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A COMPLEX ADAPTIVE SYSTEM PERSPECTIVE OF THE GREEN-RESTRUCTURING OF CLUSTERS

by Ram Mohan Sasikumar Kamath

IAMO 2024

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EXECUTIVE SUMMARY

Given the adverse effects of climate change (such as drought and flooding, damage to ecosystems and infrastructure, depletion of resources, deterioration of human health), society needs to transition to using sustainable systems of production and consumption. Regions and countries increasingly view the creation of green-clusters that can nurture green-innovation and spur new green-industries, as a solution to this challenge. In fact, the formation of green-clusters, and the greening of existing industrial clusters has been identified as an important tool to achieving the GHG-reduction goals of the European Green Deal. However, Green-clusters need not be intrinsically sustainable. Especially when green-clusters are derived from existing clusters, they will inherit unsustainable processes. This means before these clusters can help regions and nations transition, they must themselves transition to greener products and production techniques.

The green-restructuring of clusters has become a key area of interest to Evolutionary Economic Geography; and to the emerging field of Geography of Transitions, which bridges Evolutionary Economic Geography and Sustainability-Transition Studies. However, owing to extant cluster-evolution frameworks' and cluster-evolution studies' inability to settle still ongoing discussions regarding the development of clusters, scholarship risks falling behind policymakers.

This thesis contributes to the resolution of some of these discussions. Most importantly, we address the debate regarding the dynamics behind the process of clusters' green-restructuring. We then address debates regarding the role of place-based structures in shaping cluster-evolution, the role of agency in shaping cluster-evolution, the role of proximity-dimensions in shaping the greening of clusters, and the multiscalar nature of cluster-evolution. These contributions are made by answering the following research question:

How do the dynamics at the levels of agency, actor-collaboration, and structures, and the interactions between these dynamics, shape the green-restructuring of clusters?

The research question was answered through three different studies, each answering one of the following sub-research questions:

1. How does the dynamic interaction of agency, structures, and supra-regional phenomena shape the green-restructuring of a cluster?
2. What policy instruments are most effective in causing green-growth of clusters in a peripheral region?
3. How do the different dimensions of proximity shape innovation collaborations for cluster-greening?

The three studies that constitute this thesis employ a novel complex adaptive system perspective of clusters and their-evolution, which is developed in the first study. Study one involved a longitudinal analysis of the greening of the Basque pulp-and paper-cluster, over four phases between 1986 and 2019. To conduct this analysis, I created a novel cluster-evolution framework that treats clusters, and the regional innovation system and sectoral systems of innovation that contain the cluster, as complex adaptive systems. For the second study, I created an agent-based model (ABM) that can simulate a cluster's transition, as shaped by different policy instruments. The third study involved a case-study that explored how different proximity dimensions influenced collaboration for green-innovation in the Paper Province cluster in the Värmland Region of Sweden.

The thesis makes various theoretical and methodological advances. For instance, the novel cluster-evolution framework from study one holds advantages over extant cluster-evolution models (it can explain different types of cluster-restructuring and restructuring-paths, it can account for multiple forms of agency, it can explain the multiscalarity of cluster-restructuring, it can explain the distinct and combined influence of regional and industrial influences). Departing from previous studies on clusters' green-restructuring, the first study used a case-study of a cluster's green-restructuring; which unearthed rare empirical data on the greening process. With the creation of a novel ABM, the second study contributed to the emerging practice of modelling green-transitions. Unlike preceding ABMs that have been used to study cluster-evolution, this one models for innovation that makes the cluster-members (and the cluster) not only richer, but also greener.

The main findings of the thesis are that:

1. Green-restructuring and economic-restructuring are generally similar, with some differences:
   While the first study revealed that a possible differentiator between green-restructuring and economic-restructuring is the presence of deliberate destabilisation of unsustainable structures in the former, the third study found there were considerable similarities between how proximity-dimensions affect conventional innovation projects and how they affect projects meant to produce innovations for green-restructuring. The second study revealed the complex choices involved in balancing a cluster' economic-restructuring, and its greening
2. Institutional-entrepreneurs and place-leaders are pivotal to cluster-greening:
   The first study demonstrated how important the presence of institutional-entrepreneurs and place-leaders is, to green-innovation. The results show these actors are critical because they can shape both supra-regional and industrial structures, and thus possibly lead the cluster along more favourable greening-paths. Similarly, the third study demonstrated the importance of these actors, in helping ameliorate the uncertainties of the innovation projects (owing to institutional, cognitive differences between partners)

3. Greening is a multiscalar process, but place-based idiosyncrasies can be highly influential:
   The first study of this thesis provided evidence of phenomena at the national, continental and global scales shaping the greening process by either directly acting on agency, or by acting on industrial and/or regional structures. However, studies one and three also demonstrated the (disproportionate) influence of place-based idiosyncrasies (such as regional pride, or the small economies-of-scale of a cluster's firms).

Based on these results, the thesis recommends that for designing policies to support green-restructuring of clusters,

1. Policymakers must relinquish their traditional techno-economic focus, and encourage the emergence of place-leaders and institutional-entrepreneurs.
2. Policies must factor in characteristics of cluster firms (e.g. proclivity to collaborate, economies of scale, are they pioneers or followers); and must make use of place-specific institutions.
3. Policymakers must hold interim policy-evaluation that will reveal if certain policies are taking clusters along inefficient greening-paths, which may eventually become ineffective paths.

ZUSAMMENFASSUNG

Angesichts der negativen Auswirkungen des Klimawandels (wie Dürren und Überschwemmungen, Schäden an Ökosystemen und Infrastruktur, Erschöpfung der Ressourcen, Verschlechterung der menschlichen Gesundheit) muss die Gesellschaft zu nachhaltigen Produktions- und Verbrauchssystemen übergehen. Regionen und Länder sehen in der Schaffung von grünen Clustern, die grüne Innovationen fördern und neue grüne Industrien anregen können, zunehmend eine Lösung für diese Herausforderung. Tatsächlich wurde die Bildung grüner Cluster und die Ökologisierung bestehender Industriecluster als ein wichtiges Instrument zur Erreichung der THG-Reduktionsziele des Europäischen Green Deal identifiziert. Grüne Cluster müssen jedoch nicht zwangsläufig nachhaltig sein. Insbesondere wenn grüne Cluster aus bestehenden Clustern hervorgehen, werden sie nicht nachhaltige Prozesse übernehmen. Das bedeutet, dass diese Cluster, bevor sie Regionen und Nationen bei der Umstellung helfen können, selbst auf umweltfreundlichere Produkte und Produktionstechniken umstellen müssen.

Die grüne Umstrukturierung von Clustern ist zu einem Schlüsselbereich von Interesse für evolutionäre Wirtschaftsgeographie und das neu entstehende Feld der „Geography of Transitions" geworden, das die evolutionäre Wirtschaftsgeographie und „Sustainability-Transition Studies" miteinander verbindet. Da die bestehenden Cluster-Evolutionsrahmen und Cluster-Evolutionsstudien jedoch nicht in der Lage sind, die immer noch andauernden Diskussionen über die Entwicklung von Clustern zu klären, besteht die Gefahr, dass die Wissenschaft hinter den politischen Entscheidungsträgern zurückbleibt.

Die vorliegende Dissertation trägt zur Lösung einiger dieser Diskussionen bei. Vor allem befassen wir uns mit der Debatte über die Dynamik hinter dem Prozess der grünen Umstrukturierung von Clustern. Anschließend gehen wir auf Debatten über die Rolle ortsbezogener Strukturen bei der Gestaltung von Cluster-Evolutionen, die Rolle von

Handlungskompetenz bei der Gestaltung von Cluster-Evolutionen, die Rolle von Nachbarschaftsdimensionen bei der Gestaltung der Ökologisierung von Clustern und die multiskalare Natur von Cluster-Evolutionen ein. Diese Beiträge werden durch die Beantwortung der folgenden Forschungsfrage geleistet:

Wie gestalten die Dynamiken auf den Ebenen des Handelns, der Zusammenarbeit zwischen den Akteuren und der Strukturen sowie die Wechselwirkungen zwischen diesen Dynamiken die grüne Umstrukturierung von Clustern?

Die Forschungsfrage wurde durch drei verschiedene Studien beantwortet, die jeweils eine der folgenden Unterfragen beantworteten:

1. Wie gestaltet das dynamische Zusammenspiel von Akteuren, Strukturen und überregionalen Phänomenen die grüne Umstrukturierung eines Clusters?
2. Welche politischen Instrumente sind am effektivsten, um grünes Wachstum von Clustern in einer peripheren Region zu bewirken?
3. Wie formen die verschiedenen Dimensionen der Nähe Innovationskooperationen für die Ökologisierung von Clustern?

Die drei Studien, aus denen diese Arbeit besteht, verwenden eine neuartige Perspektive komplexer adaptiver Systeme auf Cluster und ihre Entwicklung, die in der ersten Studie entwickelt wird. Studie eins umfasste eine Längsschnittanalyse der Ökologisierung des Baskenlands in der Zellstoff- und Papierindustrie in vier Phasen zwischen 1986 und 2019. Für diese Analyse habe ich einen neuartigen Cluster-Evolutionsrahmen entwickelt, der Cluster sowie das regionale Innovationssystem und die sektoralen Innovationssysteme, die den Cluster umfassen, als komplexe adaptive Systeme betrachtet. Für die zweite Studie habe ich ein agentenbasiertes Modell (ABM) entwickelt, mit dem der Übergang eines Clusters simuliert werden kann, der durch verschiedene politische Instrumente beeinflusst wird. Die dritte Studie umfasste eine Fallstudie, in der untersucht wurde, wie verschiedene Dimensionen der räumlichen Nähe die Zusammenarbeit bei grünen Innovationen im Cluster Paper Province in der schwedischen Region Värmland beeinflussen.

Die Arbeit bringt verschiedene theoretische und methodologische Fortschritte. So bietet der neuartige Cluster-Evolutionsrahmen aus der ersten Studie Vorteile gegenüber bestehenden Cluster-Evolutionsmodellen (er kann verschiedene Arten von Cluster-Restrukturierung und Restrukturierungspfaden erklären, er kann mehrere Formen von Handlungsfähigkeit berücksichtigen, er kann die Multiskalarität von Cluster-Restrukturierung erklären, er kann den unterschiedlichen und kombinierten Einfluss von regionalen und industriellen Einflüssen erklären). Im Gegensatz zu früheren Studien über die grüne Umstrukturierung von Clustern wurde in der ersten Studie eine Fallstudie über die grüne Umstrukturierung eines Clusters durchgeführt, die seltene empirische Daten über den Ökologisierungsprozess zutage förderte. Mit der Entwicklung eines neuartigen ABM leistete die zweite Studie einen Beitrag zur entstehenden Praxis der Modellierung grüner Übergänge. Im Gegensatz zu früheren ABMs, die zur Untersuchung der Entwicklung von Clustern verwendet wurden, modelliert dieses ABM Innovationen, die die Clustermitglieder (und das Cluster) nicht nur reicher, sondern auch grüner machen.

Die Hauptergebnisse dieser Arbeit sind, dass:

1. Grüne Umstrukturierung und wirtschaftliche Umstrukturierung sind im Allgemeinen ähnlich, mit einigen Unterschieden:
   Während die erste Studie ergab, dass ein mögliches Unterscheidungsmerkmal zwischen grüner Umstrukturierung und wirtschaftlicher Umstrukturierung die bewusste Destabilisierung nicht nachhaltiger Strukturen in der ersteren ist, stellte die dritte Studie fest, dass es beträchtliche Ähnlichkeiten zwischen den Auswirkungen von Nachbarschaftsdimensionen auf konventionelle Innovationsprojekte und auf Projekte gibt, die Innovationen für eine grüne Umstrukturierung hervorbringen sollen. Die zweite Studie

zeigte die komplexen Entscheidungen auf, die mit der Balance zwischen der wirtschaftlichen Umstrukturierung eines Clusters und seiner Ökologisierung verbunden sind.

2. Institutionelle Unternehmer und führende Persönlichkeiten vor Ort sind für die Ökologisierung von Clustern von zentraler Bedeutung:
   Die erste Studie hat gezeigt, wie wichtig das Vorhandensein von institutionellen Unternehmern und Standortführern für die grüne Innovation ist. Die Ergebnisse zeigen, dass diese Akteure von entscheidender Bedeutung sind, da sie sowohl überregionale als auch industrielle Strukturen formen und somit den Cluster möglicherweise auf günstigere Ökologisierungspfade führen können. In ähnlicher Weise hat die dritte Studie gezeigt, wie wichtig diese Akteure sind, wenn es darum geht, die Unsicherheiten der Innovationsprojekte (die auf institutionelle und kognitive Unterschiede zwischen den Partnern zurückzuführen sind) zu verringern.
3. Die Ökologisierung ist ein multiskalarer Prozess, aber ortsspezifische Eigenheiten können einen großen Einfluss haben:
   Die erste Studie dieser Arbeit lieferte Belege dafür, dass Phänomene auf nationaler, kontinentaler und globaler Ebene den Ökologisierungsprozess beeinflussen, indem sie entweder direkt auf das Handeln einwirken oder auf industrielle und/oder regionale Strukturen einwirken. In den Studien eins und drei wurde jedoch auch der (überproportionale) Einfluss ortsbezogener Eigenheiten (wie z. B. regionaler Stolz oder die geringen Skalenerträge der Unternehmen eines Clusters) nachgewiesen.

Auf der Grundlage dieser Ergebnisse wird in dieser Arbeit empfohlen, politische Maßnahmen zur Unterstützung einer grünen Umstrukturierung von Clustern zu entwickeln,

1. Politische Entscheidungsträger sollten ihren traditionellen technisch-wirtschaftlichen Fokus aufgeben und die Entstehung von "Place-Leadern" und institutionellen Unternehmern fördern.
2. Die Politik muss die Merkmale von Cluster-Firmen berücksichtigen (z. B. Neigung zur Zusammenarbeit, Größenvorteile, sind sie Pioniere oder Mitläufer); und sie muss ortsspezifische Institutionen nutzen.
3. Die politischen Entscheidungsträger müssen eine Zwischen-evaluierung der Politik durchführen, um festzustellen, ob bestimmte politische Maßnahmen die Cluster auf ineffiziente Ökologisierungspfade führen, die schließlich ineffektiv werden können.

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1 INTRODUCTION

Given the adverse effects of climate change (such as drought and flooding, damage to ecosystems and infrastructure, depletion of resources, deterioration of human health), society needs to transition to using sustainable systems of production and consumption. Regions and countries increasingly view the restructuring of their economies, through the nurturing of green-innovation and new green-industries, as a solution to this challenge (Ingrao et al., 2018, Martinez De Arano et al., 2018).

To generate greener products and processes, and sustainable economies, authorities are turning to green-clusters such as the Spitzencluster BioEconomy in Germany, the Cambridge cluster in the UK, the Paper Province in Sweden, the IAR cluster in France, the Tehnopol cluster in Estonia, and the Green Net cluster in Finland (PriceWaterhouse-Coopers, 2011, clustercollaboration.eu, 2020). While clusters have so far been employed as policy tools to achieve competitiveness and economic targets, policymakers are increasingly interested in using them to accelerate sustainable-innovation, and the green-restructuring of economies (McCauley & Stephens, 2012, Hansen & Coenen, 2015, Stegmann et al., 2020). The formation of green-clusters, and the greening of existing industrial clusters has been identified as an important tool to achieiving the GHG-reduction goals of the European Green Deal (van der Reijden et al., 2021). Green-clusters are clusters that grow in a decoupled fashion, by developing and selling products or processes that "reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services" (UNEP, 2011, p. 16). It is expected that the geographical proximity within green-clusters will result in knowledge-spillovers; which will increase the chances of green-innovation required to instigate transitions of economies. However, Green-clusters need not be intrinsically sustainable. Especially when green-clusters are derived from existing clusters, they will inherit unsustainable processes. This means before these clusters can help regions and nations transition, they must themselves transition to greener products and production techniques.

Consequently, the green-restructuring of clusters has become a key area of interest to Evolutionary Economic Geography (EEG) (see Sjøtun &

Njøs, 2019, Trippl et al., 2020) and to the emerging field of "Geography of Transitions" (see Hansen & Coenen, 2015, Grillitsch & Hansen, 2019), which bridges Evolutionary Economic Geography and Sustainability-Transition Studies. However, extant cluster-evolution frameworks and cluster-evolution studies are yet to settle multiple debates regarding the (green-) development of clusters.

This thesis aims to contribute to the resolution of some of these debates, which I elaborate in the following sub-section.

1.1 SCIENTIFIC RELEVANCE OF THE THESIS

An industrial cluster is an interconnected, mutually dependent network of actors (such as firms, universities) and institutions, working in a particular industries, and concentrated in a particular geographical area (Porter, 1998). Firms within clusters benefit from externalities (such as a knowledge spillovers) that result from spatial and non-spatial proximities (Biggiero & Sammarra, 2010). These externalities allow clustered firms to be more innovative and competitive than non-clustered firms (Audretsch & Feldman, 1996). Clusters have therefore become a pivotal feature of the innovation and development plans of several regions around the world.

Evolutionary Economic Geography has traditionally investigated the evolution of clusters using life-cycle models. Generally, these models have the cluster going through an "ageing process" that involves the stages of cluster-emergence, growth, maturity, and decline (Martin & Sunley, 2011). There are two schools of thought on what governs this process. The first school asserts that a cluster's restructuring follows that of its industry(ies) (Neffke, 2009). The model from Ter Wal & Boschma (2011), for instance, proposes that a cluster co-evolves with the main technologies in the industry, the variety of firm capabilities, and the knowledge network of the industry. However, it has been observed that while some clusters are able to thrive even if the industry is declining, others struggle despite being in a booming industry. From this observation, came the second school, which propounds that a cluster's restructuring is a result of features and process of and within the cluster; which can cause clusters within the same industry to have different development-trajectories. For instance, Menzel & Fornahl's (2009) cluster life-cycle model explains how restructuring is shaped by the variation of heterogeneity in capabilities, and population, within a cluster.

Life-cycle models stimulated the analysis of the long-term evolution of clusters (Isaksen, 2011). However, these models have been criticised for treating cluster-evolution as a deterministic motion from emergence to decline (Frenken et al., 2015). Rather than following a pre-determined trajectory, clusters may restructure along multiple paths (Isaksen et al., 2018). A cluster may undergo path-extension, where it continually engages in incremental innovation to advance extant industrial activities (leading to eventual decline); it can undergo path-modernization, where the cluster renews regional industries by installing new technologies; the cluster may introduce industrial activities that are new to the region, but are based on extant regional structures, thus undergoing path-branching; the cluster may see path-importation, where foreign firms bring in industries new to the region; and finally, the cluster may engage in path-creation, where completely new industries, based on radical technologies, are introduced.

According to Martin & Sunley (2011), a non-deterministic model should incorporate effects of contextual dynamics, and of the dynamics of agency. Consequently, they created the "modified adaptive cycle" model, which is based on viewing clusters as complex adaptive systems (CAS). In this model, cluster-restructuring emerges from the interaction of agency and structures. Because the CAS perspective treats cluster-evolution as stochastic, the model could propose multiple possible restructuring-trajectories. Consequently, while preceding models can at most be used to analyse path-extension, this model can examine path-modernisation, creation, renewal, importation or branching.

Indisputably, the adaptive life-cycle model furthered our understanding of the open, unpredictable nature of cluster-evolution, and of how this evolution results from the interaction of agency and structures. However, this and other life-cycle models still inspire the following debates.

1.1.1 Clusters' green-restructuring

The central debate this thesis aims to contribute to, is the one on the process of clusters' green-restructuring. While EEG literature has elaborated on the green-development of regions, it is yet to ordain the same normative focus on clusters. Cluster-research is yet to explain how clusters can transition to greener industries; and it is not clear what kind of policies can support this transition (Sjøtun & Njøs, 2019).

The studies that do attempt to clarify how green-clusters can catalyse sustainability-transitions (such as McCauley & Stephens, 2012, Hansen & Coenen, 2015) have come from the field of "Geography of Transitions" (GoT). In looking to bridge EEG and Sustainability Transition Studies, GoT emphasizes investigation of how clusters and regions undergo green-restructuring. This has led to studies such as Grillitsch & Hansen (2019), and Trippl et al. (2020), which state that green-restructuring can take different paths: green path-creation by creating new green-technologies, path-importation by bringing in green technology from outside the region, green path-branching from existing industries, and finally, the path-modernisation of an existing cluster via the introduction of greener products and processes.

With a few exceptions (such as Sjøtun & Njøs (2019), most studies on clusters' green-restructuring have either made a theoretical contribution, or employed computer modelling (e.g. study two of this thesis). Consequently, we do not have sufficient understanding of how green-restructuring actually unfolds in reality. Following Grillitsch & Hansen (2019) and Trippl et al. (2020), we can infer that metropolitan regions are best placed to enable green path-creation; specialized regions have structures ideal for green path-branching or path-importation; and peripheral clusters will most probably restructure through green path-importation or path-modernisation. What we do not know, however, is whether clusters actually adhere to these expected greening-paths; and what the fundamental differences and similarities between green-restructuring, and "normal" restructuring are.

1.1.2 The role of place-based structures (in peripheral regions)

It is only recently that EEG scholarship began analysing how cluster-evolution is influenced by the regional innovation system (RIS) in which the cluster is nested; past studies have predominantly investigated how industrial structures shape cluster-evolution.

It has now been established that RIS structures such as incumbent industries, knowledge infrastructure, and regional policy can enable or hinder certain types of evolutionary-paths (Trippl et al., 2020). Isaksen & Trippl (2014) differentiate between three RIS types: the organizationally thick & diversified RIS (metropolitan regions), the organizationally thick & specialized RIS, and the organizationally thin RIS. Metropolitan regions have ideal structures for path-branching and/or path-creation. On the other hand, the structures in specialised regions, and in thin regions, will have a proclivity to support incremental innovation. This tendency makes these regions prone to evolving along path-extension or path-modernisation. Avoiding lock-in will then require path-importation.

In spite of the progress in delineating how RIS structures influence cluster paths, multiple studies have argued that there is still need for greater clarity on the effects of place-dependency (Boschma, 2017, Neffke et al., 2018). We especially have a limited understanding of the development of clusters in peripheral regions, and of policies that can help clusters in these regions. EEG has traditionally focused on the evolution of clusters in metropolitan or specialised regions, implicitly assuming that there is no innovation in peripheral areas. Growth of any form is difficult in peripheral regions because they are characterized by a lack of critical mass in industrial specialization, and by the lack of high-value, knowledge-intensive activities (Isaksen & Trippl, 2014). This view is being increasingly questioned by a rising number of papers, special issues, and edited volumes on innovation in peripheral regions (Eder, 2019).

1.1.3 The role of agency

Clusters may evolve along paths that they were not expected to take, given RIS structures (Grillitsch & Sotarauta, 2018). Clusters within the same or similar RIS may thus experience different paths. This open-ended nature of cluster-restructuring is the outcome of strategic agency (Dawley, 2014). Consequently, understanding micro-/actor-level dynamics is key to explaining clusters' restructuring (Asheim et al., 2016). The realisation that paths of structural change are constructed by agency (Simmie, 2012), has led to criticism of extant cluster-evolution models, and of regional development studies, for not paying enough attention to agency (Trippl et al., 2015).

Based on Grillitsch & Sotarauta (2018), actors can use three forms of agency to shape cluster-restructuring: technological-entrepreneurship, institutional-entrepreneurship, and place-leadership. Technological-entrepreneurship refers to product or process innovation. Creating an environment conducive for innovation requires institutional-entrepreneurship that maintains, changes, or introduces pertinent institutions. Finally, place-leaders help to align visions, ensure stakeholder participation, and guarantee benefits. However, we have little empirical evidence of how distinct actors use these different forms of agency; and how these agencies interact with structures, supra-regional phenomena, to lay out clusters' evolutionary path.

1.1.4 The multiscalarity of cluster-restructuring

The third debate surrounding cluster-evolution is that of multiscalarity. The restructuring of clusters can be thought of as a function of the interactions of agency and structures (Mazzucato, 2013). However, this perspective ignores the role of "non-local sources and influences" (Hassink et al., 2019, p. 1639).

RIS are embedded within governance systems that cross various spatial scales (Patchell & Hayter, 2013). On the other hand, agency that affects structures may be exercised by actors at various spatial scales (Dawley, 2014). This means that regional structures may be the consequence of actions at higher scales. Industrial structures may also be shaped by developments at national and supra-national levels. In other words, the effects regional or industrial structures have on cluster-evolution may be the indirect effects of supra-regional phenomena (Ayrapetyan et al., 2022).

