource pressures created by the large-scale investment wave in northern Sweden, the capacity-building and coordinating role of the state is not generally seen as insufficient by respondents in the Vaasa region. But neither has there been an overarching state-level mission to completely shift the status quo in the innovation policy framework surrounding sustainable industry transitions, a process which has been viewed as more active in the case of Sweden (Grillitsch *et al.*, 2019; Giacometti and Jessen, 2024).

ii. Regulation process: Grid expansion in Norway

The Norwegian economy, and in particular its energy sector, has been dominated by drilling and refining petrochemicals for the past five decades (OECD, 2017a). In recent years, there has been an active policy turn towards renewables, understanding that Norway's location and characteristics lend themselves well to energy-intensive industries produced by renewable energy sources (OECD, 2021; Szulecki *et al.*, 2021).

One way in which the fast-growing momentum for sustainability-focused innovation is showing in Norway's energy and industry sectors is that, like in many countries, some parts of the country are facing capacity shortages in the electricity grid. Similar to Northern Sweden (see Chapter 4), the high-voltage grid infrastructure has reached its capacity in the northern Norwegian regions, which are more sparsely populated but have a large renewable energy production capacity and further potential, especially for wind energy production. As a result of this, one of the most important questions of government planning and regulation in Norway from the perspective of sustainable industry transitions has become that of grid capacity expansion: Where to prioritise expansion, under what grounds, whom to grant connection rights, etc. Silje Ingebriidsen, Business Development Director at Alta Municipality and with

experience in the energy sector, explains: *“Especially the high-voltage 420 power grid has become a crucial question for Northern Norway. Without new capacity that benefits local ventures and enables new production facilities, I fear that no new green industry can be built in North Norway for many years”*.

A tangible example of the role played by this physical capacity-building function of the state is that of the Berlevåg hydrogen innovation venture presented as a case study in Chapter 6. While this venture has faced several challenges ranging from funding and investor confidence to building value chains and partnerships, respondents emphasise that the most decisive of these and the ultimate determinant of the fate and pace of the venture is that of grid capacity. Kjell Richardson, Business Developer at Berlevåg Municipality, emphasises: *“There is no such thing as an off-grid wind farm, because of the need to balance out spikes in production. So while we have both the available wind energy production, and the perfect downstream production facility for green hydrogen, without a grid capacity expansion we are not going to reach a sufficient production capacity to realise the next step of our vision of a green ammonia plant as a derivative of green hydrogen. Waiting for this could take three years, or it could take fifteen years”*. A project manager at the local energy company Varanger Kraft summarises further, highlighting the significant impact of these bottlenecks on the project: *“I am in discussions with large industry conglomerates every week about the investment into an ammonia plant – but right now, we are all just in a waiting game. While the hydrogen and ammonia facilities would be using up power, the new wind power still has to be connected to the grid in order to balance the energy production and consumption hikes – we cannot have a fully off-grid facility of this scale. We do not need the entire 200 MW transmission capacity all the time, but it is imperative for our local industry plans that we get to build the second part of the wind farm in full. Without the grid capacity for an expanded wind farm, there will be no*

ammonia plant, no industrial park – it is all dependent on this”. This also highlights the demand for increased flexibility in grid transmission regulations, as the required capacity in Berlevåg is technically not a demand for continuous full-capacity transmission out of Berlevåg but rather for connecting to the grid as a balancing mechanism.

Another aspect of the centrality of the grid capacity issue, as is the case also with the coordination of hydrogen infrastructure in the Finnish case, is that coordination and decision-making become more centralised, placing more authority with state-level actors. In the case of Norwegian grid capacity expansion, and energy production more broadly, this may be significant as there are several questions of local governance tied to many ongoing and past disputes around the energy system. Many municipalities have denied access requests for new energy facilities (especially wind farms) on their grounds, and much of existing energy production is owned and administered by municipal and regional energy companies and consortia. Moreover, the indigenous Sami population has frequently voiced its concerns over the adverse effects presented to reindeer herding livelihoods by the expanding energy sector, and the legal and regulatory disputes as a result of these tensions have been numerous, with a recent supreme court case being the first to rule that an existing wind farm had been completed without due concern to indigenous rights and should be removed (the parties later settled the dispute without deconstructing the wind farm) (Reuters, 2024).

In other words, the question of grid capacity expansion and its regulation is becoming a complex but crucial part of the sustainable industry transition in Norway. The capacity-building question has the power to direct and hold up innovation and industrial decarbonisation in entire regions, both when it comes to energy supply and demand ventures. Moreover, the

centralisation of more *de facto* power with the state due to the emerging bottlenecks is bringing, as an indirect impact, an added layer to already complex local and regional policy debates.

7.4.3 Promotion interactions

i. Policy process: Oil and gas electrification in Norway

Aside from regulatory and administrative issues around grid capacity expansion in Norway, the sustainable industry transition is also increasingly a matter of direct innovation policymaking and politics. In comparison with the wider Nordic region, some elements of the Norwegian innovation policy focus on renewable energy have been streamlined and targeted ‘moonshot’ type capacity-building, such as the fast rollout of one of the world’s most extensive electric vehicle charging infrastructures (OECD, 2021). On the whole, however, interview respondents align with the findings of recent research that both state innovation capacity-building in general and the momentum for sustainable industry and energy transitions, in particular, have been less pronounced than in neighbouring countries (Grønning, Moen and Olsen, 2008; OECD, 2017a, 2021; Szulecki *et al.*, 2021). Some respondents directly call out the link to the petrochemical industry: “*It feels a bit like we in Norway have been caught napping with this transition due to our long reliance on oil and gas*”. Indeed, a recent report emphasises that a balanced transition where the oil and gas sector plays a continued role in the economy has clear majority support in Norwegian politics (Szulecki *et al.*, 2021).

For industry electrification, one of the key priorities for Norway in order to live up to its international climate action commitments is the electrification of the petrochemical sector. While fossil fuels are being phased out in the long term, the emissions from their production facilities can be dealt with in the short term. This has led to specific policy support for grid

capacity expansion and increased renewable energy production to cover the increased demand from oil refineries under transition (Szulecki *et al.*, 2021).

However, these clear policy priorities are not disconnected from wider Norwegian industry and innovation capacity, and the political momentum towards electrification of existing industries is leading to the risk of adverse trade-offs in developing new sustainable industry ventures. This is noticeable in different parts of Norwegian innovation policy, but in particular in the earlier described process of building out and managing new grid capacity expansions and connections in the north of the country. As Per Erik Ramstad, Director at the Alta Kraftlag regional energy company, recounts: *“There was recently a new high-voltage line that was finished, but while we had hoped that this was great news for both new production and for new energy-intensive green industry ventures, we received a note at the end of our previous 22MW connection approval from the grid administrator that further requests would not be approved due to reserved connection capacity for the electrification of (the state-owned oil company) Equinor’s Melkøya LNG plant”*.

The Melkøya LNG plant in Finnmark is Norway’s single biggest emitter of CO₂, and its electrification was approved by the Norwegian government in 2023 and underlined as a flagship policy priority and opportunity for the regional economy (Staalesen, 2023). However, the policy trade-off between sectors has become tangible, as Per Erik Ramstad, Director at the Alta Kraftlag regional energy company, continues: *“Practically all new connection requests are now being denied, and this has become a political discussion in the industry. It is also a political discussion whether electrification of the LNG plant is right in this moment, where they do not need to do this to operate the plant”*. A recent OECD report (2021: 17) highlights this general and political paradox relating to electrification of national emissions targets: *“While*

Norway is not accountable for the emissions resulting from the oil and gas it exports according to international laws and regulations (including the Paris Agreement), the extraction and transport of fossil fuels accounts for 15% of global energy-related emissions”. Another recent report notes that Equinor’s estimated 10-12 TWh energy demand for oil and gas electrification constitutes circa 7% of Norway’s total electricity production (Szulecki *et al.*, 2021).

For the Berlevåg hydrogen venture, the involvement of state-level actors and agencies has been relatively reserved, with the exception of some grant funding from innovation agencies Innovation Norway and the National Research Council. The municipality of Berlevåg has been requesting additional support, both in terms of funding and other strategic resources, throughout the development of the hydrogen project. While the communication link exists, stakeholders in and around Berlevåg report that national-level engagement with the project is sparse. On the one hand, the Norwegian model of public policy is allowing for the persistent survival of very remote communities such as Berlevåg (Fellman *et al.*, 2008). On the other hand, there is little national-level strategising over these most remote communities as playing a decisive role in scaling up discontinuous innovation projects. Moreover, while not an EU member state, the multi-partner hydrogen project was still eligible for EU-level support which, like the other case studies, is being coordinated directly with the local administrative level rather than via the state (Teräs *et al.*, 2023). One Berlevåg-based respondent summarises the current level of momentum and engagement: *“For them, we are simply so far away and not plausible in our innovation efforts. They are looking at using renewable energy capacity for other, prioritised projects in the city regions”*.

While the relative lack of national-level support has not been fatal to the Berlevåg hydrogen project *per se* due to the high level of local commitment and risk-sharing, the lack of national-

level legitimacy is inhibiting the project's future prospects indirectly: Prioritising other localities and industry sectors over Berlevåg in the expansion of the national electricity grid is significantly slowing down the scale-up of the hydrogen project and the commitment that Berlevåg can offer when negotiating with potential industry partners to join the value chain. One respondent with long energy-sector experience describes: *“The grid capacity is clearly a problem. Our wind farm often has to curtail production on purpose because there is not enough capacity to transmit the electricity to demand areas. We also have a licence for building the second half of the wind farm, but this was recently withdrawn from us due to lacking capacity. We did manage to negotiate to get the licence back, but we do not have full concession for the grid transmission yet, so negotiations continue. As goes for the electrification of the oil industry and other decisions impeding the capacity for new production and supply, I hope the authorities do some rethinking there as this could really slow everyone down”*.

As is the case both for the grid capacity expansion efforts on their own and for the broader policy prioritisation on oil and gas electrification, the state has an important policy role to promote and enhance ventures, but in the case of sector trade-offs a question immediately arises as to the right way of making priorities. Especially from the ‘indirect’ perspective of local and regional stakeholders, state-driven innovation strategies do not include a mechanism of comparing and ranking the merit of local and regional level targets that may be very significant to some regions but do not apply across the entire country.

ii. Regulation process: Transmission network buildout in Sweden

To a large extent, the northern regions of Sweden face similar discussions over electricity grid capacity as do the northern Norwegian ones. In the Swedish case, the sustainable industry transition is already underway since several years of new and incumbent ventures competing

for capacity and resources (see Chapter 5). On the one hand, the situation becomes more straightforward as most involved stakeholders can agree on the prioritisation around grid capacity buildout. For example, as one energy executive explains: Maria Jalvemo, Program Manager at the Swedish Grid Transmission Authority, comments: *“We have really had to adapt and learn new practices at record speed, for example with regard to shortening lead times – and this is not something we should take for granted. There are still many challenges in the grid infrastructure left to figure out because of this major transition that we are facing”*.

On the other hand, after a few years of intense transition momentum, some new tensions and paradoxes have become emerged because of path dependencies and lacking overall coordination on capacity allocation. One of the tensions surrounding the state’s role in promoting grid buildout is what parameters or rules the existing capacity allocation should follow. As described earlier, the Swedish state has had an enabling and role in the initial stages of the large-scale projects, especially surrounding the HYBRIT green-steel venture and its state-owned parent companies, but also through general innovation policy mechanisms for different ventures (Algers, 2024). But at the same time, the modalities of making prioritisations along the lines of those projects in other state capacities, such as grid capacity provision, have remained unclear to involved stakeholders. The ever-evolving situation with new ventures and changing production and capacity targets does not make the equation easier. Maria Jalvemo, Program Manager at the Swedish Grid Transmission Authority, continues: *“We are still unsure of how exactly to frame a fair and transparent connection process for some actors, for example in some countries they have prioritised projects based on some measure of societal impact. What we are at least going to do is to start requiring a report from applicants of the intended use of grid capacity, so they cannot just apply for a lot of power and only later on start planning what to do with it”*.

Government agencies are, thereby, seeking to enhance the coordination and openness about more realistic targets and political priorities in order to make the most out of existing capacity and seek a fair distribution. This has taken place through both state-led and regional initiatives. Robert Eriksson, Land Development Director at Luleå Municipality, recounts actions at the regional level: *”Since the past year or so, the respective grid transmission and distribution companies, and industry stakeholders and other customers, are to an increasing extent sitting down together under non-disclosure agreements and managing to formulate common aims for grid expansion and how to make sure the available capacity is used efficiently. This process has been completely unique”*. Klara Helstad, Head of the Sustainable Industry Unit at the Swedish Energy Agency, confirms this: *“We are constantly finding new ways of working with the region, including by companies being honest about their needs to their competitors to a much greater extent than before”*.

What these measures of grid capacity regulation and expansion are yet to resolve, however, is that the ongoing uncertainty about exact capacity provision to industry ventures is having an instant effect on the risk climate among investors, partners, and customers of those ventures. This risks creating an adverse indirect impact on business and innovation, especially for start-up ventures and others that are financed mostly by external means rather than their own capital. Mikael Lindström, Head of Public Affairs at H2 Green Steel, comments: *“The changing of power allocation principles, with retroactivity and poor transparency radically changed the premises for our investment. This kind of large project financing projects need long-term stability when it comes to regulation”*. In other words, the current stage of sustainability and innovation policy and regulatory promotion in the Swedish energy sector is facing the added complexity that different ventures have different needs that do not necessarily align with how the energy system for industry has been coordinated in previous decades.

The uncertainties surrounding the nascent hydrogen infrastructure buildout are even greater, as described by Cecilia Wallmark, Director of the CH2ESS hydrogen research centre in Luleå: *“I co-authored the first Swedish plan for building hydrogen refuelling infrastructure ten years ago, and we called for a transport fleet and a network of hydrogen refuelling stations. And while the buildout of refuelling stations recently has been well funded and in line with the EU alternative fuel infrastructure regulation (AFIR), I do feel frustrated because we also need to get the vehicle fleet in place. This is a typical prioritisation question, and I am convinced this could have happened more efficiently and convincingly if there had been clearer collaboration between the agencies and the market stakeholders. Now agencies each gave support in different ways, just assuming that the refuelling stations would be maintained without support to vehicles”*. In summary, both for electricity and hydrogen gas infrastructure, the path dependencies, market-building incentives, and different stakeholder interests framing Sweden’s strong momentum in discontinuous innovation for sustainable industry transitions are leading to complex and changing pressures and indirect effects across industry sectors and regions, to which the Swedish policy and regulatory agencies are continuously seeking to align.

7.5 Discussion – Cross-case comparison and theory implications

7.5.1. Cross-case comparison

When the preceding case studies are viewed together (see Table 7.1 above), the resulting cross-case comparison gives us insight into the specific enablers at play in state-industry relational dynamics for discontinuous innovation in traditional industry settings. This is made possible, in particular, as the moment in time (major industry transformation around sustainability), type of industry (energy and material resource intensive), and general socio-institutional backdrop

(Nordic coordinated market economies) are all relatively static across the cases (Eisenhardt and Graebner, 2007).

i. Comparison across state roles

The most straightforward comparisons to analyse from the preceding case examples are those made possible through the structuring of the empirical framework, i.e. the division of the case studies into three different state role types, into policy-focused vs. regulation-focused cases, and into impacts from the state-industry interaction examples as either direct or indirect. These distinctions emerged from the data analysis process as the clearest ways to categorise the described state-industry relational dynamics. The way the different cases compare to each other along these parameters can yield further insights for understanding the roles and boundary conditions of the state's involvement in discontinuous innovation processes.

The three identified 'types' of state involvement (coordination, capacity building, and promotion) all seem to provoke relatively similar sets of direct and indirect impacts and trade-offs. The type of state-industry interaction thus does not seem to have a very significant differentiating effect on how discontinuous innovation ventures develop: for example, one type of state-industry interaction is not unequivocally prone to focus much more on direct venture-level impact than another.

However, the specific mechanism of the impact (i.e. which elements of direct and indirect impact are involved) does vary to some extent across the three types. In particular, where the state-industry interaction deals particularly with *coordination* between stakeholders, there is less risk of path dependency and resource lock-in effects surrounding the state-industry interactions. This is visible in how industry respondents describe public-private coordination

activities for sustainability transitions: almost exclusively as constructive and useful to them, without any clear downsides either directly for innovative ventures or indirectly for the surrounding innovation system. The work of the Swedish ombudsman Peter Larsson, for example, is brought up frequently by respondents with different backgrounds and always from a perspective that more of the same coordination-focused action would be crucial. Increased coordination between stakeholders to solve bottlenecks and find new resource-saving synergies was also a main theme or statement arising at several industry conferences in the case-study regions during the research period (see Chapter 3).

On the other hand, state-industry relational dynamics that revolve around *capacity-building* and *promotion* are both more politicised and potentially divisive, as these types of state intervention involve more decision-making on the allocation of resources and infrastructures. While building more capacity either in terms of physical energy infrastructure or in skills and local competencies are generally agreed across stakeholders to be crucial for innovation, and while energy-intensive industries generally agree on the political promotion of net-zero targets, the interview accounts given around the case studies on capacity-building and promotion in the energy system demonstrate the trade-offs involved in these state-level actions. For example, the Norwegian cases demonstrate how promotion and capacity-building with very direct targets can adversely impact the innovation capacity of the surrounding innovation system.

