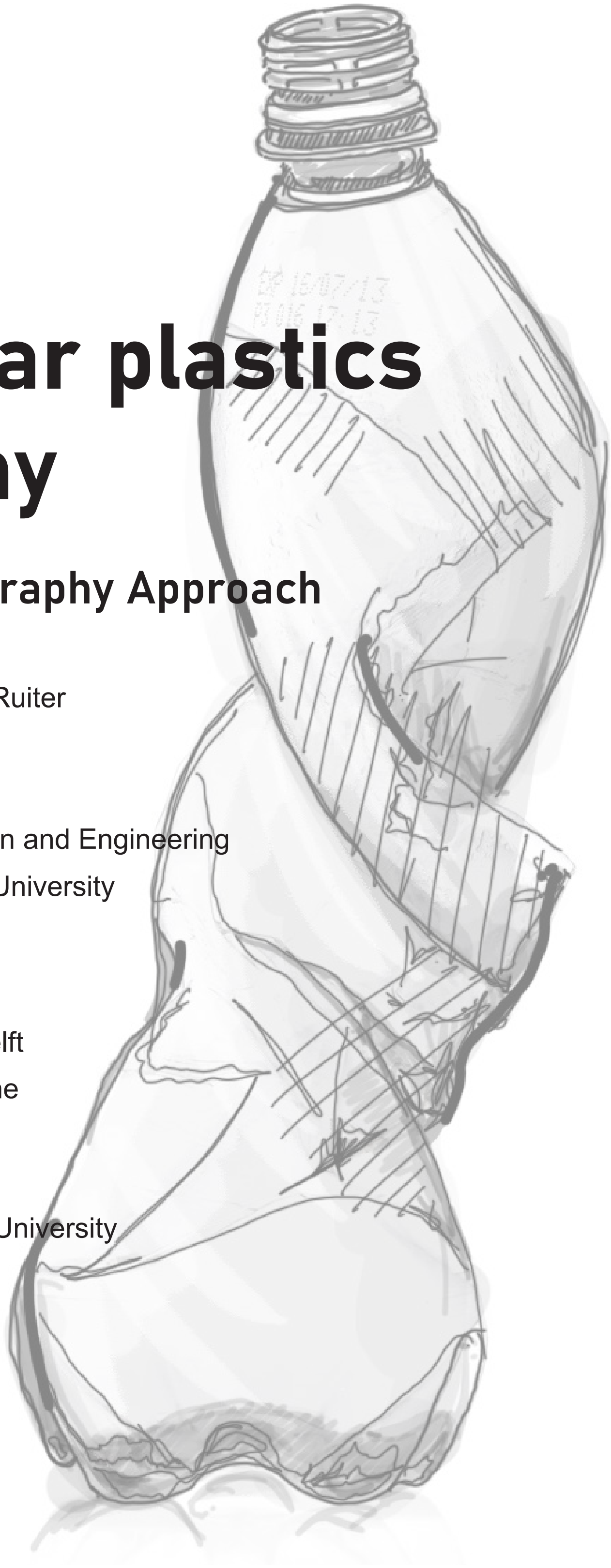

Towards a circular plastics economy

A Relational Economic Geography Approach

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Preface

During a course abroad, I was confronted for the first time with the consequences of inadequate plastic waste management. Beaches, natural parks and cities were visibly polluted, and in conversations with residents, I realised how deeply this affects people's everyday lives. It made me aware that, in the Netherlands, the environmental effects of our consumption remain largely invisible; waste disappears from view, and the responsibility often seems to follow.

Against this background, current developments in the European recycling sector are alarming. If the loss of recycling capacity continues, European waste is likely to be exported elsewhere, shifting the burden rather than solving it. Reading newspaper articles on this topic, I noticed that responsibility is frequently assigned to policymakers or foreign producers of fossil plastics, rather than to the structural conditions that make recycling economically fragile. It raised the question of why innovative solutions struggle to survive in Europe, and what is required to change that.

This ultimately shaped my interest during the search for an internship topic. In one conversation, someone mentioned that developing a viable business model for plastics was nearly impossible. That remark stayed with me. Motivated, perhaps somewhat naively, I wondered whether it might be possible to identify the missing conditions. Instead of applying for the internship, I decided to return to my Master's programme and dedicate my thesis to this question.

I first needed to meander for a good few months, reading extensively about innovation, firm ecosystems, competitive advantage and business models. All were inspiring frameworks, yet each seemed to capture only a fragment of the wider picture I was trying to understand. After a discussion with one of my supervisors, I realised that the thesis was not developing in the direction I had envisioned from the start. I decided to take a leap into the unknown and look for a new supervisor. I am grateful that, almost more by coincidence than intention, I came across my current supervisor, whose feedback not only kept me going, but also provided the missing piece I had been searching for: the theoretical framework of relational economic geography, which became the foundation of this thesis. I am equally grateful to my second supervisor for supporting me throughout and standing by me in the decisions I made along the way.

Executive Summary

Plastic waste management remains a critical bottleneck in the transition to a circular plastics economy, as current recycling technologies cannot match the scale and material quality needed to displace virgin plastics. Recent bankruptcies among European pioneering recycling firms show that technological invention alone does not guarantee market acceptance. In this thesis, I have examined the conditions needed for the system surrounding the pioneering recycling firms, referred to as innovation ecosystems, that enable the commercialisation of Dutch inventions in plastic waste management.

Methodologically, the study operationalises relational economic geography as a framework for analysing which conditions shape commercialisation across multiple scales. In doing so, a multi-scalar contextual analysis is combined with patent mapping of Y02W30-classified technologies between 2000 and 2025.

The results show that innovation activity in this domain is concentrated in (petro-)chemical firms rather than pure recyclers, and that patent activity is dominated by a small number of large applicants located in the Antwerp–Rotterdam–Rhine–Ruhr (ARRRA) meta-cluster. Furthermore, the findings demonstrate that the failure of innovative firms in plastic waste management in the Netherlands stems from an accumulation of several constraints, at its basis, high energy costs, the lack of offsets, and the use of non-targeted taxes and tax exemptions. As well as a lack of steering in policies and industrial policy. Combined with persistent labour shortages in STEM, long and complex food-approval permit applications.

For these inventions to commercialise, cluster embeddedness and regional specialisation, in addition to economies of scale, infrastructural co-location and vertical integration are important pillars. Co-location facilitates strategic coupling between firms, infrastructure and feedstock flows, enabling resource efficiency and reduced energy costs; conditions that are necessary to realise cost parity with virgin plastics. In addition, alignment through licensing, joint ventures, and open-innovation networks is a critical mechanism for scaling these technologies.

In sum, commercialisation is not determined by the invention itself, but by the relational conditions embedded in specialised industrial chemical clusters. Without alignment of infrastructural, economic and institutional conditions, inventions are unlikely to mature beyond the demonstration stage, particularly in contexts lacking targeted industrial support, as currently observed in the Netherlands.

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Glossary

Term	*Definition*
ARRRA (meta-cluster)	Cross-border Antwerp–Rotterdam–Rhine–Ruhr industrial region organised around shared ports, pipelines, logistics and petrochemical assets.
Biobased	Materials or feedstocks derived partly or fully from biological resources rather than fossil fuels.
Drop-in biobased polymers	Biobased polymers that are chemically identical to conventional fossil-based polymers and can be processed through existing industrial systems.
Novel biobased polymers	Polymers produced from biobased feedstocks that have different chemical structures than conventional polymers and may require new processing or end-of-life systems.
CAPEX	Capital expenditure required for constructing industrial plants, equipment and large-scale assets.
Chemical industry	Industry producing basic and intermediate chemicals, polymers and materials.
Chemical recycling	Industrial processes that chemically convert plastic waste into intermediates, monomers or feedstocks for new chemical or polymer production.
Cluster	Spatial concentration of interconnected firms, infrastructure, institutions and resources.
Commercialisation	Transition of an invention from pilot or demonstration stage to market-scale production and adoption.
Company	Incorporated legal entity
Depolymerisation	Chemical process that converts polymers back into monomers or oligomers.
EU ETS	European Union Emissions Trading System that regulates CO2 emissions through tradable allowances.
Exit environment	How easily investors can leave a company again, for example by selling it.
Feedstock	Raw industrial input used in chemical production, including fossil, biobased or recycled materials.
Firm	More general term for any business enterprise
Fossil feedstock	Oil- or gas-derived industrial raw materials used to produce chemicals and plastics.
Hydrocarbons (oil-based)	Oil- or gas-derived compounds used as primary industrial feedstocks in petrochemical production.
Innovation	Successful commercial application of an invention that generates economic or societal value.
Invention	Novel technology, process or material developed through research or experimentation.
Intellectual property (IP)	Legal rights protecting ownership of intangible creations such as inventions and technical knowledge.
Internal R&D	Research and development conducted within a firm using internal facilities, personnel and resources.
Licensing	Contractual agreement allowing another party to use or commercialise a technology in exchange for payment or benefits.
Mechanical recycling	Industrial reprocessing of plastic waste into secondary materials without altering chemical structure.

Meta-cluster	Network of connected clusters operating across national borders.
Monomer	Basic chemical building block that forms polymers.
Naphtha	Oil-based liquid fraction used as a feedstock in petrochemical production.
OPEX	Operating expenditure associated with running industrial facilities, including energy, labour and maintenance.
Open innovation	Innovation model based on collaboration and knowledge sharing across organisational boundaries.
Patent	Legal protection granting exclusive rights to an invention for a limited period.
Petrochemical industry	Segment of the chemical industry based on oil- and gas-derived feedstocks and integrated large-scale processing.
Polymer	Material consisting of long chains of repeating molecular units (e.g., plastics).
Research and development (R&D)	Activities aimed at creating new knowledge, technologies or processes or improving existing ones.
Scale-up	Transition from laboratory or pilot stage to commercial-scale industrial production.
Steam cracker	High-temperature industrial facility that converts hydrocarbons into basic chemical building blocks such as ethylene.
Triple helix	Collaboration model involving government, industry and academia to support innovation.
Vertical integration	When different stages of the industrial value chain are controlled by the same company.
Verbund	Integrated chemical-site model in which materials, energy flows and infrastructure are shared across many processes.
Virgin plastics	Plastics produced from non-recycled feedstocks, whether fossil or biobased, used in their first life-cycle.