There have been a few studies that demonstrated the multiscalar effects of policy actions (see MacKinnon et al., 2019), and of extra-regional actor-networks (see Neffke et al. (2018)). However, our knowledge of the multiscalar nature of restructuring is still limited (Trippl et al., 2020). For instance, while the effects of multiscalar phenomena on the RIS have been studied, there is not a lot of clarity on how the sectoral system of innovation (SSI) (Malerba, 2002) is affected, and how it in turn affects agency. Furthermore, there is acute lack of studies that explore the multiscalarality of clusters' green-restructuring (Ayrapetyan & Hermans, 2020).

1.1.5 The role of proximity dimensions in clusters' green-restructuring

The fifth and final debate this thesis addresses is regarding how proximity dimensions affect the greening of clusters. While a few studies such as Jolly et al. (2020) have provided greater clarity on the role of agency in designing greening paths for clusters, these studies do not shine enough light on how actors form and modify collaboration networks. For instance, both studies one and two of this thesis investigate how the micro-level (i.e. agency) interacts with the macro-level (i.e. structures), to shape cluster-greening. These studies, however, do not explore the dynamics at the meso-level. The meso-level lies between the micro- and macro-levels, and it is where the collaborations (which beget the innovations necessary for cluster-greening) are formed and modified.

The recognition that innovation frequently occurs through inter-organizational collaboration (Hagedoorn, 2002) led scholars to use the concept of proximity to study such collaboration at various geographic levels (see Knoben & Oerlemans, 2006, Balland, 2012, D'Este et al., 2013), including within clusters (see Arikan, 2009, Biggiero & Sammarra, 2010, Balland et al., 2022). Proximity refers to a similarity in characteristics, for actors in a network (Boschma & Frenken, 2010).

While there have been studies that investigate how proximity shapes the dynamics of collaborative networks in clusters, such as Balland et al. (2016) and Juhász & Lengyel (2018), they did not have a normative inclination. These studies analyse cluster-based networks for the purpose of innovation for profit and competitiveness; but studies that analyse networks for sustainable innovation that results in profit and competitiveness, and the firms', cluster's shift to greener operation, are very rare.

1.2 RESEARCH QUESTIONS

To contribute to resolving the debates detailed in the preceding subsection, I attempt to answer the following research question through this thesis:

How do the dynamics at the levels of agency, actor-collaboration, and structures, and the interactions between these dynamics, shape the green-restructuring of clusters?

This research question was addressed through three different studies, each answering one of the following sub-research questions:

1. How does the dynamic interaction of agency, structures, and supra-regional phenomena shape the green-restructuring of a cluster?
2. What policy instruments are most effective in causing green-growth of clusters in a peripheral region?
3. How do the different dimensions of proximity shape innovation collaborations for cluster-greening?

1.3 A COMPLEX ADAPTIVE SYSTEM PERSPECTIVE OF CLUSTER-GREENING

The three studies that constitute this thesis employ a complex adaptive system perspective of clusters and their evolution.

A CAS is composed of a dynamic network of actors that continually (re)act in response to the (re)actions of other actors, and to external stimuli (Waldorp, 1993). In a CAS, aggregate behaviour and systemic characteristics are seen as emerging from the myriad actions and interactions of its constituent actors (i.e. through the process of upward causation) (Gandolfi, 1999). Simultaneously, these characteristics may guide, and constrain, the actions of the actors making up the CAS (i.e. through the process of downward causation).

An industrial cluster is an interconnected, mutually dependent network of actors (such as firms, universities) and institutions, working in a particular field, concentrated in a particular geographical area (Porter, 1998). Clusters exhibit characteristics that make them complex adaptive systems (Martin & Sunley, 2011, Nikolic et al., 2009), such as:

1. Emergence: In CAS, macro-level structures and dynamics emerge out of micro-level behaviors and interactions. Cluster-wide properties such as pollution-levels, technological assets emerge from the actions and interactions the cluster's firms, universities etc. These properties then influence the actions of cluster members that (re)produce them.
2. Adaptation: CAS can adapt their structures and dynamics. Clusters can adapt (e.g. by reducing pollution-levels) in face of external or internal demands (Martin & Sunley, 2011). This enables clusters to survive, and even thrive, by evolving towards new (more sustainable) set of structures (Klepper, 2006).
3. Openness: CAS tend to be dissipative—subject to constant interaction and exchange with their environments. Clusters are open systems that engage in continual exchanges with its environment (Martin & Sunley, 2011).

The CAS perspective has multiple characteristics that makes it suitable for studying cluster-evolution. Firstly, it treats cluster-evolution as non-deterministic; this means it can be used to analyse various green-restructuring paths. Secondly, in a CAS, systemic properties are understood to emerge from the exertion of actor-agency. Concomitantly, these properties make constituent actors act in certain ways. This means a CAS perspective can naturally explain a greener cluster as emerging from the processes of upward-causation (agency shaping structures) and downward-causation (structures shaping agency). Thirdly, CAS are nested systems, which means a CAS can contain a smaller CAS, while being embedded in a larger one (Keshavarz et al., 2010). This means a CAS perspective can inherently factor in the effects of supra-regional phenomena on structures and agency. Fourthly, the CAS perspective allows us to locate collaboration-dynamics within the cluster at the meso-level, and analyse how proximity dimensions affect these dynamics.

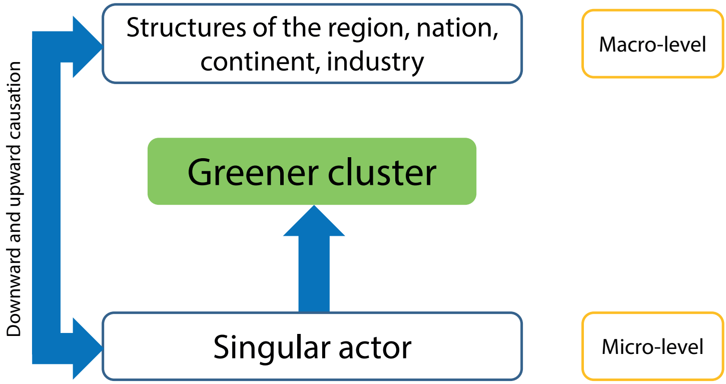

Figure 1.1: Studies one and two explore how the interactions between macro-level structures and micro-level agency lead to the emergence of a greener cluster

Source: Own illustration

The first two studies of the thesis focus on the interactions between the macro-level structures (of industry, region, nation etc.) and micro-level agency, and investigate how the processes of downward and upward causation lead to the emergence of a greener cluster, as depicted in Figure 1.1. The third study is focused on exploring the collaboration-dynamics at the meso-level, as depicted in Figure 1.2.

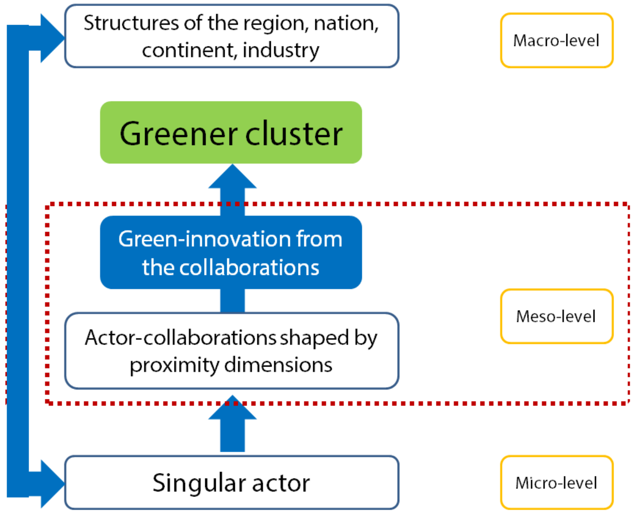

Figure 1.2: The third study explores dynamics at the meso-level (marked with a dotted rectangle), where actors collaborate for innovation

Source: Own illustration

1.4 THE THREE STUDIES OF THE THESIS

1.4.1 The green-restructuring of clusters: investigating a biocluster's transition using a complex adaptive system model

This study answers the first sub-research question. This study involved a longitudinal analysis to demonstrate how a biocluster green-restructures through the interactions of agency, regional and industrial structures, and phenomena at (supra-)national levels. To execute this analysis, I created a novel cluster-evolution framework that treats clusters, and the regional innovation system and sectoral systems of innovation that contain the cluster, as complex adaptive systems. The framework was then applied to study the greening of the Basque pulp-and paper-cluster, over four phases between 1986 and 2019. The analysis helped in the discovery of patterns of agency, structural dynamics, and of agency-structure interactions, and how supra-regional phenomena shaped structures and agency over the four phases. Based on these findings, the study recommends policymakers encourage not only green-tech entrepreneurs, but also institutional-entrepreneurs and place-leaders who can help shape both (supra)regional and industrial structures.

1.4.2 Policy instruments for green-growth of clusters: Implications from an agent-based model

This study answers the second sub-research question. In this study, I created an agent-based model that can simulate a cluster's transition, as shaped by different policy instruments. This model was used to explore the effectiveness of a) innovation grants, b) fines for pollution c) financial incentives for entrants, and d) an instrument mix of incentives and fines, on the green-growth of a peripheral-region cluster. The results indicate that designing instruments for absolutely decoupled growth of peripheral-clusters is close to impossible; and demonstrate the inherent trade-offs in designing policies for relatively decoupled growth. Based on these results, the study recommends there should be more nuanced deliberation, with greater focus on possible trade-offs, on the potential contribution of green-clusters to sustainable development.

1.4.3 How proximity shapes innovation-collaboration for cluster-greening

This study answers the third sub-research question. This study involved a case-study that explored how the five proximity dimensions from Boschma (2005) influenced collaboration for green-innovation in the Paper Province cluster in the Värmland Region of Sweden. The results indicate that institutional proximity and social proximity provide the foundation for cluster members deciding to engage in, and support, sustainable-innovation projects with partners that are institutionally, and cognitively distant. Furthermore, organizational and geographic proximity help with closing institutional and cognitive distance. Overall, the study suggests that there are significant similarities between how the proximity dimensions affect green-innovation, and how they affect innovation projects that do not explicitly aim for improvements in environmental sustainability. Based on these results, the study recommends that policy should set clear goals, and institute long-term, continual support for disruptive green-innovation; support green-innovation projects that address issues that are of interest to all cluster members; identify and grant the appropriate incentives, rewards, so as to minimise churn in the cluster's, region's innovation support system; and establish "matchmakers" that connect partners, and build collaborations.

1.5 READER'S GUIDE TO THE THESIS

Chapters two, three and four of the thesis describe the frameworks, methodologies, results and contributions, and policy-implications of the three studies that constitute this thesis. Chapter five answers the main research question by synthesizing the findings of these studies, and provides synthesized policy-recommendations for facilitating the durable green-restructuring of clusters.

2 THE GREEN-RESTRUCTURING OF CLUSTERS: INVESTIGATING A BIOCLUSTER'S TRANSITION USING A COMPLEX ADAPTIVE SYSTEM MODEL[1]

1 This chapter is based on Kamath, R., Elola, A., & Hermans, F. (2022a). The green-restructuring of clusters: investigating a biocluster's transition using a complex adaptive system model. European Planning Studies, 1-26.

2.1 INTRODUCTION

Given the threat of climate change disrupting access to essential resources, society requires a "green shift". Regions nd countries increasingly view establishing a bioeconomy as a solution to this challenge (Ingrao et al., 2018, Martinez De Arano et al., 2018). The bioeconomy emphasizes biobased production, efficient utilization of renewable biological raw material, and circular-loops (Brunori, 2013, Devaney & Henchion, 2018).

To achieve regional bioeconomies, authorities are turning to bio-clusters such as the Cambridge biocluster in the UK, and the IAR cluster in France (PriceWaterhouseCoopers, 2011). Following Porter (1990), we define bioclusters as geographic agglomerations of interconnected organisations, operating in one or multiple bioeconomy sectors: pulp & paper, textiles, biochemicals etc. Bioclusters are expected to foster biobased innovations that can lead to the bioeconomy (Cooke, 2002, Marsden, 2013). Bioclusters are also drawing interest from academia. This is the result of growing interest in the possible role for industrial clusters in promoting sustainable innovation (Lazzeretti et al., 2019); and in helping regions diversify into green growth-paths (Hassink et al., 2019, Grillitsch & Hansen, 2019).

However, bioclusters, are not intrinsically sustainable (Pfau et al. 2014, Purkus et al. 2018). Especially when they operate in sectors such as paper or textiles, bioclusters can be quite dirty (Bergquist & Söderholm, 2018). If bioclusters are to help achieve a sustainable bioeconomy, they must undergo green-restructuring. Cluster-restructuring is a complex process. Extant regional and industrial structures tend to encourage innovations that sustain these (unsustainable) structures (Belussi & Sedita, 2009). Trying to (de)stabilise these structures will be various actors using different forms of agency (Grillitsch and Sotarauta, 2018). Simultaneously, these structures and agency may be shaped by phenomena at National, Continental, or Global scales (MacKinnon et al., 2019). Although some recent work has been done on green-restructuring of clusters (see Sjøtun & Njøs (2019), Kamath et al., 2022a), we need more empirical evidence of how green-restructuring unfolds. In this study, we conduct a longitudinal investigation to demonstrate how a biocluster green-restructured through the interactions of agency, regional and industrial structures, and phenomena beyond the region.#

We executed this study by creating a novel cluster-evolution framework based on the perspective of Complex Adaptive Systems (CAS). We apply our framework to study the green-restructuring of the pulp-and-paper (P&P) biocluster in the Basque Country (Spain). We chose this biocluster because of the P&P industry's history of environmental issues, the cluster's history of sustainable growth, and the Basque region's strong cluster-based policy structure. Using our framework, we explain how the Basque biocluster moved to greater sustainability between 1986 and 2019. Through this descriptive analysis, we contribute to pivotal debates regarding the roles of agency and place-dependency in cluster-restructuring, and on the multiscalar nature of restructuring.

The rest of this paper is structured as follows. In section 2.2, we describe the debates we contribute to, introduce our cluster-evolution framework, and state the research question we attempt to answer. In the section 2.3, we describe our methodology. In section 2.4, we describe in four discrete time phases, the Basque biocluster's restructuring. In the section 2.5, we present our insights and contributions; policy implications from our findings; and avenues for future research.

2.2 TOWARDS A CAS PERSPECTIVE ON CLUSTER-RESTRUCTURING

Clusters have become a key feature of regional development plans. Clusters also draw scholarly interest from varied fields - Evolutionary Economic Geography, Sustainability-Transition Studies (STS), and Innovation Studies. While the majority of EEG literature has focused on the characterisation of successful clusters, recent years have seen several studies investigating cluster-evolution (Trippl et al. 2015). Being an emerging practice, there is still a lot of ground to cover in understanding the dynamics of clusters' restructuring.

2.2.1 Cluster restructuring

EEG has traditionally investigated the evolution of clusters using life-cycle models (which draw from the product life-cycle approach (Utterback & Abernathy, 1975)). Generally, these models have the cluster moving through the stages of emergence, growth, maturity, and decline (Martin & Sunley, 2011). There are two schools of thought on what governs clusters' "ageing". The first school asserts that a cluster's restructuring is synchronized with that of its industry(ies) (Neffke, 2009). The model from Ter Wal & Boschma (2011), for instance, proposes that a cluster co-evolves with the main technologies in the industry, the variety of firm capabilities, and the knowledge network of the industry. The argument against this perspective is that while some clusters are able to thrive even if the industry is declining, others struggle despite being in a booming industry. From this argument, came the second school, which propounds that a cluster's restructuring is driven by characteristics unique to the cluster. Models from this school aim to demonstrate how clusters within the same industry can experience different trajectories. For instance, Menzel & Fornahl's (2009) cluster life-cycle model explains how restructuring is shaped by the variation of heterogeneity in capabilities, and population, within a cluster.

2.2.2 Ongoing debates regarding cluster-restructuring

Life-cycle models stimulated greater interest in investigating the long-term evolution of clusters (Isaksen, 2011). However, these models have been criticised for treating cluster-evolution as a deterministic motion from emergence to decline (Frenken et al., 2015). Regions and clusters may actually restructure along several paths (Isaksen et al., 2018). A cluster may undergo path-extension, where it continually engages in incremental innovation to advance extant industrial activities (leading to eventual decline); it can undergo path-modernization, where the cluster renews regional industries by installing new technologies; the cluster may introduce industrial activities that are new to the region, but are based on extant regional structures, thus undergoing path-branching; the cluster may see path-importation, where foreign firms bring in industries new to the region; and finally, the cluster may engage in path-creation, where completely new industries, based on radical technologies, are introduced.

Martin & Sunley (2011) proposed that a non-deterministic model should factor in contextual influences, and agency effects. They created the "modified adaptive cycle" model, which is based on viewing clusters as complex adaptive systems. In this model, restructuring emerges from the interaction of agency and structures. Because the CAS perspective treats cluster-evolution as non-deterministic, the authors could propose multiple possible cluster trajectories. Consequently, while preceding models can at most be used to analyse path-extension, this model can examine path-modernisation, creation, renewal, importation or branching.

Indisputably, the adaptive life-cycle model furthered our understanding of the openness of cluster-evolution, and how this evolution results from the interaction of agency and structures. However, this and other life-cycle models still inspire some ongoing debates in EEG. Below, we elaborate on these debates.

2.2.2.1 The role of place-based structures

EEG scholarship has predominantly focused on how industrial structures shape cluster-evolution. More recently, it began arguing that evolution is influenced by the regional innovation system (RIS) in which the cluster is nested. RIS structures such as incumbent industries, knowledge infrastructure, and regional policy can enable or hinder certain types of evolutionary-paths (Trippl et al., 2020). Isaksen & Trippl (2014) differentiate between three RIS types: the organizationally thick & diversified RIS (metropolitan regions), the organizationally thick & specialized RIS, and the organizationally thin RIS. Metropolitan regions have ideal structures for path-branching and/or path-creation. The structures in specialised regions, and in thin regions, will have a proclivity to support incremental innovation. This tendency makes these regions prone to evolving along path-extension or path-modernisation. Avoiding lock-in will require path-importation.

In spite of the progress in delineating how place-based structures influence the evolution of clusters and regions, multiple studies have argued that there is still need for greater clarity on the effects of place-dependency (Boschma, 2017, Neffke et al., 2018).

2.2.2.2 The role of agency

Regional and cluster paths may deviate from paths that they were expected to take, given regional pre-conditions (Grillitsch & Sotarauta, 2018). It is definitely possible then that clusters within similar RIS experience different paths. This open-ended nature of cluster-restructuring is the outcome of strategic, distributed agency (Dawley, 2014). Micro-/actor-level dynamics are, therefore, crucial in explaining restructuring processes (Asheim et al., 2016). The realisation that paths of structural change are constructed by agency (Simmie, 2012), led to criticism of extant cluster-evolution models, and of regional development studies, for not paying enough attention to agency (Trippl et al., 2015).

Based on Grillitsch & Sotarauta (2018), actors can use three forms of agency to shape cluster-restructuring: technological-entrepreneurship, institutional-entrepreneurship, and place-leadership. Technological-entrepreneurship refers to product or process innovation. Creating an environment conducive for innovation requires institutional-entrepreneurship that maintains, changes, or introduces pertinent institutions. Finally, place-leaders help to align visions, ensure stakeholder participation, and guarantee benefits.

2.2.2.3 The multiscalarity of cluster-restructuring

The third debate surrounding cluster-evolution is that of multiscalarity. The restructuring of nations, regions and clusters can be thought of as a function of the interactions of agency and structures (Mazzucato, 2013). However, what is underestimated in this framing, is the effects of "non-local sources and influences" (Hassink et al., 2019, p. 1639).

RIS are embedded within governance systems that cross various spatial scales (Patchell & Hayter, 2013). Agency that affects structures may be exercised by actors at various spatial scales (Dawley, 2014). This means that regional structures may be the consequence of actions at higher scales. Industrial structures may also be shaped by developments at national and supra-national levels. In other words, the effects regional or industrial structures have on cluster-evolution may be indirect effects of supra-regional phenomena (Ayrapetyan et al., 2022).

There have been a few studies that demonstrated the multiscalar effects of policy actions (see MacKinnon et al., 2019), and of extra-regional actor-networks (see Neffke et al., 2018). However, our knowledge of the multiscalarity of restructuring is still limited (Trippl et al., 2020). For instance, while the effects of multiscalar phenomena on the RIS have been studied, there has not been a lot of emphasis on how the sectoral system of innovation (SSI) (Malerba, 2002) is affected, and how it in turn affects agency.

2.2.3 Green-restructuring of clusters

Clusters were envisaged as a means to achieve economic targets (Porter, 1990). However, they are now also being employed to achieve environmental targets. We see regions around the world have started using green-tech clusters, including bioclusters, to instigate greening of their economies (Hansen & Coenen, 2015, Stegmann et al., 2020).

Nevertheless, while EEG literature has elaborated on green regional development, it is yet to ordain a normative focus on clusters. Cluster-research has not sufficiently emphasized how clusters move into greener industries; and EEG lacks discussions on how policy can support this process (Sjøtun & Njøs, 2019). The studies that do attempt to clarify how clusters can catalyse sustainability-transitions (such as McCauley & Stephens (2012), Hansen & Coenen (2015)) have come from "geography of transitions" (GoT). In looking to bridge EEG and STS, GoT emphasizes investigation of how clusters and regions undergo green-restructuring. This has led to studies such as Grillitsch & Hansen (2019), and Trippl et al. (2020), which state that green-restructuring can take different paths: green path-creation by creating new green-technologies, path-importation by bringing in green technology from outside the region, green path-branching from existing industries, and finally, the path-modernisation of an existing cluster via the introduction of greener products and processes.

With a few exceptions (such as Sjøtun & Njøs (2019), most studies on green-restructuring have either made a theoretical contribution, or employed computer modelling (e.g. Kamath et al., 2022b). Consequently, we need greater understanding of how green-restructuring unfolds in reality. Following Grillitsch & Hansen (2019) and Trippl et al. (2020), we can infer that metropolitan regions are best placed to enable green path-creation; specialized regions have structures ideal for green path-branching or path-importation; and peripheral clusters will most probably restructure through green path-importation or path-modernisation. What we do not know, however, is whether clusters actually adhere to these expected greening-paths; and whether there are differences between green-restructuring, and "normal" restructuring. We also need more empirical evidence of how different actors use different forms of agency; and how this agency interacts with structures, supra-regional phenomena, to lay out the evolutionary path. To address these concerns, and the debates detailed in this section, we conduct a longitudinal analysis of a biocluster's green-restructuring. To conduct this analysis, we create a novel cluster-evolution framework, which we introduce in the sub-section 2.2.5.

2.2.4 How clusters restructure

Our cluster-evolution framework is based on the factors discussed in sub-section 2.2.2 - agency, place-based and industrial structures, and supra-regional phenomena. As a prelude to introducing our framework in the following sub-section, we explain how all these factors interact to guide a cluster's restructuring.

We begin with our definition of a cluster. Drawing a boundary around porous systems like clusters is fundamentally difficult (Martin & Sunley, 2003). So, for the sake of simplicity, we define a cluster as the members of the cluster. Following this, we define cluster-restructuring as cluster members transitioning. For instance, clusters will green-restructure as members transition to greater sustainability through cleaner production (by removing non-renewable inputs, introducing circular-loops, adopting clean energy etc.).

2.2.4.1 Cluster paths emerge from agency

As stated in sub-section 2.2.2, the development path of a cluster is laid out by agency. Since actors will use their agency to either advance or hinder any restructuring (Grillitsch & Sotarauta, 2018), path-development will not be a linear process. Actors in the cluster can use technological-entrepreneurship, institutional-entrepreneurship, and place-leadership to construct restructuring-paths.

2.2.4.2 Structures, agency shape each other

Clusters (and their members) are embedded within both a RIS, and a SSI; which means agency must confront, or conform to, both place-dependency and path-dependency. We define place-dependency as the process of regional structures being reproduced (Trippl et al., 2015); which forces the cluster to follow certain restructuring paths. We define path-dependency as the reproduction of the structures of the SSI; which ensures that the industry and its technologies evolve along a narrow channel (Boschma et al., 2017). Agency can end up being directed by the dependencies, in which case the cluster restructures along expected paths; or it can modify the dependencies, and take the cluster along unexpected paths.