It is important to recognise that these differences between the three types of state involvement, and in particular the relative popularity of supporting innovation processes through coordination, are likely shaped in part by the Nordic tradition of corporatism and coordinated market economies (Hall and Soskice, 2001; Fellman *et al.*, 2008; Kristensen and Lilja, 2011). Industry respondents recognise that the atmosphere of trust and openness among partners in

the innovation system and the eagerness to share information and look for synergies may be unique compared to many other regions of the world. But even in these industry settings, there is also continuous competition for both physical and human resources, and many state-driven actions to increase coordination turn out to be much more complicated to implement and maintain than they are to announce.

ii. Comparison across state-level actors

The empirical analysis has identified state-industry relational dynamics as potentially developing differently depending on the type of state actor involved. While innovation policy literature generally treats the state as a relatively homogenous actor, it is clear that there may be differences in relational dynamics between different types of state-led agencies. From the perspective of Principal-Agent theories of governance, the distance of a state-level agent from the main principal (the national government) has been shown to have a bearing on how the agent operates, for example, in the case of *peripheral agencies* (Breznitz and Ornston, 2013). Based on the empirical research, this chapter has highlighted three cases of state-industry interaction engaged through policy positions of the executive branches of government (the Ombudsman and later the Acceleration Office in Sweden, ‘Leading company initiatives’ in Finland, and oil and gas electrification promotion in Norway, all spearheaded by government ministries and departments even when implemented by a devolved agency), and three cases where decisions are engaged predominantly by state-level independent regulatory agencies rather than actors implementing an overt government policy agenda (hydrogen network operator in Finland, electricity grid operators in Sweden and Norway). This categorisation is clearly not definitive: On the one hand, government ministries are overseeing and directing national grid operators, and on the other hand, many government-adjacent offices such as the Swedish Ombudsman may well be granted a wide operating mandate akin to an independent

public agency. However, in line with the general rationale of Principal-Agent theory, grid operators are nevertheless more independent of political cycles and prioritisations for their core functions.

Comparing the empirical case studies indeed shows a difference in how state-industry relational dynamics unfold across different state-level actors. On the one hand, processes involving governmental policy actors are often more actively featured in public discourse and government communications, while processes involving independent regulatory agencies are less politicised. For each of the cases involving independent regulatory agencies, timeline analysis shows that both media coverage and respondent testimonials appear at later stages in the research period than for the cases engaged by governmental departments. On the other hand, the three cases engaged by independent grid agencies are all more complex in their state-industry relations because these cases demonstrate material bottlenecks surrounding grid expansion and capacity that the three other cases do not. For example, the electric grid capacity expansions in Sweden and Norway have led to trade-offs and industry uncertainty. In contrast, Norway's governmental mission to promote oil and gas electrification has been questioned by several stakeholders but has not formally met with a lot of regulatory bottlenecks (Staalesen, 2023).

Relatedly, what also emerges from the cross-case comparison is that the state-industry relations of governmental/policy actors often lack comprehensive engagement mechanisms with local community stakeholders. This does not mean that independent regulatory agencies unequivocally have well-working relations at the local level, but the national regulators and operators do nonetheless follow clear mandates for local engagement, while new governmental missions may not have specified this as clearly. This may, in part, explain the differences in

path-dependency and bottlenecks between different state actors: While actors closer to government departments have fewer interaction channels with local communities, this may also mean such processes do not engage as deeply in system-level transitions across different stakeholder groups and levels of governance. A transition process started by a grid operator gains less public coverage but may face more extensive implementation hurdles because these processes are more dependent on pre-existing industry infrastructure and incumbent regional industry networks.

iii. Comparison across direct and indirect impact of state-industry relations

The preceding analysis of state-industry relations identified six Nordic case-study examples and traced their perceived impact on sustainability innovation across two main mechanisms: Direct impact on innovative ventures (making use of the venture-level innovation determinants introduced in Chapter 5) and indirect impact on the surrounding innovation environment (making use of the local-level innovation drivers introduced in Chapter 6).

Comparing across the case studies, the overarching pattern is that direct impact on innovative ventures evolves largely as expected by state-level actors, whereas indirect impact on regional stakeholders brings both intended and unintended consequences. The most common of the unintended consequences is the finding that the state-industry interactions in the case studies centralise different elements of the innovation process from the perspective of local and regional stakeholders. For some initiatives, such as the Finnish ‘Leading companies’ scheme and the Norwegian promotion of oil and gas electrification, the risk-taking and risk-sharing for innovation investments becomes more centralised along the lines of pre-formulated innovation missions. For other initiatives, such as the Swedish and Norwegian grid expansion processes, the state-industry interaction either lacks an element of risk-sharing entirely or has not yet

settled on a new model, which results in trade-offs and bottlenecks as new capacity is directed towards specific ventures or facilities. Depending on which stakeholder is asked, therefore, not all of the indirect innovation impact of the described state-industry relations is useful for local industry development, and some actions are even viewed as detrimental. This is most clearly the case in northern Norway, where electrification of the incumbent oil and gas sector has taken precedence over new ventures. A similar pattern is also somewhat recognisable in northern Sweden, although new and more transparent models are actively being experimented and developed.

Looking more closely at the different innovation determinants and drivers affected in both the direct and indirect impact categories, the majority of perceived impact across the intended, direct state-industry relations relate to supporting and speeding up more mature-stage ventures and transformation processes. Some actions, like the Finnish Gasgrid TNO and the ‘Leading company initiatives’ schemes, have clear impacts on boosting very early-stage projects that may not otherwise have the enabling conditions to scale up and industrialise their operations. But most state-level actions described in the case studies are taken in relation to ventures that have already passed the very initial stages of funding, risk-taking, energy allocation, etc. This echoes many interview testimonials from both industry and local and county government, where state-level actors are generally viewed to have acted cautiously in supporting the discontinuous innovation ventures. Through state-owned enterprises, research facilities, and numerous regulators and agencies, there is of course a continuous connection and state-industry relationship from the outset. However, in terms of overt and direct support, few new measures are seen to support the scale-up of discontinuous, fast-growing ventures in the way envisioned in, for example, recent literature on mission-oriented industrial policies (MOIP) (Mazzucato, 2018; OECD, 2021; Giacometti and Jessen, 2024).

It is, again, at the level of unintended consequences, and especially at the level of regional innovation systems, where the state-industry relations have a more far-reaching and potentially pivotal impact. Where state-industry relations manage to have a constructive impact on local-level risk-sharing and venture coordination, the regional innovation systems in the Northern Nordic countries have clearly benefited. For example, the area surrounding the Gulf of Bothnia (including Vaasa, Boden and Luleå) has become increasingly networked and ambitious in its transformation agenda, partly as a result of Swedish and Finnish actions taken by gas and electricity grid operators and other agencies to open new collaboration channels and strive to guarantee investment security. In fact, actions taken in one country are even creating ripple-effects in other countries, as can be seen by the increasing momentum in North Sweden to plan hydrogen pipeline networks even in the absence of a centralised hydrogen TNO. But these more complex impacts on the local innovation environment have, in many cases, been unintended at the level of top-down overarching government missions – or at least not planned in detail – and even adverse trade-offs have not been avoided along the way.

iv. Comparison across countries

The six case-studies of state-industry relations spread evenly across Finland, Sweden, and Norway, and this opens up an opportunity to compare the process and impact of these relations between the three Nordic states. However, this comparison cannot give a comprehensive analysis of the overarching nature of state-industry support between the three. The six case examples were selected because they stood out as particularly consequential in the empirical data, not because they provide an equal and identical representation of the three countries' entire industrial and innovation policy agendas. For example, the Finnish pioneer projects are the only one of the six examples that primarily concern venture finance, but this does not imply that Sweden and Norway do not have state-level venture finance initiatives as well. Moreover,

the large-scale investment momentum and, consequently, the stage of discontinuous innovation processes in the northern Swedish case is in many ways ‘further along’ than in most other Nordic regions (Teräs *et al.*, 2023). Therefore, findings of infrastructure bottlenecks and policy trade-offs in the Swedish cases cannot be taken to imply that similar complex challenges could not emerge in other regions and countries in the future.

What can be done instead is to view the six case examples in the context of their respective countries and to consider overall findings about state-industry relations for discontinuous sustainability innovation in Finland, Sweden, and Norway. Taking into account interview testimonials and other materials about how the cases are placed within the context of the three countries, as well as existing research on their national-level innovation policy strategies, we can make careful assessments about how the described cases fit into their own country contexts and connect to the two other countries.

Even when accounting for the fact that the individual cases represent different state roles and agency types, the examples still demonstrate that the otherwise relatively homogeneous Nordic countries are remarkably different when it comes to policy priorities for supporting sustainability innovation. This is visible because the general institutional structures and industry visions are largely the same: A backdrop of CME-type market institutions as well as a relatively strong pre-existing renewable energy mix, which are blended with a strong commitment to being a global leader in carbon-neutral industry, as well as an equally strong commitment to transforming in a socially sustainable and coordinated way (Kristensen and Lilja, 2011; Teräs *et al.*, 2023; Giacometti and Jessen, 2024; Nordic Energy Research, 2024). This similarity in context is corroborated by several interview testimonials that underline that Nordic industrial traditions are clearly present even in newly-formed sustainability ventures

and that there is a culture of trust and collaboration between stakeholders that is specific to the region.

In the Norwegian case, most interviewees align with a description of two extremes where, on the one hand, the state has depended on the oil and gas sector and is now supporting its electrification, while on the other hand, there are also many initiatives and programmes to support new ventures in renewables and hydrogen (OECD, 2021; Nordic Energy Research, 2024). One respondent summarises: “*We have to remember how much the state has supported the development of the oil and gas industry, a similar scale of targeted support for new carbon-free sectors would be incredibly important for the future of Norwegian industry*”. The Norwegian government’s support and guarantee of indigenous community rights is, in general, held as somewhat stronger than in Sweden or Finland, which is linked to conflicts of interest surrounding the energy transition but also helps to safeguard the heritage of Sami communities (Koivurova *et al.*, 2015).

In the Swedish case studies, innovation policy focus in the transition is also derived from a strategy of supporting large-scale industry transition and ambitious transformation, not least those initiatives with government ownership (Edquist, 2019; Grillitsch *et al.*, 2019; Algers, 2024). However, viewing innovation from a broader perspective of various agencies and state functions, respondents view that, in general, the state’s realisation of the momentum in northern Swedish energy-intensive industry transformation came relatively late and that political pressure to favour the more populous south of the country instead may have inhibited more wide-reaching action by the state. In any case, the policy response that has been made has sought to enhance collaboration and building capacity from a holistic, society-wide perspective, even though the initial response is to meet the needs of the most large-scale

ventures. The Ombudsman for societal transformation is a clear example: Instead of narrowly supporting industry ventures, the Ombudsman's office engages with sectors across the economy, such as healthcare, housing, and education, to support the long-term sustainable development of large-scale ventures and their surrounding regions. The actions by the national grid administrator, in turn, represent one of many infrastructure-focused action areas for state involvement: From rail transport to electricity supply, the capacity of infrastructure to cope with growing sustainability ventures as well as the rest of society has been a consistent request by all major sustainability ventures in North Sweden. The policy actions being taken are generally strongly welcomed from the perspective of the industry and regional stakeholders and are generally in line with overall descriptions of the most recent turns in Swedish innovation policy (Giacometti and Jessen, 2024). However, whereas recent literature characterises Swedish innovation policy with a trend of relatively top-down, mission-oriented innovation policies (MOIP) (Ibid.), stronger regional backing by the state is also called for by many stakeholders included in this thesis: to further speed up regional infrastructure expansions, help resolve bottlenecks and adverse policy trade-offs, and extend SMEs and municipalities the same attention that the larger ventures are receiving to an increasing degree.

In the Finnish case, the emergence and development of large-scale ventures has been slower than in Sweden but has subsequently picked up speed and become more active. This partly explains the lesser focus in the Finnish context on some capacity bottlenecks identified in the other case studies (partly Finland also has a relatively more even nationwide grid capacity than the two other countries) (Business Sweden, 2023; Nordic Energy Research, 2024). The state's actions to enable this gradually scaling-up innovation momentum have, consequently, also had a more pronounced early-stage, market-building focus. As the case studies demonstrate, Finnish state action has sought to enhance entrepreneurship and new ventures in areas deemed

strategically important. Respondents from the leading energy-sector cluster on Finland's west coast corroborate that the state's role has grown with the recent increase in global investments and the need to coordinate supply chains around new technologies (e.g. hydrogen), but that the core initiative of the cluster remains at the regional level. This also aligns with recent analyses of Finnish innovation policy development, which emphasise that instead of top-down mission-oriented innovation policies (MOIP), new strategic frameworks focus more strongly on enabling ecosystem and cluster growth at the local and regional levels (Giacometti and Jessen, 2024).

The three country cases, while different, present a unified narrative: The state's role and response to discontinuous innovation in traditional industries is enabling and adaptive: is connected both to the industrial history and subsequent policy capabilities of each country, and reacts to the scale and pace at which each state's sustainable industry ventures have unfolded. For example, when comparing policy actions taken in Finland and Sweden, respectively, the momentum for Swedish large-scale ventures has been established earlier and the scale-up has been faster than in Finland, which can partly explain why the Finnish policy responses are more closely focused on early-stage coordination of new technologies and initiatives. While state-level policy incentives and support have been crucial from the early stages of new ventures, subsequent policy and regulation have also reacted, adapted to, and co-evolved with the development of those ventures. This overarching finding informs the title of this chapter, specifically the choice to label state-industry interactions as *enabling* of discontinuous innovation processes rather than directing or driving them outright.

7.5.2 Theory implications

i. Same institutions, different outcomes – the impact of material lock-ins

The preceding cross-case analysis leads to a number of theory implications surrounding the role and impact of state-industry relations in discontinuous sustainability transformations in traditional industry settings. The first of these is the realisation that similarities in the general political momentum or institutional context between state-level actors is no guarantee of similar innovation outcomes. All three states have engaged in a diverse range of state-industry interactions to support sustainability transformations, but there is significant diversity in the current trajectory of the different industry ventures under development.

Some differences in state-industry relations can be traced back to specific policy decisions, as demonstrated in the previous section. However, it is important to reflect on what lies behind this complexity in the state's operational space. Rather than only seeking to explain variance by looking for small differences in the national policy agenda, the overarching differences between the different case-study countries clearly demonstrate the decisive impact of path-dependencies and lock-in effects relating to material infrastructure that are emblematic of the hard-to-abate nature of traditional industry sectors (grid capacity, resource mix and location, ownership of resources, etc.) (McDowall, 2018; Henderson, 2021). The capacity for state-level policy decisions to create short-term transformation in these traditional industry sectors is, in other words, much more limited than in, for example, many digital technologies and consumer-facing sectors.

This does not mean that the role of the state is irrelevant to long-term development and market formation for discontinuous innovation in traditional industries. Indeed, the resource and

infrastructure dependence also necessitates active state support, not least in careful planning and expansion of transmission grid capacity. As found in chapters 5 and 6, neither large-scale ventures themselves nor local government and industry coordinators have all the required capacity to action the required transformations on their own. Rather, the role of the state is more *enabling* than *dirigiste*, and more *situational* in that it is sensitive to small variations and specific combinations of elements that shape what is required to enhance coordination and build the capacity that the business models of innovative ventures depend on. These findings corroborate research suggesting that previous literature on the state's role in innovation policy has not sufficiently accounted for the resource and infrastructure dependent characteristics of energy and industry transitions (McDowall, 2018; Henderson, 2021). Chapter 8 will focus more on this element of new theory development.

ii. Similar action, different impact – the systemic nature of sustainability transformations

The situational nature of the state's role has, in this chapter, been demonstrated in particular through case-study examples where one type of state-level support or policy action is having heterogeneous or even mutually conflicting impacts across different regions or stakeholders. The cross-case analysis section traced the discrepancies between direct impact on innovative industry ventures and (either planned or unintended) indirect impact on other stakeholders in the innovation system. Unintended consequences and market distortions from industrial policy are subject to perennial debates in economic research. However, the state-industry relations under examination do not constitute formal state aid of established companies. They are formulated from a perspective of general industry benefit, not as 'picking winners', nor as formally intended trade-offs or adverse impacts (Mazzucato, 2016).

These testimonials are telling examples of how the material resource dependent nature of the transitioning industries is amplifying the importance of transforming entire industrial-societal *systems* rather than individual sectors or stakeholders (Savaget *et al.*, 2019; Henderson, 2021). The nature of climate transitions as “wicked problems”, “grand challenges” and “deep transitions” have been described through their systemic characteristics in several industry contexts (George *et al.*, 2016; Reinecke and Ansari, 2016; Schot and Kanger, 2018). This chapter demonstrates that infrastructure, energy and resource dependencies intensify these effects by creating sharper distinctions in resource allocation between the ‘haves’ and ‘have-nots’. This makes an individual, narrow policy response or ‘mission’ that is not adapted to the regional environment difficult to implement without any adverse indirect impact (Mazzucato, 2018).

iii. Same countries, different process stages – the impact of changing state roles over time

Furthermore, the analysis in this chapter demonstrates the impossibility of categorising states and their policy actions as static frameworks for innovation policy (Garud, Tuertscher and Van De Ven, 2013; Giacometti and Jessen, 2024). The evolving sustainability transformations discussed in the case examples are highly dynamic, and the national responses and policy strategies undertaken by the Nordic states are co-evolving with the discontinuous innovation processes. A particular mechanism of state-industry relations that may have been very helpful a few years or even months earlier may gradually lose its impact, or the impact may change. The different process stages of the case studies have been traced through follow-up research efforts throughout the research project, but they may also be followed by comparing the different process stages and ventures that are at different points in their development.

For example, state-level action to support northern Swedish innovation processes is faced with the situation that different ventures and towns are at different stages in their development and thus have different needs. On the one hand, this gives the early-stage ventures much-needed information and helps state-level policies draw on first-mover cases to inform the state's response to second-movers through tools such as the Ombudsman's report (Larsson, 2022). On the other hand, the discrepancies have also intensified the challenge of delivering state support that is simultaneously useful for each different process stage. Chapter 8 will pick up where this chapter left off: In devising a new process model for analysing and comparing discontinuous innovation in traditional industries, and for outlining different stakeholders' roles and relations within those processes.

The overarching implication of this enabling nature of a state's operating horizon is that any discernible 'policy profile' or national-level agenda may change over time. Some policy topics have gradually become more salient and politicised than others while others have fallen out of favour or active use. This problematises the general categorisations of the Nordic states as having definitively 'liberalised' or changed in some other irrevocable way when it comes to their innovation policies (Ornston, 2014; Thelen, 2019).