01. Introduction

Plastics, once considered one of the greatest findings in the millennium, have become one of the defining environmental challenges of the twenty-first century (MacLeod et al., 2021; Nayanathara Thathsarani Pilapitiya & Ratnayake, 2024). Since its invention, plastic usage has rapidly increased, becoming an indispensable part of our society. The largest market for plastics is packaging, accounting for 40 per cent of global plastic consumption (Fogt Jacobsen et al., 2022), a trend accelerated by a worldwide shift from reusable to single-use containers (Geyer et al., 2017). With the forecast of plastics usage quadrupling by 2050, rethinking a society without this material will, in the short term, be unlikely (European Commission, 2025).

The challenge of plastics is complex, due to their key role in the functioning of modern economies and their dependency across a wide range of industries (Lenort et al., 2019). Meanwhile, the current end-of-life management system still lacks an effective means of preventing plastic accumulation in our ecosystems, resulting in environmental harm (Fox, 2024). The persistence of plastics in our environment, reliance on fossil feedstocks, and the global market trade mean that plastic pollution is not just limited to visible waste streams but also extends to places beyond our initial imagination, such as the depths of the ocean and into the human brain (MacLeod et al., 2021; van der Gulden, 2025). To achieve a healthy and sustainable living environment, establishing a functioning and effective plastic recycling system is of vital importance. This, however, may not be as straightforward as it sounds, due to the complexity of the chemical structures in plastics (McNeeley & Liu, 2024).

The current waste management technologies still fall short in recycling plastics in a manner that results in degradation being non-existent or extremely limited (Macheca et al., 2024) . If the degradation were non-existent, this would ideally lead to recycled plastics having the same quality as their fossil-based counterparts. This may seem like an unreachable dream, but current innovation efforts suggest otherwise, showing it can be achieved (de Jong et al., 2025). On top of that, scaling waste management inventions into innovations is crucial for addressing the concerning accumulation of plastics in our living environment and for aligning environmental ambitions with industrial competitiveness (Croce et al., 2025).

Recent developments in the European and Dutch recycling sectors reveal a troubling trend, as European plastic recycling firms and those pioneering new closed-loop inventions face financial losses and, in several cases, even bankruptcy (Redactie Change Inc, 2024). The situation has reached a level of severity, with recent data confirming that by the end of 2025, Europe will have lost recycling facilities equivalent to almost one million tonnes of recycling capacity since 2023 (Furfari, 2025). The Netherlands, Germany, and the United Kingdom have been the most affected, with the Netherlands being the frontrunner, reporting nearly one-third of total closures over the three-year period (Furfari & Europe, 2025).

To guide policymakers in supporting these firms, it is helpful to know the context in which they are embedded (Lundvall, 2016). To grasp this context, it is essential to understand the type of companies they are, their challenges, value chain, and their strategic decisions, to name a few (Croce et al., 2025). That is, to successfully invent and commercialise inventions, innovations do not just depend on the inventors but also on the system they exist in, and thus also the geographical context; only 12.5 per cent of cleantech firms are core innovators, with the remaining 87.5 per cent being manufacturers, integrators, and, e.g., operators (Croce et al., 2025).

This has led to the following research question in my thesis:

Which conditions within innovation ecosystems enable the commercialisation of inventions in plastic waste management?

In addressing this research question, I am adopting a relational approach, known as relational economic geography, which explores how firms are connected and transact whilst accounting for the various contexts in which they are embedded. This theory, however, lacks a methodological grounding; my aim in addressing this research question is, for that reason, twofold. First, since relational economic geography is theory-based, I aim to ground the theories for a practical understanding of how to derive policies and guidance for regional development. This relates to the second objective: utilising economic relational geography to develop practical solutions and recommendations that support improved regional development, thereby creating the conditions necessary for the commercialisation of inventions in plastics in the Netherlands, and promoting a circular plastics economy in the country.

At the core of this research lies two phenomena: the primary phenomenon being '*the wave of bankruptcies among Dutch pioneering companies in the field of technological advancements in plastic waste management*', and secondly, 't*he uneven regional development of innovation in plastic waste management*' as a potential response to the systemic failure reflected in these bankruptcies.

02. Theoretical Framework

02.1. Relational Economic Geography

Relational economic geography examines how actors' social and spatial connections are linked to broader structures (class, patriarchy and the state) and processes of economic change across various geographical scales (Yeung, 2005). This means that, at its essence, economic geography is about explaining economic activities in actual places(Gong & Hassink, 2020). Understanding the context in which these economic activities take place is, therefore, an essential part of economic geography (Asheim, 2020). When aiming to understand the context in which economic activities occur, it is helpful to treat 'the context' as non-universal, as there are different kinds of context across various scales, depending on the researcher's aim or academic background (Gong & Hassink, 2020). For that reason, having a comprehension of what context entails for this research is an important aspect of economic geography (Asheim, 2020).

Gong & Hassink (2020) argue that context is not a passive setting but an actively changing and constructed one (pp. 1–2). Thus, contexts can be seen as objects and events related to social life, located within specific spatial and temporal settings. Furthermore, at the basis of understanding context lies the recognition that 'we' as humans cannot see the world as it really is. As Rorty argues (as cited in Barnes, 2024, p. 1542), if that were the case, it would presume that we can be outside the social bubble in which our knowledge is produced. Acknowledging this limitation in the aim to analyse multiple contexts is, for that reason, relevant.

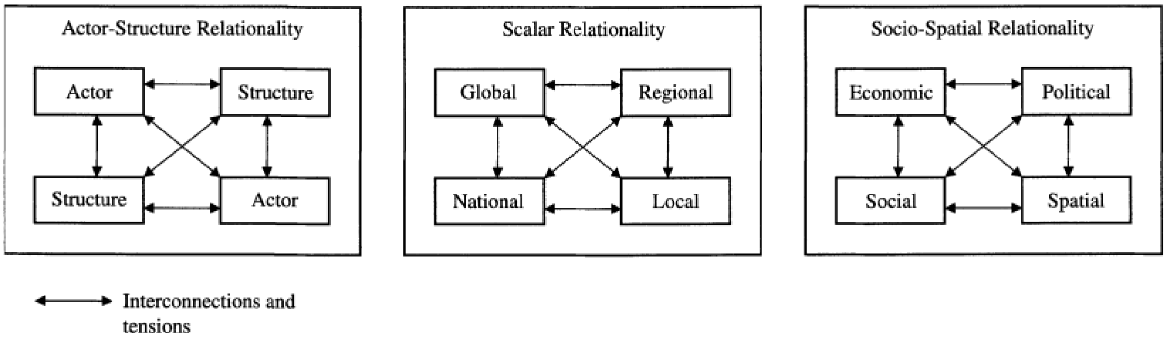
In addition to gaining an understanding of the multitude of contexts, relational economic geography focuses on the actors involved in economic decision-making, also referred to as economic agents (Bathelt & Gluckler, 2003). In this, the actors that constitute, for example, the firm are subjects whose identities, capabilities -in other words, the assets that enable them to act- are co-constituted by their relations with other actors (Boggs & Rantisi, 2003). Subsequently, in the analysis of economic agents, their relations with other agents and institutions, that is, the social structures and social relations in which they exist, lie at the core (Grabher, 1993). This aspect of relational economic geography creates a nuanced understanding of economic activity and its localised impacts (Bathelt & Glückler, 2003).

History is another crucial yet often overlooked factor in understanding regions and their economic activity (Paasi, 1991). Regions are complex manifestations of patterns, processes, and relations arising from the simultaneous interaction among different levels of social processes across various historical and geographical scales (Paasi, 1991). This interconnectedness between historical and economic contexts and actions results in a lack of understanding when addressing either in isolation (Yeung, 2005). As stated by Yeung (2005), it is simply not helpful to think of an economic agent without relating it to the network and the institutional structure in which the agent is embedded, even when the contexts seem at first glance mutually exclusive (p.44). To accomplish this, it is necessary to move beyond the mere abstraction of a situation, such as the word' firm,' towards examining the relations that constitute the, at first glance, binary category (Boggs & Rantisi, 2003).

Figure 1 illustrates the nature of this connectedness, or relationality, in relational economic geography. Relationality between the different categories emerges through interactions, interconnectedness, and tensions, resulting in significant heterogeneity and unevenness in the relational processes. Alternatively, as Yeung (2005) explains, it is not possible to think about the social without the political, or to work on the global scale without considering the local scale (p.44). When an actor is able to act within these relational structures, scales and actors, as seen in Figure 1, one can assume that this actor possesses the capacity, and thus the power, to do so (Yeung, 2005). The meaning of what power entails is not ambiguous, as power

Figure 1

Nature of rationality in relational economic geography



Note. From *Rethinking relational economic geography* by Yeung, H. W. (2005), *Transactions of the Institute of British Geographers*, 30(1), 37–51. p. 43 (https://doi.org/10.1111/j.1475-5661.2005.00150.x)

is not a 'thing' that moves, nor is it bounded to scale or territory for that matter, but rather a relational effect of social interaction (Allen, 2003). In this, people can be placed somewhere by power, but the experience of it is not a pre-packaged force from another place, nor is it an ever-present entity (Allen, 2003). Power is rather an emergent attribute, arising from interactions and interdependencies, in such a way that the sum of heterogeneous relations is greater than the individual parts (Yeung, 2005). In other words, power cannot originate from a single actor but is produced through the configuration of relations. As these emergent attributes, of which power is one, do not solely exist within a bounded region, treating regions as such poses a pitfall, as it neglects nonlocal relations and flows that shape regional development (Bunnell & Coe, 2001). Moreover, it fails to account for exogenous forces, such as capital and the state, that shape regional development (Cumbers & MacKinnon, 2003). The economic growth of one region is accordingly intimately linked to that of other regions through relations of control and dependency, market competition, culture, and other extralocal forces (Paasi, 1991; Yeung, 2005). Due to this porous state, regions constantly search for balance rather than being entities with structural coherence (Sunley, 2008). Consequently, a place cannot be reduced solely to a specific locality, 'site,' scale, or attributes (e.g., culture, built environment) when trying to understand its context (Paasi, 1991). That is, to grasp a region's context, a constant dialogue between regions, historical events, and spatial configurations, intertwining economic, historical, and social relations, will be needed (Amin, 2002; Bathelt & Glückler, 2003). This results in cities and regions not having an automatic guarantee of territorial or systemic integrity, since they are shaped by the spatiality of flow, juxtaposition, porosity, and relational connectivity (Amin, 2002).