Table 2.1: Factors that combine to shape a cluster's restructuring-path, and their interactions

Factor	Description	Interactions with other factors
Place-dependency	Place-dependency is the process of the regional innovation system's structures being reproduced; which forces the region and clusters to follow certain types of restructuring paths (Trippl et al., 2015).	Place-dependency guides agency, or it is guided by agency. Changes in RIS structures may be the result of multiscalar phenomena
Path-dependency	Path-dependency is the reproduction of the structures of the sectoral system of innovation; which ensures that the industry and its technologies evolve along a narrow channel (Boschma et al., 2017).	Path-dependency guides agency, or it is guided by agency. Changes in SSI structures may be the result of multiscalar phenomena

Continued on next page

Factor	Description	Interactions with other factors
Agency	A cluster's development path is laid out by agency of three forms - technological-entrepreneurship, institutional-entrepreneurship, and place-leadership (Grillitsch and Sotarauta, 2018).	Agency is either guided by dependencies, or guides the dependencies. Agency dynamics may also be the (indirect) result of multiscalar phenomena
Multiscalar phenomena	Multiscalar phenomena are events or processes at various geographical scales beyond the region - national, continental, or global.	Multiscalar phenomena can shape structures and agency (MacKinnon et al., 2019).

2.2.4.3 Supra-regional phenomena shape structures, agency

Both regional and industrial structures can be shaped by events such as changes in the macro-level structures at the national, continental or global scales, and black-swan events beyond the region and industry (e.g. global recessions). By influencing the structures of the RIS and/or SSI, these phenomena indirectly shape agency. Supra-regional events may also directly mould agency (Hung & Whittington, 2011).

Table 2.1 provides short descriptions of these factors, and their interactions. Synthesizing the relationships, restructuring-paths eventually emerges from agency. This agency may be directed by dependencies, or agency may condition the dependencies. In case of the former, restructuring occurs along paths expected from the structural context; in case of the latter, paths deviate from expectations (clusters in thin regions undergoing path-creation, for example). Finally, structural dynamics or agency may actually be the result of phenomena at (supra-)national scales.

2.2.5 A CAS-based framework to study the restructuring of clusters

Like Martin & Sunley (2011), we employ a CAS-based cluster-evolution framework. The CAS perspective has multiple characteristics that make it suitable for studying cluster-evolution. Firstly, it treats cluster-evolution as non-deterministic; meaning a CAS framework can accommodate different types of restructuring-paths. Secondly, in a CAS, systemic properties are understood to emerge from the exertion of actor-agency (Epstein & Axtell, 1996). Concomitantly, these properties make constituent actors act in certain ways. This means a CAS framework can naturally explain a greener cluster as emerging from the processes of upward-causation (agency shaping structures) and downward-causation (structures shaping agency). Thirdly, CAS are nested systems, which means a CAS can contain a smaller CAS, while being embedded in a larger one (Keshavarz et al., 2010). This means a CAS framework can inherently factor in the effects of supra-regional phenomena on structures and agency.

Our model treats cluster members as part of three overlapping complex adaptive systems[2]: 1) the cluster, 2) the RIS, and 3) the SSI. Following the concepts discussed in sub-section 2.2.2, and their interactions defined in sub-section 2.2.4, Figure 2.1 depicts the components and relationships in our framework. We have the regional and industrial structures at the macro-level; and the cluster actors at the micro-level. Then, we have the mutual relationships between actors and the region, and actors and the industry. Cluster members' agency is influenced by the structures of the region, and of the sector (i.e. downward-causation). On the other hand, using the three forms of agency, cluster members can influence the structures (i.e. upward-causation).

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2 Like with clusters, both the SSI and RIS can be viewed as CAS. Innovation systems are composed of actor networks and structures (Malerba, 2005), they exhibit characteristics of CAS. For instance, because of dependencies between actor behaviour and systemic institutions (Trippl et al. 2015), innovation systems exhibit the property of emergence (Martin & Sunley, 2007). Innovation systems also display non-linear dynamics (because of path-dependency), and non-determinism (because of their non-tractable nature) (Grillitsch & Sotarauta, 2018).

The final component of the framework is the external environment, which accounts for influential events and processes at scales beyond the region. We can view the RIS and SSI, and their structures, as being nested in the external environment; while the cluster (i.e., its members) is nested within the RIS and SSI. In other words, the RIS and SSI are macro-levels nested within the higher macro-level of the external environment, while cluster members are at the micro-level. We can see in Figure 2.1 that macro-level events in the environment may alter the macro-structures of the RIS and SSI, which then may lead to changes in how cluster members exercise agency at the micro-level. Furthermore, environmental events may also directly shape agency at the micro-level.

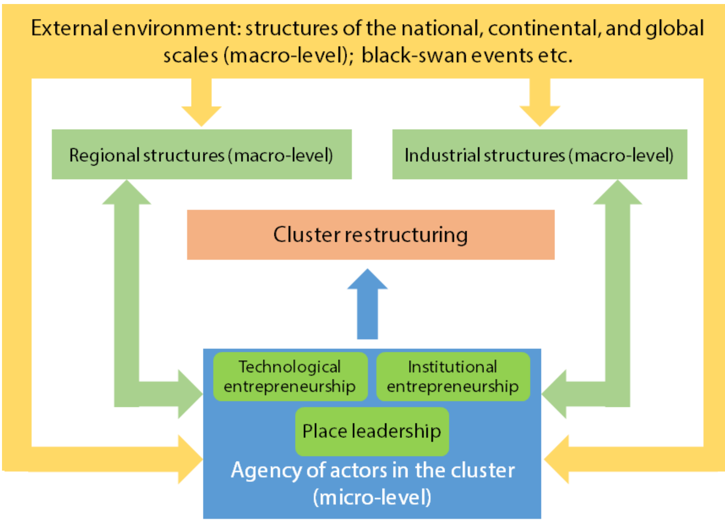

Figure 2.1: Our cluster evolution framework

The question we attempt to answer in this study is, how does the dynamic interaction of agency, structures, and supra-regional phenomena shape the green-restructuring of a cluster? With this framework of ours, a cluster's (green-)restructuring emerges from the constituent actors' agency (as depicted in Figure 2.1). How the region or sector may influence the cluster's evolution, is by shaping actor-agency within the cluster, through the (dynamics of) respective structures. How multiscalar phenomena beyond the region may shape the cluster's transition is by influencing structures, which then influence agency; or by influencing cluster members' agency directly. While structural changes at (supra-)regional scales (and in the industry) result from deliberate agency of actors at these scales, with agency from within the cluster also possibly playing a part, our framework does not explore the role of extra-cluster agency in shaping influential structural dynamics. In other words, the framework only incorporates the end-effect (i.e. the (changes in) structures), and the possible role of agency within the cluster, in engendering the end-effect. This means the framework explains the influence of extra-cluster agency indirectly, by demonstrating the effects of structural change on agency in the cluster, and thus, on cluster restructuring.

2.3 METHODOLOGY

To answer our research question, we applied our framework to the greening of the P&P biocluster in the Basque region of Spain, between 1986 and 2019. Over this period, the cluster moved to cleaner production by significantly reducing water contamination and GHGs, introducing greater circularity, and creating several biobased innovations. This restructuring was accompanied by the augmentation of revenues and productivity, in spite of the closure of several firms (Interviews; Clusterpapel, 2019a).

This cluster is an apt case because it captures the dichotomy between the normative idea of a biocluster, and what happens in reality. Traditionally, P&P production has involved acute water contamination, and significant consumption of energy and toxic chemicals (Bergquist & Söderholm, 2018). In making bleached pulp, the use of elemental chlorine severely damages aquatic ecosystems (Thompson et al., 2001). Even though the industry has considerably reduced its environmental impact over the past five decades, it still faces questions over sustainability. With stagnating profits, and growing pressure to improve environmental performance, the industry "has been seeking renewal under the emerging concept of bio-economy" (Toppinen et al., 2017, p. 2), by developing new products, processes from forest biomass (Näyhä et al., 2014). Additionally, our choice was influenced by the Basque region's history of pioneering cluster policies (Valdaliso et al. 2016); and it being one of the most innovative regions in Europe (Hollanders & Es-Sadki, 2017).

This agglomeration of P&P firms was caused by the abundance of forest biomass, and easy availability of water and hydraulic infrastructure (Elola et al., 2012). The cluster is composed of firms that are industry-followers, not pioneers (Valdaliso et al. 2016; Interviews). These firms are smaller in comparison to its peers in the P&P SSI. Owing to reasons we make clear in section 2.4, the number of P&P firms in the cluster has gradually declined. In 1973, the cluster had 30 P&P manufacturers. In 2019, this number stood at 16, after dipping to the lowest level of 10 in 2014 (Clusterpapel, 2019a). Following our definition of a cluster (in sub-section 2.2.4), we define the biocluster to be its members - the firms plus the cluster organisation. While this cluster consists of biobased companies (P&P firms), and some non-biobased companies (firms making machinery for P&P companies), for pragmatic purposes, we treat the entire cluster as a biocluster. Furthermore, as described in section 2.4, paper-machinery companies also contributed to the cluster's green-structuring.

Table 2.2: Variables for operationalising the cluster evolution framework

Structures		
	Place (Region)	**Path (Sector)**
Policy	Legislative instruments (e.g. environmental regulations)	Industrial standards
	Financial instruments (tax breaks, subsidies) promoting sustainable innovation	
Economics	Regional industrial base	Degree of concentration in the industry
		Importance of sustainability in organising supply chains (via environmental management system certification)
Knowledge, technology, infrastructure & Resources	Availability, quality of infrastructure, human-resources in the region	Production processes used in the industry
	Availability and cost of biomass in the region	Inputs (raw material, chemicals etc.), energy sources commonly used in the industry
	Availability and cost of inputs (e.g. oil, electricity etc.) in the region	Waste management techniques, and circular loops used in the industry
	Cost and availability of tertiary services (e.g. waste-management) in the region	Sunk costs, such as expensive production processes
Culture	Societal priority for environmentally- sustainable growth in the region	Priority for (radical) innovation in the industry

Continued on next page

Agency			
	Technological-entrepreneurship	**Institutional-entrepreneurship**	**Place-leadership**
	Introducing circular loops for internal or external valorisation of waste	Creating platforms, institutions, organizations	Convening different actors, negotiating with them, aligning visions
	Switching to greener, biobased energy sources	Forming or modifying formal relationships	Facilitating sharing of resources, technologies and capabilities
	Introduction of greener, biobased production processes and products	Educating actors in biobased products, processes, and business-models	
	Introducing EOP solutions for treatment of waste and effluents		
	Switching to sustainable (biological) raw materials		
Environment			
National or supranational policy; Macro-economic developments at the national, supranational or global levels (e.g. market liberalisation, recession etc.);			

Source: Own compliation based on Rotmans (2003), Lawrence & Suddaby (2006), Woolthuis et al. (2005), Isaksen & Trippl (2014), and on primary and secondary case dat[a)]

For the longitudinal analysis, we used the methodology of event-history analysis (EHA) (Poole et al., 2000). An EHA "conceives of change processes as sequences of events" (Suurs, 2009, p. 29). EHA provides historically rich accounts, which facilitate discovery of agency-structure interplay (Strambach & Pflitsch, 2018). Data for the EHA was collected through document analysis, and semi-structured Interviews. We looked for interviewees with a history of operation in the region, who were well-versed with the restructuring of the cluster. We used the snowball technique, and documentary data, such as the cluster's latest member-list, and news reports, to identify our interviewees. After one round of document analysis, we conducted a pilot interview with the director of the cluster organisation, who was known to one of the co-authors, in December 2018. This pilot interview led to the identification of further candidates, who then led us to other candidates, so on and so forth. In total, we conducted 12 interviews by July 2019. Table A1 in the Appendix lists our interviewees, and the documents we analysed.

We used both recurring and ad hoc questions for the interviews. The main themes explored through these questions were the history of the cluster's green-restructuring (influential events, and drivers and obstacles at various geographical levels etc.); the cluster organisation's contributions to this restructuring; key collaborative constellations that drove the cluster's restructuring; the role played by firms, the national government, the EU, and other organisations; regional influences on the cluster's green-restructuring (policy, infrastructure, resources etc.); industrial influences on the cluster's green-restructuring (environmental standards, priority for (radical) innovation etc.).

For building the event-history, we coded longitudinal data using the variables in Table 2.2. These variables were used to operationalise regional and industrial structures, the three forms of agency, and also environmental variables. We built the table initially with some variables identified through secondary data, and STS, EEG literature (Woolthuis et al., 2005, Lawrence & Suddaby, 2006, Isaksen & Trippl, 2014, Grillitsch & Sotarauta, 2018). The table was further populated as we coded the data. To better organise structural variables, we used an adapted version of

Rotmans' (2003) domains of systemic change: Policy, Economics (a mix of business and market parameters), KTIR (knowledge, technology, infrastructure, and resources), and Culture. We categorised agency events under technological-entrepreneurship, institutional-entrepreneurship, and place-leadership.

Coding was carried out through the following steps:

1. We assigned pieces of data to one of the regional domains, to one of the industrial domains, to a form of agency, or to environmental phenomena.
2. In case the data represented a variable not contained in Table 2.2, the table was updated to include this new variable.
3. We arranged the coded data chronologically, and determined sequential relationships.

By iterating the above steps, we discovered the interactions between supra-regional phenomena, structures and agency, which caused the cluster to restructure. By chronologically arranging the coded data, we identified four distinct phases in the Basque biocluster's transition between 1986 and 2019, which we describe in the next section.

2.4 RESULTS

Although we used Rotman's (2003) domains to organize variables in Table 2.2, we won't use them to report the results. Not all domains are important in all phases, and we only report the most important variables in each phase.

2.4.1 1986–1998: Regional dynamics drive, and sectoral dynamics hinder, greening

We begin in 1986, when Spain liberalised its economy, and joined the European Economic Community (de la Escosura et al., 2011). Up till then, lax environmental regulation in the region meant that the firms of the cluster could unabatedly discharge toxic effluents (Valdaliso et al., 2016; Interviews). Images of coloured rivers and dead fish resulted in a very poor societal image for the biocluster (Angulo, 2000). With this accession, the Basque Country had to bring its water laws in line with European standards. Facing command-and-control measures from the regional government, and growing environmental awareness in Basque society, cluster firms invested in end-of-pipe (EOP) solutions such as water-treatment plants (Angulo, 2000; Interviews). Firms also introduced circular-loops - using woodchips and paper waste as raw material (Valdaliso et al., 2008). These were the first documented instances of sustainable technological-entrepreneurship in the cluster.

Events in the SSI, however, retarded further restructuring. Liberalisation of the Spanish economy meant that the firms of the biocluster finally became members of the global P&P SSI. The global recession in the early nineteen-eighties led to progressive concentration, and increasing cost-competition in the SSI (Elola et al., 2012). Owing to their small scale, the Basque firms could not match the prices of larger foreign rivals. Consequently, several firms closed down (Clusterpapel, 2018a). For the firms that survived, economic-efficiency and productivity became prime objectives (Valdaliso et al. 2016, Clusterpapel, 2018a). The denouement was that investments in sustainability stalled, and the cluster's transition in this phase was not as progressive as that of the rest of the SSI.

In 1991, the Basque government instituted the policy for industrial competitiveness, centred on creating regional cluster organisations (Querejeta & Navarro, 2003). The P&P industry, however, refused to form a cluster organisation. This was the result of firms' low priority for social capital, which historically precluded any form of collaboration (Valdaliso et al., 2012; Interviews).

See Table 2.3 to find a summary of the dynamics in this phase.

Table 2.3: Agency and structural dynamics in phase 1. Variables marked (+)/(-) advanced/retarded the cluster's transition

<table>
<tr><th colspan="5">Phase 1 1986 – 1998</th></tr>
<tr><td rowspan="2">Structures</td><td colspan="2">Place (Region)</td><td colspan="2">Path (Sector)</td></tr>
<tr><td colspan="2">1. Stricter regional command-and-control environmental regulations (+)

2. Rising environmental awareness in Basque society (+)

2. Institution of framework for industrial competitiveness in 1991 (+ for effects in the next phase)</td><td colspan="2">1. Increasing concentration in the
market and cost-competition (-)</td></tr>
<tr><td rowspan="2">Agency</td><td>Technological-entrepreneurship</td><td colspan="2">Institutional-entrepreneurship</td><td>Place-leadership</td></tr>
<tr><td>1. Adoption of water-treatment plants(Firms) (+)

2. Using wood-chips, paper waste as raw- material (Firms) (+)</td><td colspan="2"></td><td></td></tr>
<tr><td>Environment</td><td colspan="4">1. Spain liberalising its economy, and joining the European Economic Community (+)

2. The global recession in the early nineteen-eighties (-)</td></tr>
</table>

2.4.2 1998 – 2004: The cluster organisation guides the biocluster's restructuring

In 1998, the manager of the firm of Coinpasa was finally able to convince regional firms to create a cluster organisation, the Cluster del Papel (Ahedo, 2004, Clusterpapel, 2018a). One key goal for the organisation was improving environmental performance (Interviews). The cluster's most deleterious environmental impacts emanated from firms' effluents and sludge (IHOBE, 2000). The firms were also beset by inefficient usage of water and energy. In the first phase, the cluster's green shift had fallen behind that of the SSI. For instance, the cluster continued to use elemental chlorine as a bleaching agent, even as most of the SSI had shifted to chlorine free bleaching (IHOBE, 2000, Bergquist & Söderholm, 2018).

In 1998, the Basque region passed the Environmental Protection Act, following Europe's ratification of the IPPC directive in 1996 (Ministry of the Environment and Territorial Policy, 2014). The introduction of the act was accompanied by other changes in the RIS: growing environmental awareness in Basque society, and increasing cost of waste management. Meanwhile, sustainability had started to become a competitive advantage within the SSI - with the passing of the IPPC directive firms without environmental management system (EMS) certifications were struggling to draw customers. All these dynamics contributed to the cluster associating with IHOBE, to identify cleaner production (IHOBE, 2000). In collaboration with IHOBE, the firms had the opportunity to break away from the path established in the first phase - path-modernisation through the introduction of EOP solutions, and waste-valorisation. IHOBE (2000) suggested that the cluster could install completely new production processes that would prevent production of toxic waste. However, the firms chose to continue along path-modernisation. This decision was made because the P&P industry is one where firms are risk-averse, and are required to invest in expensive processes (Toppinen et al. 2017; Interviews). The issue of high switching costs was further compounded by a place-based heterogeneity - the relatively small size of the Basque firms. Consequently, the cluster firms engaged in various instances of technological-entrepreneurship for modernisation, with the help of the cluster's paper-machinery companies. They introduced circular-loops for valorisation of waste; and turned to EOP technologies and retrofitting to reduce water contamination, atmospheric pollution, and use of toxic raw materials (Clusterpapel, 2004; Interviews). To manage sludge, some cluster firms established formal agreements for external valorisation in cement companies (Angulo, 2000; Interviews).

In 1997, Spain liberalised its electricity market (Crampes & Fabra, 2005). The uncertainties presented by this event drove the firms to begin using combined heat and power generation (CHP) (IHOBE, 2000; Interviews). Through CHP, the cluster firms reduced their GHG-emissions and power costs considerably. It also meant the cluster finally started emulating the SSI, which was on its way to become the third largest industrial user of CHP in Europe (Minett, 2006).

This phase saw two instances of place-leadership from the cluster organisation. The organisation coordinated with cluster firms, regional forestry companies, regional technology providers, and with P&P firms in Scandinavia, to explore possibilities of using waste biomass as fuel (Interviews). This campaign led some firms to adopt biomass as CHP fuel (Clusterpapel, 2005). Secondly, the cluster organisation saw an opportunity to convert toxic sludge into bricks, and launched negotiations with the concrete industry, and with the Basque government (ibid.).

With their improved sustainability, the number of cluster firms with EMS certification jumped from 7% to 25% by the end of this phase (ibid.).

See Table 2.4 to find a summary of the dynamics in this phase.

Table 2.4: Agency and structural dynamics in phase 2.
Variables marked (+)/(–) advanced/retarded the cluster's transition

<table>
<tr><th colspan="5">Phase 2 1998 – 2004</th></tr>
<tr><td rowspan="2">Structures</td><td colspan="2">Place (Region)</td><td colspan="2">Path (Sector)</td></tr>
<tr><td colspan="2">1. Institution of the Basque environmental sustainability strategy for 2002-2020 (+)

2. Increasing cost of managing toxic waste in the region (+)

3. Growing environmental awareness in Basque society (+)</td><td colspan="2">1. EMS certifications starting to become non-negotiable in organising supply-chains in the SSI (+)</td></tr>
<tr><td rowspan="4">Agency</td><td>Technological-entrepreneurship</td><td colspan="2">Institutional-entrepreneurship</td><td>Place-leadership</td></tr>
<tr><td>1. Adoption of EOP solutions, retrofitting processes for water treatment, minimising atmospheric pollutants, and toxic raw materials (Firms) (+)</td><td colspan="2">1. Formation of a cluster organisation (Firms) (+)</td><td>1. Convincing firms to form a cluster organisation (Manager of Coinpasa) (+)</td></tr>
<tr><td>2. Adoption of CHP. Adoption of biomass as CHP fuel (Firms) (+)</td><td colspan="2">2. Establishing agreements with cement companies, for valorisation of waste (Firms) (+)</td><td>2. Guiding firms in the adoption of biomass as fuel (Cluster organisation) (+)</td></tr>
<tr><td>3. Internal, external valorisation of waste (Firms) (+)</td><td colspan="2"></td><td>3. Coordinating negotiations for sludge-valorisation in brick and concrete industries (Cluster organisation) (+)</td></tr>
<tr><td>Environment</td><td colspan="4">1. Europe's ratification of the IPPC directive in 1996 (+)

2. Spain liberalising its electricity market in 1997 (+)</td></tr>
</table>

2.4.3 2004 – 2014: Formally embracing sustainable development

In 2004, the cluster organisation reached a “sustainable development” agreement with the Basque government, whereby cluster firms committed to moderate effluents, increase valorisation, adhere to IPPC standards, and to attain EMS certification (Clusterpapel, 2004; Interviews). This agreement was possible thanks to the establishment of the Basque Country’s Environmental Sustainability Strategy for 2002-2020, which was instituted in accordance with the 2001 EU Strategy for Sustainable Development (Ministry of the Environment and Territorial Policy, 2014). Following the agreement, the program for valorising sludge with the concrete industry, initiated in phase two, was institutionalised (Gobierno Vasco, 2005). By 2008, 60% of sludge was internally or externally valorised. The cluster also invested heavily in retrofitting and EOP solutions to reduce the contamination of water, and to improve energy-efficiency (Gobierno Vasco, 2005, El Diario Vasco, 2008). Significantly, the cluster completely shifted to chlorine free bleaching, which vastly reduced the cluster’s impact on the region’s waterways (Clusterpapel, 2011). Furthermore, owing to rising regional electricity prices, the cluster expanded its CHP capacity and ramped up usage of waste biomass as fuel (Lezana, 2009).

However, the biocluster’s restructuring was retarted in the second half of this phase. In 2006, the 2000 EU water framework directive was translated into the Basque water law, which required firms to install best available technologies (BAT) for lowering water contamination (Laguardia, 2006). While this legislation improved the cluster’s overall sustainability, not all firms could afford BATs, and they ended up paying fines that affected them financially. In the aftermath of the 2008 recession, the construction industry in the region nosedived. As a result, all programs of converting sludge into bricks and cement were suspended (Interviews). In 2013, Spain stopped paying premium prices for the clean-electricity produced using CHP (El Diario Vasco, 2014). The recession, and the removal of electricity premiums, severely affected firms’ margins. Consequently, they halted further investments in CHP (and other environmental technologies), closed multiple CHPs, and also lowered clean-power production (El Diario Vasco, 2014; Interviews). Meanwhile, in the SSI, EMS certifications had become mandatory in establishing supply-chains. All these macro-level changes contributed to the closure of multiple (unsustainable) firms in this phase (Interviews; Clusterpapel, 2019a).

In spite of these difficulties, firms' actions (along with higher recycling of paper in the region) caused the cluster's carbon emissions per ton of product to fall considerably. The cluster also achieved 100% EMS certification, and could continue being part of global supply-chains (Ereño & Sancho, 2010; Clusterpapel, 2015).

See Table 2.5 to find a summary of the dynamics in this phase.