On the whole, the trend across all three states seems to be a focus on increasingly system-based innovation policies that focus on supply-chain coordination and aim to support both demand and supply side stakeholders (Edquist, 2019; OECD, 2021; Giacometti and Jessen, 2024). The empirical analysis in this chapter supports that general trend but also clearly suggests that the discontinuous sustainability transition in traditional industry sectors amounts to new realities in the state's role, to which the Nordic state actors are now adapting. The focus turns, for example, to shortening agency lead times for increased investor confidence, on guaranteeing

resource capacity, and on enabling a fast-paced ‘re-industrialisation’ of regions that had not been centre-stage of new large-scale ventures for several decades (Sörlin, 2023). This is indicative of a political economy where state-level coordination is as crucial as ever, especially in its capacity for policy adaptation and experimentation, but takes even more adaptive and situational forms than in the corporatist processes that defined the countries’ industrial history in earlier decades (Fellman *et al.*, 2008; Jäntti and Vartiainen, 2009; Ornston, 2009; Kristensen and Lilja, 2011; Breznitz and Ornston, 2013).

iv. Implications for the future of Nordic Varieties of Capitalism

This chapter has hitherto focused predominantly on analysing patterns in deliberate innovation policy and regulation. But what do these findings imply for future research on political economy, from a broader perspective of socio-economic institutions, which seeks to understand how the institutional setting of the Nordic context relates to decarbonisation and other industry transformations? This penultimate sub-section of the chapter presents some implications based on the empirical analysis on which future research can build.

Comparative political economy literature has analysed enabling factors that create a conducive environment for successful innovation and compared different countries’ innovation profiles with each other (Thelen, 2019; Hall and Soskice, 2001; Acemoglu, Johnson and Robinson, 2005; Breznitz, 2021; Iammarino and McCann, 2006). However, when it comes to discontinuous innovation processes, such as sustainability transitions, the existing literature presents a similar blind spot as the strategy literature on innovation: Because of how disruption and innovation are commonly defined, some institutional structures and settings are assumed as categorically more favourable than others to sustain any kind of breakthrough or discontinuous innovation (Casper, 2007; Ornston, 2014). This thesis demonstrates an

‘anomaly’ to general characterisations of Nordic innovation capacity. The case studies in this thesis present innovation processes that are outside of the large metropolitan start-up hubs, but nonetheless display fast-paced growth and discontinuous innovation instead of incremental change as per the general assumption of the original theory on Varieties of Capitalism (VoC) (Hall and Soskice, 2001; Casper, 2007). Indeed, the business case and incentive structure in the Northern Nordic setting, when successful, seems very powerful in producing first-mover advantages in many niches of industry transformation, whether decarbonisation or digitalisation.

The established framework of Varieties of Capitalism distinguishes between different sets of relational features in a national economy in terms of how firms interact through *corporate governance, education and training, inter-firm relations, and employee relations* (Hall and Soskice, 2001). These institutional features in the national economy are theorised to shape each other over time into an interlocking system of *institutional complementarities*, which gives rise to institutionally derived competitive advantage for different types of industrial activity. Based on empirical research into different capitalist economies, two ideal types are presented: Coordinated Market Economies (CMEs), such as Germany and the Nordic countries, and Liberal Market Economies (LMEs), such as the United Kingdom and the United States. In this model the CME system of corporate governance is based on close relations between company boards and executives, allowing for privileged information and mutual trust which enables long-range investments and risk-taking. The system of inter-firm interactions is also based on trust and non-market coordination, allowing for reputational monitoring and technology transfer. Employee relations are based on coordinated wage bargaining and strong union involvement, decreasing wage pressures and labour competition among companies and improving the long-term accumulation of skills and tacit knowledge. Finally, the education and

training system is based on highly-specialised skills provision through higher education, again decreasing labour competition and enabled by the interplay of the other institutional features. The long-term, coordinated nature of these mutually complementing institutional elements is viewed to create a conducive environment for incremental innovation in complex process industries, such as heavy machinery, whereas the system is less tailored towards radical, fast-paced innovation that requires fast changes (such as agility in layoffs and fast capital build-up).

The existing VoC literature does not directly address the applications of the framework to ask what creates a national advantage for *discontinuous* innovation, where sector fundamentals are being substantively transformed through a step-change. However, the characterisation of radical innovation in VoC literature closely resembles many operative factors of Christensen's (1997) model of *disruptive* innovation, which is discontinuous but still driven by market competition through boom-and-bust type cycles and creative destruction. While not formally addressed in the original model, it is clear that the LME context and the general 'Silicon Valley model' better complements such processes (Casper, 2007).

However, this thesis demonstrates that there are other modes of discontinuous innovation, especially in the context of decarbonisation in traditional industry settings. How are institutional complementarities in the national economy shaping or supporting these? Based on the empirical research in this thesis, figure 7.2 below considers how the institutional elements of the Nordic countries are interacting with discontinuous innovation processes. On the one hand, this is to improve our understanding of discontinuous innovation in frameworks and typologies of comparative political economy, such as Varieties of Capitalism. On the other hand, this analysis also seeks to update our knowledge of the Nordic region as a context for innovation.

Table 7.2: Benchmarking case studies against Varieties of Capitalism ideal-types

	Coordinated Market Economy (CME) Ideal type	Nordic Discontinuous Innovation Case studies	Liberal Market Economy (LME) Ideal type
Corporate governance	Patient capital, relies on informal knowledge and dense interpersonal networks; Limited management autonomy	In some cases state-coordinated or incumbent capital, but in other cases active role for global venture finance	Equity market uses public information; Autonomous management remunerated via stock options
Inter-firm relations	Industry associations and government collaborate to diffuse knowledge; open contracts	In some cases learning clusters based on regional industry associations, in other cases incumbent dominated; Growth through close relations to both incumbent alignment, national policy, and global markets	Formal contracts; Knowledge transfer via labour markets
Employee relations	Industry-level wage bargaining; active role for works council and labour unions	In community-engaged cases (esp. incumbents) strong union involvement and coordinated transition planning; Wage bargaining follows national law but flexible labour market especially for some managerial roles	Market relations between employee and employer; Flexible labour market; Wages and inflation controlled via macroeconomic policy
Education and training	Specific skills, acquired through state-subsidised apprenticeships and research institutions	In all cases reliance on formal state-subsidised training but new in-house models for some highly specific skills	Generic skills certified through qualifications, in-house specialisation

The table demonstrates that not all empirical case studies of this thesis fit neatly into the general model of a CME. In particular, in the case of large-scale green steel innovation, ventures like H2 Green Steel are combining some aspects of traditional Nordic industrial strategy (e.g. by its strong ties to the Stockholm corporate governance networks) with a finance and scale-up

strategy that is less familiar in the Nordic setting and is driven by venture capital investments from various global partners representing the entire steel value chain. In this case, corporate governance *blends* elements from both CME and LME examples, but still more strongly anchored in the CME setting.

The system of inter-firm relations in the empirical cases similarly follows a CME model for the most part. However, the non-market mechanisms for knowledge transfer and collaboration are very strongly linked to regional industry and research clusters rather than being shared across entire nation-states. The energy-sector cluster in Vaasa from Chapter 6 is a clear example of this, especially because a relatively large part of venture finance in Vaasa also traditionally hails from within the cluster rather than from larger financial centres. However, the case studies also demonstrate that regional or cluster-specific complementarities cannot function properly without the support of a well-working multi-level coordination mechanism, i.e. links to national stakeholders and global markets.

The trend of blending between traditional CME-type institutional structures and adapted settings continues for the two other elements of the VoC framework. The employee relations present in organisations across all the empirical cases follow national legislation in the Nordic states, which tends strongly towards the CME ideal-type when compared to LMEs but has also evolved a great deal since the original VoC theory (Kristensen and Lilja, 2011). Ventures and technologies surrounding sustainable industry transition require a combination of skills and backgrounds: partly research-intensive process industry skills that are strong in the Nordic region and partly more specific engineering and project management skills called for by large-scale sustainability technology ventures (such as hydrogen production and downstream applications, DRI steelmaking, battery technologies, etc.). Innovative ventures have met this

with different strategies, from upskilling to attracting skilled experts from foreign markets. This has resulted in a more diverse labour pool, both within and between individual firms, than is traditionally present, which has provoked more creativity and experimentation in combining different employee relations traditions.

Finally, the empirical research tells a similar story about education and training system developments in the Nordic context as the developments described for the three other model elements. On the one hand, the state-driven education network described in the original VoC framework about CME-type states is still widely present in all the Nordic states, with a strong focus on teaching specific skills through a strong network of vocational and technical education providers. There are signs of blending where additional complementarities are incorporated into the otherwise CME-type model of regional skills clustering. In cases of fast scale-up of new technologies, the existing training and research programmes are already being complemented not only by the hiring of foreign experts but also through more extensive in-house reskilling, where firms have full control in shaping the direction of skills acquisition akin to an LME-type setting. In more extreme cases like the Berlevåg hydrogen project, where there is a need for specific research-intensive skills but no skill-intensive cluster in place, this aspect of the venture has been administered fully by remote-working partners from other country contexts. In this way, training and skills development for discontinuous technologies and sustainability transformations have brought about a shift and extension of the pre-existing vocational and higher education training programmes.

This brief overview suggests that the fundamental tenets of Nordic country contexts remain broadly in place when it comes to supporting discontinuous innovation in traditional industry settings, rather than having ‘liberalised’ or otherwise moved completely away from the pre-

existing industry tradition (Ornston, 2014; Thelen, 2019). The realities and interdependencies of undertaking industry transformation have prompted ventures that rely predominantly on the incumbent industry traditions of CME-type non-market coordination. However, there is no clean-cut dichotomy between incumbents following CME-type complementarities and external start-ups or investors demanding a more LME-type environment: Instead of working as two separate industry logics, some new elements are pursued purposefully by ventures to complement the pre-existing institutional foundations. As all empirical case studies demonstrate, the Nordic CME-type innovation setting is applied in the context of sustainable industry transitions through blending of traditional institutional complementarities at the regional level and more direct links to global investors, partnerships, and policy stakeholders. This creates a particular advantage for ventures which already have strong networks in both of these spheres, for example, by being heavily integrated and interconnected in a regional innovation system while at the same time benefiting from close financial ties with global investors (for example, by way of coordination efforts by the Wallenberg investment empire and others in the Stockholm finance hub) (Thelen, 2019; Glimstedt and Zander, 2013). In this way, the future direction of the innovation setting in the Nordic countries, at least within the context of industry transitions centred in the northern resource-intensive regions, will likely continue evolving through experimentation and adaptation in both policies and institutional complementarities but retain many key elements of non-market coordination as featured strongly in the Nordic industrial tradition (Kristensen and Lilja, 2011).

This section also demonstrates that the VoC theory framework is useful, but potentially in need of adaptation when it comes to analysis of how institutional complementarities shape *discontinuous* innovation. Firstly, the primary scope for categorising institutional complementarities might be adapted to focus on the core of industry networks rather than

political boundaries: To focus on the level of regional clusters, or regional innovation systems, when making categorisations. As has been shown by the previous chapters, the relational networks surrounding innovative ventures are defined by the regional industry environment, and while other regions and sectors in a country may share many similarities, they also often feature very different innovation systems and operating logics (Asheim and Coenen, 2005; Asheim, Boschma and Cooke, 2011; Pisano, 2015; Breznitz, 2021). Secondly, an expanded framework based on the current analysis could demonstrate that institutional advantage for *discontinuous* innovation may be particularly dependent on blending elements from the two original VoC ideal type models, where one set of institutional complementarities (in this case, the CME) is purposefully and proactively combined with alternative operating procedures to form additional complementarities specifically for advancing discontinuous, step-change transformation. As described in the preceding analysis, all elements included in the VoC framework demonstrate signs of this blending, where general processes of non-market coordination in an innovative cluster are enhanced in many ways by integrating more LME-type processes and stakeholder strategies, yet without altering their fundamental CME-type regional innovation systems.

Tying together this final part of the chapter's discussion, a clear case exists for increased *comparative research on innovation* also at the socio-institutional level of comparing how different types of discontinuous innovation may be enabled in different countries and institutional settings. This is the only way to avoid confusing and paradoxical theory implications when viewing discontinuous innovation ventures taking on contexts and processes that existing research would not have expected or even thought possible (Henderson, 2021). Further research is needed to consider what the preceding analysis suggests about the development of similar discontinuous innovation ventures (for example, in green steel and

hydrogen innovation) in other parts of the world, and how such ventures may interact with the institutional complementarities present in those places.

7.6 Conclusion

This final empirical chapter of the thesis has focused on the state-level perspective: State-industry relational dynamics enabling discontinuous innovation in traditional industries. Across the three Nordic country contexts, the role of state policy and regulation comes across as enabling and adaptive: It is neither path dependent by specific actions nor by specific institutions, because the systemic nature of discontinuous industry transformations means that specific policies can have different effects in different situations (Henderson, 2021). This makes the role of state-level actors for discontinuous innovation different and more complicated than state support for other innovations, which is usually more predictable in one way or another (Mazzucato, 2018).

This chapter finds that stakeholders across the Nordic countries are undergoing continuous experimentation and policy adaptation to find the best ways to support discontinuous innovation (Kristensen and Lilja, 2011; Schot and Steinmueller, 2018; Giacometti and Jessen, 2024). This does not take place automatically, and too narrow innovation policy structures or missions carry risks: The impact on one type of venture or innovation process may have different or even adverse indirect effects on others. This implies a clear need for new models and theory development to inform the literature on innovation policy surrounding the characteristics of discontinuous innovation in traditional industries, especially in the context of sustainability and decarbonisation. Even in the world-leading innovation systems of the Nordic states, there has not been a simple answer to the question of state intervention to drive innovation for sustainable industry transitions without risking indirect lock-ins and adverse

effects for other sectors or societal actors. However, a number of supportive and evolving state-level innovation enablers have been described and analysed in this chapter.

This chapter has also offered an introductory discussion about the theory implications of the impact of the wider Nordic socio-institutional setting on these processes (Hall and Soskice, 2001; Kristensen and Lilja, 2011). While the examples are taken from different contexts in the Nordic innovation systems, the overarching message they provide about the development of these countries is that stakeholders in Nordic sustainability innovation apply a model of *blending* institutional complementarities from different innovation contexts in order to shape a competitive advantage for discontinuous innovation. While the traditional CME-type variety of capitalism remains a relevant shaper of industry incentives, some of the most successful stakeholders brought up in this thesis combine the traditional Nordic industry background with more globalised business models to secure their finance and scale-up.

The penultimate chapter of this thesis will engage directly with the empirical findings of all three empirical chapters and develop new theory frameworks for analysis, categorisation, and process modelling of discontinuous innovation in traditional industries.

Chapter 8 – Discussion and theory implications for discontinuous innovation in traditional industries

8.1 Introduction

The three previous chapters have presented the empirical analysis undertaken as part of this thesis. Each of the chapters has analysed one of the three perspectives identified in Chapter 2 on how discontinuous innovation processes are organised in traditional industry settings: The industry venture perspective, the local stakeholder perspective, and the national policy perspective. This chapter consolidates the findings of the empirical chapters to present a set of overarching theory contributions that address the primary and auxiliary research questions of the thesis. The tools for further theory development presented by this chapter invite new avenues of research to study innovation contexts that, if using pre-existing frameworks, may not have been understood as transformative in the first place but which are, in fact, hosting and developing some of the most transformative industry change processes of our time.

The chapter is divided into two sections, both summarising a specific set of theory contributions and outlining steps for further research. The two areas of theory contribution reflect the open questions presented in Chapter 2: On the one hand, expanding the study of discontinuous innovation to analyse traditional industry settings, especially surrounding sustainability transitions. On the other hand, expanding the application of process models for understanding the roles and relationships of stakeholders in shaping discontinuous innovation processes over time.

The first section elaborates on the issue of defining, characterising, and categorising settings of sustainable industry transition using a theory lens of discontinuous innovation: How do these

settings compare with each other and with other settings of discontinuous/breakthrough innovation? Based on the empirical analysis, the section presents *a new comparative theory framework for analysing discontinuous innovation ventures* and discusses its applicability for further research. The central contribution of this framework is that it enables us to understand why different breakthrough innovation processes develop differently depending on their initial strategic positioning and driving stakeholders. In particular, the new theory framework clarifies some substantive differences between innovation phenomena surrounding ongoing sustainability transitions in traditional industries and our common benchmarks for discontinuous innovation, most notably the narrower construct of *disruptive* innovation and its application in the benchmark case of the ‘Silicon Valley model’ (Christensen, 1997; Kaplan, 1999; Casper, 2007). Understanding these differences means we learn to appreciate the innovative capacities of places and ventures that, for many different reasons and not least the changing values centred on environmental sustainability, many other innovation frameworks would have overlooked (Breznitz, 2021; Fu, 2020).

The second section and area of theory development builds on the first by adding an analytical focus on process and change. This highlights the need to understand the changing roles and relationships of stakeholder groups at different times during a discontinuous innovation process. The sub-section presents *a new process model for analysing discontinuous innovation from a relational (inter-stakeholder) perspective*. The process model builds on the new theory framework developed in the first half of the chapter, and the empirical findings from the three empirical chapters, and connects these in a schematic model to illustrate the situational nature of the roles and relationships between stakeholders at different times during the discontinuous innovation process. The process modelling contributes, in particular, with an understanding of how differently discontinuous innovation processes may be shaped by their surrounding

innovation system stakeholders, even when that system and its stakeholders may seem static and constant (Garud, Tuertscher and Van De Ven, 2013; DeJordy *et al.*, 2020). The process model goes some way to explain the empirical variation demonstrated by this thesis even across very similar regions and countries. The section concludes by discussing what the process model may tell us if applied to other settings where the fundamental tenets of the innovation system are different.