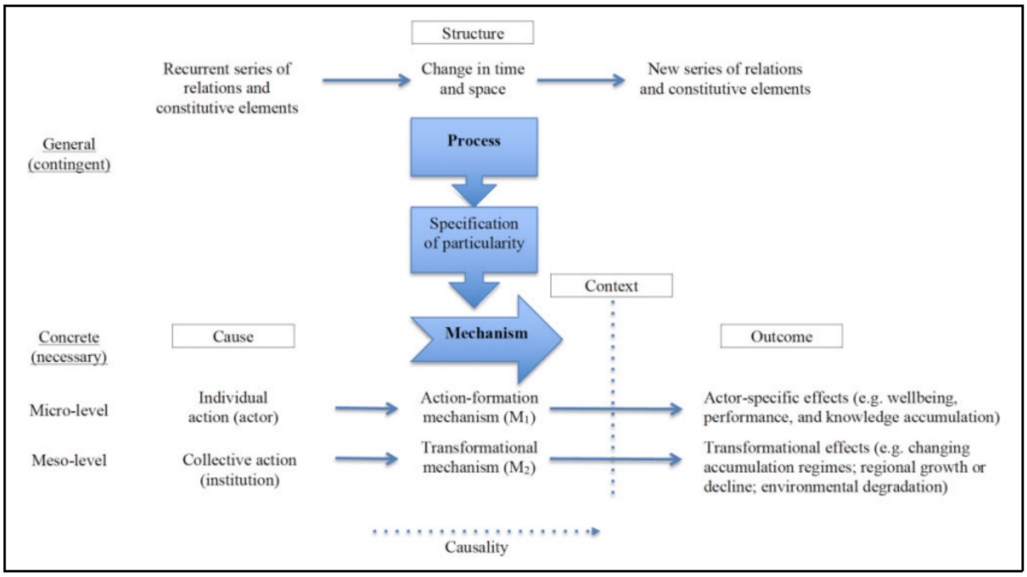
As space is thus relative and consists of a multiplicity of interactions occurring across scale, a one-size-fits-all paradigm should be avoided (Hassink, 2019). As Hassink (2019) states, this does not mean that research findings cannot have trans-contextual relevance (p. 280). Even with specific outcomes being highly contextual and unique, the underlying mechanisms that cause them can be identified, abstracted, and applied or understood in broadly similar contexts (Yeung, 2019). To identify these underlying causal mechanisms, Yeung (2019, p. 246) distinguishes between mechanisms and processes, which are often conflated, thereby risking the analytical efficacy of geographical analysis. As noted by Hassink (2020), process, in Yeung's (2019) definition, is a contingent change at a relatively high level of abstraction, whereas mechanism is a necessary relation connecting a causal condition with specific socio-spatial outcomes in context (Figure 2) (p. 280). Therefore, 'general processes' cannot serve as causal explanations for geographical outcomes. A process alone is not an explanation; for an explanation to be complete, specific mechanisms must be identified in relation to these process(es) (Yeung, 2019). Subsequently, an explanation based on mechanisms can be considered a mid-range theory; mid-range theories are neither narrow hypotheses used for everyday research problems nor the ‘grand theories’ developed to unify a theory that explains all the observed regularities of social behaviour, social organisation, and social change, as Gong and Hassink (2020, p.2) note, drawing on Merton (1968).

That is, to understand regional development, it is necessary to move from pure descriptions of a phenomenon to descriptions of what actually produces it or is a condition for it, as Yeung (1997) references Bhaskar (1989) (p. 59). In other words, it is essential to specify the description of the actors’ purposive action in a specific context. This can be at the micro-level (individual action-formation mechanism) and at the meso-level (collective action that leads to transformational mechanisms) (Yeung, 2019).

In sum, to understand processes such as ‘the wave of bankruptcies among pioneering companies’ and ‘uneven regional development in innovation activity,’ the underlying mechanisms producing these outcomes must be specified. Such mechanism-based explanations operate at the level of mid-range theory, enabling a clearer identification of the conditions under which bankruptcies in innovative recycling firms might be counteracted.

Figure 2

The difference between structure, process and mechanism. From Yeung (2019).



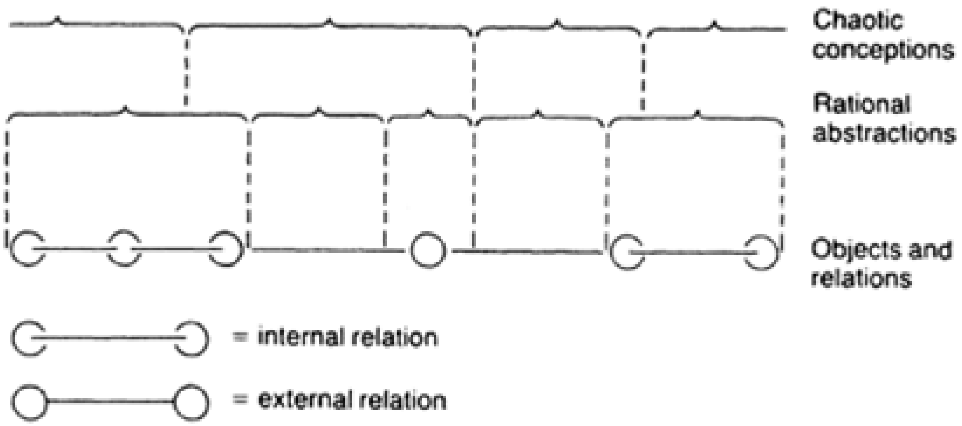
Note: Yeung, H. W. (2019). Rethinking mechanism and process in the geographical analysis of uneven development. Dialogues in Human Geography, 9(3), 226–255. https://doi.org/10.1177/2043820619861861

02.1.2. Identifying the causal mechanisms

As mechanisms are not deterministic and thus do not produce the same outcome in different contexts (Yeung, 2019), it becomes relevant to 'isolate' a significant element of the reality in which causal power exists (Sayer, 2010). These rational abstractions (Figure 3) isolate coherent and causally significant aspects of reality. This is different from 'chaotic conceptions', where things are grouped or separated only because of how the data is organised, which can mix unrelated elements (Gong & Hassink, 2020; Sayer, 2010).

Figure 3

Rational abstractions and chaotic conceptions. From Sayer (2010).



Note. *Sayer, A. (2010). Method in social science (2nd ed.). Routledge. https://doi.org/10.4324/9780203310762*

Furthermore, to understand how mechanisms interact and align across time and space in the context of regional development, it is necessary to understand the dynamics that occur when they connect (Yeung, 2015). To operationalise this, I am adopting the framework proposed by Van den Berghe (2018), which distinguishes three types of coupling mechanisms according to how relations emerge and interact across scales and forms (discursive, material, and institutional). As Yeung's notion of mechanisms remains rather foundational, Van den Berghe (2018) offers more concrete tools for classifying and analysing them. Also referred to as coupling mechanisms in his framework (See Figure 4).

- Tactical coupling refers to short-term, situational mechanisms that enable actors to seize opportunities or address immediate challenges, although they may occasionally persist for more extended periods (Silva, 2016; Van den Berghe et al., 2018).

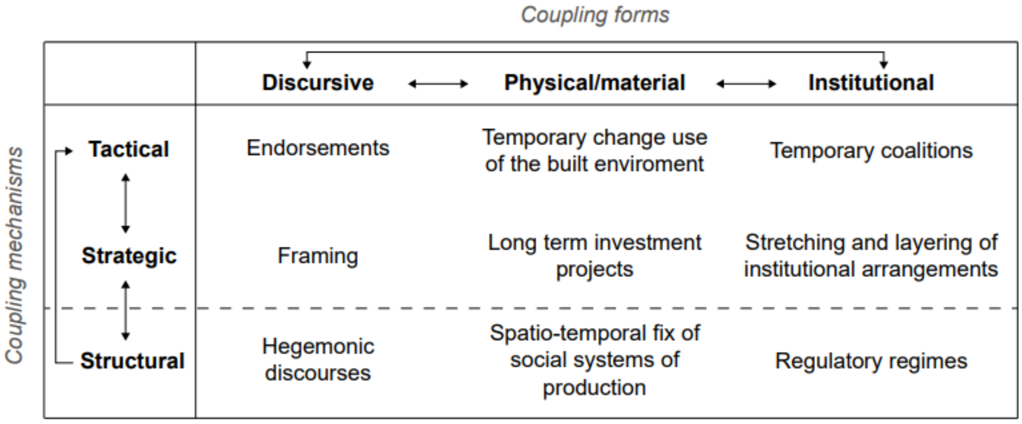
- Strategic coupling usually unfolds over the long term, focusing on how local and global processes connect and generate outcomes (Coe et al., 2004; Jacobs & Lagendijk, 2014).