Table 2.5: Agency and structural dynamics in phase 3
Variables marked (+)/(–) advanced/retarded the cluster's transition

Phase 3 2004 – 2014			
	Place (Region)		**Path (Sector)**
Structures	1. Institution of the Basque environmental sustainability strategy, and Basque water law (+). 2. Increasing cost of electricity in the Basque country (+) 3. Improved recycling of paper-waste in the region (+)		1. EMS certifications becoming non-negotiable in organising supply-chains in the SSI (+)
	Technological-entrepreneurship	**Institutional-entrepreneurship**	**Place-leadership**
Agency	1. EOP, retrofitting, and BATs to improve energy-efficiency, to reduce water contamination (Firms) (+) 2. Adoption of ECF or TCF bleaching (Firms) (+)	1. Entering into the sustainable development agreement in 2004 (Firms and cluster organisation) (+) 2. Institution of agreements with the concrete industry, for valorisation of sludge (Cluster organisation) (+)	

Continued on next page

	Technological-entrepreneurship	Institutional-entrepreneurship	Place-leadership
Agency	3. Expanding cogeneration capacity, greater usage of biomass fuel (Firms) (+) 4. Internal valorisation of waste (Firms) (+) 6.Halting investments in CHP, and other environmental improvements (Firms) (-)	3. Suspension of agreements for external valorisation of sludge, in 2008 (Firms) (-)	
Environment	1. The EU establishing the water framework directive in 2000, and the sustainable development strategy in 2001 (+) 2. The global recession of 2008 (-) 3. Spain removing premiums for green-electricity, in 2013 (-)		

2.4.4 2014 – 2019: The Basque country formally embraces shifting to a bioeconomy

In 2015, the Basque country formally embraced a shift to the bioeconomy, inspired by the European Horizon2020 bioeconomy work program of 2014. Subsequently, the government organised an event to envision a Basque bioeconomy (Innobasque, 2019). By 2018, the region had decided to focus on a forest-based bioeconomy. Utilisation of forest resources is deeply ingrained in Basque culture, with the sector employing 20,000 people, and representing 1.5% of GDP (Martinez de Arano et al. 2018). This thematic choice placed the P&P biocluster at the forefront of the region's planned transition. Cluster firms were involved in multiple biobased innovation ventures in this phase. In a notable case, the cluster firms Papelera Aralar and Voith created Araflush, claimed to be the world's first completely biodegradable hygienic wipe (Aranguren, 2017). To manufacture Araflush, Voith invented a novel biobased production-process (Papel Aralar, 2015; Interviews). Between 2014 and 2016, IHOBE financed two projects where firms attempted to produce biofuel from waste (IHOBE, 2017; Interviews). While both projects were abortive (Interviews), they are noteworthy because the cluster had started to reflect the trend in the global SSI, of P&P firms installing biorefineries to produce next-generation biofuels (Bergquist & Söderholm, 2018).

From 2018, the cluster's biobased initiatives were formally shaped by the region's planned shift to the bioeconomy. Neiker-Tecnalia, the research agency defining the roadmap for the region's forest-bioeconomy, organised the event "Bioeconomy in Euskadi: challenges and opportunities", where cluster firms discovered possible new biobased business models (Euskadi.eus, 2018). Subsequently, the cluster organisation introduced a bioeconomy working group (in collaboration with Neiker-Tecnalia), which identified six new wood-based products the firms could create (Clusterpapel, 2018b; Interviews). In 2018, the region financed multiple projects where firms collaborated with Neiker-Tecnalia to create cellulose-based plastic (Interviews).

Over the last two phases, the cluster reduced the consumption of water, gas and electricity; and lowered water contamination and sludge production (Clusterpapel, 2019b). Crucially, this greening was accompanied by economic performance; revenues had almost increased to pre-2008 levels, the export rate was close to its highest, and productivity had improved markedly from 2008 (Clusterpapel, 2019a). In spite of the progress made over three decades, the cluster still faces different challenges. In 2019, the proportion of cluster firms with EMS certification fell to 89% (Clusterpapel, 2019b). Secondly, the cluster was yet to meet annual targets it committed to in 2016, for valorising sludge (Euskadi.eus, 2018; Interviews). Towards resolving these issues, the cluster has committed itself to a future of innovation based on forest-biomass (Murcia, 2018).
See Table 2.6 to find a summary of the dynamics in this phase.

Table 2.6: Agency and structural dynamics in phase 4
Variables marked (+)/(–) advanced/retarded the cluster's transition

<table>
<tr><th colspan="4">Phase 4 2014 – 2019</th></tr>
<tr><td rowspan="2">Structures</td><td colspan="2">Place (Region)</td><td>Path (Sector)</td></tr>
<tr><td colspan="2">1. The Basque government designating the transition to the bioeconomy an official mission in 2015 (+)

2. Financial instruments from IHOBE, Basque government for biobased innovation projects (+)

3. Robust regional forestry industry and infrastructure, easy availability of forest-based biomass (+)</td><td></td></tr>
<tr><td rowspan="3">Agency</td><td>Technological-entrepreneurship</td><td>Institutional-entrepreneurship</td><td>Place-leadership</td></tr>
<tr><td>1. Creation of cellu-lose-plastic (Firms + Neiker-Tecnalia) (+)</td><td>1. Educating firms of possible biobased products and business models (Neiker-Tecnalia+-Cluster organisa-tion) (+)</td><td>1. Coordinating with Basque firms and clusters, to define the region's forest-bioecon-omy roadmap (Neiker-Tecnalia) (+)</td></tr>
<tr><td>2. Introduction of a novel biobased production-process for wipes (Firms) (+)</td><td>2. Introduction of a bioeconomy work-ing group within the cluster (Cluster organisation+ Neiker-Tecnalia)</td><td></td></tr>
<tr><td>Environment</td><td colspan="3">1. EU establishing a Horizon2020 work program for the bioecono-my in 2014 (+)</td></tr>
</table>

2.4.5 The dynamics behind the restructuring of the Basque biocluster

Based on the above phases, we now discuss the patterns of agency dynamics, structural dynamics, and multiscalar interactions. Figure 2.2 is a timeline that depicts the interactions led to the Basque biocluster's transition.

Concerning agency, we observed that the three forms of agency were exercised by diverse actors over the four phases. In phase one, we only saw firms exercising only technological-entrepreneurship. Phase two saw firms exercising both technological-entrepreneurship and institutional-entrepreneurship. This phase also saw three instances of place-leadership (once by the manager of Coinpasa, and twice by the cluster organisation). In phase three, there were several instances of technological-entrepreneurship by firms. Along with the cluster organisation, they also engaged in a few instances of institutional- entrepreneurship. Phase four saw further instances of technological-entrepreneurship by firms. However, while the instances in phases one to three pushed the cluster along green path-modernisation (as firms made their processes incrementally greener through retrofitting etc.), technological- entrepreneurship in phase four had more to do with green path-creation, as firms laid the foundations of industries based on new technologies (bioplastics, biobased production processes, biofuels). This disruptive technological-entrepreneurship was encouraged by the cluster organisation's institutional-entrepreneurship, and a research organisation's institutional-entrepreneurship and place-leadership (and by place-dependency dynamics looking to support biobased innovation). From this summary, we infer institutional-entrepreneurship and place-leadership were as important as technological-entrepreneurship. We also see that the two most active, most influential actors were the firms, and the cluster organisation. Over the four phases, firms' technological-entrepreneurship combined with the cluster organisation's institutional-entrepreneurship and place-leadership to cause the emergence of a greener cluster. Following the characteristics of the framework detailed in sub-section 2.2.5, we have only included in our analysis, agency from organisations and individuals within the cluster, and from the research agency, which worked within the cluster.

Concerning structural dynamics, we observed that regional structures shaped agency more often than industrial structures. On this basis, we can argue that place-dependency was the more influential dependency. In phase one, regional dynamics drove firms to begin prioritising sustainable production (through path-modernisation). Industrial dynamics, however, limited the transition that could have been achieved. While the dependencies generally worked in separation over the cluster's greening, in phase two, we saw an instance where they complemented each other. The dependencies combined to direct actor-agency to continue innovating for greening through modernisation, rather than innovating for greening through path-creation. In phase three, place-dependency was the main structural driver of the cluster's restructuring. Regional dynamics (such as the institution of the Basque environmental sustainability strategy) caused actors to exercise agency that advanced greening. In the fourth phase, once again, place-dependency was the key structural driver; regional dynamics encouraged actors to embrace the bioeconomy, and engage in biobased innovation for path-creation.

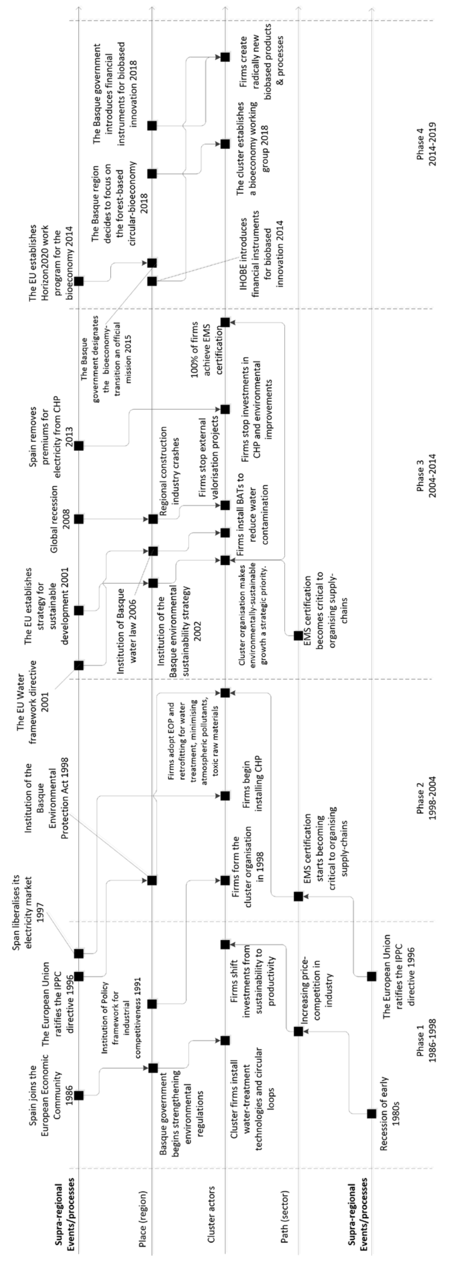

Figure 2.2: A timeline showing how agency, structures and supra-regional phenomena interacted during the cluster's green-restructuring

We can attribute place-dependency shaping agency more often to two reasons. Firstly, the cluster is predominantly composed of relatively small industry-follower firms. This place-based heterogeneity meant that the firms had to play catch-up with the green-restructuring of the SSI (for instance, with the adoption of chlorine free bleaching, CHP, biorefining etc.). Secondly, the heterogeneity in terms of the sub-sectors the firms operated in, in their attitudes towards innovation, and resources they possessed, meant that path-dependency rarely affected every firm identically (Interviews). With place-dependency, this heterogeneity was not as important, because new regional policy, increasing costs for waste-management etc. affected all firms similarly.

Regarding agency-structure interactions - in complex adaptive systems, the relationship between agency and structures is a bidirectional one. However, in this case, structures were driving agency for most of the restructuring process (i.e. for the first three phases). The inability of agency to proportionally shape structures was caused by the relatively smaller scale, and hence, limited agency, of this biocluster's firms (Valdaliso et al. 2016; Interviews). It was because of this limited agency that the firms in the biocluster were pushed by the dependencies to follow green path-modernisation, in spite of the Basque region being one of the most innovative metropolitan regions in Europe, offering conditions conducive to green path-creation. In phase four, cluster actors combined the three forms of agency to produce innovations that finally disrupted this path, and sowed the seeds of green path-creation. While these instances of agency were instigated by place-dependency, they have started shaping the dependencies. For instance, the biodegradable wipes produced by Aralar, and the biobased production-process invented by Voith, are being emulated by other, larger firms in the P&P SSI (Interviews). The innovations also played a key role in shaping the region's shift to the forest-bioeconomy.

Finally, regarding multiscalarity of the cluster's greening, we found that several supra-regional phenomena were influential (see Figure 2.2). There were two supra-regional events that shaped agency through their effects on industrial structures - both occurring in phase one (the recession of the early nineteen-eighties, and the introduction of the EU IPPC directive). Spread over the four phases, there were five events that shaped agency through their effects on regional structures. In two cases, supra-regional events circumvented structures, and acted directly on agency; firstly when Spain liberalised its electricity market, and firms started using CHP (phases one and two); secondly when Spain removed premiums for green-electricity, and firms stopped investments in CHP (phase three).

2.5 DISCUSSION

This study was conducted with the goal of advancing understanding of how and why bioclusters undergo green-restructuring. We achieved this goal by creating a novel cluster-evolution framework, and then executing a longitudinal analysis of the Basque P&P biocluster's transition. In conducting an empirical study, we have furthered knowledge from preceding studies on green-restructuring, which have predominantly been of a theoretical or modelling nature. The characteristics of our framework allowed us to make contributions to ongoing debates around the multiscalarity of restructuring, and around the roles of agency and place-dependency. We discuss our insights and contributions here.

2.5.1 The empirics of green-restructuring

Our first contribution to cluster-research is that we conducted an empirical investigation of a cluster's green-restructuring. A central argument for us using a CAS-based model, is that it offers a non-deterministic view of cluster-evolution. With this perspective, path-development becomes an ongoing process, and clusters may change restructuring-paths. This view is all the more important because of the urgent need to decarbonize different types of clusters at distinct "life" stages (Geels et al., 2017). Being located in a highly innovative region, we would have expected the Basque biocluster to green through path-creation. However, this cluster turned out to be an exemplar of clusters that do not adhere to such expectations. The non-determinism of our framework allowed us to demonstrate how (and why) the biocluster greened through path-modernisation for most of its life; and how it finally started greening through path-creation at a later stage. Of course, we cannot state how common such deviations are, with this singular case.

The findings of our empirical investigation bring us to another important question - whether there is a fundamental difference between "normal" restructuring and green-restructuring? The discussion regarding the differences is especially important for bioclusters, since the concept of the bioeconomy, much like that of sustainable development, is a contested one (Wilde & Hermans, 2021). Furthermore, truly decoupled growth of clusters is quite difficult (Kamath et al., 2022b). One of the differences between restructuring and green-restructuring could be the deliberate destabilisation/destruction of unsustainable systemic structures (Turnheim & Geels, 2012, Trippl et al., 2020). Within our case, we did see deliberate destabilisation; for example, the regional government introducing command-and-control regulation in phases one and three (following EU requirements), and the removal of unsustainable firms from supply-network in the P&P SSI, in phases two and three. These examples suggest that greening-paths are different from economic restructuring-paths. However, since we only investigate one case, this is not sufficient evidence. While we used our framework to analyse green-restructuring of a biocluster, it can possibly be used to study (green-)restructuring of other types of clusters. This presents an opportunity for future case-analysis using the framework, to establish the distinctions and similarities between greening and economic restructuring. The challenge here is identifying what changes to the macro-level and micro-level variables are required for this analysis.

There are also other avenues for future research. We can explore how the framework can be modified to include components for the analysis of meso-level (i.e. the level between macro and micro) processes such as the formation and modification of actor-networks. We can also investigate how to include components that represent individual actors' capabilities (as functions of their resources and attitudes). The challenge here will be expanding the framework while limiting how much more complicated it becomes.

2.5.2 The multiscalarity of green-restructuring

Since our CAS-based framework can analyse interactions within nested systems, we were able to discover influential multiscalar interactions in the Basque cluster's greening. We showed that phenomena at the national, continental and global scale can act either directly on agency and greening, or through their effects on structures. These phenomena could be relatively predictable structural changes at these scales (like the institution of national policies), or black-swan events (like global recessions). Studies in the past have elaborated how higher-scale processes affect place-dependency. What this study did differently is that it also demonstrated how these processes affect path-dependency; and how SSI dynamics in turn affect agency.

We did not see any instances of agency from beyond the cluster in our analysis. However, this does not mean our framework disregards the role of higher-scale actions (while over-emphasizing the actions of cluster members). Structural dynamics that affected agency within the cluster emerge (partly) from regional, supra-regional agency. For example, modifying the laws of the region requires institutional-entrepreneurship from regional (and national) policymakers. While we did not explore the extra-cluster entrepreneurial processes behind influential structures effects, we did demonstrate the influence of these processes on the cluster's greening, by illustrating how the structural dynamics they engendered affected agency within the cluster, and thus, its restructuring.

Whereas we chose to club all supra-regional scales into one "external environment" component, we must note that the framework can be modified to have separate components for events and structures in the National Innovation System (NIS) (Freeman, 2002) and Global Innovation

System (GIS) (Binz & Truffer, 2017). This choice of a single component was made to minimise the complexity of the framework, but it does lead to vagueness. While this was not such a critical issue in our case, since there were not many instances of upward-causation, inclusion of separate NIS and GIS components will be necessary when analysing clusters known to exert strong influence on national structures, and global value-chains.

2.5.3 Structures-agency interactions, and policy-implications

We learnt that regional or cluster-based idiosyncrasies can render path-dependency not as effective as place-dependency, in shaping green-restructuring. We demonstrated how regional structures can either act separately from industrial structures, or combine with them, to facilitate or hinder greening. Place-dependency and path-dependency combined to force this cluster to take a modernisation path, instead of a creation path, for most of the restructuring process. It could be possible in other cases that the dependencies combine to prevent even path-modernisation, and cause an unsustainable lock-in.

The policy implication here is that policymakers aiming to drive green-restructuring should not just encourage technological entrepreneurs, but also institutional-entrepreneurs and place-leaders who can help shape both supra-regional, and industrial structures (which governments may not have a lot of control over). From our analysis, we infer that institutional-entrepreneurship and place-leadership can be as important as technological-entrepreneurship in the greening process. So much so that technological-entrepreneurship may not be possible without the other forms of agency. We saw how several instances of technological-entrepreneurship - adoption of biomass as CHP fuel, and valorisation of waste in the cement industry (in phase two), and also the innovations that disrupted path-modernisation (in phase four) – were made possible by institutional-entrepreneurship and place-leadership. Policymakers tend to have a techno-economic focus, especially with regards to the bioeconomy (Bogner & Dahlke, 2022); but techno-entrepreneurs themselves see the need for institutional-entrepreneurs and place-leaders (Wilde & Hermans, 2021). Regional governments can themselves play this role, or they can follow the Basque government, and establish cluster organisations. We saw how the cluster organisation helped advance the Basque cluster's restructuring, by connecting it to the regional government, to foreign firms, and to other industries as well. In essence, durable green-restructuring requires intermediary-actors (Kivimaa, 2014) that build the necessary institutional support at various administrative levels, and help cause bottom-up changes in industrial structures, if required.

3 POLICY INSTRUMENTS FOR GREEN-GROWTH OF CLUSTERS: IMPLICATIONS FROM AN AGENT-BASED MODEL[3]

3 This chapter is based on Kamath, R., Sun, Z., & Hermans, F. (2022b). Policy instruments for green-growth of clusters: Implications from an agent-based model. Environmental Innovation and Societal Transitions, 43, 257-269.

3.1 INTRODUCTION

The notion of green-growth has emerged as a dominant policy response to climate change (Dale et al., 2016). Green-growth theory asserts that green-technological innovation will allow us to relatively or absolutely decouple economic growth from resource use and carbon emissions (Solow, 1973, Hickel & Kallis, 2020). Therefore, policies that promote the creation and adoption of green-innovations are paramount to achieving some level of decoupled green-growth. As a response, over the last decade, innovation policy literature has become increasingly focused on innovations targeting transitions and green-growth (Schot and Steinmueller, 2018). Scholarship has become increasingly interested in how green industrial clusters can contribute to sustainable innovation and green-growth (Hansen & Coenen, 2015, Boschma et al., 2017). Green-clusters grow in a decoupled fashion by developing and selling products or technologies that "reduce carbon emissions and pollution, enhance energy and resource efficiency, and prevent the loss of biodiversity and ecosystem services" (UNEP, 2011:16).

In this study, we explore implications for policies to advance the green-growth of clusters. Here, we are specifically interested in policies for greening of clusters located in peripheral regions. According to the typology introduced by Tödtling & Trippl (2005), we can distinguish between metropolitan, specialized and peripheral regions. However, we have limited understanding of the prospects for the development of green-clusters in the various types of regions, and of the differences in required policies. Until recently, research has focused on the evolution of metropolitan or specialised regions, implicitly assuming that there is no innovation in peripheral areas. Growth of any form is difficult in peripheral regions because they are characterized by a lack of critical mass in any industrial specialization, and by the lack of high-value, knowledge-intensive activities (Isaksen & Trippl, 2016). This view is being increasingly questioned, which is reflected by a rising number of papers, special issues, and edited volumes on innovation outside of agglomerations (Eder, 2019). To fill in the knowledge gap of green-growth in peripheral regions, we address the question, *What policy instruments are most effective in causing green-growth of clusters in a peripheral region?*

To answer this question, we built an agent-based model (ABM) to simulate the transition of a peripheral cluster of firms. With this ABM, we aim to advance understanding of policy instruments that promote green-growth and innovation, and of the emerging practice of modelling socio-technical transitions (Holtz et al., 2015, Köhler et al., 2019). The simulations are based on the idea that the emergence of green-growth in peripheral regions commonly involves the deployment of green-technologies developed elsewhere, i.e. greening through importation (Grillitsch & Hansen, 2019). Mere availability of a green-technology does not guarantee widespread adoption, policy support is often a pivotal catalyst for adoption (del Río González, 2005). In this regard, several studies have argued for the application of different policy instruments (Nauwelaers et al., 2009, IEA, 2011). Using the ABM, we explore the effectiveness of three individual instruments, and an instrument-mix, on the peripheral cluster's green-growth.

The instruments are

1. Financial incentives to attract external actors in a green industry,
2. Grants provided to qualifying innovation projects being run by local cluster actors, and
3. Imposition of fines on firms that cross a certain level of pollution. The instrument-mix we explore is a combination of incentives for foreign actors and fines.

In the following section, we introduce the reader to the complex adaptive systems perspective that guides our ABM. In section 3.3, we describe the characteristics of the agents and processes within our agent-based model. In the section 3.4, we present and interpret the results of the simulation. In section 3.5, we discuss the strengths and limitations of our model, lessons from our findings, and implications for how scholarship views green-clusters and decoupled growth.

3.2 TOWARDS AN ABM TO SIMULATE ON CLUSTERS' GREEN-GROWTH

In this section, we discuss the perspective of complex adaptive systems (CAS), which underlies the approach of agent-based modelling. We detail why clusters can be viewed as CAS, and how green-growth can be viewed as the evolution of the cluster-CAS's macro-level properties.

3.2.1 Clusters as complex adaptive systems

A CAS is composed of a dynamic network of actors that continually (re) act in response to the (re)actions of other actors, and to external stimuli (Waldorp, 1993). In a CAS, aggregate behaviour and various systemic characteristics are seen to emerge from the myriad actions and interactions of its constituent actors (i.e. the process of upward causation) (Gandolfi, 1999). At the same time, these characteristics may guide, and constrain, the actions of the actors making up the CAS (i.e. the process of downward causation).

An industrial cluster is an interconnected, mutually dependent network of actors (such as firms, universities) and institutions, working in a particular field, concentrated in a particular geographical area (Porter, 1998). Industrial clusters exhibit characteristics that make them complex adaptive systems (Martin & Sunley, 2011, Nikolic et al., 2009), such as:

1. Emergence: In CAS, macro-level structures and dynamics emerge out of micro-level behaviors and interactions. Cluster-wide properties such as pollution-levels, financial assets emerge from the actions and interactions the cluster's firms, universities etc. These properties then influence the actions of cluster members that (re) produce them.
2. Adaptation: CAS can adapt their structures and dynamics. Clusters can adapt (e.g. by reducing pollution-levels) in face of external or

internal demands (Martin & Sunley, 2011). This enables clusters to survive, and even thrive, by evolving towards new (more sustainable) set of structures (Klepper, 2006).

3. Openness: CAS tend to be dissipative—subject to constant interaction and exchange with their environments. Clusters are open systems that engage in continual exchanges with its environment (Martin & Sunley, 2011).

3.2.2 Green-growth is the transition of a cluster CAS

Green-growth implies that, among other changes, the cluster's financial standing should improve as pollution-levels decrease. When we view a cluster as a CAS, its green-growth can be perceived as a transition of its macro-level properties (such as pollution, financial assets etc.); where these properties become more sustainable, and guide actor behaviour that drives further transition. These changes at the cluster-level will only emerge through the adoption and creation of green-technologies at the actor-level (i.e. upward causation). In parallel, cluster-level structures (such as the availability of grants) will attempt to shape actors' choices that advance (or retard) decoupled growth (i.e. downward causation). Essentially, what we model in our ABM are these processes of upward and downward causation, and how they possibly lead to green-growth of the cluster.

3.2.3 Peripheral regions and green-growth

Peripheral regions are characterised by low-levels of clustering, and a lack of industrial specialisation (Isaksen & Trippl, 2016, Grillitsch & Hansen, 2019). These regions are dominated by small-and medium-sized enterprises. They can host a few large firms (Grillitsch & Hansen, 2019).

Peripheral firms engage in low-levels of collaboration, leading to little knowledge-exchange (Isaksen & Trippl, 2016, Grillitsch & Nilsson, 2015). Amongst the various types of regions, innovation rates are lowest in peripheral regions. Furthermore, innovation by peripheral firms is mostly of an incremental nature (Shearmur, 2011, Isaksen & Trippl, 2016).