8.2 A new comparative theory framework for analysing discontinuous innovation ventures

8.2.1 Material resource dependence brings variation between innovation settings

With the aim of better understanding the innovation enablers at play in industry-wide sustainability transitions as well as other transformation settings that diverge from established frameworks, Chapter 2 of this thesis outlined the research agenda of developing a comparative framework typology that could be used to distinguish between different strategies and processes for discontinuous innovation.

If there are no parameters along which to categorise and compare innovation processes that are bringing about disruptive, step-change transformations to industries and societies, it becomes difficult to set up tailored hypotheses or models for how such phenomena develop in innovation contexts that are different from conventional benchmark models. The ongoing sustainability transition in industry brings this problem to the fore especially because the most hard-to-abate industry sectors, which are undertaking significant step-change transitions, are traditionally viewed as slow-changing and incremental and are therefore not familiar or favoured settings

for researching and theorising breakthrough innovation (McDowall, 2018; Lee and Malerba, 2017; Fagerberg, 2018).

As there are no existing theory frameworks for the study of innovation that clearly define these different mechanisms involved in industry disruption and breakthrough innovation, it is necessary to develop one. As Chapter 2 emphasises, a suitable existing construct to anchor this theory development to is *discontinuous innovation*: Innovation where existing industry structures and knowledge regimes transform through a step-change (Kaplan, 1999; Utterback, 1996). On the one hand, the construct is broad enough to encompass very different types of innovation activity, from the ideal type of disruptive innovation and the ‘Silicon Valley model’ for innovation to the hard-to-abate industry transformations studied in this thesis (Christensen, 1997; Casper, 2007). On the other hand, no existing categorisations attached to this construct allow for broad comparison between different types of discontinuous innovation processes and their development in different industry settings (Breznitz, 2021). Informed by the empirical case studies, this chapter sets out to develop a new comparative theory framework.

The empirical case studies demonstrate settings in which innovation processes are substantively different from what existing literature streams on discontinuous or breakthrough innovation would expect. In particular, the studied innovation processes are organised along markedly different lines from an ideal-type ‘Silicon Valley model’ of market-driven disruptive innovation (Christensen, 1997; Casper, 2007; McDowall, 2018; Schot and Steinmueller, 2018). The latter is often based on case contexts that are deeply rooted in social networks and end-user markets (such as the digital platform economy), where new ventures can enter competitive markets or create new market niches without many bottlenecks in resources and regulation (Ansari, Garud and Kumaraswamy, 2016; Ozalp, Cennamo and Gawer, 2018). For example,

in many digital markets government regulation takes many years to consolidate after new technologies and market niches have been shaping the sector. In contrast, the sustainable industry transition in steelmaking and hydrogen is crucially dependent on existing material resources and supply chains, and the regulatory regimes thereof. One of the most consequential discussions connecting all the case studies and involved stakeholders is the question of how to structure and allocate renewable energy resources and grid capacity. And this is far from the only enabling factor: The preceding chapters lay out several interlinked challenges relating to the use, allocation, transport, and repurposing of natural resources and material infrastructure, as well as societal factors, relating not only to skilled personnel but to the functioning of the wider innovation system and society around new ventures (Edquist, 2019). The case studies have identified what these factors are and how different stakeholders have engaged to mitigate them.

Based on this analysis of the empirical case studies, we can theorise at the inter-industry level that *the degree of material resource dependence* is a fundamental feature that dictates how discontinuous innovation processes are organised differently in different industry settings (Pfeffer and Salancik, 2003). The dependence on specific resources shapes the relationship between a new venture or technology and the surrounding, pre-existing innovation system (Breschi, Malerba and Orsenigo, 2000). For example, sustainability transitions in traditional industry settings, by definition, face crucial resource constraints (especially for energy and materials) in order to succeed in decarbonisation, and this affects the viability of innovation and its dependence on pre-existing models and stakeholders. In many other breakthrough innovation settings, especially surrounding digital technologies and software innovation, these resource dependencies are less central to the viability of a new venture. One way of categorising innovation processes is thus to distinguish between sectors where these constraints of material

resource dependence are more prevalent and central to corporate and policy strategy, than in others.

An example of where this distinction may be applied is the analysis of how agglomeration patterns differ for different kinds of innovation activity. During the past decades of digital innovation and the internet revolution, innovators have become accustomed to the fact that features such as location and infrastructure, while crucial for enabling innovation, are not as defining as are social network relations with highly skilled innovators in research centres, often connected through global platform organisations (Gawer and Cusumano, 2014; Ozalp, Cennamo and Gawer, 2018). While hardware programming and material resources are a factor in digital innovation, innovation viability in many aspects of digital technologies is still predominantly driven by the uptake of new users and spread through social networks (Seidel, Hannigan and Phillips, 2020). This might be labelled as relatively more *social network dependent* innovation, which is centred on metropolitan high-tech clusters but can be done from anywhere on the globe and has become driven by new digital business models, created new markets, and shifted how entire industries operate and interact with consumers (Furr, Ozcan and Eisenhardt, 2022). Social network dependent contexts of discontinuous innovation also have the feature of being able to scale up the diffusion of new innovations very quickly.

In contrast, in more material resource dependent industry sectors, many of which are currently grappling with sustainability innovation (such as steel, hydrogen, forestry, and many other process industries) there are substantive challenges related to physical and material features that define the location, transition pathway, and technological trajectory of an industry, as the case studies in Chapters 5-7 have demonstrated. Indeed, these dependences on material resources are at the core of what make these sectors hard-to-abate from a sustainable

development perspective (Henderson and Clark, 1990; McDowall, 2018). Digital solutions and global networks for learning and research are crucial for these industries, too, but the core rationale of these innovation contexts, including their sustainability targets and the speed at which new solutions can be scaled up (i.e. the industry clock speed (Mendelson and Pillai, 1999)), is fundamentally dependent on material resources and physical infrastructures.

However, more careful consideration reveals it to be difficult to create a useful and generally applicable dichotomy between material resource dependent and ‘other’ industry sectors at the level of an entire industry. There are several heavily market-driven and end-consumer-focused dynamics present in traditional industry sectors, too, such as steel and petrochemical commodity markets, and because different regional contexts present different market and resource characteristics, the centrality of different material elements is sure to vary across cases even within the traditional and hard-to-abate sectors. Moreover, many industry sectors are undergoing sustainability transition processes that make them increasingly linked to platform companies and digital software innovation (for example, the automotive industry). Overall, it would be very hard to categorically decide that a whole industry sector either is or is not ‘fully’ material resource dependent. This is also supported by theory and research on sociomateriality, which emphasises that both social processes and material affordances continuously shape innovation processes – the effect of neither is ever absent in any innovation context (Orlikowski and Scott, 2008; Van Osch, Bohnsack and Avital, 2010).

8.2.2 New comparative theory framework for viewing differences between innovative ventures

Instead of trying to maintain dichotomous categorisations between entire industries, the empirical case studies therefore motivate us to find more nuanced theory parameters for categorising discontinuous innovation at the level of *individual ventures and innovation processes*. The variation found in the case studies, both in terms of stakeholder roles, innovation strategies, and local community engagement, is clearly shaped by the material resource dependent innovation setting wherein these innovation processes are taking place. What we thereby need to clarify and define is the parameters under which these differences occur – the specific ways in which different discontinuous innovation processes differ from each other. As has been found through each of the case studies, discontinuous innovation processes are distinctly situational and innovation strategies may be different even for stakeholders dealing with the same technology in the same geographical area (Garud, Tuertscher and Van De Ven, 2013; DeJordy *et al.*, 2020). This analysis is, therefore, more granular than comparing entire industry sectors to each other.

One clear distinction arising from the empirical data is that different ventures and their innovation processes may be categorised by their *driving logic of discontinuous innovation*. The emergence of discontinuous innovation, by definition, involves a degree of detachment from existing market incentives and continuous innovation processes (Kaplan, 1999). When it comes to the scale-up and diffusion of discontinuous innovation, the kind of stakeholders and partnerships that are spearheading and enabling the venture (for example, investor relations and government relations) significantly shape its strategic positioning and future trajectory. This power to shape venture trajectories is often more substantive than for a sustaining (i.e. continuous, whether incremental or radical) innovation venture because the latter works within

the existing innovation logic rather than building a new one. The material resource dependent nature of sustainability transitions in traditional industry settings further emphasises the potential distinctions caused by early-stage incentive structures and business models, because as the case studies have demonstrated, ventures taking on these transitions face a number of early-stage business risks, high initial development costs, and infrastructure bottlenecks (McDowall, 2018).

The empirical case studies in green steel and hydrogen align roughly with two distinct driving logics and incentive structures: *Market-driven discontinuity*, and *policy-driven discontinuity*. At the core, these two are not mutually exclusive as no innovation process would succeed without an element of both market competition and policy support. The two are intertwined especially in contexts of sustainability transition: On the one hand, the motivation for industry to respond to the climate crisis is subject to increasing policy pressure from governments and international organisations (Henderson, 2021). On the other hand, most innovation ventures involving private stakeholders operate at least partly on the incentive of existing markets and predicted returns from successful innovation (Utterback, 1996; Fagerberg, 2005). Nevertheless, the case studies demonstrate how the original strategic positioning for a specific venture can be traced to one of these logics. For example, in the case of the two green-steel ventures analysed in Chapter 5, H2 Green Steel initially approached their innovation mission strongly on market-driven terms, seeking to be a first-mover with a pioneering business model in place by the time policymakers and regulators caught up with the development in European steel markets. HYBRIT, in turn, does have a market-driven incentive as a consortium of profit-seeking incumbent enterprises but also framed the initial motivation for its innovation process with a strongly policy-driven motivation to cut Swedish industry emissions, in close coordination with the government (especially given that two out of three joint venture partners

are government-owned). As is shown in the case studies, the incentives and stakeholder relations of both ventures have been dynamic and mutually complementing, but the initial approach and strategic choices of the founding figures can be broadly categorised into these two logics.

The second core parameter of distinction suggested by the empirical case studies relates to how innovative ventures choose to interact with their surrounding industry context. More specifically, the strategic positioning and impact of a discontinuous innovation process vis-à-vis the wider industry environment (for example, competitors, regulators, or user groups) can take different forms. Discontinuous innovation, while bringing in truly distinctive innovations through a step-change shift, may have divergent impacts on the existing industry landscape depending on the strategy chosen by a venture. These impacts are visible both as changes in dominant technologies, market structures, and knowledge regimes, as well as leading business models or infrastructure networks. Again, the material resource dependent nature of sustainable industry transitions renders this distinction particularly relevant: On the one hand, there is increasing pressure to rapidly displace heavily polluting technologies and energy sources, but on the other hand, doing so requires system-level coordination and involves mitigating a great many dependencies on these polluting technologies in the existing industry infrastructure, such that very few elements of sustainable industry transition and decarbonisation can be fully detached from pre-existing industry processes (Henderson, 2021; McDowall, 2018; Fagerberg, 2018).

The empirical case studies suggest that the distinction in industry impact may be categorised into two broad (and not necessarily mutually exclusive) types of strategic positioning. Some ventures seek ambitious and discontinuous innovation while also complementing the existing

industry environment and knowledge regime, thus innovating without making it fully redundant. On the other hand, discontinuous innovation may also be driven by a complete separation between incumbent and disruptor technologies and business models, seeking a paradigmatic overhaul of the existing industry environment. After all, the very concept of *disruptive innovation*, along with its original case studies in American steelmaking, is built on the assumption of strict separation and competition between old and new technological and intellectual regimes (Christensen, 1997; Ansari, Garud and Kumaraswamy, 2016).

In labelling these groups, a parallel may be drawn to classic Schumpeterian economics: *creative accumulation* versus *creative destruction* (cf. Breschi, Malerba and Orsenigo, 2000). These labels also remind us that making definitive judgments based on industry-level impact (e.g. whether creative destruction has occurred) is only possible *post hoc*. But through qualitative process research into the inter-stakeholder relational dynamics of ventures, we may still learn how different ventures are choosing to drive innovation and interact with their industry environment during their innovation process. For example, while words like ‘disruption’, ‘overhaul’, and ‘radical’ appear in many interview testimonials in the empirical case studies, so too do phrases such as ‘recombining familiar technologies’, ‘building on existing infrastructures’, and ‘coordinating a system-wide transition’. In fact, possibilities for a destructive overhaul in the Nordic context of traditional, hard-to-abate industry sectors are broadly dismissed throughout the case study material as relatively unlikely and generally undesirable, while coordination and resilient communities are reaffirmed to be high on the agenda both for industry ventures and policymakers. There is consequently no definitive example of creative destruction taking place in the empirical case studies because all ongoing Nordic green steel and hydrogen innovation seeks an approach of discontinuous systems change through creative accumulation. That being said, examples in Chapters 6 and 7

demonstrate how the competition for both limited energy and infrastructure resources and skilled labour may lead to creative-destruction-type strategies and outcomes in the long term. There are also other climate-tech settings in the world where it seems like a stricter separation between new solutions and incumbent industry settings is being maintained – these venture strategies would fall into the category of creative destruction (Henderson and Newell, 2010; Seba, 2014).

The current focus for theory development is specifically on discontinuous innovation processes, as these step-change transformations may be seen as evolutionary turning points during which the dominant innovation rationale for a sector is negotiated through the actions and relationships between innovators and their surrounding industry context (Kaplan, 1999; Garud, Tuertscher and Van De Ven, 2013). Similarly, as the level of analysis is within-industry relational dynamics between ventures, this chapter departs from earlier taxonomy frameworks by not differentiating between different levels of component knowledge as a basis for categorising innovations (Seidel and O’Mahony, 2014). From a relational, systemic, and situational perspective of discontinuous innovation processes, the exact intensity of component skills involved will inevitably vary among different stakeholders and teams, as some actors will focus more heavily on technological innovation while others are more concerned with innovation of organisational and institutional structures. Therefore, the choice is made to differentiate based on ventures’ relational dynamics to the surrounding industry and innovation context instead of by trying to ‘box in’ ventures based on the specific skillset of individual innovators.

Based on the research agenda and open question set out in this thesis, and the two sets of differentiating factors that emerge from the empirical case studies, Figure 8.1 below presents a

synthesised model for a new comparative theory framework of discontinuous innovation processes at the level of individual ventures, resulting in four *modes* for the strategic positioning of their external relational dynamics.

Figure 8.1: New comparative theory framework for discontinuous innovation ventures

Strategic positioning of discontinuous innovation (venture-level analysis)	Creative Accumulation	Creative Destruction
Market-driven discontinuity	<i>First-mover mode</i>	<i>Disruption mode</i>
Policy-driven discontinuity	<i>Coordination mode</i>	<i>Paradigm mode</i>

The four resulting quadrants, labelled in line with their characteristics as the *first-mover mode*, *coordination mode*, *disruption mode*, and *paradigm mode* (elaborated in the next sub-section), are designed to be applied in practice by populating them with illustrative examples of innovation ventures (both past, ongoing, and potential future innovation) that are driven by the corresponding mode of discontinuous innovation. This thesis thus argues that theory development on discontinuous innovation for the sustainability transition can and should be analysed with the same terminology and theory model as any discontinuous innovation venture. It may not be useful to try to define a ‘sustainability-only’ mode of discontinuous innovation, because most for innovators, incentive structures and institutions in practice operate flexibly across the divide between sustainability-focused and ‘other’ innovation. That being said, as the empirical case studies and the emergent theory framework both emphasise, many settings of sustainability innovation that are making headlines today have in common a material resource dependent innovation context, not least in the ambition of eliminating greenhouse gas emissions in hard-to-abate sectors, which affects their strategic positioning and thus the

innovation mode that best describes them. Moreover, due to the inherent characteristic of these material resource dependent challenges as deeply interlinked at the systemic level, it seems likely that discontinuous innovation processes for sustainability transitions would also be at least partly policy-driven at their core (rather than exclusively motivated and financed by market-based competition) (Henderson, 2021).

8.2.3 Applying the theory framework for analysis of discontinuous innovation ventures

In demonstrating the application of the new theory framework, this chapter zooms in on the case example of the steel industry, and in particular on the case studies in green steel and hydrogen innovation that are included in this thesis, and that form the empirical background for the inductively derived framework. Figure 8.2 below presents the theory framework as populated with these case-study examples, and the subsequent paragraphs will elaborate on the interpretation and further application of the framework.

As presented in Chapter 2, the green steel transition was introduced as a case study for three main reasons. Firstly, the steel industry is a traditional, hard-to-abate industry sector, which is undergoing a significant and discontinuous transformation to decarbonised value-chains, but is a different and more material resource dependent sector than those usually described in terms of discontinuous or disruptive innovation (such as digital platform technologies). Secondly, the steel industry has undergone many other kinds of overhaul and innovation in recent years besides decarbonisation, thus demonstrating the closeness between sustainability and ‘non-sustainability’ innovation and the need for a theory framework that can be applied to both. Thirdly, it is suitable when analysing different forms of discontinuous innovation and expanding the reach of this research to the context of sustainability innovation, to return to the

steel industry, which was originally used as a case study for Christensen’s (1997) model of disruptive innovation.

Figure 8.2: Modes of discontinuous innovation in the steel sector

Strategic positioning of discontinuous innovation	Creative Accumulation	Creative Destruction
Market-driven discontinuity	<u>First-mover mode</u> <i>Example: Market-driven ventures that seek to bring commercially viable ‘green steel’ by using green or blue hydrogen to cut steel plant emissions (Elements of H2GS)</i>	<u>Disruption mode</u> <i>Example: Mini-mills outcompeting integrated steel plants (Christensen, 1997)</i>
Policy-driven discontinuity	<u>Coordination mode</u> <i>Example: Research and development projects, policy frameworks and business consortia exploring solutions for a carbon-free steel value chain (Elements of HYBRIT)</i>	<u>Paradigm mode</u> <i>Example: Sweeping replacement and ban of blast furnaces in steelmaking</i>

i. Coordination mode

Some discontinuous innovation ventures are characterised by markedly policy-driven incentive structures (such as research spin-outs, regional innovation consortia, and government innovation grants). In these settings, nascent innovation niches lack a clear firm-level competition incentive in the existing market, and industry actors without a collaborative context or consortium to create a system-wide incentive are likely to wait to spend resources until market dynamics or regulatory changes compel them to act. The actors that do undertake such innovation need credible long-term commitment and collaborative practices from partners across the innovation system to coordinate a large-scale overhaul of the industry and the

emergence of a new industry logic. Consequently, this type of innovative venture often leverages and builds on existing industry structures through creative accumulation, even as the ambition of the venture is discontinuous and aims to bring in entirely new and different value propositions to what existed before.