- Structural coupling occurs when broader subsystems (e.g. politics, regions, industries, innovation clusters) align and generate new regimes, markets, or institutional configurations. Unlike tactical or strategic couplings, these are not entirely within the control of individual actors (Van den Berghe et al., 2018).

With structural coupling forms, (sub)systems (often referred to as categories, such as politics, region, city, industries) can couple, creating new or different forms of regimes, democracies, or markets (Van den Berghe et al., 2018). Yeung (2019) emphasises that these couplings should not be viewed as separate entities but as interrelated processes. On top of that, each can manifest as discursive, material, or institutional forms (Van den Berghe et al., 2018). It should be noted that the framework should serve as a guide rather than a rigid model, as a rigid blueprint might hamper the identification of what is actually happening in a setting (Huijs, 2011).

Figure 4

Coupling forms and mechanisms. From Van den Berghe (2018).



	Discursive	Physical/material	Institutional
Tactical	Endorsements	Temporary change use of the built enviroment	Temporary coalitions
Strategic	Framing	Long term investment projects	Stretching and layering of institutional arrangements
Structural	Hegemonic discourses	Spatio-temporal fix of social systems of production	Regulatory regimes

Note. Van den Berghe, K. (2018). Planning the Port City: A contribution to and application of the relational approach, based on five case studies in Amsterdam (The Netherlands) and Ghent (Belgium) [Doctoral dissertation, Ghent University]. https://doi.org/10.17418/phd.2018.9789463551533

02.1.3. Innovation ecosystem

Since I am concerned with the system the firm builds around a certain invention to achieve commercialisation, I am interested in the firm's system and its ultimate aim with it. Porter (1985) emphasises this aim as creating more value than the firm's rivals (pp.60-78). Adner and Kapoor (2010) reframe this as the focal firm's ability to create and capture value depends on whether interdependencies within the ecosystem are resolved (pp.306-307). Thus, successful and strategic commercialisation is contingent on systemic alignment rather than on firm-level performance alone. Hence, an invention never stands alone: it is embedded in the system where the focal firm operates, shaped by ongoing changes within that system. Adner and Kapoor (2010) state that, in doing so, the focal company is heavily dependent on actors upstream and downstream in the value chain (p.307). From a relational economic geography perspective, the various contexts are also part of this system, which I will also refer to when addressing the term 'innovation ecosystem'.

From this perspective, following Van den Berghe (2018), innovation ecosystems are rooted in tactical and strategic coupling mechanisms that operate at the micro-level and are embedded in the socio-economic and institutional contexts at meso and macro scales (Gong & Hassink, 2020).

02.2. Inventions and Innovations

At the heart of technological change lies innovation, which is essentially a process of learning (Dicken, 2015). These learning processes have a distinctive geography that affects economic growth and technological change (Feldman & Kogler, 2010), and are inherently complex and interdependent (Kahn, 2018).

Innovation is shaped by its social and economic environment during both its development and use (Dicken, 2015). It is fundamentally a process embedded within social and institutional contexts (Dicken, 2015). However, the term 'innovation' can be misleading, often leading to misunderstandings about what it truly entails (Kahn, 2018). One common misconception is that innovation must be entirely radical and novel, while this can be true, it can also be incremental and modest in scale (Kahn, 2018). As Kuczmarski (1996) describes, innovation is best understood as a pervasive mindset that enables businesses to look beyond the present and envision the future (p.7). Adding to this notion of innovation is Nelson's (2009) definition, which states that the distinction between inventions and innovations lies in the economic usefulness of the invention: inventions are considered new technological developments, whereas innovations are those inventions that are economically useful and diffused (p. 995). This economic usefulness will become clear upon market introduction, and the products will become commercially available and accepted (Gross et al., 2018). Defining when an invention is fully commercialised can be challenging, as judgment is needed to define when a technology is 'widespread', 'mature' or 'established' (Gross et al., 2018). As Gross et al. (2018) note, no standard quantitative definitions of commercialisation exist in the literature (p. 687). If a technology fails to make its products economically viable, the invention and the startup holding it risk failure and falling into the 'Valley of Death' (Giraldo-Builes et al., 2022).

Innovation is considered an essential instrument at all levels of development policy (Trajtenberg, 1990), as technological development is a priority for countries that aspire to support economic development and growth (Moreno et al., 2006). As further stated by Rodríguez-Pose and Crescenzi (2008), this perception of innovation solely as a means of economic development and growth overlooks key factors related to the context in which innovations occur and the potential and barriers that territories face in implementing innovations produced elsewhere (p. 54). Especially since innovations are not placeless processes, but inherently territorial, embedded (Asheim, 1999), and consequently cannot be fully understood independently of the social and institutional conditions of the region in which they are developed or commercialised (Asheim, 1999; Rodríguez-Pose & Crescenzi, 2008).

The traditional approach to innovation, which primarily focuses on the national level, can be misleading because it assumes homogeneity across regions. Examining smaller areas, such as regions, is often more useful in understanding innovation (Iammarino, 2005). Using a micro-meso-macro approach is helpful, as it facilitates understanding the socio-institutional factors influencing innovative performance while also analysing heterogeneity and path dependency (Iammarino, 2005; Rodríguez-Pose & Crescenzi, 2008). Additionally, such cross-scale analysis is helpful because regions do not rely solely on their internal capacity to generate innovation; they also utilise inputs from other regions. (Rodríguez-Pose & Crescenzi, 2008).

Patents can be a valuable tool for understanding innovation activity in regions. Although an imperfect proxy, patents can be used to identify regions of innovation, as they are the only manifestation of inventive activity that spans virtually every field of innovation in the most developed countries, provide information on the residence of the applicants and inventors, and thirdly are accessible over long series of yearly records (Trajtenberg, 1990; Moreno et al., 2006). Nonetheless, errors arise when relying solely on patent counts, as patent data captures only those inventions that inventors choose to patent, thereby understating the full extent of inventive activity (Nelson, 2009). Secondly, as further stated by Nelson (2009) patent data may overstate innovation processes, as patents are tied to inventions rather than innovation (p. 995). This necessitates the use of multiple indicators to fully understand the value of a patent and determine whether its invention constitutes an innovation. Moreover, they do not consider informal technological activity and tend to underestimate the amount of innovative activity among medium and small firms (Moreno et al., 2005). Technology output data represent the outcomes of inventive and innovative processes, even though some inventions may never be patented and some patents may never be developed into innovations (Moreno et al., 2006). Notwithstanding, patenting procedures require innovations to have novelty and utility, and imply that the invention is worth the costly endeavour of patenting (Moreno et al., 2005). This, in turn, suggests that patented innovations, particularly those granted abroad, are expected to have economic value (Castaldi et al., 2024).

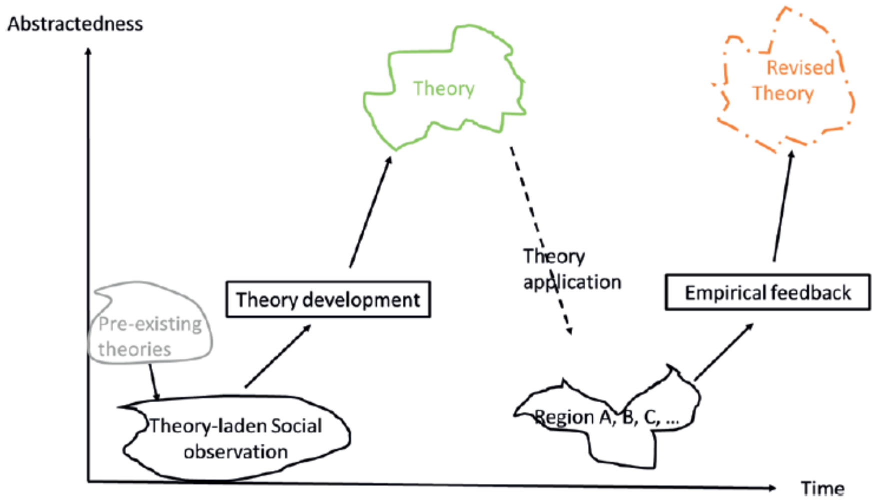
03. Methodology

03.1. The approach

To realise the twofold aim of this research, I have examined two phenomena: the primary phenomenon being 'the wave of bankruptcies among Dutch pioneering companies in the field of technological advancements in plastic waste management', and secondly, 'the uneven regional development of innovation in plastic waste management' as a potential response to the systemic failure reflected in these bankruptcies. In analysing these, I moved beyond merely describing what drives regional innovation and instead focused on uncovering the underlying causal mechanisms (Yeung, 1997). This required a reflective and iterative process of isolating the essential mechanisms that have shaped the context in which inventions were commercialised (Sayer, 2010; Yeung, 1997). That is, the goal is to identify which findings have trans-contextual relevance, meaning the causal mechanisms that extend beyond the specific regional setting (Gong & Hassink, 2020). In doing so, I used the (re-)theorising framework proposed by Gong and Hassink (2020) as the outset and main guidance (see Figure 5).

In this theorising process, a crucial step is the observation of social phenomena (Gong & Hassink, 2020). Such observations, however, are not made from a blank slate; they are influenced by prior notions, perceptions, academic training, and personal experience (Sayer, 2010). It is therefore essential to first acknowledge and understand these preconceptions, as they act as the lenses through which social observations are made. This is what is referred to as pre-existing theories in Figure 5 (Gong & Hassink, 2020). In this research, the pre-existing theories are informed by the first phenomenon: a wave of bankruptcies among pioneering companies in the field of plastic waste management technologies. Subsequently, I examined, through the emerging lenses, the social observations of uneven regional development in innovation activity. Hereafter, I identified, through an iterative process, a set of patterns that constituted, influenced, manifested, and drove the phenomenon of uneven regional development in innovation in plastic waste management (Gong & Hassink, 2020). Subsequently, the identified patterns were organised into categories that provided the foundation for the conditions, a process through which the underlying causal relations, or the 'why' behind observed patterns, are explained (Yeung, 1997).