Owing to the relatively weak support system for innovation, peripheral firms are unlikely to find all the resources necessary for innovation, within these regions. Consequently, to create green-growth paths, they must collaborate, with extra-regional actors, or use imported knowledge and technologies. Studies such as Grillitsch & Nilsson (2015), Grillitsch & Hansen (2019) argue that (green) growth in the periphery will be centred on the activities of a few innovative firms in the region, attracting foreign agents, and importing (green) knowledge and technologies.

3.2.4 The sustainability treadmill

In our ABM, the agents are essentially on a type of technological treadmill (Cochrane, 1958). In its original form, the treadmill theory refers to a race to continually update technology in possession, to lower production costs. Failure to update technology leads to relatively higher costs, and to bankruptcy.

In our model, we apply this idea with a modification – agents are in a race to continually innovate, update green-knowledge and green-technologies, lower pollution and become more sustainable (while becoming financially richer). If they fail to innovate, their pollution rises (on both a relative and absolute basis), as the performance of their green-technologies deteriorates with time. With failure to innovate, the agents become (relatively) dirtier, fall behind in the sustainability treadmill, and eventually, fall off and perish (as their dirtier products lose share in the market).

3.3 METHODOLOGY

The most effective and accurate model of a CAS is one which is itself, a CAS. Therefore, the most suitable option to model cluster evolution is agent-based models. To answer our research question, we created an ABM in the Netlogo 6.1 modelling environment. Netlogo has an easy-to-use GUI, and does not require a lot of programming effort, letting us focus on the model's logic.

ABMs can be relied upon to examine how a system will respond to developments such as the introduction of new policy. There are multiple instances of ABMs being used to explore various emergent phenomena in industrial clusters. Dilaver et al. (2014) investigated the relationship between the entrepreneurial character of a region and the emergence of clusters. Agents in the model run innovation projects to create new knowledge. When these projects succeed, agents reap financial rewards. Successful projects can also lead to the creation of spin-offs. Experiments revealed a positive correlation between the entrepreneurial nature of the region and cluster development (because of higher spin-off formation). Canals et al. (2008) investigated the link between the willingness of actors to collaborate (to share knowledge, resources), and the intensity of clustering in a region. In the model, firms randomly collaborate. Experiments revealed that spatial clustering was more intense when the willingness to collaborate was high. Vermeulen & Pyka (2014) simulated the mediating effects of agents being able to collaborate with extra-regional actors. Agents in this ABM collaborate and share inputs for innovation. Rewards from successful innovation, which are abilities to create more advanced technological artefacts, are equally shared among the collaborators. The model demonstrated that when agents are able to collaborate with external actors, the artefacts created are much more radical. Finally, Zhang (2004) modelled how the emergence of clusters begins with the appearance of some inspiring entrepreneurial agents. In the model, an entrepreneurial firm randomly appears and makes a large profit, which inspires other firms to enter the landscape. Each firm is given some level of technological assets. Firms that fail to make a profit fail to innovate, leading to their exit. These processes combine to cause spatial clustering of firms.

While our model has been inspired by the features of these models, unlike preceding ABMs, we do not model for innovation that merely leads to richer agents; rather, we model for innovation that makes the agents (and the cluster) not only richer, but also greener. Moving away from extant models of cluster-based innovation, we simulate processes of environmentally-sustainable innovation. Firm-agents collaborate and contribute resources to projects aimed at effecting incremental or radical green-innovation. Succesful projects help agents not only reap financial rewards but also new green-knowledge and improved green-technologies; which help agents lower their pollution, and become more sustainable. Additionally, we make a further contribution to the field of modelling cluster-based innovation - by conducting experiments to determine which instruments can effectively stimulate green-growth.

3.3.1 Structure of the agent-based model

We describe below, the variables in the ABM; the main agent behaviours, and processes, within the ABM; and the macro-level parameters that we track. For greater detail on the ABM, we welcome the reader to view the Overview, Design concepts, Details (ODD) protocol in the supplementary materials.

3.3.1.1 Agent-properties and global variables

In our ABM, there are a number of agents (i.e. firms), clustered in a landscape with characteristics of a peripheral region. The behaviours of these agents are governed by two sets of variables - agents' own and global. The main agent variables are 1) Financial capital, 2) Knowledge capital, 3) Reputational capital, 4) Pollution-levels, 5) Radical project experience, and 6) Incremental project experience. The main global variables are

1) probability of collaboration 2) Probability of radicalness 3) Probability of innovating 4) Innovation potential 5) Cluster-size 6) Decay rate. The first five global variables are informed by the postulations of Tödtling & Trippl (2005) and Isaksen & Trippl (2016), and data from the European Innovation scoreboard for 2019-2020. The definitions of these variables are given in Table 3.1.

We can use this model to simulate cluster-transition in any region, by controlling the global variables. To answer our research question, we simulate the greening of a cluster in a peripheral region. We operationalise the features of the periphery, as detailed in sub-section 3.2.3, by controlling values for the following global variables:

- Percentage of large firms: we only have a small percentage of large firms in the cluster, at initialisation.
- Probability of collaboration: we have used the range of values for modest regions (0 to 27%) from the European RIS scoreboard.
- Probability of radicalness: we have used the range of values for modest regions (0 to 55%) from the European RIS scoreboard.
- Probability of innovation: At initialisation, we have used the lowest value for modest regions (2.2%) from the European RIS scoreboard.

We use data for "modest innovator regions" because they resemble most closely, peripheral regions. They are regions whose overall innovation scores are below 50% of the European average. The ranges for probabilities for collaboration, innovation, radicalness are lowest for modest regions. To simulate conditions of metropolitan or specialized regions, we simply change the range of values for the above global variables (using data for "strong innovators" or "innovation leaders" from the scoreboard).

As the model runs, the ranges for probability of collaboration and probability of radicalness are always adhered to. This way, the agents always collaborate and engage in radical innovation at rates that are characteristic of peripheral firms. We do not maintain a range for the probability of innovating, and for the percentage of large firms, as we treat them as an emergent variables shaped by agents' innovation activities.

Table 3.1 The agents' own and global variables that guide agent behaviour

Variable	Definition
Agents' own	
Financial capital	Financial capital in possession of an agent.
Knowledge capital	Green-knowledge and green-technologies possessed by an agent.
Reputational capital	Reputation, sustainability credentials of an agent.
Pollution-level	Represents how polluting an agent's operations are.
Radical project experience	The number of successful radical innovation projects an agent has participated in.
Incremental project experience	The number of successful incremental innovation projects an agent has participated in.
Global	
Probability of collaboration	This is the probability of firms collaborating for a (green) innovation project. Defined as ratio of number of firms collaborating in an innovation project to the total number of firms. The range of values for this variable is obtained from the range of values for "Innovative SMEs collaborating with others" for modest regions, from the European RIS 2019-2020 scoreboard.
Probability of radicalness	The probability of a (green) innovation project being a radical one. Defined as the ratio of number of successful radical innovation projects to total number of successful projects. The range of values for this variable is obtained from the range of values for "Sales of new-to-market and new-to-firm innovations" for modest regions, from the European RIS 2019-2020 scoreboard.
Probability of innovating	The probability of a (green) innovation project succeeding. Defined as the ratio of number of successful projects to total number of projects. The initial value for this variable is obtained from the lowest value for "Product or process innovators" for modest regions, from the European RIS 2019-2020 scoreboard. There is no range used for this variable.
Innovation potential	This is the ratio of the number of successful projects to the total number of firms at a point time.
Cluster-size	This is the number of agents in the cluster, at any given point in time (note: split agents are counted as one agent).
Decay rate	This is the rate at which the agents' three capital asset stocks decline with each time-step, and also the rate at which the agents' pollution rises with each time-step.

3.3.1.2 Agents' action-space

The objective of the agents in the simulation is to survive, and grow, for as long as possible. The agents exist in an environment where demand for their products is positively correlated with their sustainability (applying the idea of the sustainability treadmill from sub-section 3.2.4). Consequently, each agent's survival depends on its ability to increase knowledge-capital, financial capital, and reputational capital. The challenge facing agents is that with time, the capital stocks they hold diminish, while pollution climbs. In the model, assets decrease by the formula C(1 – dr) , while the pollution increases by the formula P(1 + dr). "C" is the value of the capital-asset in the prior time-step, "P" is the pollution-level of the agent in the prior time-step, and "dr" is the decay rate.

The agents' knowledge capital (which is green-knowledge, green-technologies and associated machinery and equipment possessed by an agent) decreases with each time-step. As the sustainability performance of its green-technologies decreases with time (due to deterioration of machinery and equipment), the agent's knowledge capital loses value. With their physical technology assets deteriorating, and the technology becoming relatively inefficient, agents' products and processes become dirtier, as the pollution-level of each agent increases (both in relation to other agents' products and processes, and on an absolute basis). When an agent's pollution-level crosses 100, the agent will cease to exist (an emulation of the government forcing a highly polluting firm to close).

Agents' financial capital decreases when demand for their products comes down. As agents' knowledge capital decreases, the sustainability of their products and processes come down. This causes the relative competitiveness of products to go down, reducing demand for them. Lower demand forces agents to use their reserves to survive; hence the reduction in financial capital each time-step. When the financial capital for an agent falls under 10, the agent will cease to exist. With declining value of green-technology and knowledge, declining sustainability for their products, the reputational capital of the agents decreases each time-step. When the reputational capital for an agent falls under 10, the agent will cease to exist.

Agent survival and growth requires innovation at a rate that staves off rising pollution and decreasing assets. New knowledge and technology assets are created or adopted through green-innovation projects. Successful projects endow agents with rewards in the form of capital assets and lower pollution. Initially, most projects are incremental in nature, and green-technologies are assumed to be available "off-the-shelf" (applying the idea of greening through importation (Grillitsch & Hansen, 2019)). After multiple instances of incremental innovation, the peripheral agents can develop more advanced green-technologies through radical innovation projects. Through (incremental) innovation projects, agents can obtain new knowledge and tech, which help them (slightly) lower pollution. While innovation lowers pollution on an absolute basis, it can also make them cleaner in comparison to other agents; which increases demand for the agent-firms' products. So agents also reap financial asset rewards through innovation. Along with green-innovation success, comes greater reputation. So, the agents also gain reputational capital. With successful radical projects, the firm-agent moves onto a new green-technology that surpasses the sustainability of technologies in possession. The asset rewards and pollution-reduction in this case, therefore, are higher than from incremental innovation. However, radical innovation is rarer, with lower chance of success. Engaging in radical innovation projects requires agents to first succeed in several incremental innovation projects. Without green-innovation, agents turn dirty, with higher levels of pollution and lower levels of capital. This leads to firm-agents ceasing to exist, and the cluster dying. Green-innovation in the model has three steps – initiating projects, innovating, and reaping rewards for successful innovation.

3.3.1.3 Initiating green-innovation projects

To start an innovation project, an initiator agent collaborates with between one and five agents that possess the highest levels of knowledge capital. Once a project is initiated, links are formed between the project partners. Any firm-agent can initiate a green-innovation project. At a time, an agent can only be a member of one project (unless it splits into two divisions, in which case the agent can participate in two projects simultaneously). For this exploratory model, we have not factored in the effects of any proximity dimensions (such as geographical, social, institutional, cognitive or organizational (Boschma, 2005)) in the collaborative process; we aim to incorporate these dimensions in future versions.

The number of projects successfully initiated in a time-step is the product of probability of collaboration and a random positive integer below the variable "number of projects in a tick", which is input by the observer. Some of the projects are randomly chosen to be radical innovation projects. In the beginning stages, most projects are incremental innovation projects. The chances of an initiated project being a radical project are positively correlated with the innovation potential. With time, if there are several successful incremental innovations, the innovation potential rises, and so can the number of radical projects.

3.3.1.4 The act of innovation

After the agents have collaborated on a project, they innovate using green-technologies that present the possibility of new capital rewards, and reduction in pollution. To execute the project, project-partners commit capital to the project. The chances of project success are directly proportional to the total knowledge, financial, and reputational capital committed to the project, the total number of successful radical/incremental projects that the partners have been a part of, and the global variable probability of innovating. Chances of project success are lower when the project is a radical one. The capital an agent commits to the project is proportional to its capital stocks, and the number of successful projects it has been part of. This way, richer, more experienced agents are able to commit more capital.

A project succeeds or fails within one time-step. When a project succeeds, a few things happen. Firstly, the probability of collaboration increases (by the ratio of the number of partners in the project to total number of agents). The increment occurs as long as the probability of collaboration stays under the upper limit of its range (see Table A2 in the Appendix). Secondly, the probability of innovating is updated (by calculating ratio of successful projects to total number of projects undertaken), as long as it stays under the value of one. Thirdly, the radical project experience or incremental project experience for each partner is increased by one. Next, if the project that succeeded is a radical one, probability of radicalness is updated (by calculating ratio of successful radical projects to total number of successful projects). The updating occurs as long as the probability stays under the upper limit of its range (see Table A2 in the Appendix). By maintaining the ranges for probability of collaboration and radicalness, we ensure that the agents always behave as peripheral firms. Fifth, if the successful project is a radical one, a spin-off firm-agent is created from the initiator agent (like in Dilaver et al. (2014)). This spin-off will have 25% of the parent's knowledge and financial capital, pollution-level, and past experience with successful projects; and 50% of reputational capital. Finally, the links that were formed between the project-partners are removed (which is the first event that occurs when a project fails).

3.3.1.5 Rewards from green-innovation

Successful innovation immediately rewards all participating agents equally (like in Vermeulen & Pyka (2014)), with capital-assets and lower pollution. After each successful project, the agents will have their financial, knowledge and reputational capital doubled (in case of a radical project), or rise by 25% (in case of an incremental project). Pollution is halved (in case of a radical project), or decreases by 25% (in case of an incremental project). See Table A3 in the Appendix, for the equations that govern capital increments, and pollution decrements.

As firms become richer, they can be involved in multiple innovation projects. If any of an agent's three capital-stocks go above 100, the agent is allowed to participate in two innovation projects within the same time step. The model enables this by splitting the agent into two separate agents that represent internal divisions that can independently carry out innovation-projects (conceptually, we think of this splitting as a rich, large firm reorganising into independent divisions that are focused on one particular product-line, or a certain market). The parent agent's financial and knowledge capital, its pollution, and its past experience with successful projects are split into two, and each half is inherited by the two divisions. Since there are no new firms being created, but rather independent internal divisions, the two new agents are counted as one when the model calculates cluster-size.

3.3.1.6 Agent death

Rewards are tempered by decreasing capital and increasing pollution in each time-step. See Table A3 in the Appendix, for the equations that govern capital decrements, and pollution increments. If the financial or reputational capital falls under the value of 10, or if the pollution-level for an agent goes above 100, the agent will cease to exist. With the death of an agent, the innovation potential of the cluster is updated (as the ratio of the number of successful projects surviving agents have executed, to the number of agents).

3.3.1.7 Macro-level patterns and end-state of interest

We track the following macro-level variables, to gauge the progress of the cluster's green-growth:

1. Pollution-levels: This is the sum of the pollution-levels of all the agents that make up the cluster.
2. Cluster-size: This is the number of agents existing at any point in time (note: split agents are counted as one agent).
3. Knowledge capital: This is the sum of the knowledge capital stock of every agent in the cluster.

4. Financial capital: This is the sum of the financial capital stock of every agent in the cluster.
5. Reputational capital: This is the sum of the reputational capital stock of every agent in the cluster.
6. Ratio of pollution to financial capital: Green-growth requires economic growth to decouple from pollution. We track this ratio to see if as the cluster's pollution-levels go down, its financial capital stock goes up.

Besides these six parameters, we also track the number of successful projects and the number of successful radical projects. The desired end state, where the simulated cluster has transitioned and decoupled, is one where pollution has declined, cluster-size has increased or at least remained the same, capital stocks have increased, and the ratio of pollution to financial capital is trending down. The least desired state is when the agents have died out as pollution increased and capital stocks have been depleted.

3.3.2 Experiments with instruments shaping green-growth

In the ABM, we conducted experiments to simulate the effects of three individual instruments, and an instrument-mix, on peripheral agents' innovating behaviour, and on the green-growth of the cluster. The three instruments were

1. Financial incentives used to attract external actors having experience with the imported green-technologies,
2. Grants provided to qualifying innovation projects being run by cluster actors, and
3. Imposition of fines on cluster actors that cross a certain level of pollution.

We chose these instruments because we wanted a group of instruments with different purposes. While grants and incentives for foreign actors are both economic instruments for technology-push, fines are a regulatory instrument for demand-pull. The instrument-mix we explored is incentives and fines being applied simultaneously. This combination ensured that while our study did not analyse the effect of so-called "sermons" (i.e. communicative policy tools that stimulate stakeholder participation, learning and collaboration (Wieczorek & Hekkert, 2012)), we covered the "carrots" and "sticks" of innovation policy. Incorporating communicative tools is something we aim to explore in future research. The four experiments we conducted are summarised in Table A4 in the Appendix.

3.3.2.1 Model initialisation for experiments

For each of the experiments, we initialised the model with a total of 50 agents, with 3% of the firm-agents being "large" firms. For the large firms, financial capital and reputational capital were assigned random initial values between 50 and 100. For the small firms, financial and reputational capitals were random values between 10 and 50. The model was initialised with agents having random pollution-levels between 0 and 100. For agents with a pollution-level of under 50, knowledge capital is a random value between 25 and 75. These greener agents are given the colour green. For all other agents, knowledge capital is 25. These "dirtier" agents were given the colour red.

At initialisation, the radical project experience and incremental project experience for each agent was set to 0. We assigned probability of collaboration a value of 14% (roughly mid-point of the range) and probability of radicalness, a value of 28% (roughly mid-point of the range). At initialisation, the model gave probability of innovating a value of 0.022 (lowest possible value), and innovation potential, value of 0.01 (meaning only 1 out of 100 agents can come up with a successful innovation). The number of projects initiated in a tick is the product of probability of collaboration and a random positive integer below five (number of projects in a tick). A project could have between 2 to 6 partners (we chose to use this range based on an overview of projects in a cluster we previously studied. Between 2014 and 2019, there were 27 collaborative projects in this cluster, only four of which included 6 or more partners). We set the decay rate at which assets decline and pollution rises at 0.1%. For the range of possible variable values at initialisation, see Table A2 in the Appendix. Once started, the simulation runs till either of two conditions is met - when the number of agents in the cluster is less than the number of projects in a tick (5), or when the number of ticks is greater than 300.

3.3.2.2 Imposition of fines on polluting firms

Fines refer to financial capital that is instantly reduced from an agent's stock when its pollution-level is equal to, or crosses, 33. Every time-step, the model finds agents that do not satisfy this criterion, and fines them. Fine levels range from 0% to 25% of each agent's financial capital. For this scenario, we varied fine levels from 0% to 25%, with jumps of 5%. At each fine level, we executed 100 simulation runs, for each of the macro-level patterns of interest.

3.3.2.3 Introducing grants for local innovation projects

Grants refer to financial capital that is given to a particular project, which is added to the financial capital that has already been committed to a project, by project partners. Grant levels range from 0% to 25% of the financial capital possessed by the project. In each time-step, during the act of innovation, the model will check if particular projects can receive grants. The chances of a project receiving a grant are positively correlated with capital stocks committed to it, and the number of successful incremental/radical projects that the partners have been part of (following Banal-Estanol et al. (2016)). For this scenario, we varied grant levels from

0% to 25%, with jumps of 5%. At each grant level, we executed 100 simulation runs, for each of the macro-level patterns of interest.

3.3.2.4 Incentives for attracting entrants

Incentives refer to financial capital that is bestowed to the entrant, immediately upon entrance. Incentives range from 0% to 25% of the financial capital an entrant possesses at entry. The probability of a new agent entering the cluster is positively correlated to the incentives set. Only one entrant may enter the cluster in each tick, and it may be a large or small agent. Entrants upgrade the knowledge capital of the cluster by bringing in new, higher-value green-technology and knowledge. Entrants' knowledge capital, ranging between 75 and 100, is higher than of cluster agents. An entrant's pollution-level is the same as the lowest pollution-level among cluster-agents. Entrants' experience with successful incremental and radical innovation is random values between the mean and maximum experience among the cluster-agents. Once they enter the cluster, entrants will behave like any other cluster agent. If they fail to innovate, they can turn dirty, become asset poor, and cease to exist. For this scenario, we varied incentive levels from 0 to 25%, with jumps of 5%. At each incentive level, we executed 100 simulation runs, for each of the macro-level patterns of interest.

3.3.2.5 Introducing an instrument-mix of incentives and fines

In this final scenario, every time-step, some entrants may enter the cluster and receive incentives, and some agents may get fined. For this scenario, we varied both incentive and fine levels from 0 to 25%, with jumps of 5%. At each combination of incentives and fines, we executed 100 simulation runs, for each of the macro-level patterns of interest.

3.4 Results

We now present the variations of the macro-level patterns of interest for each scenario. We first discuss results for the individual instruments, then for the instrument-mix.

Agent-based modelling often entails, as in our case, stochastic settings, and may generate rich and complex patterns. To investigate the uncertainty of the modelling results and how the uncertainty or variations of the model outputs can be attributed to various input variables, a sensitivity analysis needs to be conducted symmetrically (Ten Broeke et al., 2016). We used RNetLogo, and its extended R packages, nlexperiment and nlrx, to execute a sensitivity analysis. We welcome the reader to view the setup and results of this analysis in the supplementary data.

3.4.1 Green-growth shaped by fines, grants, incentives

We started off our experiments by first analysing the effects of the three policy instruments individually. In the simulation where we imposed fines on polluting firms, we saw that as fines increase, the number of successful (radical) projects decline. We also saw that the cluster-size drops below the initial value at all fine levels, with the reduction in size trending slightly up with fine-levels. Asset-stocks stay below initial levels at all fine-levels, with the reduction in stock trending up with fines. Decreasing innovation success causes a decline in asset values, leading to a shrinking cluster. Pollution stays below initial values, and drops more with increasing fines. However, with declining innovation, this drop in pollution has to be attributed to shrinkage in cluster size. Decreasing pollution causes the ratio of pollution to financial capital to trend down. Overall, fines seem to retard the green-growth of the cluster by failing to encourage green-innovation.

In the simulation of grants for qualifying projects, we saw that increasing grant levels lead to higher levels of innovation (unlike with fines). Like with fines, asset values and cluster-size drop below their initial values at all grant-levels. However, we saw that with rising grants, the magnitude of reduction in size and assets diminish. We observed that with rising grants, the drops in pollution levels increase. With cluster-size increasing with grants, we can attribute this increasing reduction in pollution to rising levels of innovation. We also saw that rising grants causes the ratio of pollution to financial capital to decline. For this scenario, we ran another set of simulations, with a larger grant range of between 0 to 200%. We did see a positive effect where the magnitude of reduction in cluster-size and assets decreases; but even with a grant-level of 200%, an inflection to rising cluster-size and stock-levels does not occur. This tells us that simple financial grants alone are not sufficient to cause a richer, decoupled cluster (unless perhaps when they reach extra-ordinary levels that dwarf private investment).

In the simulation of incentives for entrants, what we saw is that with increasing incentives, the number of successful (radical) projects increase. Rising innovation leads to cluster-size and capital assets moving up from their initial values. However, this is only after incentives cross certain threshold. Below these thresholds, innovation is not high enough to lead to increasing size and capital stocks. Although pollution drops below initial values at all incentive-levels, raising incentive levels diminishes the amount of reduction in pollution. This demonstrates that we cannot optimise for pollution-reduction and capital-augmentation simultaneously. We will have to either give up a bit of capital or some pollution-reduction, in choosing one of many states where pollution has dropped, and capital stock has risen. High incentives seem to aid decoupling, as the ratio of pollution to financial capital fall with increasing incentives. We also ran a second set of simulations for this scenario, where entrants' experience with successful innovation was the same as the maximum experience among the cluster-agents. What we saw was that with more experienced entrants, the inflection points where asset-values and cluster-size start increasing from initial values, are at lower incentive-levels than in the first case. This is because of higher innovation levels, which also lead to higher magnitude of asset and cluster-size augmentation.

We welcome the reader to view the graphs we have provided in the supplementary data, which depict the variation of the macro-variables of interest in each of the above scenarios.

3.4.2 Green-growth shaped by an instrument-mix of incentives and fines

We now come to the scenario where entrants are incentivised to come into the cluster, and where agents can be fined. Figure 3.1 depicts how pollution in the cluster varies with increasing levels of incentives and fines. Figure 3.2 depicts how the ratio of pollution to financial capital of the cluster varies. Figure 3.3 depicts the variation of cluster-size, knowledge capital of the cluster, financial capital of the cluster, reputational capital of the cluster, the number of successful radical projects, and the number of successful projects.