Several settings of ongoing discontinuous innovation surrounding energy and industry, exemplified here by systemic ventures to transform and decarbonise the steelmaking value chain, can be seen to fit into the *coordination mode* at different parts of their innovation process. In particular, out of the two green-steel innovation ventures examined in Chapter 5, the HYBRIT consortium is a clear example of a breakthrough venture that emerged within a strongly policy-driven logic and has continued its innovation process largely following this strategic positioning up until the industrialisation stage, albeit that HYBRIT is also continuously anchored in incumbents' profit-seeking goals and belief that ongoing innovation will bring competitive advantage in future markets. The HYBRIT innovation development company has closely coordinated with the industry incumbents that own it in order to create as seamless a transition as possible for the existing steelmaking facilities, thus demonstrating its positioning of creative accumulation.

H2 Green Steel, in turn, has partially aligned with the coordination mode as well, especially in its efforts to coordinate crucial infrastructure investments and expansions in Northern Sweden. Across the other case studies in Chapters 6 and 7, many ventures and partnerships also operate within the coordination mode. The case of hydrogen innovation in Berlevåg, Norway, is a clear example of a venture that is driven strongly by the local community's policy preferences while a 'bankable' business case is still lacking due to various infrastructure bottlenecks. Moreover, a nationally and regionally derived policy-driven positioning is present for hydrogen

innovation ventures in Finland, where the Vaasa energy cluster operates through competition in existing markets but does so through experimenting and building highly coordinated projects and offerings in pre-market segments, many of which are supported in part by public-sector stakeholders.

ii. First-mover mode

In contrast, in the competition-driven discontinuity equivalent of a similarly cumulative innovation setting (upper-left quadrant), there is a firm-level competition advantage present through the existing market mechanism, which the innovator leverages to legitimate and scale up its discontinuous innovation process. This we may call the *first-mover mode*. The new innovation may in itself be significantly discontinuous but be anchored and grounded in the existing competitive industry environment and market incentives, which create an impetus for new initiatives and enable the first-mover to maintain its legitimacy and competitive edge. While innovators need significant resources to innovate, they have more clarity towards profitable firm-level strategies and investment opportunities in the first-mover mode.

Some of the examined green steel and hydrogen innovators currently find themselves in this innovation mode as their business model relies on the fast-paced scale-up of hydrogen production for a distinct market-driven purpose (such as substituting the use of coal in the steel reduction process). The initial approach and continuous business case of H2 Green Steel is the clearest example of this innovation mode in practice, with a market-driven business case that hinges on a wide partnership and finance network and the expectation of being able to charge ‘green premiums’ from downstream customers for offering the first commercially available large-scale batches of near carbon-neutral steel. Here, the primary focus is not on research and development to promote a long-term, system-level overhaul of the entire steelmaking supply

chain but rather on bringing to market as fast as possible a commercially viable, efficient and modular implementation of near zero-carbon steelmaking, which can compete in existing steel markets and also otherwise transform existing infrastructures without destructively displacing them. Further examples of first-mover mode type venture strategies can be found in the Swedish hydrogen case-study ventures (see Chapter 6): most of these are crucially anchored to an immediate industrial business case rather than to a nationally or regionally supported policy priority, consequently leading to easier scale-up for a few individual ventures but potentially lower levels of network coordination than e.g. in the Finnish case-study examples.

iii. Disruption mode

Even when innovative ventures bring about discontinuous step-changes in industry, the new theory framework highlights that they can often be cumulative in their development due to path-dependency in technological advancement and resource allocation within a sector. However, discontinuous changes and industry realignment in these settings may also emerge through competition-driven creative destruction, where there is a pronounced gap and little complementarity between disruptors and incumbents, and consequently, an increasing turnover in market entry and exit as the innovation process unfolds. This is, as already referenced above, akin to disruptive innovation as perceived in many cases of high-technological innovation of recent years and what we may call the ‘Silicon Valley model’ of benchmarking such innovation (Casper, 2007; King and Baatartogtokh, 2015; Kumaraswamy, Garud and Ansari, 2018; McDowall, 2018). For the steel industry, this strategic positioning resembles what Christensen’s (1997) original theory of disruptive innovation envisioned when describing the proliferation of mini-mill steel plants that outcompeted large, integrated steel plants by being more cost-efficient (albeit at first of lower quality) than incumbent steel plants.

It is notable, however, that innovation processes in the case studies of this thesis follow almost exclusively other modes of discontinuous innovation. Both green-steel case studies involve similar technological shifts towards mini-mill type facilities as the ones Christensen (1997) described, but neither current nor planned future innovation strategies for either green steel venture involve displacement of existing industry infrastructure or knowledge in the sense of a *disruption mode* type development. In fact, the SSAB steel company has even pledged that the industrialisation of HYBRIT's technology will be followed by reskilling rather than redundancies. The market-driven disruption wave from integrated plants to mini-mills was limited in both time and place (predominantly concentrated in the US) (Christensen, 1997). A more disruptive dynamic also seems at hand for example in the UK, based on news reports on the transition of Tata Steel's Welsh steel plant in Port Talbot toward a mini-mill-type concept (Davies, 2024). Sustainability transitions in other contexts may well take on disruption mode characteristics in their strategic positioning.

iv. Paradigm mode

Finally, the *paradigm mode* describes developments where discontinuous innovation fuels a comprehensive shift away from the existing industry architecture, incentive structures, and value chains through a paradigmatic system-wide transition (Riemer and Johnston, 2019). Structures and stakeholders of the previous industry paradigm are simply made redundant and left behind, driven especially by overarching policy decisions and regulations. For example, several envisioned but not yet implemented policy developments within the sustainable industry transition, such as an aggressive phase-out or outright ban of coal-fired blast-furnace steel mills, may take on a more creative-destructive turn than the currently more cumulative and market-driven developments seen in the innovation processes surrounding carbon-free steel. Another example may be a systemic phase-out of nuclear energy, which has taken place

at the level of individual countries, or ongoing policy discussions around the timeline for banning the production or use of internal combustion engines.

As mentioned, there are no conclusive examples in the current case studies of a policy-driven, paradigmatic shift that would destructively displace existing industry networks and knowledge regimes. That being said, several interview testimonials point to both potential future opportunities from decisive state policies (e.g. strongly favouring specific technological pathways at the expense of others in transport or industry) and to the risk of collateral damage from the creative destruction brought about by forceful technological *dirigisme*. Such potential risks are most notably demonstrated in this thesis by the Norwegian case, where oil and gas electrification may develop at the expense of other types of sustainable industry ventures in Northern Norway. These examples show the value of a relational and process-focused perspective when theorising and comparing innovation processes: While we are uncertain about the future trajectory of a specific technology or industry shift, we can consider how different innovation modes adopted in the present may align or misalign with political or commercial goals for the future (Garud and Gehman, 2012; Garud, Tuertscher and Van De Ven, 2013; Gümüşay and Reinecke, 2022).

8.2.4 Wider implications and literature contributions of the new theory framework

The previous paragraphs have demonstrated the application of the new comparative theory framework to analyse and compare the case-study ventures included in this thesis. The framework sheds light on the diverse business models and innovation pathways taken by discontinuous green steel and hydrogen ventures, and shows how these differences in strategic positioning allow ventures to complement each other's innovation processes while simultaneously competing for resources. The framework also adds more nuance to the finding

that the Nordic case studies in green steel and hydrogen innovation develop differently than breakthrough ventures following the success benchmarks of a ‘Silicon Valley Model’, which in the theory framework is presented as the *disruption mode*.

A similar mapping, comparing and categorising the strategic positioning of discontinuous innovation ventures, can also be applied to other industry sectors. The new theory framework increases the nuance of the analysis of discontinuous innovation, as it makes it possible to compare drivers of discontinuous innovation processes, not least for sustainability transitions, in a way that cannot be captured with conventional taxonomies of innovation (such as product vs. process, radical vs. incremental, or sustaining vs. discontinuous) (Schmookler, 2013). The proposed framework does not offer definitive dichotomies between different industries. Aligning with the recent ontological broadening of innovation literature away from linear, evolutionary and technologically determinist lenses, this chapter argues that different enablers of innovation are co-constitutive in both a relational and situational sense (Garud, Tuertscher and Van De Ven, 2013). But the new comparative theory framework nonetheless demonstrates how different innovation enablers and strategic pathways may complement or conflict with each other at the system level, and may also change over time as technologies and markets mature. For example, the application of the new framework to discontinuous innovation in green steel and hydrogen in the Nordic context finds that these processes are particularly material resource dependent and cumulative in nature, and develop through a mix of market-driven and policy-driven incentive structures. Using the same framework, this innovation profile can readily be compared with similar ventures in other regions, or with discontinuous innovation ventures in other industry sectors.

This section of the chapter has thereby distilled the findings of the empirical research and theory development in this thesis when it comes to innovation and sustainability: Industry stakeholders may face different enablers for innovation even within the same sector, and the sustainability transition has brought even more variation in innovation contexts, which shapes the strategic positioning for innovative ventures. In particular, industry decarbonisation ventures in the examined settings are *material resource dependent*, i.e. their core strategy and success factors are inextricably linked to dependencies on material resources and physical infrastructure networks. The empirical cases and the new theory framework emphasise that such sectors and innovation settings can also be dynamic and transformative, especially in the context of the mounting pressure towards sustainability and decarbonisation. This thesis thereby demonstrates the benefits of researching sustainability-focused innovation not as conceptually separate from ‘day-to-day’ innovation but as an instance of *discontinuous innovation*, which develops through step-changes but may still be heavily anchored and connected to incumbent industry processes and infrastructures (Kaplan, 1999; Henderson, 2021; McDowall, 2018). The presented new theoretical framework offers an opportunity to map out different kinds of discontinuous innovation ventures based on their incentive structures and how they position themselves in the industry. Among the most important distinctions is that between *disruption mode* processes akin to a ‘Silicon Valley model’ and more accumulation-type processes examined in the empirical case studies on Nordic green steel innovation.

Moreover, beyond the general mapping of industry ventures, the proposed theory framework is helpful for understanding the general role played by, for example, state policymakers for the strategic positioning of a specific venture, and to expose potential misalignment of priorities between stakeholders. This thesis, with its relational (inter-stakeholder) lens, thereby

contributes with more analytical nuance to the literature on different *systems*, such as the role of regional and national innovation systems in sustainability transitions (Cooke, 2004; Henderson, 2021; Edquist, 2019). For example, when connecting the proposed theory framework to types of state roles such as coordination, capacity-building, and advocacy as identified in Chapter 7, it becomes clear that different state roles may align differently with ventures depending on the ventures' initial incentive structure and strategic positioning vis-à-vis with the surrounding innovation system context. State-level stakeholders, as well as regional policymakers and industry stakeholders, may use the new theoretical framework to compare different innovation trajectories and consider the potential implications of policy initiatives and regulation.

The same is true for private ventures weighing the benefits and alignment opportunities for new investments and business strategies, and for universities considering new research and collaboration strategies. The overarching contribution to existing innovation literature on innovation systems and sustainability transitions, and to more specific literature on different stakeholders' efforts to bring about these transitions, is to demonstrate that instead of one prescriptive strategy or level of state intervention, each innovation context for a 'green window of opportunity' (GWO) presents a unique combination of stakeholders and their potential strategic positioning and impact (Garud and Gehman, 2012; Lema, Fu and Rabellotti, 2020). The new comparative theory framework is a tool for unpacking those different stakeholder strategies and roles.

Yet, it is also clear that these innovation modes are highly situational in both time and place. As introduced by the open questions listed in Chapter 2, one crucial source of nuance and change in how discontinuous innovation processes are organised relates to temporal dynamics

in the early-stage development of technologies and markets. This was recognised at the outset of the empirical study, by choosing a process lens for analysing discontinuous innovation (Garud, Tuertscher and Van De Ven, 2013). For example, how and under which conditions may ventures ‘move between’ the different innovation modes set out in the new framework, and what does this imply for their relational dynamics and the roles of other stakeholders? The next section of this chapter addresses this question by developing a new process framework to complement the new comparative theory framework.

8.3 A new process framework for discontinuous innovation

Previous research has formulated different frameworks for understanding how the dynamics of innovation and technology diffusion depend on the maturity and innovation stage of a specific technology (Geroski, 2003; Thompson, Purdy and Ventresca, 2018). For example, Santos and Eisenhardt (2009) illustrate the ambiguity of operating in nascent market settings by presenting the *Claim-Demarcate-Control* framework of how the strategy and aim of firms change as a market setting matures. However, as also found in the literature review in Chapter 2, these existing research frameworks are often specifically based on market-disruptive industry contexts, where the roles and strategies of both new entrants and incumbents take a particular shape that may not be applicable in other contexts. For example, the *Claim-Demarcate-Control* framework is by definition based on innovation on a ‘clean slate’ where new entrants undertake nascent market formation to claim their market space (Santos and Eisenhardt, 2009).

For breakthrough sustainability innovation in traditional industry settings, researchers point to the novelty of environmental targets, combined with the difficulty of decoupling these targets from existing projects and infrastructures, as factors that likely create specific challenges that are different from the innovation challenges that nascent industry segments have ‘normally’

been assumed to face (Hockerts and Wüstenhagen, 2010; Adams *et al.*, 2016; McDowall, 2018; Savaget *et al.*, 2019; Lema, Fu and Rabellotti, 2020). This thesis finds the Nordic case studies into green steel and hydrogen to be a particularly material resource dependent innovation context, where pre-existing infrastructures and value chains are heavily shaping strategic decision-making for new ventures. Discontinuous innovation for sustainable industry transitions is far from a ‘clean slate’, and existing frameworks for industry evolution under ‘clean slate’ conditions may not be useful in capturing these stakeholders’ development.

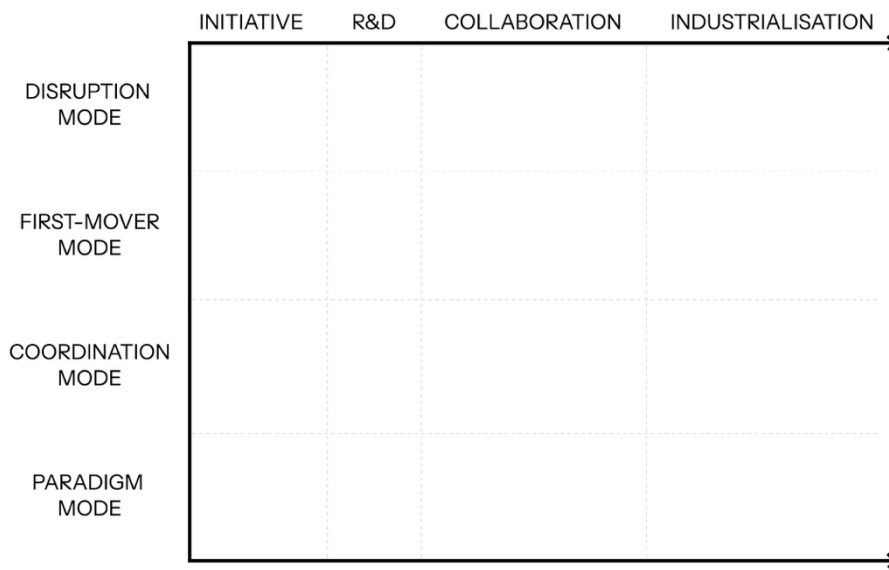
This lack of existing process tools for analysing how different kinds of discontinuous innovation processes evolve in their early stages becomes clear when building on the new theory framework and the four modes of discontinuous innovation developed in the previous section. For example, the empirical case studies included in this thesis indicate how the steel industry has undergone ‘movement’ between different modes of discontinuous innovation (as per Figures 8.1 and 8.2 above). Over time in the steel industry, for example, there seems to be ample horizontal movement discernible over previous decades – i.e. between industry processes of creative destruction (such as during the proliferation of mini-mills in Christensen’s (1997) original research) and creative accumulation (current-day processes of industry decarbonisation), and vice versa. Similar change is shown by the case studies to occur vertically, i.e. between policy-driven discontinuity and market-driven discontinuity. While the sustainability transition is generally a system-level phenomenon that spans across sectors and where a clear market-competition incentive has not yet emerged (thus potentially giving policy-driven innovation strategies a clearer early-stage incentive), some stakeholders in the steel industry are nonetheless pursuing carbon-free steel innovation independently with a strategy of competitive scale-up and growth strongly anchored in existing market mechanisms.

However, these general observations of temporal variations during and between innovation processes do not provide further insight into the actual process mechanisms of discontinuous innovation (Garud, Tuertscher and Van De Ven, 2013). The previous section outlined a new comparative theory framework for categorising and comparing different innovation modes based on the strategic positioning of ventures. The present section builds on that comparative framework by developing a process framework for tracing how different discontinuous innovation pathways evolve in their early stages. Like the *Claim-Demarcate-Control* model and similar frameworks of industry and market development, this new process framework is developed to capture the enablers of movement between different innovation stages. However, recognising the material resource dependent innovation setting described in the empirical case studies, this section takes a broader scope of innovation enablers than simply user-driven market-building, to be applicable for analysing more diverse contexts (Santos and Eisenhardt, 2009). The new process framework achieves this increased nuance by capturing not only linear process development but also the changing relational dynamics between different stakeholder groups as included in this thesis: Venture strategy (Chapter 5), local industry networks (Chapter 6) and national policy and regulation (Chapter 7). Findings and contributions to existing literature on innovation processes and innovation systems are discussed at the end of the section.