Figure 5
Process of theorising. From Gong and Hassink (2020).

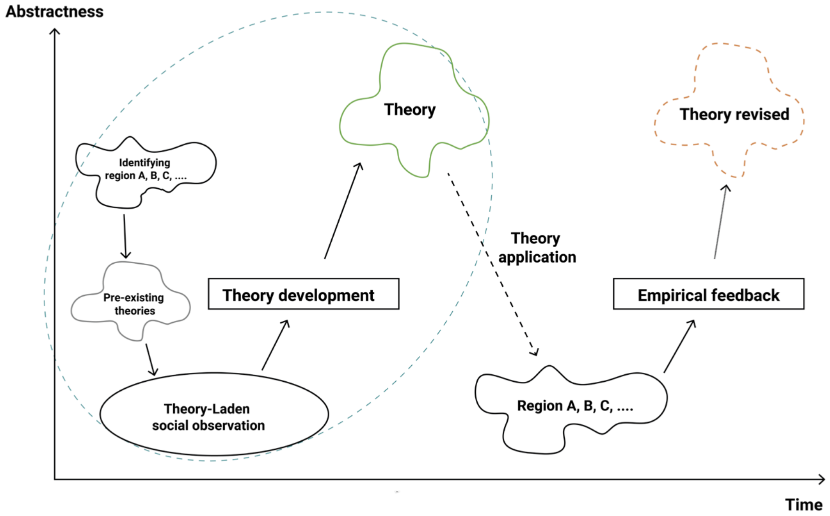


Note. Gong, H., & Hassink, R. (2020). Context sensitivity and economic-geographic (re) theorising. Cambridge Journal of Regions, Economy and Society, 13(3), 475–490. https://doi.org/10.1093/cjres/rsaa021

In this approach, generalisations are being emphasised, focusing on 'what' happens rather than 'why' it happens (Gong & Hassink, 2020; Sayer, 2010). Subsequently, when implementing generalisation, it is also important to use abstraction to identify the actual causal mechanisms, as abstraction involves analytically isolating key components or relations that produce observed patterns (Gong & Hassink, 2020; Sayer, 2010). Furthermore, as Sayer (2010) notes, generalisations are not an end in themselves. Treating them as such can be limiting, as it overlooks the historically and culturally dependent nature of the phenomena (Sayer, 2010).

Figure 6

Process of theorising. Adapted from Gong and Hassink (2020).



Note. *Gong, H., & Hassink, R. (2020). Context sensitivity and economic-geographic (re) theorising. Cambridge Journal of Regions, Economy and Society, 13(3), 475–490. https://doi.org/10.1093/cjres/rsaa021*

This thesis differs from Gong and Hassink's (2020) approach in that their study assumes the regions to be examined as already defined. In contrast, I do not assume predefined regions. For that reason, I included an initial step to identify regions with high innovation activity in plastic waste management (see Figure 6). Moreover, not all stages proposed by Gong and Hassink (2020) are included within the scope of this thesis. As their framework is meant to develop a new theory or revise existing ones, this is not the aim of this research. For that reason, I have not adopted the complete theorising development phase. Instead, in the theory development phase, I have identified patterns that emerge into categories and, subsequently, into conditions, rather than developing a full theory. That is also why the 'theory application' phase, which involves testing and refining the developed theory with other scholars across various contexts, is excluded (see Figure 5). Therefore, the applicability of the conditions developed in this research still needs to be thoroughly tested to understand their relevance across various contexts. Thus, to answer the research question guided by the phases in the approach by Gong and Hassink (2020), the following sub-questions will be answered:

Identifying the regions:

1. Which regions exhibit high levels of innovation activity in plastic waste management?

The social observations:

2. What are the contexts contributing to the wave of bankruptcies at the macro and meso scales?

3. What are the contexts contributing to the uneven regional development of innovation in plastic waste management at the macro, meso and micro scales?

The theory development - partly

4. What is the theory that can address systemic failure reflected in these bankruptcies?
5. What are the primary considerations when grounding relational economic geography for empirical application?

Below, the methods for each phase, as shown in Figure 6, are explained in more detail.

03.2. The identification of the regions

To identify the regions with the highest levels of innovation in plastic waste management. My proxy for innovative activity refers to patent applications at the European Patent Office (EPO) from 2005 to 2025, classified by the inventor's region in Europe. This time period is due to the 20-year term of technology patents (European Patent Office, n.d.-a). Since applying at the EPO is difficult, time-consuming, and expensive, it indicates that the invention is considered potentially lucrative (Moreno et al., 2005).

In this research, I focused on technologies to mitigate waste from plastic packaging, as this type of plastic accounts for 40 per cent of global plastic consumption (Fogt Jacobsen et al., 2022). Moreover, I used concordance tables, such as the CPC and IPC, to link industry classes to technological classes, enabling the identification of patents within specific industries (European Patent Office, n.d.-c). I used the IPC section and class Y02W30 to identify inventions in the EPO database, which stands for technologies that mitigate climate change related to solid waste management (European Patent Office, n.d.-d). Since the patent data retrieved is highly specific and time-bound, it is important to acknowledge that additional patent applications may be filed after the data collection period. Furthermore, the European Patent Office (EPO) retains patents in its database as long as the required fees are paid, regardless of whether the company that filed the patent is still operational (European Patent Office, n.d.-b). As a result, the EPO database included patents from dissolved companies, which introduced a limitation: the data does not fully reflect the current population of active firms. This makes the patent dataset inherently dynamic and potentially misaligned with real-time innovation activity. Moreover, as not all of these technologies focus on plastic recycling, I employed a Boolean to filter for technologies specifically for solid waste management related to plastic packaging and films:

- *(ta any "packag*" OR desc = "packag*") AND cpc = "Y02W30" AND (ta = "plastic*" OR desc = "plastic*")*
- *Query language: en / de / fr*
- *Sort by: Relevance*
- *Filters:*
    - *Applicants - country: DE*
    - *Inventors - country: DE*
- *Earliest publication date (family): 2005-01-01 to 2025-12-31*

When attempting to spatialise patent data, several challenges arose. First, the patent documents are not machine-readable, and the way the applicant's and/or inventor's location is reported is inconsistent. Additionally, these location references are written in text rather than expressed as coordinates, making them unsuitable for immediate georeferencing. Furthermore, national

differences in postal systems require country-specific approaches.
To address these issues, the patent documents are first processed with OCR software to ensure machine-readability and then converted to a structured CSV format. Next, the extracted location information is standardised and linked to country-specific postal codes. Since postal codes can be connected to geographical coordinates via external georeferenced datasets, the data can be spatialised. Based on this link, heatmaps can be generated to visualise regional concentrations of patenting activity in plastics innovation. Appendix A -D contains the codes.

A significant limitation in interpreting the heatmaps arises when a single patent is associated with multiple postal codes. In such cases, the presence of multiple inventors or applicants can artificially inflate the perceived level of innovation activity in certain regions, even when only one invention is involved. Additionally, some patents might not be accurately georeferenced; therefore, it is essential to triangulate the data with literature on patent distribution to prevent misinterpretations.

03.2.1. Literature as a means of triangulation

Triangulation can contribute significantly to improving the validity and reliability of the collected data (Yeung, 1997). As the patents are country-specific, I first employed a literature review of academic papers and reports on innovation activity in European member states to understand (1) which countries hold the most regions with innovation activity, and (2) how innovation activity historically developed in the European member states. This will allow a better understanding of which member states have the greatest potential to host regions with high plastic innovation activity. Furthermore, literature that extends beyond simply identifying countries and addresses regions with high innovation activity will serve as a check to see whether my findings align with existing research. Triangulation of data with academic literature has been applied throughout the thesis.

03.3. The pre-existing theories and theory-laden observations

Gong and Hassink (2020) argue that, in context-sensitive disciplines such as economic geography, social observation is the starting point for assessing how social structures and processes depend on context and, consequently, for identifying causal mechanisms. I utilised open data sources, including newspapers, academic literature, reports, and datasets, to conduct these observations in this research (Gong & Hassink, 2020). As mentioned in the theoretical framework, there is no single exclusive context that predicts the overall truth or explains the mechanisms at work (Gong & Hassink, 2020). To understand the different contexts that influence the regions where innovations are developed, I began by examining why companies in the Netherlands' plastic waste management sector struggle to survive. That is, observations gathered from open data sources on this phenomenon served as a guide to understand the perspectives through which the regions where inventions in plastic waste management are commercialised are viewed.

After identifying the perspectives that cause companies pioneering in plastics inventions to struggle, and where the most innovative activity takes place in plastic waste management, I analysed the history and the socio-economic context across scales (Paasi, 1991). To ground relational economic geography into a practical theory is neither a purely deductive nor an inductive process, as it often operates simultaneously in a deductive-inductive dialogue (Yeung, 1997). For that reason, I used an iterative approach that combined inductive and deductive reasoning; in the initial phase, I attempted to understand and abstract from specific observations and discourses, starting inductively by analysing empirical materials such as news articles and reports to identify recurring themes. In the next phase of theory-laden observation, I switched to a deductive approach, applying broader insights and theories to interpret and organise these observations within a wider conceptual framework. Finally, a more detailed, context-specific analysis was conducted inductively via case studies (discussed in more detail below).