From Figure 3.1, we see that the pollution has dropped below its initial value throughout, but the reduction in pollution increases significantly after the fine-level of 2.5%. Above this level of fines, incentives do not have a major effect on the magnitude of pollution-reduction. Below this level, we see increasing incentives lead to lower reduction in pollution. The figure suggests we keep fines above 2.5% for optimum reduction in pollution. Looking at changes in the cluster's capital-assets, graphs b, c, d in Figure 3.3, we see that capital-stocks are maximised when fines are kept below 2.5%, and incentives are kept at the highest level. Coming to innovation rates, looking at graph f in Figure 3.3, we see total innovation success is highest when fines are kept at zero, and incentives at 25%. This combination of incentives and fines also maximises cluster-size, as per graph a. For radical project success, it is better to keep both fines and incentives high (see graph e in Figure 3.3). Finally, increasing fines and incentives both cause the ratio of pollution to financial capital to decline.

The decline due to increasing incentives is more gradual than due to increasing fines. Figure 3.2 suggests we keep both incentives and fines at the highest level to optimise for this ratio.

3.5 Discussion

Over the past decade, the field of innovation policy has seen increasing emphasis on studying the design of policies promoting green-clusters, clusters that undergo decoupled green-growth. There is however, limited knowledge on which policies can instigate green-growth in clusters. To contribute to this knowledge gap, we created an agent-based model.

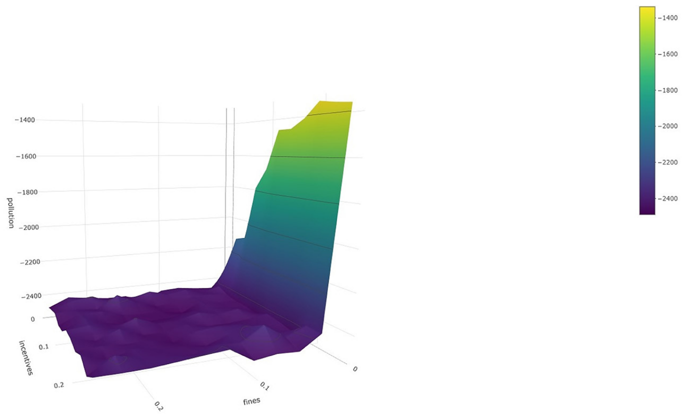

Figure 3.1: Variation of pollution in the cluster, with increasing levels of incentives and fines

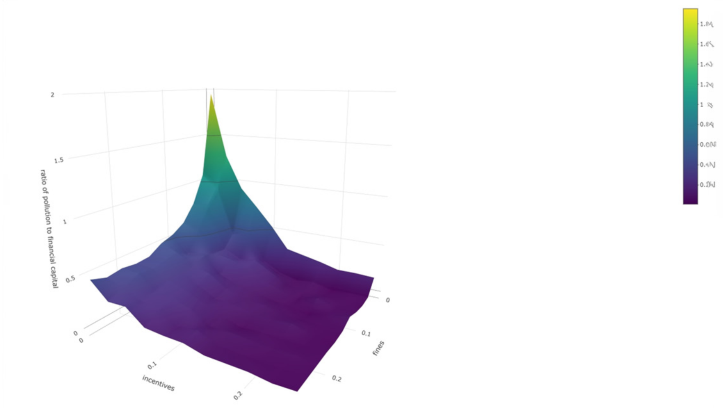

Figure 3.2: Variation of the ratio of pollution levels to financial capital of the cluster, with increasing levels of incentives and fines

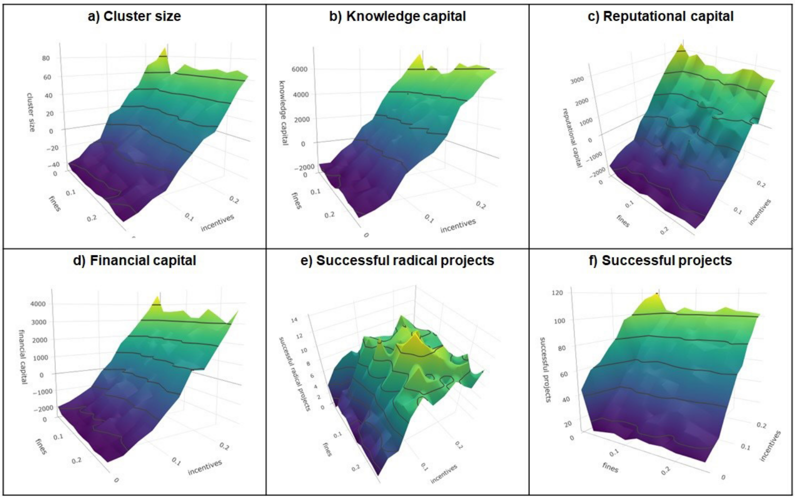

Figure 3.3: Variation of cluster-size, knowledge capital of the cluster, financial capital of the cluster, reputational capital of the cluster, the number of successful radical projects, and the number of successful projects, with increasing levels of incentives and fines

This ABM stitches macro-level and micro-level perspectives together, enabling us to see how a cluster decouples through agents' green-innovation. Our model is a virtual laboratory that allows for experimentation and projection – by modifying the set-ups of extant instruments or through the introduction of new instruments. We can for instance, explore the effects of reducing the pollution threshold above which agents are fined. We can also, with some changes in the model, explore the effects of other instruments such as public procurement guarantees, technology standards on the cluster's decoupling. In spite of these strengths, the model also has some limitations that present avenues for future research. As an exploratory model, its rules and agents are somewhat simplistic and abstract. Agent behaviour can be further developed by, for instance, factoring in the effects of different proximity dimensions, such as geographical, social, institutional, cognitive or organizational, in the process of agents collaborating. We also have the opportunity to refine rules and agent-behaviours, and to validate simulation results, using empirical data (which is the temporal dynamics of global variables such as probability of collaboration, and of macro-level parameters such as pollution (the dynamics of which may be shaped by instruments)) from real-life clusters, in future versions of the model.

While our ABM can model the transition of clusters in any region (by controlling for global variables), we used the model to explore how green-growth of a peripheral-region cluster is shaped by different instruments. To operationalise the characteristics of peripheral regions, we use data for "modest innovator regions" from European Innovation scoreboard for 2019-2020. In this section, we discuss the lessons from our findings, results, and implications for how scholarship views green-clusters and decoupled growth.

3.5.1 The effectiveness of different instruments

From our simulations, we saw that fines are the least effective of all instruments. The model suggests that fines retard the green-growth of the cluster by failing to encourage green-innovation. The model also showed us that while grants encourage innovation, innovation rates are not high enough to cause the emergence of a decoupled cluster. This is true even for grant-levels of 200%. This tells us simple financial injection is not enough to spur cluster transition, unless they are raised to extra-ordinary levels several orders of magnitude larger than private investment. However, raising grants to such levels may be out of reach for most peripheral-region governments.

From the simulation of incentive-driven green-growth, we saw that incentives are able to cause a richer, more sustainable cluster to emerge, after a certain incentive threshold. An exploratory process is required to find the thresholds for different conditions. We found that higher the experience of the entrants, lower the incentive levels required for the decoupling to begin. That incentives were the most effective in driving the transition of a peripheral cluster conforms to the postulations of Isaksen & Trippl (2016), Grillitsch & Nilsson (2015), Grillitsch & Hansen (2019), which call for green-growth policies focussed on attracting foreign actors and knowledge into the periphery. It is important to note here that unlike grants, incentives introduce into the cluster not just financial capital, but also advanced knowledge-capital, and reputational capital.

3.5.2 Implications for decoupled growth of clusters

Our intention in this study was to create an exploratory ABM to simulate the green-growth of a cluster in any type of region. We did not intend this to be an advanced predictive model. We envision for predictive powers to be incorporated in future iterations. From the results of our exploration, we can infer certain implications for how we think about green-clusters and sustainable development.

What we saw from the simulation of green-growth shaped by the instrument-mix is that it can be optimized for each macro-variable (see

Table 3.2 below); there is no one combination of incentives and fines that optimises for all of the macro-variables simultaneously. These results indicate that absolutely decoupled growth of peripheral-region clusters is close to impossible. Rather, it is possible to achieve various states of relative decoupling. However, optimising for decoupling (low ratio of pollution to financial capital) requires foregoing optimisation of some other macro-variables. For instance, maximizing innovation rates requires a mix of high incentive-levels and low fine-levels, but if we want to minimise the ratio of pollution to financial capital, the model suggests we keep both incentives and fines high.

Table 3.2: How various instrument combinations optimise for different macro-variables

	High Incentives	Low Incentives
Low Fines	Optimise for augmentation of capital and cluster-size, total innovation success	
High Fines	Optimise for pollution-reduction, pollution to financial capital ratio, and radical innovation success	Optimise for pollution-reduction

Our results demonstrate how complex the nature of designing an effective instrument-mix for the green-growth of clusters is. We see the inherent trade-offs in designing an instrument-mix for relatively decoupled growth of clusters. There is no way to maximise reduction in pollution, or augmentation of assets, without sacrificing some capital, or some pollution-reduction.

Even green-clusters working with sustainable technologies will have some level of pollution. Pollution-levels for sustainable technologies will be less than those for non-sustainable ones, but the second law of thermodynamics will still apply on the former as well. In this regard, our results confirm some of the criticism of the decoupled growth theory, that it under theorizes the contested notion of sustainable development in the "greening" process (see Hickel & Kallis, 2020, Ward et al., 2016). Based on our simulations, we opine that there should be more nuanced deliberation, with greater focus on possible trade-offs, on the potential contribution of green-clusters to sustainable development (see Hansen & Coenen, (2015), Wilde & Hermans (2021)).

3.5.3 A landscape of possibilities

Because complex adaptive systems are indeterministic, ABMs cannot be prescriptive tools; rather, they provide us with a landscape of possibilities. The results of our instrument-mix simulation show that there is a landscape of several possible states of relative-decoupling (beyond the inflection points where cluster-size and assets start rising above initial values). Policy makers will first have to figure out what the inflection points are for their region. The next challenge is to gauge if there is a better local optimum, or a global optimum. This determination can be done by closely studying, and comparing with, other peripheral clusters that have enjoyed relatively greater decoupling. Alkemade et al., 2009 recommend that while attempting to move through such landscapes, authorities should be mindful of modifying instrument combinations, once information indicating policy-ineffectiveness becomes available. Without timely modification, the cluster may get locked into a particular growth path and find it very difficult to move to better optima. Authorities must, for instance, avoid progressively concentrating grants into projects innovating with one particular technology, because future performance and externalities can be unclear.

4 HOW PROXIMITY SHAPES INNOVATION-COLLABORATION FOR CLUSTER-GREENING

4.1 INTRODUCTION

While clusters were envisaged as tools to achieve competitiveness, and economic targets (Porter, 1990), multiple regions and nations are starting to use clusters to catalyse sustainable-innovation, and the green-restructuring of economies (McCauley & Stephens, 2012, Hansen & Coenen, 2015, Stegmann et al., 2020). The formation of green-custers, and the greening of existing industrial clusters has been identified as an important tool to achieiving the GHG emission-reduction goals of the European Green Deal (van der Reijden et al., 2021).Consequently, the development of green-clusters is increasingly becoming a key area of interest to both Evolutionary Economic Geography and Sustainability Transition Studies (see Hansen & Coenen (2015), Boschma et al. (2017), Sjøtun & Njøs (2019), Kamath et al. (2022a)).

However, in spite of the rising interest in green-clusters, Evolutionary Economic Geography is yet to sufficiently emphasize how clusters move into greener industries; and how policy can support this process (Sjøtun & Njøs, 2019). The central argument for policies establishing green-tech clusters is the benefit that comes from geographical proximity - knowledge-spillovers that increase the chances of green-innovation required to instigate greening of regional and national economies. However, studies such as Boschma & Frenken (2010), Binz et al. (2012), Essletzbichler (2012), McCauley & Stephens (2012), and Lopolito et al. (2022) have demonstrated that geographical proximity is neither a necessary, nor a sufficient condition, for effective green-innovation collaborations. These studies show how the creation of disruptive green-innovation can involve actors that are spatially-distant, but are linked by non-spatial proximities such as social proximity (which results in trust). Based on this evidence, we can infer that green-cluster policies must focus on not just spatial proximity, but also on non-spatial proximities that encompass social, cultural aspects. There is, however, little research on how (non-spatial) proximities shape collaborations for green-innovations (Lopolito et al., 2022). In this context, this paper attempts to answer the question – how do the different dimensions of proximity shape innovation collaborations for cluster-greening?

We adopt Boschma's (2005) definition for proximity – it is a "nearness" between organisations, which increases trust, decreases uncertainty, and enables collaborative learning and innovation. Proximity has many dimensions (Knoben & Oerlemans, 2006). Here, we apply the framework from Boschma (2005) that distinguishes between five dimensions: cognitive, organizational, social, institutional and geographical proximity. There are studies that explain how (certain) proximity dimensions influence sustainable innovation and transitions. For instance, Hodson & Marvin (2009), Späth & Rohracher (2010, 2012), and Wirth (2013) demonstrate the importance of institutional proximity (shared values and norms, shared politics and goals, shared visions) in facilitating transitions. Bridge et al. (2013), McCauley & Stephens (2012) explain how geographical & cognitive proximity may accelerate sustainable innovation. What is rarer in literature, however, are studies that demonstrate how each of the proximity dimensions (interact to) mould green-innovation collaborations in certain places.

In an attempt to fill this knowledge-gap, we investigate through a qualitative case-study approach, how the five proximity dimensions influence collaboration for green-innovation in the Paper Province cluster in the Värmland Region of Sweden. The paper province is a green-cluster that is derived from a preceding cluster specializing in the manufacturing of pulp and paper. This is a cluster that was not intrinsically sustainable, and has been undergoing green-restructuring through (collaborative) green-innovation. Over the past decade, the cluster has been transitioning away towards a broad portfolio of sustainable products based on forest biomass (Bugge, 2016; Interviews). According to the European Secretariat for Cluster Analysis, the paper province is a one of the most innovative European clusters (clustercollaboration.eu, 2020). This ongoing greening of a highly innovative cluster presents an appropriate context for the exploration of how proximity affects the organisation of green-innovation projects.

The rest of this paper is structured as follows. Section 4.2 describes the five proximity dimensions we will be using as our analytical framework, and details preceding work on proximity and sustainability-transitions.

Section 4.3 describes our methodology. Section 4.4 presents our case-study results on how proximity shapes green-innovation-collaboration in the paper province; finally, in section 4.5, we discuss our findings and contributions, and policy-implications.

4.2 PROXIMITY AND THE GREENING OF CLUSTERS

The few studies that do attempt to clarify how clusters can go green have come from the field of "geography of transitions" (Hansen & Coenen, 2015). In looking to bridge Evolutionary Economic Geography and Sustainability Transition Studies, geography of transitions emphasizes investigation of how clusters and regions undergo green-restructuring. This has led to studies such as Grillitsch & Hansen (2019), and Trippl et al. (2020), which postulate that clusters within the same, or similar regions can green along different paths.

This open-ended nature of cluster-greening is the outcome of strategic agency. Actor-level dynamics within the cluster are, therefore, crucial in explaining how clusters evolve towards greater sustainability. However, cluster-evolution studies have come in for criticism, for not paying sufficient attention to the role of agency (Trippl et al., 2015).

4.2.1 Exploring proximity effects on cluster-greening, at the meso-level

Recent studies such as Jolly et al. (2020), and the studies in chapters two and three of this dissertation, have provided greater clarity on the role of agency in designing the greening paths for clusters. However, these studies do not shine enough light on how actors form and modify collaboration networks. For instance, both Kamath et al. (2022a) and Kamath et al. (2022b) view clusters as complex-adaptive systems, and investigate how the micro-level (i.e. individual actors' agency) interacts with the macro-level (i.e. (supra-)regional and industrial structures), to shape cluster greening. However, these studies (self-admittedly) do not explore how the collaborations (which beget the innovations necessary for cluster-greening) are formed and modified.

In this study, we adopted the same approach as these studies and treat clusters as complex-adaptive systems. While these studies focused on the micro- and macro-levels, we will emphasize the dynamics of the meso-level. The meso-level lies between the micro- and macro-levels, and it is where actor-collaborations are formed or modified (Boshuizen, 2009) (see Figure 4.1). We investigated how proximity dimensions shape these collaborations, in a cluster that is green-restructuring.

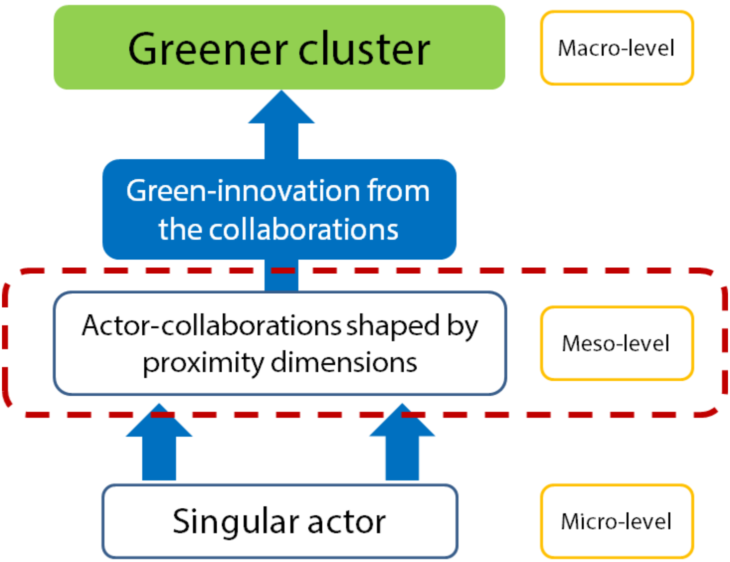

Figure 4.1: We view clusters as complex-adaptive systems, and focus on how proximity dimensions shape actor-collaborations at the meso-level

While there have already been studies that investigate the effects of proximity, on the formation of collaborative networks in clusters, such as Balland et al. (2016), Juhász & Lengyel (2018), and Abbasiharofteh & Broekel (2021), they did not have a normative inclination. Unlike these studies, ours is not an analysis of cluster-based networks for the purpose of innovation for profit and competitiveness, but of networks for sustainable innovation that results not just in profit and competitiveness, but also the cluster's shift to greener operation. The reviews conducted by Petruzzelli et al. (2011), Cuerva et al. (2014), and Díaz-García et al. (2015) showed that green-innovations may be more complex than conventional innovations, and may require greater collaboration with actors that distant (cognitively at least). Furthermore, Kamath et al. (2022b) unearthed evidence that suggests that greening-paths are different from economic restructuring-paths. Consequently, we are also interested in possible differences and similarities between the effects of proximities on green-innovation collaborations and on collaborations that do not prioritise sustainability.

4.2.2 The dimensions of proximity

Proximity refers to a similarity in characteristics, for actors in a network (Boschma & Frenken, 2010). The recognition that innovation frequently occurs through inter-organizational collaboration (Hagedoorn, 2002), led scholars to use the concept of proximity to study such collaboration, and knowledge-exchange networks, at various geographic levels (see Knoben & Oerlemans, (2006), Balland, (2012), D'Este et al. (2013)), including within clusters (see Arikan (2009), Hermans (2021), Kabirigi et al. (2022), Balland et al. (2022)). Within clusters, the landscape of collaboration for innovation, and of the exchange of knowledge and resources, is not uniform (Giuliani, 2007). While some organisations may collaborate with multiple partners, others may have thin collaboration networks, in spite of having possible suitors in the vicinity. The principle of geographical proximity not being a sufficient or a necessary condition for collaborative innovation was established by Giuliani & Bell (2005). Following this seminal study, there have been multiple investigations on separating the influences of different types of proximity (such as Boschma (2005), Balland (2012), Mattes (2012)).

Though there are debates on the types of proximity, we will use as a framework for our study, perhaps the most influential classification of proximity – Boschma's (2005) five proximities:

1. Geographical proximity
   Geographical proximity is the physical distance between actors, or the time it takes to travel between the locations of the actors. The transfer of knowledge, especially of a tacit nature, can be easier when there is spatial proximity (Howells, 2002). This is because physical nearness enables frequent face-to-face meetings at a low cost. The geographical agglomeration of organisations in clusters create knowledge spillovers, and actors that are not part of innovation projects can learn from them (Maskell, 2017). These externalities allow clustered firms to be more innovative and competitive than non-clustered fathers (Audretch & Feldman, 1996). These externalities are, however, prone to erosion over time (Pouder & St. John, 1996), and organisations must form alliances with actors outside the agglomeration, in order to avoid spatial lock-in.
2. Cognitive proximity
   Two actors can be said to be cognitively proximate if they have similar knowledge bases, and competencies. Cognitive proximity is a crucial deciding factor in the formation of innovation alliances (Nooteboom, 2007). Actors tend to collaborate with partners that are cognitively proximate (Breschi & Lissoni, 2006). This is because organisations find it easier to absorb and exploit new knowledge when it is near to its own. However, a high degree of cognitive similarity is detrimental to the creation of novelty. On the other hand, cognitive distance increases chances of radical innovation, but too much distance prevents communication, comprehension between partners.

3. Organizational proximity

   This form of proximity denotes the degree of (in)formality in the relationship between partners. Organizational proximity is the "degree of control and rate of autonomy under which knowledge is exchanged and learning processes are carried out" in the collaboration (Coenen, et al, 2010:297). A high degree of formality (through clear, extensive contracting, for instance) reduces uncertainty regarding timelines, roles, and reward-sharing. However, such degrees of formality may be difficult to establish in innovation projects, which can be complex, non-deterministic; and require partners to be entrepreneurial, and flexible regarding timelines and rewards. Highly formal, hierarchical relationships limit autonomy and adaptability, which then hinders entrepreneurship. Ideally, innovation-collaboration must have loosely coupled, flexible alliances that have space for entrepreneurship and iterations.

4. Social proximity

   Social relations at the micro-level (i.e. between individuals) modulate the outcomes of any organizational undertaking (Uzzi, 1996), including cooperation for innovation. Social proximity is high when individuals from partner organisations have friendships, or shared experiences from the past; which lead to trust, and reduces chance of conflict. Higher levels of trust lead to more interaction and open sharing of (tacit) knowledge and resources. Collaborations based on social proximity can also be more durable than those based purely on economics. Repeated collaboration with the same partners, however, precludes further learning and innovation. Social proximity can play a key role in collaborative innovation projects through the mechanism of "closure" (Boschma & Frenken, 2010) – where partners are brought into a project by an actor that shares social relations with all of them.

5. Institutional proximity

   The performance of cooperative ventures is determined not only by micro-level social relations, but also by macro-level institutions. The actions of organisations are determined not just by formal institutions (e.g. laws), but also by informal institutions (e.g. cultural values and norms) (Hofstede et al., 2005). Institutional proximity, whether formal (from operation under the same legal frameworks) or informal (from speaking the same language, sharing the same values and norms etc.), provide a foundation of trust, on which organisations can cooperate. However, continual cooperation with institutionally proximate partners prevents the creation of disruptive innovations, which require experimentation with radical technologies, and the destabilisation of incumbent institutions.

These proximities are not always independent of each other. To begin with, spatial and non-spatial proximities are correlated with each other (Balland et al., 2016). For instance, geographical proximity may lead to greater social proximity (and also diversity in social relations), because physical nearness enables frequent meetings. These meetings can also reduce cognitive distance. Clustering may also cause the formation of institutional proximity among organisations (Ponds et al., 2007). Proximities can also substitute each other; for instance, organizational, social and geographic proximity can replace each other (Cassi & Plunkett, 2015). Issues rising from cognitive distance may be solved through geographical proximity, which enables organisations to closely monitor each other's' innovation activities (Malmberg & Maskell, 2002). In this case, organisations need neither social proximity nor organizational proximity to learn from each other. In places where the institutional set-up is weak (e.g. when there are IP protection laws), actors will have to depend on social proximity (i.e. trust) to ensure win-win collaboration (Kanack & Keefer, 1997). Finally, in the absence(presence) of certain types of proximity, other types of proximity may not work(be absent). High organizational proximity (i.e. formality/heirarchy) may disappear any social proximity. In cases where there is no institutional proximity, effective innovation-collaboration may not be possible even if there is social and organizational proximity (Gertler, 2003).