8.3.1 Need for a process framework

Figure 8.3 below provides a framework structure for the new process model: The strategic positioning of discontinuous innovation processes (Y-axis) over time as plotted by venture stage (X-axis). This sub-section will focus on the development of this framework structure, before moving to populate the framework with process models for the empirical case studies in the following sub-section.

Figure 8.3: New process framework for discontinuous innovation ventures (axes only)



The horizontal axis of Figure 8.3 has been populated with four discontinuous innovation stages as identified through the green steel case studies in Chapter 5: Initiative, R&D, Collaboration, and Industrialisation. While other stages and turning points for discontinuous innovation exist, the four venture stages in question are chosen as a suitable framework structure for process analysis not only because of their emergence as fundamental themes in the empirical case study but also because they capture four different substantive elements of innovation and scale-up (rather than, for example, different stages of venture finance) (Kaplan, 1999). This allows for a more comprehensive process perspective that reflects how different parts of a venture's operations build on each other and are interlinked over time.

Moreover, as the empirical analysis in Chapter 5 has demonstrated, the four featured innovation stages do not follow each other in a fully linear sequence: While the processes of initiative (and early scale-up) precede the industrialisation stage, the empirical case studies show how

elements of both R&D and collaboration may be introduced at different stages in the scale-up process (see Figure 5.2). This adds further motivation to base a process framework on venture stages rather than on the linear passage of time: As we know both from the literature on entrepreneurship and *industry clockspeed*, and as evidenced by empirical analysis in this thesis, different venture stages take different amounts of time across different sectors, as well as between different ventures within an industry (Mendelson and Pillai, 1999; Gümüşay and Reinecke, 2022). The process modelling of individual ventures will account for different stages taking different amounts of time (more on this in Figure 8.4 below). In this way, the framework structure focuses on the temporality of the discontinuous innovation process: While essentially based on linear time, the horizontal axis focuses on key innovation stages, recognising on the one hand that the duration of these stages is variable, but on the other hand that these four stages are fundamental determinants for discontinuous innovation ventures and using them to frame a process model provides an opportunity to compare different processes with each other in a comprehensive way.

The vertical axis of Figure 8.3 builds on the previous section of this chapter by featuring a ‘flattened’ version of the new comparative theory framework of discontinuous innovation presented in Figures 8.1 and 8.2. As concluded at the end of the previous section, the categorisation of different ventures into four discontinuous innovation modes is best understood as an approximation of innovation processes that are very dynamic at the core and may fluctuate or even change their operating logic and strategic positioning to other discontinuous innovation modes over time. For example, if a venture started in a heavily market-focused way, within the *disruption mode* or *first-mover mode*, but over time starts depending more heavily on government coordination and collaborative consortia (not only in regulating market-driven prices but in fundamentally shaping the value chain), it may shift into

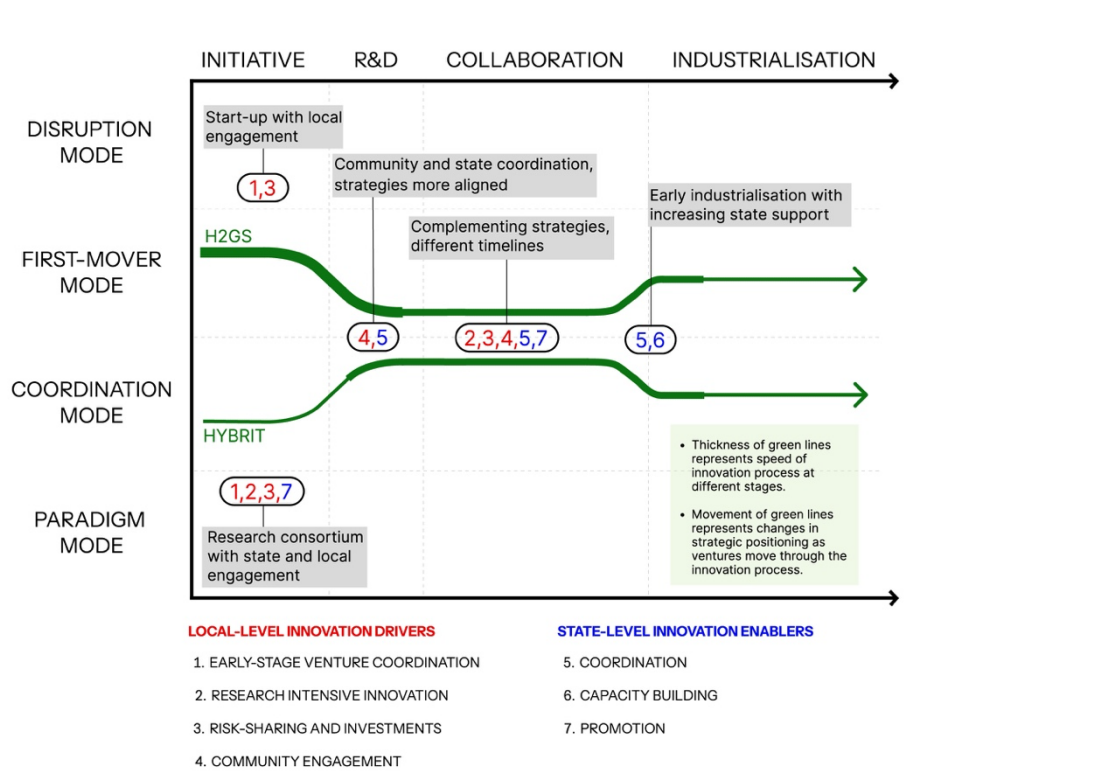
a *collaboration mode* or even a *paradigm mode* positioning. The value in theorising on these processes by tracing a venture's discontinuous innovation mode is that this can inform stakeholders who engage with the venture about its overarching business model and innovation strategy.

Beyond tracing the innovation strategy of an individual venture across different innovation modes, the new process framework also allows for tracking and visualising how the innovation processes of several ventures compare to each other and may even interact with each other over time. As found in Chapter 5, where two green steel ventures were compared, the two ventures never overlapped completely but became more interdependent at some stages of their processes. We can model and present these interacting processes in the same figure with the new process framework, thereby deepening the analysis of how and when two ventures interact in their innovation strategies. Moreover, we can include process analysis on innovation-driving factors of the local industry context (see Chapter 6) and enabling factors of national policy and regulation (see Chapter 7). This allows us to trace how and at which stages these factors shape a venture's innovation strategy, as well as how they may impact ventures differently.

8.3.2 New process models for discontinuous innovation ventures

Figure 8.4 below presents a visual representation of the new process framework for discontinuous innovation, as populated with process model examples based on the two green steel case-study ventures examined in Chapter 5. The following paragraphs elaborate on the different layers of the process models as well as how the process framework may be applied to other case studies discussed in this thesis. The concluding paragraphs of the section will discuss wider implications and contributions to literature.

Figure 8.4: Process models for Nordic green steel innovation ventures



Ventures are presented in the process model with green process lines, making their way from left to right through the innovation stages (as per Chapter 5) and positioning themselves along an innovation mode (as per Figure 8.1 of this Chapter) as they do so. There are two venture processes on display in Figure 8.4: H2 Green Steel and HYBRIT from the Chapter 5 case studies on green steel innovation.

The positioning and movement of the two process models follow from the analysis conducted in the previous sections and chapters: HYBRIT starts with a *coordination mode* strategic positioning, but moves gradually closer to the *first-mover mode* as its timeline priorities and scale-up strategy are altered, whereas the industrialisation stage is once again mainly following the *coordination mode* as large-scale investments are made by the consortium members and

green-steel markets are yet to form. H2 Green Steel starts firmly within a *first-mover mode* strategic positioning but is gradually influenced more by the *coordination mode* as several elements of the innovation strategy become intertwined with regional resource dependencies as well as HYBRIT's proof-of-concept R&D process. Well into the industrialisation stage, the success of H2GS hinges on elements from both modes, but the business model is fundamentally driven by nascent market formation and 'green premiums' and is still more strongly anchored in the *first-mover mode*. While not as closely interlinked as during their period of early-stage scale-up and industrialisation, the two innovation strategies remain more closely interlinked than at their earliest process stages.

The varying thickness of the green lines represents the relative length of different process stages, with thicker lines illustrating a faster innovation process. The H2 Green Steel process has been relatively fast-paced, while the HYBRIT process has gradually become faster than initially expected. In addition, as elaborated in the previous section, the process framework follows venture stages for both process models simultaneously, even though HYBRIT was initiated four years before H2 Green Steel (see Chapter 5 Figure 2). Combining these two elements of the process model, we can follow the relative strategic positioning of the two ventures: They moved closer to each other's strategies at similar stages in their development, but in terms of the actual timescale, this came slightly earlier in time for the less research-intensive H2 Green Steel start-up venture.

Interaction of venture processes with the *regional innovation system* is represented by the red list and red numbers in Figure 8.4 that specify local-level innovation drivers interacting with the two green steel innovation processes. This is based on the empirical case studies in Chapter 5 in combination with the case studies and analysis in Chapter 6, with four local-level

innovation drivers: *early-stage venture coordination*; *research-intensive innovation*; *risk-taking and investments*; and *community engagement* (See Table 6.1).

The regional industry network has laid the groundwork for early-stage coordination and risk-taking incentives for the two green-steel ventures since before either of them had formally launched. Chapter 4 has outlined the early-stage strategic development in regions throughout the Nordic countries, and in particular in northern Sweden, as ongoing since many years before the Paris Agreement, in anticipation of increased demand for renewable energy and other resources, such as land use and permitting by large-scale industry sites. Without these early-stage processes at the regional industry level, neither of the two green steel ventures could have formed their initial incentive structure (particularly not H2 Green Steel, which operates on a market-driven basis and timescale and without state ownership). Moreover, local-level risk-sharing remains crucial, as the municipal and regional level stakeholders are investing in crucial infrastructure without guarantees of full-scale industrialisation and the associated tax revenue. The regional capacity for *research-intensive innovation* was not initially geared towards fossil-free steelmaking, but the capacity for this has been quickly built up around the two ventures and has been supporting HYBRIT in particular (and, by extension, has been strengthening the business case and labour attractiveness of H2 Green Steel as well, with proprietary R&D by H2 Green Steel initiated later).

The element of *community engagement* has been impacting both innovation processes consistently, but partly in different ways: HYBRIT and its parent companies initially took a more traditional industry role and engaged through strong union connections and public consultations, while H2 Green Steel has engaged in a variety of ways to open more community dialogue. Through several joint working groups and advocacy efforts, the two green steel

ventures have at later stages sought to navigate a set of crucial resource dependencies and regulatory bottlenecks: Railroad capacity, harbour expansion, grid capacity and connectivity, and housing provision, as well as the safeguarding of the rights of indigenous communities. The early-stage processes of permitting and land use, which regional-level stakeholders had the capacity to shape on their own, were fundamental in securing a smooth initial scale-up of the green steel ventures. Both ventures are reported by respondents to be relatively less active in new citizen engagement efforts at the latter industrialisation stage, but they do maintain active communication through several local and regional platforms. Especially given the material resource dependent nature of the innovation setting, the sustainable growth of the surrounding region is a core strategic feature for both ventures, and they both, therefore, remain involved in ‘society-building’ initiatives spearheaded by different public or quasi-public stakeholders.

Figure 8.4 also presents the role and engagement of *national-level policy and regulation* enablers in the blue list and blue numbers, with the same visualisation logic as the red number and arrows described above. This is based on the empirical case studies in Chapter 5 in combination with the analysis in Chapter 7, with three identified forms of state-level enablers: *coordination*, *capacity-building*, and *promotion* (see Table 7.1).

The engagement and impact of national-level efforts look different for the initial process stages of the two green-steel ventures. State-level policies of *promotion* are noticeably more present for HYBRIT (which is logical considering it operates with a *coordination mode* type innovation strategy). Two out of three HYBRIT parent companies are state-owned enterprises, and the first initiative for forming the consortium was backed and incentivised by government ministers (thus providing initial directionality for the innovation process, cf. Algiers, 2024;

Mazzucato, 2018; Schot and Steinmueller, 2018). For both ventures and to an increasing degree over time, a set of top-down state innovation-policy measures and funding have enabled the successful development of the venture (Algers, 2024).

While many aspects of the regional industry environment were influencing the early stages of the ventures, the bulk of the national-level activities materialised at a relatively later stage (and indeed too late, from the perspective of some regional stakeholders). The first element of clear state-driven *coordination* was the appointment of the Ombudsman for large-scale industry transition ventures when both green steel ventures were already firmly up and running (see section 7.4). As the scale-up stages brought the two ventures closer to each other in their innovation strategy and the focus was turned on navigating resource dependencies in pre-market conditions, key *capacity-building* efforts by national stakeholders did not always align with the expected timeline of the green-steel innovation processes (H2 Green Steel being pressured by its own market-driven business model, and HYBRIT by the competition for resources with H2 Green Steel and by its own successful R&D process). Regional stakeholders were facing growing pressure and risks on local taxpayers' funding to finance infrastructure capacity expansion, and national regulators and agencies (such as the grid administrator) were increasing their efforts, but there were initially relatively few high-level policy decisions to mitigate remaining state-level bottlenecks as recommended by the Ombudsman (Larsson, 2022).

For both capacity-building and coordination, some substantive state-level decisions were only made during 2024, well into the early industrialisation phase of the green steel ventures: For capacity-building, increased national funding support for housing expansion, and for coordination, a grid capacity allocation decision that prioritised the first stages of both green

steel ventures' first-phase industrialisation. In sum, the national coordination and capacity-building efforts came following widespread lobbying by regional stakeholders and was, at that stage, similar for both venture processes but out of sync with the general pace of venture scale-up.

8.3.3 Applying the process framework for analysis of discontinuous innovation ventures

Based on the preceding example of elaborating the green-steel case studies of Chapter 5 through process modelling, we can draw a number of wider conclusions about the development of these two discontinuous innovation ventures over time, as shaped by the regional industry environment as well as national-level policy and regulation. Turning first to the elements of the regional industry environment, the process model reveals the crucial impact of strategic decisions taken at the local industry level that fundamentally shape the viability and attractiveness of large-scale discontinuous innovation ventures. It is certainly no coincidence that both of the first large-scale green steel ventures in the world emerged in the same region, less than 100 miles and less than four years apart. The regional industry stakeholders who realised their strategic advantage for large-scale, renewable-energy intensive industry developments in the years before the Paris Agreement could not have planned specifically which ventures would emerge in their region, but they laid the foundations and regional capacity in terms of infrastructure, energy, and local governance, which at the time when HYBRIT and H2 Green Steel emerged was not readily available anywhere else.

Secondly, the process model serves to illustrate how the agency of regional-level industry and governance stakeholders has been instrumental in creating a coordinated appeal for increased national-level support in capacity-building and coordination, even as there has been a lack of outright policy-driven promotion and prioritisation of the two northern Swedish green steel

ventures. The role of the state in enabling the two ventures has been crucial, both in terms of policy and regulation, but the leadership for shaping this policy response and making the case for continued and growing support has been the most consistent at the regional level. This is visible in particular in the numerous coordinating bodies and working groups forming at the regional level for interactions both between industry companies and between industry and regional government.

Thirdly, the interactions between the green steel ventures and the regional industry environment are revealed by the process model to have been front-loaded, especially in comparison to the state's response. As industrialisation ramps up, communication between the green steel ventures and regional stakeholders is continuous, but the main challenges and collaboration streams have already been identified and highlighted, and the foundation for local community rapport in support of the ventures has been laid. This stage of continuity during the implementation and industrialisation phase should not, however, be taken as a diminishing impact of the local industry and community level. On the contrary, the long-term resilience of the regional industry community will be fundamental for ensuring that the green-steel ventures are successful once fully operational.

Turning then to the elements of state-level policy and regulatory agency, the process model reveals the opposite of the previous point: i.e. the efforts of the state have predominantly been reactive and are commonly viewed by regional industry stakeholders as cautious and insufficient given the scale and pace of the green steel ventures. This demonstrates a significant paradox at the heart of the Swedish state's involvement in sustainable steelmaking: On the one hand, the state and its affiliate stakeholders in Stockholm have been masterminding the steel transition for several years, especially in the case of HYBRIT, but also through close and

continuous connections between H2 Green Steel and the incumbent industry and finance sector, who keep in close communication with government actors (Thelen, 2019). On the other hand, the ‘follow-up’ of this industrial-policy promotion of the steel transition, through state-driven orchestration by way of significant capacity-building and proactive state-driven coordination, has been relatively gradual and thereby lacking an overarching sense of transformative national interest from an innovation policy perspective (exceptions to this are singular missions of some state agencies, such as the national grid authority, which has been active in its coordination and capacity-building efforts throughout).

Moreover, the process model reminds us of the complexity of systemic innovation policy measures in a setting where several ventures face interlinked resource dependencies at different stages in their development: While the state’s overall response is homogeneous, the needs and timing of the two green steel ventures are not identical and may sometimes even be directly at odds with each other. For example, the uncertainties surrounding grid capacity allocation processes particularly impacted H2 Green Steel’s business case given its reliance on strict delivery schedules to maintain its funding and viability. While the state is aiming to support the industrialisation of each venture, it faces a situation where the two ventures are again further away from each other in their strategic positioning and specific needs. This echoes the empirical findings in Chapter 7 of indirect impact and implications on other ventures and parts of the regional innovation system from the state’s policy and regulatory actions.

Similar process analysis based on the new process framework may be expanded to increase the understanding of other settings of discontinuous innovation. The process models presented above for the green steel ventures do not constitute an ideal-type model of how innovation strategies ought to evolve nor how regional industry and state stakeholders ought to enable

them, but instead presents an analysis of how the two ventures have evolved to date, based on the empirical case studies. Other process models will show different implications, but there may also be overarching trends. For example, how similar would the models be if the hydrogen innovation case studies included in Chapter 6 were analysed using the new process framework? These case studies are regional rather than venture-specific, and the ventures described have not reached their industrialisation stage in the same way as the green steel ventures, but overarching themes may still be envisioned with a suggestion of what a venture-specific process model may look like.