03.4.2. The sources

I employed an archival research strategy (Saunders et al., 2023), using secondary qualitative data as the primary source of information. This included market reports, publicly available interviews, news articles, and industry analyses. The rationale is that archival and open data represent key sources of information for both regulatory bodies and companies (Saunders et al., 2019). Moreover, since archival research is deeply embedded in everyday life (Hakim, 2012; Saunders et al., 2019), this method is particularly relevant for understanding the different contexts (Gong & Hassink, 2020). Nevertheless, it is essential to note that when using data from secondary sources, they are originally intended for different purposes; therefore, I must be aware of their nature and original intent (Saunders et al., 2023). Additionally, when working with archival data, a key limitation is the interpretive aspect of the research process. My academic background, theoretical perspective, and preexisting assumptions inevitably influence the selection, reading, and interpretation of data. This subjectivity can influence the patterns I observe, the gaps I identify as important, and my interpretation of events or narratives.

03.4. Case studies

In theorising economic geography and identifying the causal mechanisms that shape a specific situation, the analysis begins with contextual differences to determine which dynamics extend beyond the original setting (Gong & Hassink, 2020). For this reason, I conducted a case study approach.

As both phenomena relate to the success of companies pioneering in plastic waste management, I have selected this type of company for my case study. Since pioneering companies in this field are not a uniform group, I will choose two companies based on the following criteria:

- Same IPC technology class (Y02W30)
- Similar purposes (to reduce plastic packaging waste via depolymerisation)
- Their location in earlier found regions
- Experiencing the same hurdles in commercialising the invention

The decision for the purpose criteria is motivated by the fact that the most widely produced thermoplastic, with an annual production of around 70 million tons, is polyethene terephthalate (PET). This plastic is primarily used in packaging, bottles, and textiles (McNeeley & Liu, 2024). Chemical recycling becomes essential when PET waste is unsuitable for mechanical recycling, typically due to environmental exposure-induced degradation, the presence of dyes, pigments, other plastics, additives, dirt, and other contaminants (McNeeley & Liu, 2024). Through chemical recycling, PET is broken down into intermediate forms, allowing impurities to be selectively removed before it is reconverted into PET (McNeeley & Liu, 2024). In principle, this would enable an infinitely recyclable system. Since PET production methods are already well established, current innovation efforts focus primarily on the depolymerisation stage (McNeeley & Liu, 2024). Depolymerisation is the process of breaking down a polymer into its individual units, which are referred to as monomers (McNeeley & Liu, 2024).

The inventions resulting from the criteria analysed here, and the companies working to commercialise them, modify the chemical structure of PET to develop alternatives and aim to improve chemical recycling processes, ultimately contributing to a circular plastics economy in the Netherlands.
Patent data will be used to assess technological class, invention purpose, and barriers to commercialisation, providing a comparative baseline for case selection and analysis.

As stated by Yin (1984), the need for a case study arises when (1) an empirical study has to examine a contemporary phenomenon within its real-life context, especially when (2) the boundaries between the phenomenon and its context are not clearly evident (Yin, 1984). In situations where the boundaries between the phenomenon and its context are unclear, the strength of a case study, as Yin (1984) stated, lies in its ability to encompass both, as they are inherently intertwined.

Given the objective of developing actionable strategies and recommendations to promote a circular plastics economy in the Netherlands, the Dutch case study will be the main focus of analysis. Therefore, I selected at least one case embedded in the Dutch context, which will serve as the primary case to examine patterns, develop categories, and formulate concepts and theories. Conversely, the secondary case functioned as a comparative example to understand differences and gain deeper insights into the underlying mechanisms and their 'why' (Gong & Hassink, 2020).

As inventions are embedded in various contexts, for example, the Dutch case is situated within the historical, political and economic context of the Netherlands, multiple scales and levels of detail are applicable. This means that when investigating the economic decisions of companies holding inventions, a more concrete and detailed approach is needed than the foundational approach provided by Yeung (1997; 2019). For that reason, I used the framework of Van den Berghe (2018) for the case comparison at the firm level, which discusses several causal mechanisms and their coupling forms more concretely.

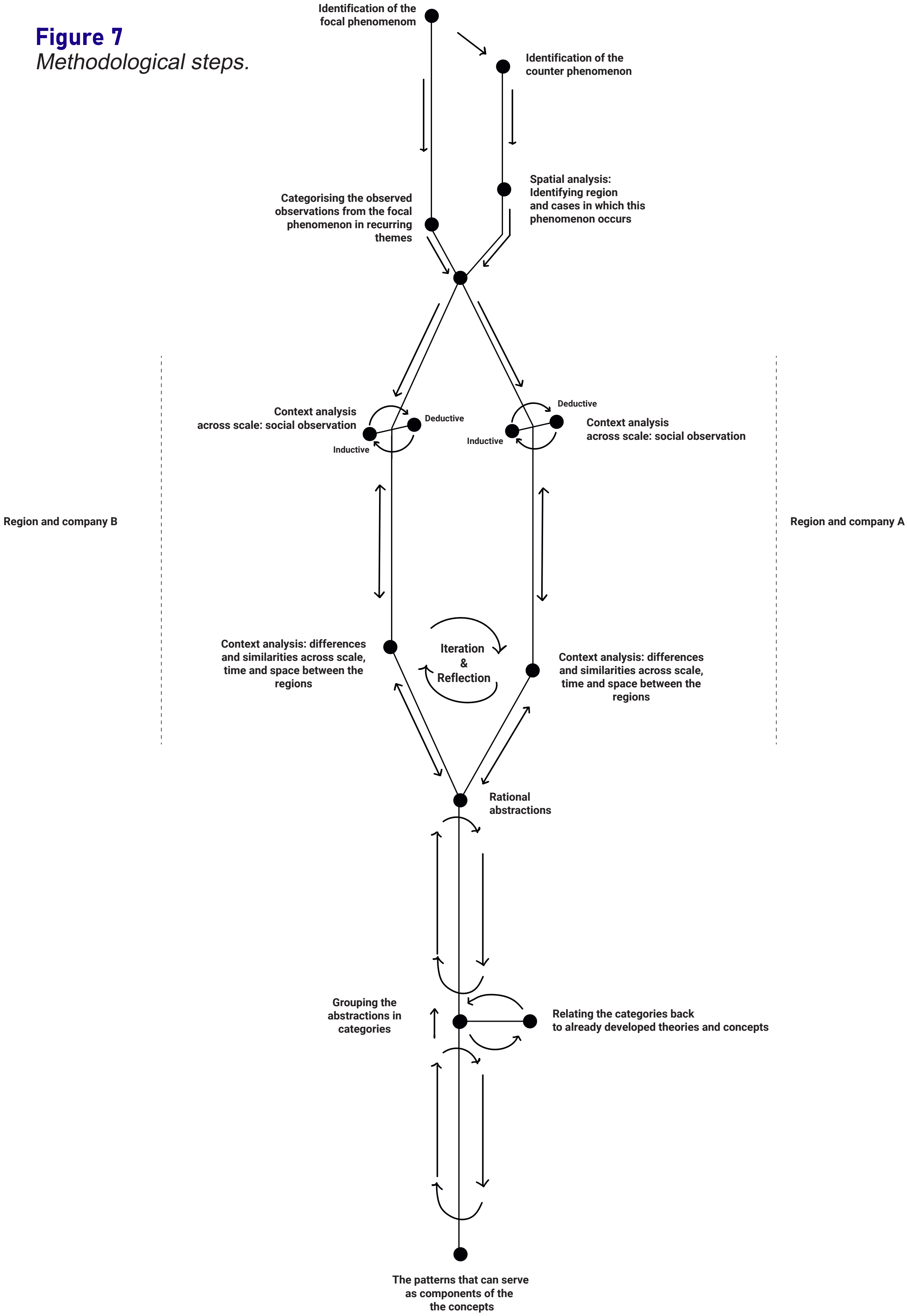
After comparing the cases to understand their differences and to move towards developing a theory, I used rational abstractions (Sayer, 2010). Rational abstractions are based on object connections and take local context and specificity into account (Gong & Hassink, 2020). An abstraction is often thought of as 'vague' or 'removed from reality. ' This is not the case in this research; an abstract concept can be clear rather than vague, since there is nothing inherently unclear about abstractions (Sayer, 2010). As Yeung (2005) stresses, the meaning of these abstractions emerges from the interaction with others (see Figure 1); you cannot fully grasp the global scale without understanding its connection to the local (p. 44). To employ an iterative abstraction (Yeung, 1997), I will utilise several tools to enhance iteration, including tables and visualisations in which the different patterns derived from the similarities and differences are noted across scales. The identified patterns will then be organised into categories that form the basis for the concepts (Yeung, 1997). Following this, the emerging concepts serve as the basis for constructing a theory that addresses the research question of this thesis.

Consistent with Gong and Hassink (2020), who define (re-)theorising as the revision and reconfiguration of existing theories and concepts (regardless of their origin), I have not introduced entirely new theoretical constructs but instead reconfigured and revised those drawn from other academic fields. In conceptualising these abstractions into conditions, I am using the criteria by Yeung (1997), who distinguishes effective conceptions by their reproducibility, precision without oversimplification, coherence, and explanatory power (Yeung, 1997).

Below, Figure 7, and in Appendix E, are the methodological steps outlined:

Figure 7

Methodological steps.



Note. Author’s own visual synthesis; methodological steps inspired by Gong and Hassink’s (2020) context-sensitivity approach and Yeung’s (1997) guidelines in realist research.