4.2.3 Proximity, green-innovation and transitions

Recently, scholarship from Geography of Transitions started investigating how physical nearness influences the collaborations between actors looking to create and scale green-innovation (Yu & Gibbs, 2018). However, greening need not be a spatial phenomenon – it can emerge from a network of actors that are geographically distant (Fontes & Sousa, 2016, Hassink et al., 2019). This means that the role of the other dimensions of proximity, in directing green innovation and greening-processes, has to be researched (Coenen et al., 2010, Raven et al., 2016). Nevertheless, there is a lack of studies that analyse factors that influence organisation of collaborations that lead to valuable green-innovations (Dangelico & Pontrandolfo, 2015, Zhao et al., 2018). There are a few studies that aim to address this knowledge gap by connecting theories of sustainable innovation and transitions, to the theory of proximity. Here, we review some relevant ones.

Coenen et al. (2010) conducted a case-study to research how proximity dimensions fashion the development of green-technology niches. In a study of the aquifer thermal energy storage niche in the Netherlands, the study found that all five dimensions of proximity were influential in the evolution of the niche. The authors state that in paticular, geographical proximity was important because the niche was quite dependent on the availability of underground heat and cold. Institutional proximity at the provincial level was also key; evidenced by the emergence of experiments in only four of the Netherland's provinces. While geographical proximity was important throughout the evolution of the niche, cognitive and social proximity were important in the formative stages of the niche; and organizational and institutional proximities became more important as interactions increasingly implicated broader institutional contexts, and as they turned more formal over time. The investigation also showed that proximities need not automatically exist, but rather, have to be created through actor agency. This is especially the case when actors are innovating with a radical sustainable technology. Initially, very little proximity existed between the stakeholders of the sustainable niche. Continual experimentation with the new technology created social proximity and trust, which then led to open knowledge-exchange and cognitive proximity. Institutional proximity was created through interactions with pertinent regulations, while organizational proximity was created through the founding of intermediary actors.

Ghassim (2018) analysed how proximity dimensions affected sustainable innovation within the mining industry in Norway. By running a regression analysis on survey data, the study found that engineering-related cognitive and formal institutional proximity were important to the introduction of process innovations, formal institutional and science-related cognitive proximity were key to the creation of product innovations, and organizational and informal institutional proximity were important to social innovation.

Liu et al. (2021) studies the evolution of Green Innovation Networks (GIN) across the provinces of China. Through a social-network analysis, the study found that geographical proximity magnified the effects of the other proximities. For instance, in the incipient stages, geographical proximity enhanced the cognitive proximity between actors. There was also some evidence of the proximities being substituted by others. For instance, geographical proximity could sometimes replace institutional proximity, and vice versa. Over time, the importance of geographical proximity increased, while that of cognitive proximity decreased (due to convergence of knowledge and education). Institutional proximity was important when the technologies were in being developed, but its importance declined as the technologies, and associated institutions, attained some level of maturity.

Finally, Lopolito et al. (2022) studied the effects of proximity on the evolution of the networks of the Italian Biofuel niche. Through a regression analysis, they established that social proximity was influential through the niche's existence. Social relations became more important to the formation of actor-links over time. Cognitive and institutional proximities became more important to link formation as the niche became mature. The authors also found that organizational proximity did not play any role in the niche's development.

Following these studies, we aim to further advance understanding of how proximity influences the organisation of green-innovation projects. Unlike the above studies that had niches, nation-sized networks, or national industries as their units of analysis, our emphasis is on how proximity fashions sustainable-innovation-collaboration in industrial clusters. In spite of research stating that geographical proximity is neither necessary nor sufficient to engender green-innovation, policymakers are increasingly looking to clusters to accelerate sustainable innovation and green-growth (Carvalho et al., 2012, Derlukiewicz et al., 2020). However, studies such as Kamath et al. (2022a) have shown that policies that can help achieve decoupled green-clusters are very difficult to design. In this context, our study attempts to contribute to understanding of how spatial and non-spatial proximities fashion collaboration for sustainable-innovation in a cluster that is green-restructuring; and what the implications are for green-cluster policy.

4.3 Methodology

To achieve our research objective, we used a qualitative case-study approach. As per the review conducted by Balland et al. (2022), a considerable share of notable research on the relationship between proximity and innovation-collaboration has been of a quantitative nature, with only slight differences in measurements, or statistical methodology. It is not surprising then that of the four studies that we reviewed, only one (Coenen et al. 2010) used descriptive qualitative data to demonstrate the effects of proximity.

According to Yin (2003), we can use a case-study approach when 1) we are trying to answer "how" and "why" questions 2) we do not interfere with the behaviours of people involved in the study, and 3) we have to understand the contextual conditions because they are relevant to the phenomenon under study. The phenomena we are studying here is the formation of collaborative networks for green-innovation within a cluster. These networks are formed within the context of different proximities within the cluster – physical nearness, similarity in values and norms, laws, similarity in knowledge-bases, social relations etc. Understanding this context is crucial because we aim to explore how these proximity variables affect decision-making. Since we only collect information on projects that have been/are being executed, and do not engage in action-research, we do not in any way affect behaviours.

A case-study is also appropriate because we need more empirical evidence of the processes that drive clusters' green-restructuring. Leaving aside a few exceptions (Sjøtun & Njøs (2019), Kamath et al., (2022b)), most studies on clusters' greening have either made a theoretical contribution, or employed computer modelling.

We conducted our case-study on the paper province cluster in the Värmland region of Sweden. The paper province is a leading pulp and paper (P&P) cluster, recognised by the European Union as a highly innovative, "gold-label" cluster (Jolly et al., 2020, clustercollaboration.eu, 2020). The cluster organisation was founded in 1999 (Paper province, 2018); and today comprises over a hundred members, including very large to small P&P firms, paper-machinery firms, energy companies, logistics companies, startups creating novel biobased products, Karlstad university, research centres, and consultancies. The cluster also connects these actors to an incubator for biobased startups, the Karlstad municipality, and the Swedish innovation agency.

Even though the P&P industry has considerably reduced its environmental impact over the past five decades, it still faces questions over sustainability. To improve its environmental performance, the industry "has been seeking renewal under the emerging concept of bio-economy" (Toppinen et al., 2017:2), by inventing products, processes based on forest biomass (McCormick & Kautto, 2013, Näyhä et al., 2014). This is exact scenario is playing out in the case of the Paper province. Since 2012, the cluster has been in the process of converting itself from a traditional cluster, into a platform that supports the cooperation of different types of actors, for the purpose of biobased innovation (Grundel & Dahlström, 2016; Interviews).

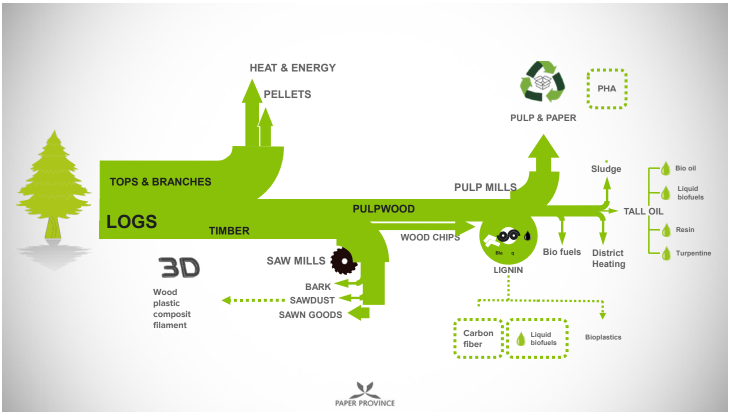

Figure 4.2: The Paper Province has transformed into a platform supporting various wood-based innovation (from Tomani (2017))

This transformation is being undertaken in order to achieve the region's smart-specialisation goal of restructuring to a sustainable, circular forest-based bioeconomy (Haarich, 2017; Interviews). The members of the cluster have subsequently collaborated (within and without the cluster) to produce a variety of wood-based innovations (see Figure 4.2), such as biobased absorbents, biohydrogen, biobased fertiliser, and biopackaging, and also to set-up testbeds to upscale biobased innovations (Bugge, 2016; Tomani, 2017; Interviews). Värmland's biobased industry has had such success with decoupled growth (see Figure 4.3) that it has made the region a pivotal player in Europe's emerging bioeconomy; and the paper province, a role-model for a platform that facilitates collaborations between heterogeneous actors (clustercollaboration.eu, 2020; Interviews).

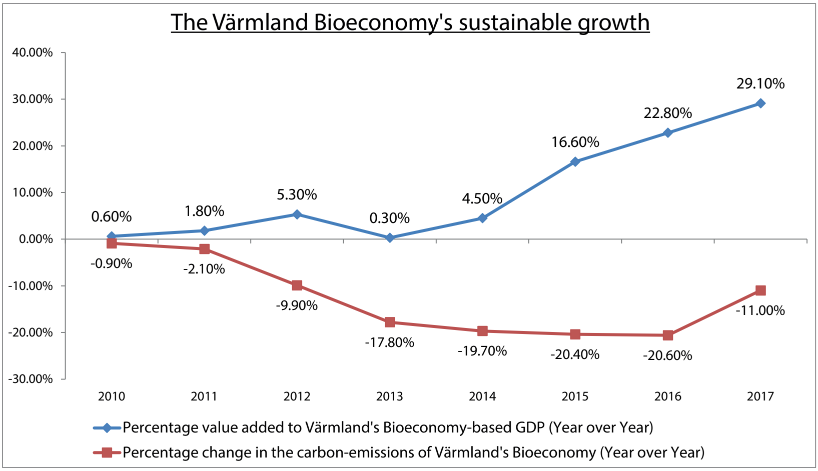

Figure 4.3: Through the Paper Province, the Värmland region has been undergoing decoupled growth (based on data from paperprovince.com (2019))

We investigated how the projects that engendered these innovations were organised and executed under the influence of different proximities. Data for the investigation was collected through a series of semi-structured interviews conducted between May and November 2022. The interviewees were individuals involved in these projects (or in one case, in studying such projects), and were identified through two sources – press releases on various innovation projects on the paper province organisaw-The interviewees were from the Paper province cluster organisation, mid-to-large P&P companies, biobased startups, an energy company, Värmland region's government, Karlstad University, Kristinehamn Innovation Park, Sting Bioeconomy incubator, and the Research Institutes of Sweden (RISE). Table A5 in the Appendix lists our twelve interviewees.

We used both recurring and ad hoc questions for the interviews. The questions were mostly open-ended, and the main themes explored through the questions were:

Table 4.1: Variables used to operationalise the proximity dimensions (based on Boschma (2005), Boschma & Frenken (2010), Balland (2012))

Proximity dimension	Variables
Cognitive proximity/distance	1. Project partners having similar/different knowledge-bases and capabilities
Institutional proximity/distance	1. Project partners having same/different values, objectives (e.g. profit vs sustainability) 2. Project partners working under the same/different regulatory framework (e.g. public innovation funding frameworks) 3. Project partners speaking the same language (e.g. Swedish)
Organizational proximity/distance	1. Hierarchical and formal/flat and informal relationships in projects, with no room/room for open, democratic discussions 2. Inflexibility/flexibility from partners with regards to work-packages, timelines, contributions 3. Non-Willingness/willingness to go through iterations of the project 4. Actors providing translation and mediation
Social proximity/distance	1. Actors frequently collaborating with the same partners because of social relations/actors collaborating with partners that they do not share social relations with 2. Collaboration networks based on trust/economic rationales 3. Actors providing/not providing closure (i.e. connecting partners)
Geographical proximity/distance	Actors collaborating with partners that are physically close/far

- What was the thought-process that led to the creation of a particular partnership? What was the role of different partners?
- Geographical proximity:
  - How spatially close were the partners in the project?
  - What were the (dis)advantages of partners being close to/far from each other?
- Cognitive proximity:
  - What was the level of (dis)similarity in the knowledge and capabilities among the project-partners?
  - What were the (dis)advantages of such cognitive (dis)similarity?
  - How were any issues arising from cognitive (dis)similarity resolved?
- Organizational proximity:
  - What was the degree of formality in the partnerships for green-innovation?
  - What were the (dis)advantages of this level of (in)formality?
  - How did partners being members of the paper province, or of other networks, affect the collaboration?
  - What were the effects of power differentials?
- Social proximity:
  - Had the partners worked together in projects before? Were there social relations (friendships etc.) between the representatives of the partners?
  - What were the effects of partners (not) having worked together and/or representatives (not) having social relations before a particular project?
  - Were there actors that provided closure?
- Institutional proximity:
  - What were the values, goals, languages that partners shared?
  - What were the (dis)advantages of these commonalities/dissimilarities?
  - How did the partners arrive at similar expectations for the project's outcomes?

4.4 RESULTS

4.4.1 Institutional proximity

The paper province's restructuring to a circular forest-based bioeconomy was instigated by the Swedish Innovation Agency, Vinnova, granting long-term funding for executing the transition. The grant was won by a consortium that included the Paper province and its members, Karlstad University, Region Värmland, the County Administrative Board, local authorities, and the Swedish Forest Agency (Haarich, 2017; Interviews). The consortium was explicit in its grant application, that it aimed not merely for a technological transition, but a systemic socio-technical restructuring that would be driven by triple-helix partnerships (Grundel & Dahlström, 2016; Interviews).

The Värmland region has a history of developing/transforming its sectors, such as ICT, steel, and manufacturing, through the triple-helix approach (Kempton, 2015; Interviews). The case seems to be no different with the pulp and paper-transition, as the triple-helix was visible in the organisation of the projects we analysed; with many of them involving diverse companies (e.g. large P&P firms, biobased startups, waste-processing firms, energy companies), research and knowledge actors (e.g. Karlstad University, RISE), and policy/governmental actors (e.g. paper province, municipalities). From being a cluster of just six large P&P mills, the paper province counts as its members today, varied organisations; from a natural tourist organisation, to logistics and legal firms. This enables the paper province, and organisations such as RISE and Region Värmland, to cause and support green-innovation collaborations with a level of actor-heterogeneity that the consortium partners believe is necessary to foster a systemic restructuring (Klitkou et al., 2020; Interviews). However, this variety brings with it, institutional distance in the form of distinct perspectives, values and norms, goals, and "internal logics".

These differences do cause complications; for instance, partners have had to navigate differences in expectations (e.g. knowledge actors want to advance science, but companies want cost-effective solutions for tangible issues), and preference for agility (e.g. startups move faster than P&P mills, which move faster than universities). The transition has also come in for some criticism regarding the lack of sufficient involvement of the fourth helix, civil society. Attempts to bring in more civil society partners have been thwarted by visions and expectations that diverge from those of the triple-helix members (Grundel & Dahlström, 2016; Interviews).

Despite these issues, our analysis revealed that innovation projects benefit from proximity that emerges from the shared values/goals of sustainability, financial gain, and regional pride. Firms in the region have a strong desire for creating new products from forest-biomass, and from waste and side-streams. The resultant innovation constellations are driven not just by sustainability targets and wanting to contribute to the greening process, but also by the impulse to become more financially efficient, more competitive, and to identify and profit from new revenue streams in the emerging bioeconomy. In summary, collaboration in this cluster is based on the convictions "environmental sustainability, and social sustainability goes hand-in-hand with financial sustainability", and "[green] innovation - it should result in profit, in a sellable product". Collaboration is also driven by a certain degree of regional patriotism. Among the actors is a feeling that "we [must] stick together here, we need to collaborate". There is a determination, which comes from the notion that Värmland is the "underdog" of the Swedish regions, to demonstrate that the region is not a peripheral one, and that it can become a global hub for biobased innovation.

Crucially, formal institutional proximity provides a robust foundation for collaboration. Innovation partners operate in an institutional context that provides strong, continual support for the transition from across the political spectrum, and across the geographical/administrative scales. A smart-specialisation strategy centred on the forest-bioeconomy; and the surety provided by longevity of the VINNOVA funding (valid for ten years) and of other funding agreements (such as the one between Region Värmland and Karlstad University, and between Sting Bioeconomy and startups creating biobased products/processes) for biobased innovation, have provided clarity of purpose, and conviction to undertake complex, long-term innovation projects that have no guarantee of succeeding (Dahlström, 2013, Kempton, 2015, Andersson & Grundel, 2021; Interviews).

4.4.2 Cognitive proximity

The "Värmland approach" to innovation-collaboration involves bringing together different competencies, knowledge-bases, technologies (Interviews). Cognitive distance does cause issues with communication, and knowledge-exchange. Actors sometimes have to strike a balance between making partners understand, and protecting intellectual property. Ensuring comprehension takes time, and in some cases, mediators (such as RISE, paper province, Karlstad University) have had to play the role of translators. In spite of these issues, we gleaned from our interviews that a certain level of cognitive distance is viewed favourably by cluster members. Organisations that have been involved in green-innovation share the view that innovation "happens when you mix new capabilities, when you mix things you have not mixed before"; however, there needs to be a "common [cognitive] denominator".

As stated in sub-section 4.1, that denominator is innovating with certain types of forest-biomass, and with waste-streams. This causes partnerships involving varying degrees of cognitive distance. For instance, in a project to create bioplastics and biohydrogen from wastewater, we found that four P&P firms had collaborated with scientists from three different types of universities, and a biotechnology SME (packagingeurope.com, 2019; Interviews). Some of these partners also collaborated with a fish-farm to develop fish-feed from wastewater. In a project that aimed to create biochar from waste, P&P firms collaborated with a bioenergy company, the Swedish Forest Agency, Karlstad University, a nursery, and a biofuel SME (Khafagi, 2021; Interviews). In another project, in order to create bio-absorbents from their waste-streams, a P&P firm collaborated with a startup that brought in valorising processes that are new to the firm (pulpapernews.com, 2021; Interviews). While it was eventually abortive, there was also a project driven by several large P&P firms, to establish a biorefinery to create methanol or ethanol from forest biomass (Jolly et al., 2020; Interviews).

Regional actors have established six testbeds that serve as collaboration platforms, which are meant to engender forest-biomass based innovations across sectors (paperprovince.com, 2021; Interviews). Consequently, the beds bring together actors with different amounts of cognitive (and institutional) distance, as long as these partners collaborate for innovation with the technologies each testbed is meant for; such as surface treatment technologies for coated paper and board, wood-tissue technologies, processes for valorising biomass, development of packaging materials, and 3D-printing with cellulose (paperprovince, 2018, s3vanguardinitiative-smr.eu, 2022)

4.4.3 Social proximity

The foundation of the Värmland region's innovation system is the enduring collaboration between partners from the three helices. Stable, long-term social relationships and very little turnover within organisations such as (the paper province, region Värmland, Karlstad University, Kristinehamn Innovation Park etc.) have led to an innovation system that is "very much built on trust". The Värmland bioeconomy network, which is basically the paper province network, is small, relatively simple, and has much less employee turnover when compared to others in Sweden (such as the ICT network in Stockholm) (Interviews). Key individuals in the innovation support system have thus been working together for several years; and are quite easy to quickly get access to, when an actor requires resources or knowledge.

The paper province organisation sees trust as being central to getting companies to collaborate (with other companies, or with universities etc.), and so, invests heavily in working groups, and in open-innovation opportunities (Klitkou et al., 2020; Interviews). For instance, the cluster had an initiative where firms could "borrow a professor" from Karlstad

University, in order to help solve issues in their factories. The cluster started this scheme so that the smaller firms of the region could begin establishing a relationship with the university and obtain valuable expertise; something they were hesitant to do. We found that companies were more open to trust, and to sharing of information and resources when biobased-innovation projects are centered on common issues such as waste-valorization, and not on core products such as paper, or packaging. Evaluations by the paper province (and our interviews) show that companies that were once involved in such projects tend to want to be involved again, in the future.

While stable relationships do lead to partnerships being repeated often, there are also many instances of socially distant actors cooperating (and subsequently becoming socially proximate). One actor that enables such projects is the incubator Sting Bioeconomy, which connects (foreign) startups, new entrepreneurs to large, established companies, Universities etc. It is not, however, the only actor that offers closure. Kristinehamn Innovation Park, past employees, the testbeds, and the paper province have all acted as matchmakers for first-time partners (Jolly et al., 2020, Klitkou et al., 2020; Interviews). For instance, when an energy and waste-management company wanted to create biodegradable waste-bags, it approached the paper province, which then matched it with appropriate P&P companies. In another example, the Kristinehamn Innovation Park was able to match to match a startup from the UK, to key regional partners.

4.4.4 Organizational proximity

The institutional and cognitive distances that drive the paper province's innovation projects also present certain risks. Differences in internal-logics, values, and end-goals; and failure to learn from and understand each other can result in project failure.

Partners address this risk with a willingness to patiently learn, recalibrate, and iterate. The iterative process of arriving at outcomes that are acceptable to all the partners is founded on organizational distance. Collaboration for green-innovation in the paper province is generally of an open, informal, and flexible nature. Flexibility extends to funding arrangements as well. For instance, Region Värmland's agreement to fund paper province's innovation-support activities comes with considerable latitude. Within projects, larger companies are often open to contributing some time, resources without payment, so that smaller partners can receive more of the public project-funding. Sting Bioeconomy's contracts with the startups it supports (financially and/or with closure) offer the firms the option of annulling the contract after 11 months, if they feel they are not receiving the necessary support. The degree of flexibility, informality is higher when the partners share social relations (Interviews).

While projects are always guided by formal agreements (that (broadly) define problems to be solved/objectives, the problem-owners, role-definitions etc.), they involve multiple (unplanned) informal, democratic discussions that cause learning and mutual understanding, remove points of friction, convergence of goals and expectations, and determination of succeeding steps and work-packages.

Our interviewees admitted these open debates "can be sensitive, can be difficult, [and] can be tricky", retard progress, and can result in timelines being missed. While they opined that hierarchical relationships would engender more efficient project execution, there is also awareness of the importance of organizational distance, to creating disruptive innovation. Organisations realise that the green-innovation process is inherently non-linear, and that they need to adapt, to close the institutional distance, so that chances of project-success increase. This is why they see the need to "evaluate regularly and see if we are going in the right direction". In large projects, there will be a "steering group" that is composed of the problem owners (e.g. P&P mills wanting to valorise waste streams), and mediating actors that are socially equidistant from all the partners (such as the paper province, RISE etc.). Mediators facilitate the formal process of setting overall goals, and coordinate the interim informal evaluations; while the steering group ensures that the partners do not lose track of the overall objectives, defines roles to be played by each actor, and clearly communicates to the partners, expected outcomes.

4.4.5 Geographic proximity

When the paper province organisation was created, there was an explicit aim of physically locating it such that cluster members could be reached in an hour by car; so that physical meetings could be quickly, easily held. The paper province views the spatial clustering of companies, competencies, and capabilities as central to the bioeconomy-transition. Proximate availability of the required capabilities, resources, and support has made the cluster an attractive location for foreign biobased startups, companies to relocate to.

The social proximity that is the "backbone" of the regional innovation system is facilitated by geographical proximity. Physical proximity allows for frequent (unplanned, informal) in-person meetings, which breeds familiarity and understanding, social relations, and eventually, more trust. While there is an appreciation among actors, for the advantages presented by geographical proximity, not all the projects we analysed enjoyed these benefits; and yet, they succeeded. We gleaned that physical proximity is not a key factor in every partnering-decision; as long as partners are able to converge around the same goals and expectations, and gradually close the initial cognitive distance. The COVID-19 pandemic forced most meetings to go virtual, and there are now plans from some actors, to move more meetings into the virtual space. This may not become a dominant trend, as the cluster members operate in a traditional industry where most of the innovation is done on the factory-floor.

4.5 DISCUSSION

Clusters are no more just tools to achieve competitiveness, profit and employment. They are transforming into tools that regions, nations use to achieve more sustainable economies that grow in a decoupled fashion. The expectation from green-clusters is that geographical proximity will facilitate the exchange of tacit knowledge, knowledge spillovers that raise chances of green-innovation. However, research has demonstrated that spatial nearness is neither a necessary nor sufficient condition to engender green-innovation. In other words, we need more information on how non-spatial proximities influence collaboration for green-innovation within clusters.

The question we attempted to answer was - how do the different dimensions of proximity shape innovation collaborations for cluster-greening? While studies such as Grillitsch & Sotarauta (2018), Jolly et al. (2020) explain the role of agency in driving greening, they do not sufficiently explain how the collaborations, which beget the innovations necessary for cluster-greening, are formed and modified. Following Kamath et al. (2022a) and Kamath et al. (2022b), we also view clusters as complex-adaptive systems. However, unlike these studies, we focus on meso-level; the level between macro and micro, where actor-collaborations are established or altered. To answer our research question, we investigated how proximity dimensions, as defined by Boschma (2005), shape innovation-collaborations in a cluster that is green-restructuring. The cluster in question is the highly innovative Paper Province, which has been successfully restructuring towards more circular, more sustainable operations since 2012.

Through this study, we advance the still nascent practice of analysing the effects of proximity dimensions on collaborations looking to create and scale green-innovation, and of empirically investigating (meso-level) processes that drive greening of clusters. Below, we discuss the results of our investigation, and present some recommendations for designing policy to instigate cluster transitions.