In the case of hydrogen innovation in Vaasa, Finland, the analysis in Chapter 6 describes a *network model* in the regional industry environment, where industry-led consortia and research programmes are drawing on a wide ecosystem of local suppliers and innovators. In this innovation setting, ventures such as the “Power-to-X-to-Power” hydrogen consortium would be categorised predominantly under the *coordination mode*. Many such projects in the region are ultimately incentivised by government funding schemes and regional policy priorities more than an immediately scalable business case. That being said, the Vaasa energy ecosystem is closely linked to global innovation processes and supply chains, and over time the market-driven element for these ventures may develop to be the predominant growth driver. Due to Vaasa’s networked character, the process model may be somewhat different to *coordination mode* ventures like HYBRIT: There is a stronger presence of state-driven orchestration surrounding the energy transition in the Vaasa region than in northern Sweden, and it is, in particular, stronger in incentivising and orchestrating early-stage ventures seeking to transform the energy system (the presence of the hydrogen TNO of Gasgrid is a good example of this). In terms of engagement with the regional industry environment, the profile of the Vaasa region suggests that it is more evenly spread than in the case of the green steel ventures, not least as

the relative pace of scale-up and industrialisation for Vaasa-based ventures is more moderate than for the billion-euro green steel innovation strategies in Sweden.

Indeed, hydrogen innovation ventures in northern Sweden, characterised in Chapter 6 as a *scale-up model*, would likely display many similarities to the green-steel process models from the same innovation setting (hydrogen innovation is also part of the technological focus for both of those ventures). More specifically for nascent hydrogen ventures in the region, from pipeline and storage projects to industrial applications, there is even less proactive state-driven orchestration or policy directionality than for green steel where state-owned enterprises are involved. There is no incumbent gas pipeline infrastructure in northern Sweden from before, most thought leadership in the sector comes from northern Sweden-based stakeholders, and there is no appointment of a national hydrogen TNO like in Finland. Instead, most engagement in hydrogen innovation processes takes place between ventures themselves – in particular, well-funded large-scale ventures tied to off-takers and a full value chain like HYBRIT and H2 Green Steel – and other regional industry stakeholders. For example, several different stakeholders are individually exploring options for building stretches of hydrogen pipelines for their own industry applications. If plotted as a process model, even as hydrogen network infrastructure and large-scale production or storage by definition would benefit from networks and coordination across co-located industries, most of these ventures would initially be characterised as *first-mover mode* strategies that are operating strictly in line with a direct and pre-arranged market application. The exception to this is heavily research-driven ventures (such as the HYBRIT development and the CH2ESS research centre), in which government agencies and innovation funding bodies have had a more continuous orchestrating role. Innovation processes emanating from these would likely evolve in line with a *coordination mode* innovation strategy.

Finally, in the case of northern Norwegian hydrogen innovation, Chapter 6 described a *community model* based especially on the case study of the Berlevåg hydrogen innovation venture. As a grant-funded research project, this venture started firmly with a *coordination mode* innovation strategy and remains almost exclusively promoted by local and regional, rather than national, policy promotion and regulatory coordination. The state is involved in policy promotion on electrifying oil and gas production, as found in Chapter 7, and this has adverse impacts in terms of restricting grid capacity and resources for other projects in northern Norway. In Berlevåg, there is continuous local industry engagement in terms of risk-sharing and very strong community leadership throughout the local area. From the regional industry side, there would therefore need to be stronger efforts in connecting to the national policy level to gain support in navigating resource dependencies. The other possibility would be for projects like the Berlevåg hydrogen innovation venture to become more market-driven, changing over to *first-mover mode* innovation strategies. However, while continuous regional industry action has been taken to connect the Berlevåg project to a commercial hydrogen value chain, this trajectory also remains blocked by grid connectivity bottlenecks.

8.3.4 Wider implications and literature contributions – The role of time and place for discontinuous innovation

In summary, the preceding process analysis into the innovation strategies and relational dynamics of discontinuous innovation ventures offers several theory implications for existing literature on innovation processes as they connect to both regional and national enabling factors and stakeholders. The new process framework also demonstrates how different process stages for discontinuous innovation imply different needs and different risks for ventures over time. The temporal variation has previously been underexamined, with existing innovation system models assuming a static form rather than something that changes over time (Garud, Tuertscher

and Van De Ven, 2013). As the process models suggest, a venture's dependence on resources and other stakeholders often implies that the overall innovation strategy remains similar, but the needs and complementarities supporting innovation may still change over time and place.

For example, the different enabling roles of the state are very time-sensitive, as taking a specific policy action at a certain process stage may have a different impact from another. The early stage of discontinuous innovation processes, from initiation to industrialisation of ventures, has its own substantive process stages, which both regional/local and national and both public and private stakeholders are a part of shaping. Especially in the material resource dependent settings found in the empirical case studies, the early-stage innovation process does not happen on a 'clean slate' or in a vacuum, but in a situational and context-specific environment (Thompson, Purdy and Ventresca, 2018; DeJordy *et al.*, 2020). These findings can complement other process models of market-building and diffusion in more mature innovation settings, such as *Claim-Demarcate-Control* (Santos and Eisenhardt, 2009). However, rather than presenting an ideal-type model for early-stage discontinuous innovation, the presented framework aims to enable future process modelling of discontinuous innovation processes, providing a model for tracing and comparing interactions between a venture and its surrounding stakeholders.

In terms of the role of *place*, the process analysis and presented framework build on the findings of the empirical chapters by elaborating on the relationships between ventures and their innovation context. In particular, the presented process models suggest that the regional innovation system provides the majority of the *ex-ante* directionality and context to discontinuous innovation processes in traditional industry settings, while the role of the state and national level stakeholders is to support and strengthen that development *post hoc* and mitigate resource dependencies. The role of place for innovation systems has been known in

earlier literature, in the form of different typologies for innovation systems as well as models for place-based innovation and demand-side innovation policies, and this thesis underscores the consequential role of places and regions for shaping the future of industry and innovation (Edquist, 2019; Breznitz, 2021).

The process analysis in this thesis suggests that for material resource dependent innovation settings, the role of place and space goes beyond providing a contextual backdrop. Because the resource dependencies of existing industries are at the core of the discontinuous innovation process in these innovation settings, the role of place becomes the fundamental motivator and agenda-setter of the innovation process, the shaper of the complex playing field of overlapping industry needs and resource dependencies, as well as the orchestrator of many national and global-market interactions. These roles are taken on as much for the ventures that follow a market-driven logic as for those with a policy-driven background. That the regional industry environment in the north of the Nordic countries takes on this innovation-driving role in the empirical case studies is evident when referring back to Pisano's (2015: 4) definition of an innovation system as "*a coherent set of interdependent processes and structures that dictates how the company searches for novel problems and solutions, synthesises ideas into a business concept and product designs, and selects which projects get funded*". Investors and government ministers may be credited with initiating particular projects or ventures. Still, the regional innovation system has framed the logic of pursuing resource-intensive industry transition projects in the north of Sweden, Finland, and Norway in the first place. The success of individual ventures is tied to the success of the future vision of these regions as resilient and sustainable industry communities (Giacometti and Teräs, 2019). Future studies are required to conduct similar process research in other discontinuous innovation settings. For example, is this agenda-setting role or the regional innovation system transferable to other parts of the

world or to other innovation settings that feature a high degree of material resource dependence?

Based on general literature on innovation processes in different sectors, we can hypothesise that many contemporary digital-technology ventures, especially when set in metropolitan start-up and finance clusters, may follow a different strategy trajectory if plotted onto the new process framework but still demonstrate a strong innovation-driving impact of the regional innovation system. In a ‘Silicon Valley model’ innovation setting, the operation and incentive structure of new ventures is often firmly within the market-driven *disruption mode* (Saxenian, 2000; Casper, 2007; Kumaraswamy, Garud and Ansari, 2018). However, while the process curve of such ventures would likely stay within the uppermost section of the new process framework in Figure 8.4, the relative frequency and timing of regional and national level enabling factors would likely be similar to that of the green steel case studies, with a defining role for the local and regional networks and a more arms-length, enabling role for national-level policies. For example, the role of early-stage risk-sharing in such environments is based on dynamic venture capital markets rather than non-market coordination, but these are risk-sharing mechanisms nonetheless (Casper, 2007; Lazonick and Mazzucato, 2013; Breznitz, Forman and Wen, 2018). For Silicon Valley itself, researchers have pointed to an initially important role of state action but also to an autonomous and self-strengthening regional innovation system that has become arguably the most successful in the world (Mazzucato, 2011; Storper *et al.*, 2015). While the innovation setting and strategic positioning of ventures are significantly different from the case studies covered in this thesis, the innovation-driving importance of regional networks is shared.

Finally, the new process model thereby also clarifies the findings from this thesis vis-à-vis the expected role of the state in enabling discontinuous innovation. Based on the evidence laid out both in the case-study chapters and in the process analysis, the Nordic governments and their affiliated agencies and regulatory bodies are not automatically taking an implementing role of mission-oriented innovation policy (MOIP), overall innovation directionality, nor of demand-side policies for discontinuous innovation for sustainable industry transitions, as understood by existing literature on innovation policy (Mazzucato, 2018; Edquist, 2019; Giacometti and Jessen, 2024). The Nordic states are taking various innovation policy approaches that are fundamental to the ventures examined in the case studies, however, in none of the cases is the trend toward state-directed innovation very strong. Rather, as found above, the core of the innovation directionality is framed by local-level innovation drivers, with state policies and regulatory actions shown to have a crucial role as ex-post enablers of success and scale-up progress. In some cases, the early-stage directing role of states is stronger, but overall, the concrete strategy and execution of discontinuous innovation processes and the identification of the main drivers shaping the innovation process take place predominantly through the interaction between venture initiators and the stakeholders of the regional innovation system.

Therefore, the contributions of this thesis align with the literature on the importance of regional innovation systems and clusters for driving innovation rather than on detailed top-down innovation directionality provided by national governments. As will be discussed in the next and final chapter, more research is needed in different sectors, including for different country contexts, new technologies, and sustainable energy and traditional industry settings, to examine how the roles of state-directed policy and regional-level innovation drivers may be variable across time and place.

8.4 Conclusion

This chapter has tied together the analysis of the preceding empirical chapters by increasing our theoretical understanding of sustainability transitions as systemic processes of discontinuous innovation. In doing so, it has presented and analysed case studies from pioneering hydrogen and green-steel innovation taking place in the Nordic region, and on the basis of this research, proposed a set of new theory frameworks that help understand how sustainability-focused innovation, understood through a lens of discontinuous innovation processes, may work differently for different ventures and in different innovation settings. It is particularly important to theorise based on these empirical cases, as they are some of the first ventures in the world where industrial-scale decarbonisation has reached commercial scale.

The material resource dependent innovation setting faced by the case-study ventures has implications both for the mutual relations between them (in terms of indirect complementarities and overlapping resource dependencies) and for the role and impact of regional industry stakeholders and state policy and regulation on their future development. The four modes of discontinuous innovation in the new comparative theory framework illustrate this diversity in strategic positioning. The new process framework demonstrates how these factors are also temporal: The interaction of these elements of the innovation processes with each other looks different at different process stages. The comparative and process-focused theoretical frameworks developed based on the case studies can be applied in other settings, allowing us to theorise how discontinuous ventures and strategies may align or misalign with present-day industry contexts where large-scale sustainability transition has not yet been proliferated.

Chapter 9 – Conclusion

This concluding chapter brings together the central messages laid out by the findings of the thesis for both theory and practice, discusses potential research limitations and their mitigation, and highlights future research avenues.

9.1 Summary of findings: Regional coordination and risk-sharing as crucial stakeholder roles in Nordic green steel and hydrogen innovation

This thesis describes the strategies and stakeholder interactions that drive a set of pioneering sustainability innovations in traditional industry settings. The inductive case studies are centred in the northern regions of the Nordic countries, which host first-of-a-kind innovation in several sectors. Among the empirical case studies, the thesis includes the first in-depth comparative analysis of the innovation processes of the world's first industrial-scale ventures for steel decarbonisation using green hydrogen.

The empirical case study chapters have shown how the strategic positioning and innovation trajectory of ventures can look very different, especially compared to global ideal types such as the general 'Silicon Valley model' of market-driven industry disruption (Casper, 2007; Christensen, 1997). But despite their differences, Nordic first-movers in green steel and hydrogen have fundamentally complemented and shaped each other's development, especially when it comes to mitigating shared resource bottlenecks and lowering business risks in the regional industry environment. These findings suggest that, particularly in the case of Nordic steel decarbonisation, discontinuous innovation in traditional industries involves a high dependence on non-market coordination even between ventures that initially have very different business models. The successful scale-up of green steel innovation ventures has been

much more complex than simply securing funding and renewable resources: It has required aligning new value-chain partners across sectors and sharing early-stage innovation risks among a variety of stakeholders both globally and within the region.

This thesis also finds that policy and industry stakeholders in regional innovation systems and clusters have a crucial innovation-shaping role. The case studies of Chapter 6 demonstrate this by showing how differently local-level stakeholder actions can shape the prevalent incentives and business models of discontinuous innovation, creating large differences even between innovation contexts that are structurally very similar. At face value, the institutional and material conditions for hydrogen innovation ventures appear relatively constant across the north of the Nordic countries (Kristensen and Lilja, 2011). However, three different combinations of local-level innovation drivers have shaped the size and type of innovation processes that have become characteristic for each case study region. The key drivers include, in particular, the engagement of local stakeholders in early-stage risk sharing that supports discontinuous innovation ventures before new market incentives and value chains have been formed. Such risk-sharing is present in each case study, but the actions and stakeholders driving it are different.

The importance of local and regional alignment is further strengthened by the resource and infrastructure dependent nature of sustainability innovation for hydrogen and other renewable energy technologies (McDowall, 2018; Henderson, 2021). These findings suggest that in the case of Nordic hydrogen innovation, discontinuous innovation in traditional industries is highly dependent on innovation-shaping actions taken by stakeholders at the local and regional levels. Moreover, this strong role of the regional innovation system is evolving and based on continuous experimentation, rather than a static background context that is left up to external

global industry and state policymakers to rearrange. In a time of increasing calls for state-directed industrial policy, these findings offer an alternative perspective that illustrates how many aspects of successful innovation in fields of breakthrough sustainable technologies are orchestrated by the stakeholders that are closest to the innovation processes themselves. The findings point to a broader political discussion about the division of labour between national and regional government when it comes to public risk-taking for innovation (Lazonick and Mazzucato, 2013).

Consequently, from the perspective of state policy and national innovation systems, this thesis finds that the role of the Nordic states in enabling discontinuous sustainability innovation is important but not straightforward. While local-level stakeholders shape the fundamental innovation trajectories, successful scale-up and industrialisation inevitably depend on enabling factors that only state-level actors can provide (Giacometti and Jessen, 2024; Algers, 2024). In particular, the case studies demonstrate different policy and regulatory experimentation to mitigate regulatory bottlenecks and speed up infrastructure capacity, with various degrees of state-led directionality in supporting specific ventures or technology choices. In some cases, pre-existing state intervention models to support declining industry clusters have been reframed to support ones that are now undergoing rapid expansion (Larsson, 2022). In other cases, energy and infrastructure agencies are grappling with the need to reform their process to incentivise new technologies while also avoiding gridlock as many different types of ventures scale up at the same time, with different needs and priorities. The timeline for these new state strategies is particularly urgent in regions with the highest inflow of new investments and innovation ventures, some of which have consequently experienced bottlenecks and even adverse effects from existing policy prioritisation in the *status quo*.

These findings suggest that the role of the Nordic states in enabling discontinuous innovation in traditional industries, especially in the case of sustainability and decarbonisation, involves a degree of complexity that is higher than in innovation and industrial policy in general, and that has to be continuously aligned and orchestrated across several agencies and policy priorities. In light of the case studies in this thesis, a state role of maintaining synthesised, top-down directionality over all aspects of the system-wide sustainability transformations, with implications affecting the state's actions in each individual case, seems unlikely to succeed. This also broadly aligns with the traditional role of Nordic states in innovation policy as active but not *dirigiste*, and as strong in policy experimentation and adaptation (Fellman *et al.*, 2008; Jääntti and Vartiainen, 2009; Kristensen and Lilja, 2011; Breznitz and Ornston, 2013) A complementary analysis at the end of Chapter 7 also finds that the general institutional complementarities characterising the Nordic countries are still largely in place in shaping industry and innovation (Hall & Soskice, 2001; Kristensen and Lilja, 2011; Thelen, 2019). However, especially the larger-scale ventures from the case studies seek finance, talent attraction, and supply chain strategies that blend aspects of the Nordic institutional advantage with other aspects of institutional advantage from other innovation contexts. Overall, the findings suggest that further policy experimentation, adaptation, and political debate are likely to take place, both in the Nordic countries and elsewhere, surrounding the desired role and actions of the state in supporting innovation for sustainable industry transitions.

9.2 Summary of contributions: A new comparative research perspective on discontinuous innovation

Based on its empirical findings, this thesis contributes to the literature with a new perspective to inform the theory and practice of innovation in a transitioning world. The change pressures at the core of this research are climate change and sustainability transition, which give rise to

the need for system-level transformation of many traditional, hard-to-abate industry sectors that rely on fossil fuels and greenhouse gas emissions for their core processes and business models (Lema, Fu and Rabellotti, 2020; Henderson, 2021). These industry settings are clearly different from those that predominantly figure in global benchmark models and examples of breakthrough innovation (Christensen, 1997; Fagerberg, 2018; McDowall, 2018). In order to support policy and strategy for sustainable industry transitions, theory on innovation needs to be able to characterise, categorise, and analyse breakthrough innovation in settings that previous models would have overlooked.