04. Results

04.1. Regions with high innovation in plastic waste management

04.1.1. Historical context of innovation activity in European Member States

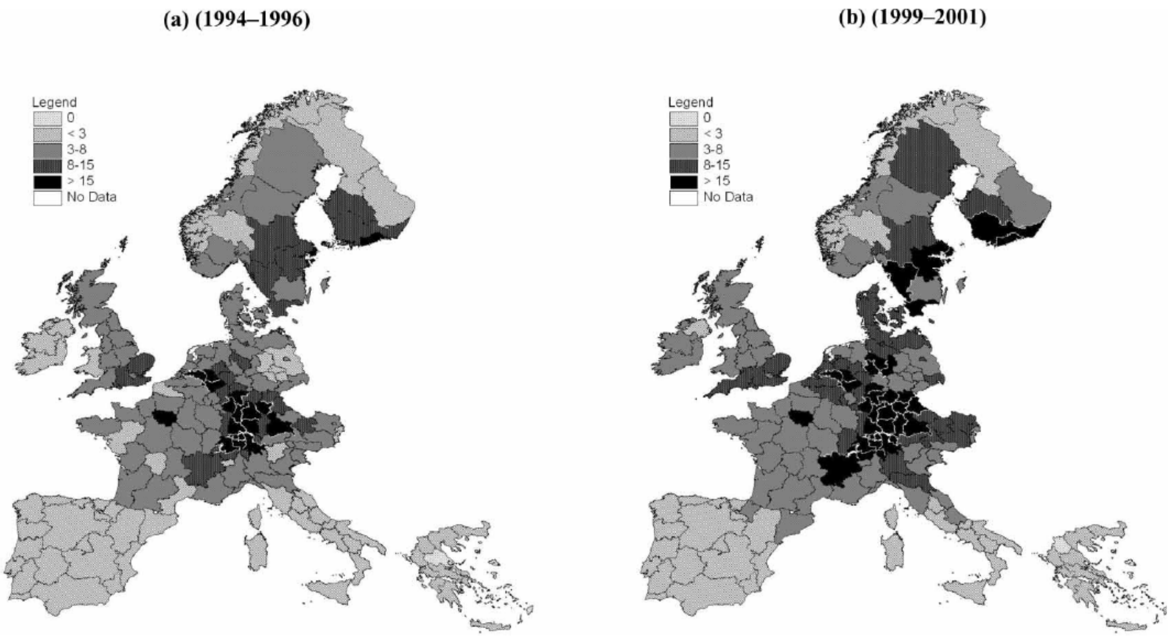
European Union member states regard innovation and the inherent learning processes as crucial drivers of economic growth and technological advancement (Dicken, 2015; Moreno et al., 2005). Nonetheless, even this aim to enhance innovation activity, as rated by patent activity, is unevenly distributed across the European Union; a handful of large countries account for roughly 70 per cent of patent applications (Moreno et al., 2006). Innovation activity seems to be concentrated mainly in German regions (Paci & Usai, 2000). Other regions that do show innovation activity are predominantly located in the core of Europe, including Switzerland and Western Germany, Luxembourg, and most regions of Austria (Moreno et al., 2006). In contrast, in these studies, the southern European regions seemed to exhibit almost no technological patenting activity, see Figure 8 (Moreno et al., 2005; Paci & Usai, 2000).

Within Europe, innovation in a given industry and region correlates positively with specialisation in that industry rather than with diversity in the region's innovation system (Moreno et al., 2006). Consequently, clusters with high innovation levels are highly specialised, reflecting strong relatedness among firms (Zhao et al., 2010). This contrasts with the United States, where regional diversity plays a more prominent role in local innovation production (Audretsch & Feldman, 1996). As Moreno (2006) highlights, this would indicate that increased regional specialisation is conducive to greater innovative output (p. 1249). Nevertheless, spatial patterns of innovation activity do differ across technology classes (Breschi, 2000), as firms base their location decisions primarily on economic criteria, including proximity to customers and suppliers, infrastructure quality, and the availability of human capital (Zhao et al., 2010).

A possible explanation for the difference between the United States and Europe in the development of innovation activity is the significant presence of small and medium enterprises in traditional sectors in Europe, where innovation is more incremental and mainly carried out in operational plants (Moreno et al., 2006; Paci & Usai, 2000).

Figure 8

Distribution of innovative activity in the European regions. From Moreno et al. (2006).


(a) (1994–1996)
(b) (1999–2001)

Note. *Innovation clusters in the European regions. European Planning Studies 14(9), 1235–1263 by Moreno, R., Paci, R., & Usai, S. (2006)., 1 https://doi.org/10.1080/09654310600933330*

04.1.2. Current trends in innovation activity in European Member States in plastic waste management

Since 1990, Europe has consistently led innovation in plastic waste management, with a particular emphasis on microplastics processing and mechanical–physical methods (e.g., density-based separation and washing) (Mendonça et al., 2025). The European Patent Office's recent analysis reflects this focus on traditional technologies, as the steady number of patent applications for waste management technologies continues, with European applicants accounting up 44 per cent of all plastic-related patent activity (Mendonça et al., 2025). Also at present, worldwide patent activity shows that patent grants are concentrated in a few countries, with nearly 50 per cent granted to the United States and Japan (Dicken, 2015; European Patent Office, 2015). In particular, China, South Korea, Japan, the United States, and Germany are the top three countries in terms of shares of international patent families related to plastic waste management technologies (Eurostat, 2023). Notably, China is by far outpacing the rest of the countries, with 8390.09 patent filings related to recycling and secondary raw materials annually. In comparison, Japan comes second with 1598.02 patents (Eurostat, 2023). Among European member states, Germany patents the most in this field, with an annual average of 78.85 patents (Eurostat, 2023).

The largest European patent applicants stem primarily from the chemical and tyre industries, although three pure-recycling companies, including the German firm Erema, rank among the top twenty (Mendonça et al., 2025). Of the companies, BASF is one of the leading applicants in Europe, with a diversified portfolio centred on mechanical processing, chemolysis and depolymerisation (Mendonça et al., 2025). Other leading German patentees include Bayer (chemicals), Krones (packaging) and the Fraunhofer Gesellschaft (public research) (Mendonça et al., 2025). Despite differences in sectoral origin, most top applicants patented similar technological inventions: washing and cleaning, selective dissolution, density/gravity recovery and mechanical separation (Mendonça et al., 2025).

In addition to these companies, universities and startups also contribute substantially to patent filings in this field (Mendonça et al., 2025). Approximately 80 per cent of startups and 66.6 per cent of universities focus on advanced recycling processes (chemolysis, pyrolysis, and enzymatic depolymerisation). In contrast, recovery-technology patents (e.g., contaminant removal from water and selective dissolution) remain comparatively sparse (Mendonça et al., 2025). This disparity likely reflects the technical and economic hurdles of recovery innovations (Mendonça et al., 2025). Geographically, the United Kingdom, France, and Germany host the most startups that file patent applications, followed by Sweden, Italy, and the Netherlands. This is also seen in universities, as the majority of patents issued by universities are in Germany and France (Mendonça et al., 2025).

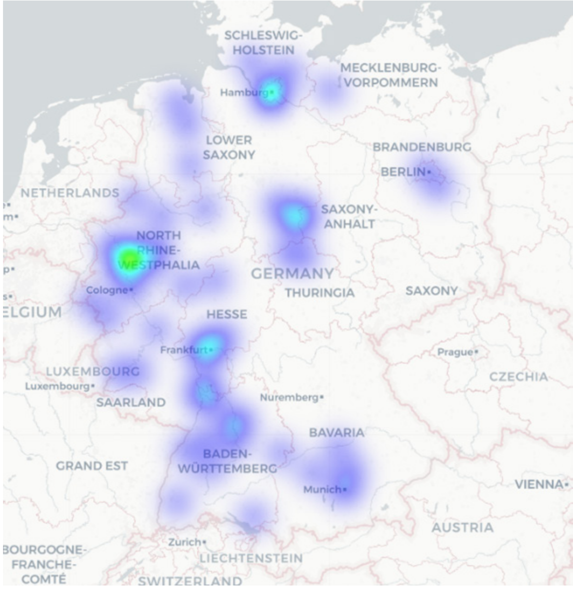
Mapping the patents

Since Germany exhibits the highest patent activity in this technological field, a detailed analysis was conducted on this country. Additionally, as the research aims to address the systemic failure of the commercialisation of inventions in the Netherlands, this country was also examined more thoroughly.

The mapped patents in plastic waste management tend to cluster in certain cities and regions, as shown in Figures 9 and 10. It is seen that most activity is located in Köln, Aachen, and Frankfurt, with smaller, more distant clusters in Berlin and Hamburg. This same distribution is seen in the Netherlands, where the main activity appears to be in the southern part of Limburg,

Figure 9

Patent activity in Germany.



Note. This figure shows the mapped patent actvity in Germany. Created by the author.

Figure 10

Patent activity in the Netherlands.

Note. This figure shows the mapped patent actvity in the Netherlands. Created by the author.

where Chemelot is located. Also, the areas near the ports tend to be where patent activity occurs: the Port of Rotterdam, Eemshaven, and Amsterdam (see Figure 10).

This clustering in Germany is similar to that found by Moreno et al. (2005) and Fornahl and Brenner (2009), who analysed a dataset of 186,145 patent applications over ten years and assigned them to regions using postcode data. They show that patent activity is far from evenly distributed across both technologies and regions. However, although large and densely populated regions generate higher absolute patent counts, population density does not correspond. Fornahl and Brenner (2009) stress that the observed clustering is primarily driven by the fact that a small number of inventors dominate patenting activity, most of whom are affiliated with large firms (pp. 174-175). Innovation clusters might therefore reflect the presence of a few large firms rather than the demographic characteristics of regions.

This corresponds with the OECD (2025a) report, which found that innovation outcomes in southern Germany are associated with major innovation hubs, including leading companies in the manufacturing and services sectors (pp. 130-131).

The principal centres of innovation in plastic waste management, as measured by patent intensity in the literature, are Munich, Stuttgart, Düsseldorf, and the Rhine-Main region (Fornahl & Brenner, 2009). In the chemical and related technological fields, Rhineland-Palatinate and Düsseldorf frequently serve as hubs (Fornahl & Brenner, 2009). These results correspond with the patterns observed in Figures 9 and 10. However, a difference here is that, after mapping patent activity in plastic waste management, focusing on patents classified under IPC code Y02W30, the Rhine-Ruhr metropolitan region stands out as the area with the highest concentration of patent activity in plastics. Cities such as Cologne, Düsseldorf, and Bonn are central to this trend, with major chemical companies such as Evonik and Bayer nearby. This region also has strong innovation capacity in other domains, including textiles, soaps and detergents, fabricated metal products, specialised machinery and nuclear fuel (Fornahl & Brenner, 2009). Notably, patent activity in plastic waste management appears highly spatially embedded within a region historically recognised as a chemical stronghold: the Rhineland chemical cluster (Scholz et al., 2024), which is part of a broader (petro-)chemical cluster, the Antwerp-Rotterdam-Rhine-Ruhr area (ARRRA).