4.5.1 Effects of proximity, proximity-interactions in the Paper Province's green-restructuring

From the results, we can infer that the proximity dimensions in this case were not independent of each other. Decisions regarding green-innovation collaboration in the cluster were influenced by the interactions of the different dimensions. Here, we synthesize these interactions, and depict them in Figure 4.4 below.

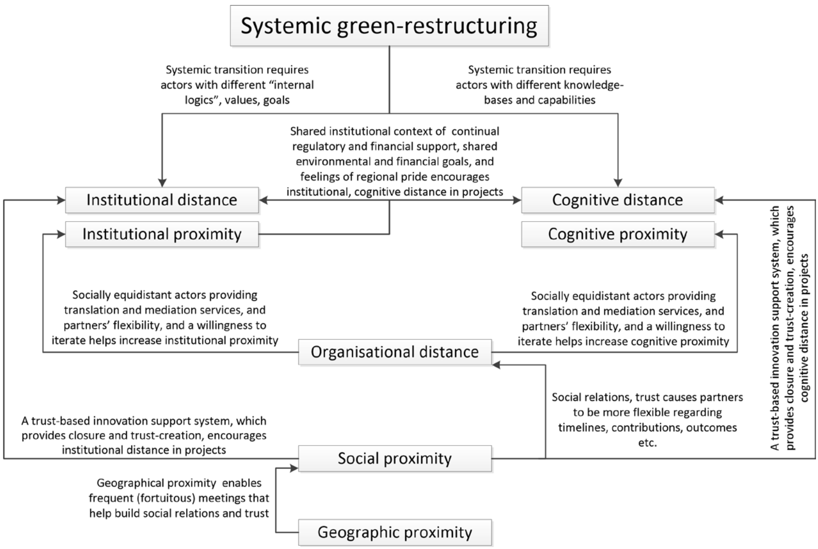

Figure 4.4: Interactions between proximity dimensions in the case of the paper province

The genesis of the dimensions' interactions is the objective of the paper province and its partners; which is systemic green-restructuring of the cluster. The paper province and its consortium partners have largely succeeded in achieving this goal. This success has been driven by multiple (radical) green-innovations ensuing from projects involving institutionally and cognitively different partners.

As we explain below, institutional proximity and social proximity provide the foundation for cluster members deciding to engage in, and support, sustainable-innovation projects with partners that are initially institutionally, and cognitively distant.

The shared institutional context of supportive regulation and public funding for green-innovation, regional patriotism, and a shared desire for profit and environmental sustainability encourages initially distant actors to come together, to undertake complex long-term innovation projects (that do not guarantee financial or sustainability rewards), and to work through differences. What also motivates collaboration among diverse actors, is a trust-based innovation support system that provides closure and mediation; thus generating social proximity, and increasing partners' willingness to patiently work to close cognitive and institutional distances.

Partners are able to successfully navigate the uncertainties presented by institutional, cognitive differences by being organizationally distant. Organisations display an awareness of the difficulties, inefficiencies, and risks partner-heterogeneity presents; however, they are also conscious of the need for diversity, to produce novelty. Partners are thus, willing to be patient, flexible with contributions, agreements, and timelines. Socially equidistant actors provide translation and mediation, and ensure that the core objectives are achieved, even as the project goes through multiple iterations. The organizational distance in projects is higher when there is social proximity between partners. Finally, trust and social proximity is enabled by geographical proximity. Physical nearness makes it easier to find competent partners, and facilitates frequent (fortuitous) meetings that help build social relations.

4.5.2 Proximity effects – innovation vs green-innovation

Moving away from past studies that analysed the dynamics of collaborative innovation in clusters, we investigated the dynamics for innovation-collaborations that not just results in new profit and competitiveness, but also greener products and processes, and hence, a greener cluster. From this analysis, we observed that there are similarities between how proximity dimensions influence collaboration for conventional innovation (i.e innovation that aims for just profits) and collaboration for green-innovation. Like in the case of conventional innovation, geographical proximity enabled frequent (un)planned meetings for knowledge-exchange, and rapid, easy identification of partners for green-innovation; green-innovation projects benefitted from organizational distance (loosely coupled, flexible alliances); cognitive distance helped in the creation of radical green-innovation; social proximity (shared past experiences and trust) facilitated more open sharing of knowledge and resources; and finally, institutional proximity (shared regulatory context, shared values and goals) provide a foundation of trust, on which organisations can cooperate.

While the overall effects of the proximity dimensions seemed similar, there were some subtle, but important, differences in the variables of institutional proximity. Unlike in the case of conventional innovation, sharing the value of sustainability was decisive in the organisation of projects (regional pride was also pivotal but we understand this was probably a case-specific factor). This congregation around sustainability was crucial because these projects involved very complex partnerships involving very different organisations (like what was observed in the review of green-innovations by Petruzzelli et al. (2011), Cuerva et al. (2014), and Díaz-García et al. (2015)).

4.5.3 Implications for cluster-greening policies

From our findings, we have the following recommendations regarding the design of policies for clusters' green-restructuring:

- **Encourage institutional, cognitive diversity, but in an institutionally proximate context**
  Policymakers should encourage diversity in innovation-projects; for instance, by making public funding contingent on having heterogeneous partners. However, policy must also ameliorate the inherent risks, uncertainties of such projects by setting clear goals, instituting long-term, continual support for disruptive innovation, and where applicable, by tapping into feelings of regional pride and determination to compete.
- **Support projects around common cognitive denominators**
  Policymakers should support green-innovation projects that address issues or technologies that are of interest to all cluster members. Firms maybe not be so keen to innovate around core product/process technologies; but may be more willing to invest resources into projects to develop technologies that aim to valorise waste, for instance. Policymakers can combine with other actors in the triple-helix to establish testbeds around some key technologies with transversal interests.
- **Minimise turnover in the innovation system**
  Policymakers should identify and grant the appropriate incentives, rewards, so as to minimise churn in the cluster's, region's innovation support system. Low employee turnover results in long-term social relations, quicker access to support, and a trust-based innovation system that is more durable than one based on economic rationales.
- **Provide closure, translation, mediation**
  "Match-makers" that are socially equidistant from other actors play a decisive role - that of connecting partners, and building collaborations. Once collaborations are formed, partners must be provided with translation and mediation services that ensure cognitive, insti-

tutional differences are reconciled, and that core objectives are met. Actors such as the cluster organisation, the regional government, or custom-built platforms can provide these services.

5 DISCUSSION

This thesis was conducted with the objective of advancing understanding of how and why clusters undergo green-restructuring. This objective was fulfilled by addressing the question, *how do the dynamics at the levels of agency, actor-collaboration, and structures, and the interactions between these dynamics, shape the green-restructuring of clusters?*

The research question was answered through the following sub-research questions and studies:

1. How does the dynamic interaction of agency, structures, and supra-regional phenomena shape the green-restructuring of a cluster?
2. What policy instruments are most effective in causing green-growth of clusters in a peripheral region?
3. How do the different dimensions of proximity shape innovation collaborations for cluster-greening

5.1 Theoretical and methodological contributions of the thesis

To answer the first sub-research question, I invented a cluster-evolution framework that treats cluster members as part of three overlapping complex adaptive systems: 1) the cluster, 2) the Regional Innovation System, and 3) the Sectoral System of Innovation. The framework was then applied to study the greening of the Basque pulp-and-paper cluster, over four phases between 1986 and 2019. This study revealed the framework's advantages over extant cluster-evolution models:

- Explain the multiscalarity of cluster-restructuring: Unlike extant frameworks, this framework not only facilitates analysis of how multiscalar processes affect the region/place-dependency, but also how they affect the industry/path-dependency; and how the resultant dynamics affect the greening process.

- Explain the distinct and combined influence of regional and industrial influences: Existing models emphasize the influence of industrial structures on cluster-evolution. Through the case-study, the framework showed how regional and industrial structures separately, or in combination, influenced actor agency and greening.
- Account for multiple forms of agency: This new framework allowed analysis of how multiple forms of agency (technological-entrepreneurship, institutional-entrepreneurship, and place-leadership) from various actors combined to shape the cluster-greening process.
- Explain different types of restructuring: Unlike traditional cluster-evolution models, this new framework does not treat clusters as merely tools for economic growth. Consequently, it was used to study the greening of a cluster. With appropriate changes to, or further development of, the agency and structure variables, the framework could possibly be used to analyse different types of restructuring.
- Explain different restructuring-paths: Finally, in contrast to life-cycle models, this model is a non-deterministic model. Consequently, it allows the examination of cluster-trajectories beyond the standard path of emergence to decline.

Thanks to the above advantages, the study has contributed to reconciling ongoing debates in EEG, regarding the multiscalarity of cluster-evolution, the role of agency, the role of regional structures, and also regarding the differences and similarities between green-restructuring and economic restructuring of clusters. This study also made a methodological contribution. Departing from previous studies on green-restructuring (such as Grillitsch & Hansen (2019), Trippl et al. (2020)) that have a theoretical or modelling focus, the study used a case-study of a cluster's green-restructuring; which unearthed rich empirical data that delineates clearly, how agency and structures (and supra-regional phenomena) interacted to caste the cluster's greening.

The second sub-research question was answered by creating an agent-based model that simulated a cluster's greening, as shaped by different policy instruments. Like the first study, this study also treated clusters as complex adaptive systems, and cluster-members' green-innovation behaviour as being guided by the structures of the regional innovation system. The main theoretical contribution of this study is in giving us a more nuanced understanding of the effectiveness of, and trade-offs involved in, different types of policy instruments for cluster-greening. This helped address the lack of sufficient EEG research on policies that can drive the green-restructuring of clusters (Sjøtun & Njøs, 2019). The study also advanced understanding of the complexities of achieving decoupled cluster-growth in peripheral regions; which is the type of regional innovation system that EEG has least researched (Eder, 2019). With the novel ABM, the study also contributed to the emerging practice of modelling green-transitions (Holtz et al., 2015, Köhler et al., 2019). Unlike preceding ABMs that have been used to study cluster-evolution, this one does not model for innovation that merely leads to richer cluster-members; rather, we model for innovation that makes the members (and the cluster) not only richer, but also greener.

The third sub-research question was answered by conducting a case-study of green-innovation collaborations in the Paper Province cluster in the Värmland Region of Sweden. There is a lack of research on factors that shape the organisation of collaborations for green-innovations (Dangelico & Pontrandolfo, 2015, Zhao et al., 2018). A few studies have attempted to close this knowledge gap by exploring how proximity-dimensions moulded green-innovation networks in niches, nation-sized networks, or national industries. This study, however, is the first instance of an investigation into how proximity dimensions (as defined by Boschma(2005)) shape the formation of cluster-based networks that aim to create innovations that lead to not just profits, but also greater sustainability performance. This main theoretical contribution of the study is in demonstrating the similarities, and subtle differences, between how proximity affects collaboration for pure for-profit innovation, and how it affects collaboration for green-innovation.

5.2 How clusters green-restructure

With the sub-research questions answered in the preceding three chapters, we can now discuss the main research question.

The first and second studies showed how cluster-greening emerges from dynamics at the level of actor-agency, or the micro-level. Cluster-members' deciding to engage in (collaborative) green-innovation is the "seed" from which the process of cluster-greening materialises. These studies also demonstrated how these decisions are not made in a vacuum, but are shaped by processes and events at the level of structures, or the macro-level. The structures that influence green-innovation behaviour within the cluster can be from the region or higher geographic levels, or from the industry. Structural dynamics at the national, continental, global levels will act on the agency of cluster members either through their effects on the regional or industrial structures, or directly.

To create green-innovation, actors engage in technological entrepreneurship by themselves, or as we shown in studies one and three, in collaboration with other actors. As evidenced in the third study, the dynamics at the level of actor-collaborations, or the meso-level, is shaped by the five proximity dimensions of cognitive, institutional, social, organisational, and geographic proximity. For the green-restructuring of the cluster-CAS, green-innovation collaborations at the meso-level must involve institutionally and cognitively different partners. This diversity brings along with it, risk of project-failure. This risk and uncertainty is ameliorated by 1) place-leaders that provide translation and mediation services, and ensure that the core objectives are achieved, even as the project goes through multiple iterations; and 2) (regional/national) structures that set clear goals, and provide long-term, continual support for disruptive green-innovation. Supportive policy-structures are not always present in all contexts, which is why institutional entrepreneurs, who can bring in new helpful institutions, are pivotal to the success of green-innovations. However, as observed in study two, institutional entrepreneurs may have to make some tough decisions regarding the inherent trade-offs involved in policies to support green-innovation.

Studies one and three showed us that the green-innovations that emanate from these collaborations may either be incremental innovations (such as retrofitted processes), in which case the cluster may gradually green through path-modernisation; or they may be disruptive innovations (such as new types of biofuels) that require technological-entrepreneurship to be coupled with place-leadership and institutional entrepreneurship, in which case the cluster may green through path-creation. In the case of the latter, the innovations may end up reshaping the structures of the region and industry. New structures may then encourage further green-innovation behaviour from the members of the cluster; which then leads to further restructuring of the cluster, and also maybe of the region and industry (which is what was witnessed in study three).

5.3 LESSONS REGARDING CLUSTER-GREENING

Here, I synthesize the findings of the studies that constitute this thesis.

5.3.1 Green-restructuring and economic-restructuring seem to be generally similar, but also have differences

Discovering the fundamental differences and similarities between "normal" economic-restructuring, and the green-restructuring of clusters is crucial because there is still some debate regarding the effectiveness of green-growth and green-clusters, in solving the issues presented by climate change (Hickel & Kallis, 2020, Wilde & Hermans, 2021).

The first study revealed that one possible differentiator is the presence of deliberate destabilisation/destruction of unsustainable systemic structures in greening paths. From the study, I discovered this destabilisation/

destruction could be through, for instance, command-and-control regulation that pushes cluster members to adopt certain green-technologies; or through industry standards that cut-off certain cluster members from global supply-networks. On the other hand, the third study found there were considerable similarities between how proximity-dimensions affect conventional innovation projects and how they affect projects meant to produce innovations for green-restructuring; with a subtle difference only in institutional proximity: green-innovation partners must share the value of sustainability because these projects involve complex collaborations between very different organisations.

The second study added to the debate on the effectiveness of green-clusters, in facilitating green-growth. The results revealed how even green-clusters working with sustainable technologies will possibly cause some pollution; which makes absolutely decoupled growth of clusters quite difficult. This study thus calls for greater research on how to balance clusters' economic-restructuring (which brings innovation and profits), and clusters' greening; and on tackling the complex process of designing policies for the green-growth of clusters.

5.3.2 Institutional-entrepreneurs and place-leaders are pivotal to cluster-greening

The results of both the first and third studies show how crucial institutional-entrepreneurs and place-leaders are, to the green-restructuring of clusters.

The first study demonstrated how green-tech innovation may fail in the absence of these actors. Furthermore, institutional-entrepreneurs and place-leaders are also critical because they can shape both supra-regional and industrial structures, and thus possibly lead the cluster along more favourable greening-paths. Similarly, the third study demonstrated the importance of these actors, in helping ameliorate the uncertainties of the innovation projects (owing to institutional, cognitive differences between partners). These actors provide the decisive service of connecting innovation partners; provide translation and mediation, so that there is greater institutional and cognitive proximity among partners; and ensure a supportive institutional context that encourages creation of disruptive innovation.

In other words, these institutional-entrepreneurs and place-leaders fulfil the responsibilities of intermediaries (Kivimaa, 2014), which are actors build the institutional support at various administrative/geographic levels, and also can help cause bottom-up changes in industrial structures.

5.3.3 Greening is a multiscalar process, but place-based idiosyncracies can be highly influential

The first study of this thesis provided evidence of the multiscalar nature of the cluster-greening process. Phenomena at the national, continental and global scale can act either directly on agency and greening, or through their effects on industrial and/or regional structures.

However, there is also evidence from this thesis, of the (disproportionate) influence of place-based idiosyncrasies. In the first study, we saw how the Basque cluster predominantly greened through incremental innovation and path-modernisation, even though the Basque region offered very well-suited conditions for greening through radical innovation and path-creation. This deviation from the expected greening-path was the result of a local idiosyncrasy - limited agency from the relatively smaller economies-of-scale of the cluster's firms.

5.4 SYNTHESIZED POLICY-RECOMMENDATIONS

Here, I provide recommendations for designing policies to support green-restructuring of clusters, based on the main findings of the thesis.

1. **For durable green-growth, establish place-leaders, institutional-entrepreneurs**
   The evidence uncovered through this thesis calls for policymakers to relinquish their traditional techno-economic focus, and encourage the emergence of place-leaders and institutional-entrepreneurs. Regional governments can establish a cluster organisation, innovation parks, or custom-built platforms/testbeds to play these roles; or the regional government can itself play this role.

   Place-leaders provide closure, the act of connecting cognitively, institutionally different organisations together for green-innovation projects. They also provide mediation, and translation, so that the initial cognitive, institutional differences are reconciled. Thirdly, place-leaders ensure that there is clarity regarding expected contributions, timelines and outcomes, and that the core objectives are met, as the project rolls through multiple iterations.

   Disruption of unsustainable cluster CAS requires systemic change, which means green-innovation projects should have cognitive, institutional diversity. However, such projects inherently possess high-levels of uncertainty and risk, which can only be ameliorated by institutional entrepreneurship that set clear targets, provides long-term, continual regulatory and fiscal support for disruptive green-innovation.

   Without place-leaders and institutional-entrepreneurs that can modify supra-regional and industrial structures when required, green-tech innovation may fail to cause clusters' greening.

2. **Policies must be informed by place-based idiosyncrasies**
   Local peculiarities can be powerful determinants of clusters' greening paths. Policies must factor in characteristics of cluster firms (e.g. proclivity to collaborate, economies of scale, are they pioneers or followers); and must make use of place-specific institutions, such as regional pride, which can be strong motivators to form innovation collaborations.

   In looking to design policies to encourage green-innovation, policymakers must look to support projects around challenges or technologies that all or most cluster members have an interest in. Members maybe more willing to collaborate for innovation around transversal issues (like circular loops), than for innovating with core products/processes (details of which they would want to keep secret).

   What can aid policy-design that incorporates such place-based factors is low turnover in the region's innovation support system. Low churn results in long-term social relations, which ensures quicker, better access to cluster-specific information for policymakers. Consequently, policymakers should identify and grant the appropriate incentives, rewards, so as to minimise churn.

3. **Interim policy evaluation is very important**
   Clusters' green-growth, and designing effective policies to support this growth, are both complex processes. As we saw in study two, possible futures for a cluster looking to green, are multiple; they exist on a landscape. Certain policies will take clusters along inefficient greening-paths, which may eventually become ineffective paths. It is therefore crucial to hold interim policy-evaluations. Without these evaluations that may reveal possible policy-ineffectiveness, clusters may get locked-into paths that take it towards sub-optimal levels of decoupling.

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APPENDIX

Table A1: The interviewees, and documents from which data was collected for study one

No	Organisation, designation	Date
1	Cluster organisation, Director	December 2018
2	Pulp and paper company, CEO Cluster organisation, Former Director	January 2019
3	Pulp and paper company, General Manager	January 2019
4	Agricultural Research and Development Agency, General manager	January 2019
5	Pulp company, CEO	January 2019
6	Pulp and paper company, CEO Cluster organisation, Former Director	January 2019
7	Regional cluster development agency, Divisional Head	January 2019
8	Pulp and paper company, Plant Manager	February 2019
9	Cluster organisation, Former Director	February 2019
10	Regional Environmental Management Agency, Coordinator	February 2019
11	Climate consultancy, Managing Director	February 2019
12	Paper-machinery company, Senior Vice President	July 2019
No.	**Document analysed**	
1	Journal Articles: Ahedo (2004), Crampes & Fabra (2005), Elola et al. (2012), Minett (2006), Querejeta & Navarro (2003), Valdaliso et al. (2008, 2012, 2016)	-
2	Reports from the Cluster Organisation, Clusterpapel (2004, 2005, 2011, 2015, 2018a, 2018b, 2019a, 2019b)	-
3	News reports: Angulo (2000), Aranguren (2017), El Diario Vasco (2008, 2014), Innobasque (2019), Lezana (2009), Murcia (2018), Papel Aralar (2015)	-
4	Reports from regional agencies: Ereño & Sancho (2010), Euskadi.eus (2018), Gobierno Vasco (2005), IHOBE (2000, 2017), Ministry of the Environment and Territorial Policy (2014),	-

Table A2: Possible values of variables, and the values at time of initialisation

Variable	Possible values
Agents' own	
Financial capital	Model sets to any random value between 50 and 100 for large firms. Model sets to any random value between 10 and 50 for small or medium firms
Knowledge capital	Model sets to 25 if pollution greater than 50. Model sets to some random value between 25 and 75 if pollution is lower than 50
Reputational capital	Model sets to any random value between 50 and 100 for large firms. Model sets to any random value between 10 and 50 for small or medium firms
Pollution-level	Model sets to any random value under 100
Radical project experience	Model sets to zero at initialisation
Incremental project experience	Model sets to zero at initialisation
Colour	Green for agents with pollution-levels lower than 25. Red for agents with pollution higher than 25
Size	Model sets size at 5 % of financial capital
Shape	Extant agents are circular in shape, Spin-offs are triangular, Entrants are pentagonal
Non-agent variables	
Probability of collaboration	Any value between 1 % and 27 %. For our experiments, we set initial value as 14 % (roughly midpoint of the range)
Probability of radicalness	Any value between 1 % and 55 %. For our experiments, we set initial value as 28 % (roughly midpoint of the range)
Probability of innovating	Model sets Initial value at 2.2 %
Innovation potential	Initial value is 0.01
Cluster-size	Any value between 30 and 100. For our experiments, We set initial value as 50
Percentage of large firms	Any value between 0 % and 5 %. For our experiments, we set initial value as 3 %
Decay rate	Can be any value between 0 and 1 %. For our experiments, we set a rate of 0.1 %

Continued on next page

Variable	Possible values
Maximum possible project size	For our experiments, projects have between 2 and 6 members
Number of projects in one tick	Can be any value between 5 and 8. For our experiments, we use a value 8
Grants for innovation projects	For our experiments , we set a range of between 0 % and 25 %
Fines for polluters	For our experiments , we set a range of between 0 % and 25 %
Incentives for entrants	For our experiments , we set a range of between 0 % and 25 %

Table A3: How capital assets and pollution decrease/increase with time, or increase/decrease with successful green-innovation

Variable	Decrement (each time step)	Rewards (from innovation)
Financial capital	Decreases at a rate between 0 and 1 % (as set by user). We use a rate of 0.1 %	Increases by 25 % with incremental innovation. Doubles with radical innovation.
Knowledge capital	Decreases at a rate between 0 and 1 % (as set by user). We use a rate of 0.1 %	Increases by 25 % with incremental innovation. Doubles with radical innovation.
Reputational capital	Decreases at a rate between 0 and 1 % (as set by user). We use a rate of 0.1 %	Increases by 25 % with incremental innovation. Doubles with radical innovation.
Pollution-level	Increases at a rate between 0 and 1 % (as set by user). We use a rate of 0.1 %	Decreases by 25 % with incremental innovation. Halves with radical innovation.

Table A4: The experiments conducted in the model, by introducing different instruments

Experiments	Description	Instrument settings
Imposing fines on polluting firms	Fines refer to financial capital that is instantly reduced from an agent's stock when its pollution-level is equal to, or crosses, 33.	Fine levels range from 0% to 25% of an agent's financial capital.
Introducing grants for innovation projects	Grants refer to financial capital that is given to a qualifying project.	Grant levels range from 0% to 25% of the financial capital that has already been committed to the project
Introducing incentives for attracting entrants	Incentives refer to financial capital that is bestowed to the entrant, immediately upon entrance.	Incentives range from 0 % to 25% of the financial capital held by the entrant
Introducing instrument-mix of incentives and fines	Every time-step, some entrants may enter the cluster and receive incentives, and some agents may get fined.	Incentive levels range from 0 % to 25% of the financial capital that has already been committed to the project. Fine levels range from 0 % to 25% of each agent's financial capital.

Table A5: The interviewees, and documents from which data was collected for study three

No.	Organisation, designation	Date
1	Biobased startup, CEO	May 2022
2	RISE, Major projects manager	May 2022
3	RISE, Senior researcher	May 2022
4	Pulp & paper mill, CEO	May 2022
5	Karlstad University, Associate professor	May 2022
6	Paper Province, Deputy CEO	June 2022
7	Energy company, Business development manager	June 2022
8	Region Värmland, Deputy Area Manager	September 2022
9	Karlstad University, Professor	September 2022
10	Biobased startup, COO	September 2022
11	Kristinehamn municipality, Innovation manager	September 2022
12	Sting Bioeconomy, Managing director	October 2022

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