The primary theory contribution of this thesis is, therefore, to present a new theory perspective in innovation that helps us analyse innovation settings with more nuance to the specific context and enabling mechanisms of step-change transformations. In particular, this thesis argues that such analysis can best undertaken through a broadening and deepening of the construct of *discontinuous innovation* (Kaplan, 1999). If more diverse industry contexts and instances of step-change transformation and breakthrough innovation can be characterised as instances of discontinuous innovation, they can be compared on equal terms and modelled on their own terms, rather than being categorised as static or inferior versions of general benchmark models for innovation. This updated theory perspective is particularly relevant to better understand the enablers of sustainable industry transition in traditional industry settings. Under ‘normal’ conditions of sustaining innovation and business as usual, these traditional sectors and rural industry towns are viewed only in narrow cases as conducive to transformative, disruptive, or breakthrough change and innovation (Christensen, 1997; Casper, 2007; Ornston, 2014). In the context of the mounting pressure on system-wide industry transition and decarbonisation, that is no longer the reality, and a new, more accurate theory perspective is required. The primary

contribution of a new theory perspective is therefore featured as the main title of the thesis: *Discontinuous innovation in traditional industries*.

The inductive theory building undertaken in Chapter 8 synthesises and operationalises the findings of the thesis into two new theory frameworks that can be built upon by future research and applied to research in other empirical contexts. Based on the uncovered empirical processes, the new comparative theory framework presents a simple categorisation with two parameters that give rise to four modes describing different types of strategic positioning of discontinuous innovation ventures. The new framework may be refined and applied more broadly but is particularly useful in highlighting the variety of available strategic positions for ventures pursuing discontinuous innovation in traditional industries, as these processes are under-researched and not well understood in previous literature. For example, applying the framework to innovation in steelmaking clarifies how and why the two case studies in this thesis are different both from each other and from the market-disruptive form of steel innovation earlier described by Christensen (1997) in the US context. The new theory framework increases the comparative nuance of the analysis of discontinuous innovation processes, not least for sustainability contexts, and makes it possible to compare discontinuous innovation ventures in a way that cannot be captured with conventional taxonomies of innovation (such as product vs. process innovation, radical vs. incremental innovation, or sustainaing vs. discontinuous innovation) (Schmookler, 2013).

Moreover, as already demonstrated across the case studies in this thesis, the categorisation made in the new comparative theory framework is not static or discreet. Instead, it focuses on innovation strategies and processes that may change over time, especially at the early and pre-market stages of discontinuous innovation. The new process framework builds on the new

comparative framework of four discontinuous innovation modes and makes it possible to model how and why the strategic positioning of discontinuous innovation ventures may change as a venture develops. In particular, this is done by including into the process model systemic elements of both local-level (industry and policy) and state-level interactions, tracing which features are the most consequential in driving and shaping the innovation strategy of the venture. For example, applying the new process framework makes it possible to clarify and understand the process mechanism shaping the empirical findings of a driving and innovation-shaping role for regional-level industry and policy stakeholders, while the role of most state-level actions in the case studies is one of general policy directionality but predominantly *ex-post* support and enabling regulation. The new process model allows for both the analysis of different driving factors of discontinuous innovation processes, and how different processes may shape each other's trajectories at the systemic level, in a way that was not possible in pre-existing literature on innovation.

9.3 Practical contributions: Innovation for sustainability in industry, the state, and regional policy

As pre-existing research has not developed clear models for studying innovation within the transition to sustainability, there is also a lack of comprehensive practical models for policymaking and business strategy on how these transitions can be managed. For managers of various industry companies, better explanatory models of the successes and challenges involving sustainability-related innovation strategies, and how these may take different forms, will directly help these companies formulate and manage their own strategy for the sustainability transition (Pisano, 2015). Literature on innovation has only recently started accounting for the effect of different industrial contexts and traditions in, for example, the evolution of new business models (Breznitz, 2021). In particular, there is no existing

framework that situates and compares different innovation strategies for sustainability. The theory contribution of this thesis provides a suitable anchor for more contextually informed strategy analysis, with potential for application by strategists in various industry settings beyond the ones brought up in this thesis.

For policymakers, this research can inform the shaping of system-wide innovation and economic policy. While there is ample research on the effectiveness of innovation and development policy, there are few studies that follow how those policies directly interact with stakeholders and ventures and, subsequently, which actions are better at enabling a sustainable, successful, and innovative industry environment. However, directly linked to the main contributions of this thesis, there are different applications to be drawn for policymakers within different parts of public governance, such as regulatory agencies, national government and ministries, and in particular, regional and local government.

Many state agencies are forming new strategic models for adapting regulations and permitting processes to a sudden inflow of many prospective large-scale industry projects. The frameworks developed in this thesis can guide these policy decisions by increasing the capacity of policymakers to compare the profiles and challenges of different ventures and industry sectors based on their strategic positioning. For national government, this thesis carries the potential for similar analytical tools, but also a set of examples that show the complexity of the role and timing of state leadership surrounding industry transitions and the value of continuous policy experimentation. The new frameworks can help national policymakers in clarifying their high-level policies and missions to account not only for a whole-system perspective of different stakeholders but also the varying and changing needs and challenges of these different stakeholders, for example, between incumbent and start-up ventures with similar goals but

different approaches. Finally, for regional and local government, this thesis provides a set of case studies that demonstrate and trace the direct agency and impact of regional-level coordination for driving innovation and sustainability transitions, and how this can take on different forms. The new theory framework models can be applied in planning more effective future regional-level action to support discontinuous innovation, including better orchestration across stakeholders and more inclusive alignment between formal policymaking and informal networks.

From the perspective of practitioners in other industry and country contexts, the empirical focus of these findings is narrow but relevant. In terms of industry sector, the description of drivers and enablers of the first innovation processes for steel decarbonisation, as well as a set of first-of-a-kind hydrogen innovation processes, carries broader relevance both for the steelmaking and energy sectors and for other hard-to-abate industry transition contexts. In terms of country context, the description of success factors and challenges in the regional and national innovation systems and wider Nordic societies preview potential future development trajectories for other parts of the world facing large-scale industry decarbonisation. Even in the Nordic innovation context, where specific institutional features give rise to world-leading learning economies and innovation systems, innovation processes for sustainable industry transition involve challenges and controversies. Understanding these can inform other global regions undergoing discontinuous innovation in traditional industries.

9.4 Limitations: Pioneering cases in surprising settings

This thesis undertakes inductive theory-building through a defined set of qualitative methods that are deemed as the most conducive to reaching the research aims of the thesis (Langley, 1999; Eisenhardt and Graebner, 2007; Corbin, 2014; DiBenigno and Kellogg, 2014; Bremner

and Eisenhardt, 2022). While purposeful measures have been taken throughout the research project to guarantee the overall research quality and trustworthiness of the findings and contributions (see Chapter 3), there are inevitably elements in the research design and its execution that give rise to limitations.

Firstly, the constructivist philosophical foundations of the research design, and the subsequent research focus on qualitative case studies, limit the risk of observation bias in terms of capturing both formal and informal stakeholder dynamics but also expose the research process to a higher risk of confirmation bias (Corbin, 2014; DiBenigno and Kellogg, 2014; Eisenhardt, Graebner and Sonenshein, 2016; DeJordy *et al.*, 2020). The undertaken case studies were limited by these methods due to the time and analytical detail needed to draw clear findings and conclusions in any specific case. The thesis would have benefited from complementary evidence through a broader focus on additional case ventures and examples (for example, a more comprehensive analysis of all hydrogen innovation ventures in each region, or of all discernible aspects of state innovation policy), to achieve fuller counterfactual evidence of the models described. While this was beyond the scope of the thesis, the research process sought to mitigate the limitation through theoretical sampling to include and illustrate broader themes of innovation policy and strategy without including all of them as formal case studies (Heckathorn, 1997; Eisenhardt and Graebner, 2007).

Secondly, the empirical focus of the thesis is on contemporary innovation processes that demonstrate first-of-a-kind developments in sectors and markets where many elements have not yet materialised. Simultaneous analysis of ongoing innovation processes is a crucial part of the research design for this thesis as it strengthens the trustworthiness of empirical analysis especially when it comes to informal networks (Morse *et al.*, 2002; Bremner and Eisenhardt,

2022). However, the temporal dimension also inevitably presents a research limitation, as we cannot account for the unknown future of the innovation processes described in the case studies. The findings and conclusions of the thesis are therefore limited to the initiation, scale-up, and early industrialisation phase of the included ventures, as well as to the present stage of development for regional and national enablers and policies. The thesis does not speculate as to the future of these ventures or, for example, how and to what extent some of them will end up disrupting or displacing present-day industry, as such judgements can only be made *post hoc*. However, the theory contribution of this thesis focuses on understanding discontinuous innovation *processes* and their strategic positioning (Garud, Tuertscher and Van De Ven, 2013). These are changeable over time, and most accurately analysed in real time.

Finally, the industry and country context of the thesis presents a natural limitation to the transferability of the findings, especially given the leading position and distinct institutional characteristics often ascribed to the Nordic countries in global scoreboards and literature on industry and innovation (Kristensen and Lilja, 2011; Ornston, 2018; World Intellectual Property Organization., 2024). This was inevitable given that the selection of the cases was driven by the prevalence in the Nordic context of some of the most developed examples of sustainable industry innovation anywhere in the world – especially regarding steel decarbonisation. While it is impossible for process analysis to ever be neutral of the institutional context, the qualitative research design of this thesis has nevertheless made it possible to keep different institutional enablers in mind throughout the analysis, as well as to comment on what the potential differences may be to other empirical contexts. As the final section will emphasise, broadening the findings of this thesis to other innovation settings is a fundamental step for further research on discontinuous innovation in traditional industries.

9.5 Future research avenues: Understanding innovation in a transitioning world

The discernible future research trajectories based on this thesis and its contributions are methodological, empirical, and theoretical. Firstly, in terms of research methodology, the research design for this study was formulated as a piece of exploratory and inductive theory-building research. Further research focusing on the included case studies or broadening the scope to similar cases in other contexts can benefit from broader methodological diversity, bringing benefits of data triangulation from multiple sources and mixed methods. For example, the new theory framework of different strategic positioning could be operationalised into quantitative measures for large-N studies tracking the discontinuous innovation modes present among ventures in different sectors at different times.

Secondly, future research is needed to broaden the findings and theory frameworks of this thesis into different sectors and different country contexts. Given the cases and findings based on Nordic examples in green steel and hydrogen innovation, the natural follow-up for future research is to analyse and compare these to innovation processes that emerge in the same sectors but in other parts of the world. Moreover, while the sectors included in this thesis have a lot in common with the challenges of other traditional industry settings, especially when it comes to sustainability and decarbonisation, it is relevant for future research to undertake similar research on other sectors and technologies, especially other technologies for hard-to-abate industry decarbonisation and energy transition. This thesis has demonstrated a narrow set of processes and strategic models that the observed case study stakeholders have applied. It is possible to conclude that these case studies operate differently from each other and from general benchmarks or ideal-type models for innovation, such as market-driven disruption akin to a ‘Silicon Valley model’. However, these findings cannot speculate on what trajectories or innovation modes will be followed in other cases of discontinuous innovation in traditional

industries. Therefore, the new theory frameworks developed by this thesis are designed to be applicable in various empirical contexts in future research. This will allow for more definitive and transferable models and strategies for discontinuous innovation to be developed over time.

To conclude, this thesis invites a more comprehensive future research agenda on the comparative analysis of innovation, and fully aligns with calls made by previous research for increased contextual nuance in the study of innovation (Breschi, Malerba and Orsenigo, 2000; Storper *et al.*, 2015; Edquist, 2019; Fu, 2020; Breznitz, 2021). The focus and contributions of this thesis particularly encourage more active study of *discontinuous innovation* and related constructs, such as breakthrough and disruptive innovation, from a comparative perspective that recognises that successful innovation can look different in different places and at different times and therefore requires different things from innovators, managers and policymakers (King and Baatartogtokh, 2015; Kivimaa *et al.*, 2021; Weigelt, Lu and Verhaal, 2021). This is important because settings of discontinuous innovation are, by definition, particularly changing and uncertain. On the one hand, discontinuous innovation is inherently more changing and dynamic than (both radical and incremental forms of) sustaining innovation, which makes it more adaptable to the agency and situational drivers of the stakeholders shaping innovation. As demonstrated in this thesis, this can lead to surprising and different innovation trajectories than a specific sector or location may have been used to or expected to follow, especially if the point of departure is a narrow ideal-type model for what innovation inevitably looks like. But on the other hand, an additional layer of complexity comes from external contexts of change that provoke discontinuous innovation. The urgency of sustainability transitions in industry frames the importance of new theory-building research in the context of traditional industry settings, which has been the specific context of this thesis (Henderson, 2021; Garud and Gehman, 2012; Fagerberg, 2018; Gambardella and McGahan, 2010). There are several other

salient trends of global change and system transition as well, which are provoking transformations and discontinuous innovation in unexpected places. This thesis concludes with a call for more theory and research to tackle these challenges and to provide tools that can help both single ventures and entire societies innovate and develop in an uncertain world.

Abbreviations and acronyms

BF	Blast Furnace
BOF	Basic Oxygen Furnace
CBAM	Carbon Border Adjustment Mechanism
CH2ESS	Centre for Hydrogen Energy Systems Sweden
CO2	Carbon dioxide
CME	Coordinated market economy
DRI	Directly Reduced Iron
EAF	Electric Arc Furnace
EIF	European Investment Fund
EU	European Union
ETS	Emissions Trading Scheme
H2	Hydrogen
H2GS	H2 Green Steel (from September 2024 renamed as Stegra)
Haelous	Hydrogen-Aeolic Energy with Optimised eLectrolysers Upstream of Substation
HYBRIT	Hydrogen Breakthrough Innovation Technology
LME	Liberal market economies
LNG	Liquified Natural Gas
LTU	Luleå Technical University
MNC	Multi-national corporation
NIS	National innovation system
R&D	Research and development
RIS	Regional innovation system
SME	Small and medium-sized enterprise
SWF	Sovereign Wealth Fund
UiT	The Arctic University of Norway (Universitetet i Tromsø)
VoC	Varieties of Capitalism

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Appendix: List of interviews

Overview and description of interview respondents

Respondent number	Role	Country
Main interview period		
1	Västerbotten municipality executive	SE
2	Norrbottn County Council director	SE
3	Innovation agency fellow	NO
4	Innovation agency director	NO
5	Swedish government advisor	SE
6	HYBRIT executive	SE
7	Västerbotten industry executive	SE
8	H2 Green Steel director	SE
9	HYBRIT director	SE
10	Ostrobothnian County Council executive	FI
11	Innovation agency director	NO
12	H2 Green Steel manager	SE
13	H2 Green Steel manager	SE
14	H2 Green Steel director	SE
15	HYBRIT executive	SE
16	Business incubator executive	NO
17	Finnmark energy industry director	NO
18	Finnmark energy company director	NO
19	Innovation agency director	NO
20	Finnmark business park executive	NO
21	Berlevåg Municipality director	NO
22	Finnmark energy company director	NO
23	Finnmark energy company manager	NO
24	H2 Green Steel executive	SE
25	H2 Green Steel executive	SE
26	H2 Green Steel executive	SE
27	Finnmark County Council director	NO
28	Boden Municipality executive	SE
29	Boden Municipality executive	SE
30	Ostrobothnia regional association executive	FI
31	Vaasa industry association director	FI
32	Regional council director	NO
33	Västerbotten municipality executive	SE
34	Norrbottn industry association executive	SE
35	Norrbottn industry association executive	SE
36	Finnmark energy company director	NO

37	Finnmark energy company executive	NO
38	Luleå Municipality director	SE
39	Boden industry association executive	SE
40	Energy agency director	SE
41	Norrbottn Country Council executive	SE
42	Nordic Council agency fellow	SE
43	Norrbottn industry executive	SE
44	Västerbottn industry director	SE
45	Luleå Municipality executive	SE
46	HYBRIT director	SE
47	Luleå Municipality director	SE
48	Infrastructure agency director	SE
49	HYBRIT executive	SE
50	Steel decarbonisation executive	FI
51	Norrbottn university executive	SE
52	Vaasa university director	FI
53	Energy agency executive	FI
54	Ostrobothnia energy company executive	FI
55	Vaasa energy company director	FI
56	Energy agency director	SE
57	Vaasa industry decarbonisation director	FI
58	H2 Green Steel director	SE
59	Energy industry manager	NO
60	Energy industry executive	SE
61	HYBRIT director	SE
62	Luleå university director	SE
63	Stockholm university director	SE
64	Energy industry executive	FI
65	Innovation agency director	NO
66	Investment fund director	FI
67	Vaasa industry association manager	FI
68	Innovation agency director	FI
69	H2 Green Steel director	SE
70	Boden industry association executive	SE
71	Boden municipality executive	SE
72	Luleå municipality executive	SE
73	Västerbottn industry director	SE
74	HYBRIT director	SE
75	Luleå energy company director	SE
76	Västerbottn energy company manager	SE
Second background interview period (2020)		
77	Municipality director	SE
78	Industry executive	SE

79	Municipality manager	SE
80	Municipality manager	SE
81	Incubator executive	SE
82	Municipality executive	SE
83	Regional association manager	SE
84	Industry director	SE
85	Industry manager	SE
86	University research director	SE
87	Industry manager	SE
88	Regional association director	FI
89	Government advisor	SE
90	Regional association director	SE
91	Municipality director	SE
92	County council director	SE
93	Innovation agency director	SE
94	Energy company executive	SE
First background interview period (2018)		
95	Energy agency executive	FI
96	Industry director	FI
97	Angel investor	FI
98	Energy industry director	FI
99	Regional association coordinator	FI
100	Industry manager	FI
101	Venture capital investor	FI
102	Industry manager	FI
103	Member of Parliament	FI
104	Industry director	FI
105	Former government minister	FI
106	Municipality executive	FI
107	Industry executive	FI
108	University research executive	FI