04.1.3. Micro analysis - Profiling the companies behind the patent filings

As aforementioned, most patent activity occurs at large, well-known firms, with BASF being the largest applicant. Of the patent dataset derived from the EPO, 8 per cent of the applications were from startups and scaleups. In contrast, companies with an international presence, such as BASF and Krones, accounted for 62 per cent. Small- and medium-sized enterprises (SMEs) filed 16 per cent of the analysed patent applications. Within the startup/scaleup category, patent applications are heavily concentrated among a few players. Only one is a spinoff from a research institute or university; the rest originated independently. Most are not located near the ARRRA cluster.

Table 1

Share of applicant types in EPO filings (2000–2025) - Netherlands.

Category	Percentage
SMEs	16 %
Multinational	62 %
Research institute	10 %
University	4 %
Startup/scale up	8 %

Note. Data retrieved from the European Patent Office patent database (August 2025).
See Appendix G for dataset.

The lead applicant in the Dutch plastic waste management field is a major multinational chemical company now operating under SABIC Global Technologies. Several startup and scale-up companies, namely Avantium, Ioniqa, QCP, Quinlyte, and Umincorp, have also filed relevant patents.

In the derived patent dataset of the Netherlands, 25 per cent of applicants were startups/scaleups. Of these, only Avantium seems to have transitioned beyond the startup phase, is actively pursuing commercialisation, and operates production facilities within one of the identified clusters. Other mentionable startups, such as Quinlyte and Ioniqa, although not geographically located in the ARRRA-cluster, maintain strong ties to Chemelot through investments from its venture capital branch, thereby integrating them, at least partially, into its network (Portfolio - Brightlands Venture Partners, n.d.).

From the Dutch startups and scale-ups in the dataset, many originate from collaborations, such as consortia, spin-offs, or subsidiaries, and maintain close ties with larger firms and/or research institutions. Spinning off ventures is a proven route for commercialising research outputs, offering immediate integration into clusters (Lejpras, 2014). Research has shown that spin-offs, particularly those emerging from research institutions, tend to display higher innovative potential and capabilities in their early stages than other newly founded firms (Lejpras & Stephan, 2008).

Table 2

Share of applicant types in EPO filings (2000–2025) - Germany.

Category	Percentage
SMEs	25 %
Multinational	32 %
Research institute	8 %
University	0 %
Startup/scale up	25 %
Other	10 %

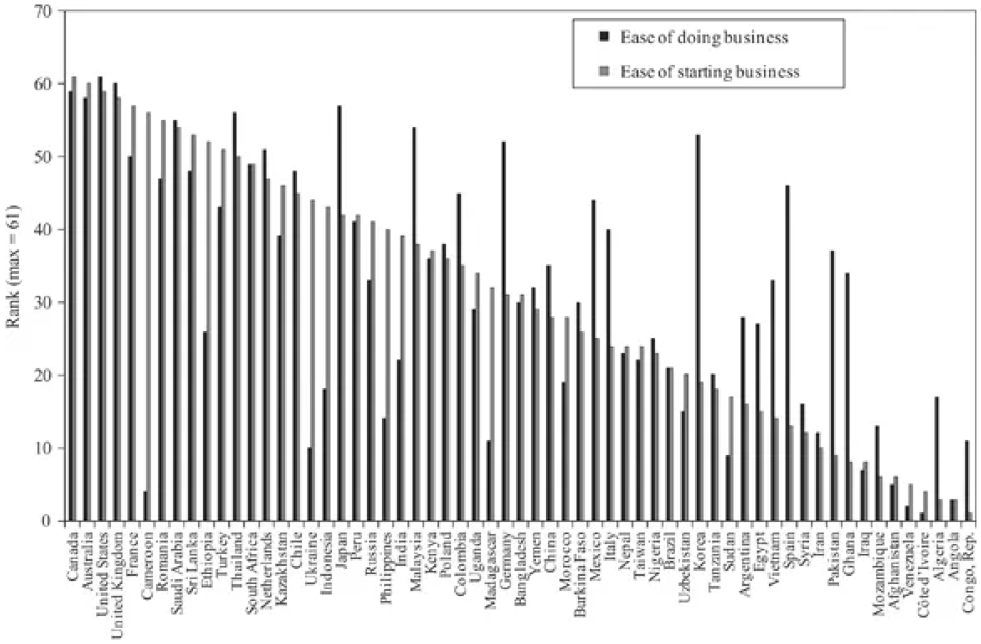
Note. Data retrieved from the European Patent Office patent database (August 2025).
See Appendix G for dataset.

The contrast between Germany and the Netherlands in the number of startups and their origin is not surprising, as the World Bank ranked countries in 2009 based on the global differences in how supportive their environments are for starting and running businesses (Smith et al., 2011), see Figure 11. Smith et al. (2011) note that countries like Germany, that score highly on 'ease of doing business' but lower on 'ease of starting a business', generally see high-growth entrepreneurship driven mainly by established corporations and business groups (p. 8). In contrast, countries where starting a business is easier but where doing business is less so overall tend to have relatively unregulated environments and weaker infrastructure. Since Germany has a much higher 'ease of doing business' than the Netherlands, yet the Netherlands makes 'starting a business easier', this might reflect the higher numbers of startups in Netherlands in comparison to Germany.

Besides, while private R&D is high in Germany, it is concentrated in large companies and specific regions, leading to low R&D expenditure by small and medium-sized enterprises (SMEs or Mittelstand) (0.20% in 2021 vs. 0.42% EU average) (European Commission, 2025). This possibly further reflects the declining share of SMEs engaged in innovation activities in Germany (European Commission, 2025).

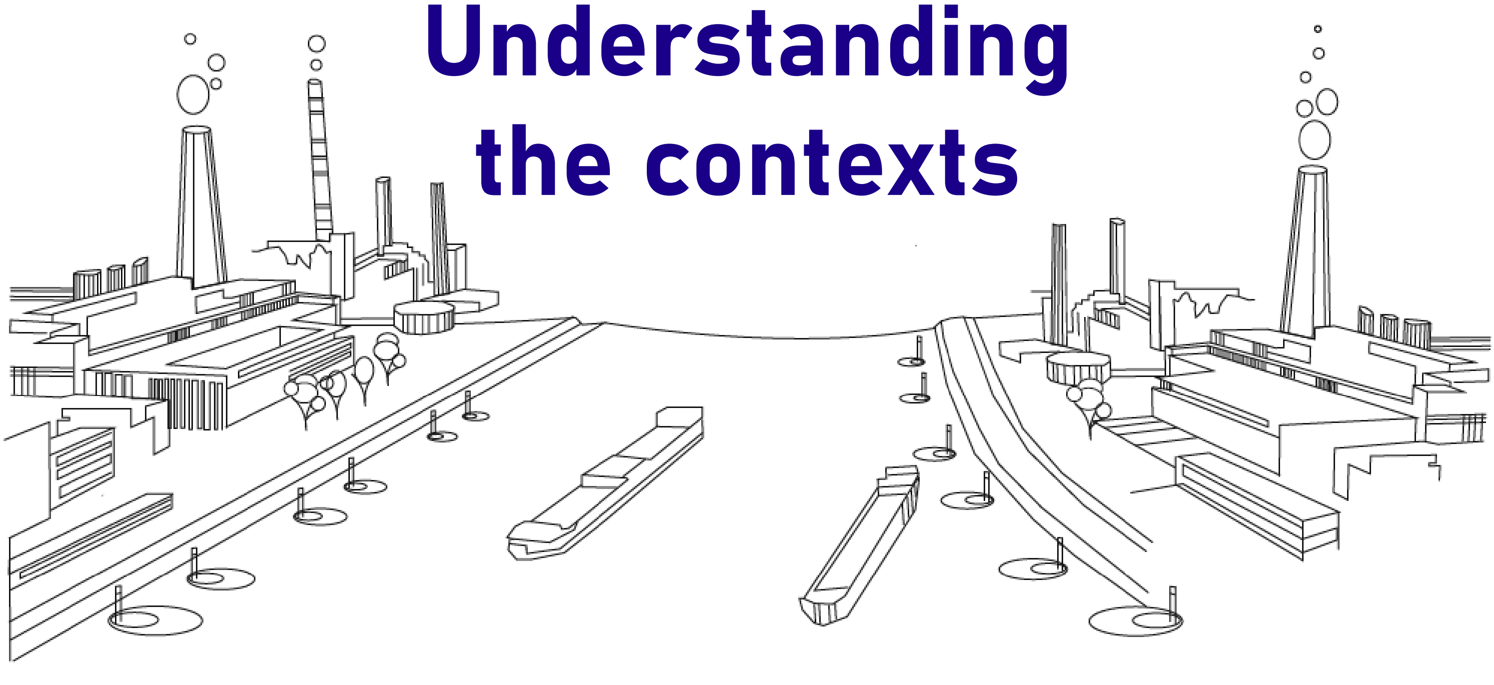
Figure 11

Global differences in supportiveness for starting and doing business. From Smith et al. (2011).



Note. from Smith, J. K., Smith, R. L., & Bliss, R. T. (2011). Entrepreneurial finance: Strategy, valuation, and deal structure. https://search.ebscohost.com/login.aspx?direct=true&scope=site&db=nlebk&db=nlabk&AN=390616

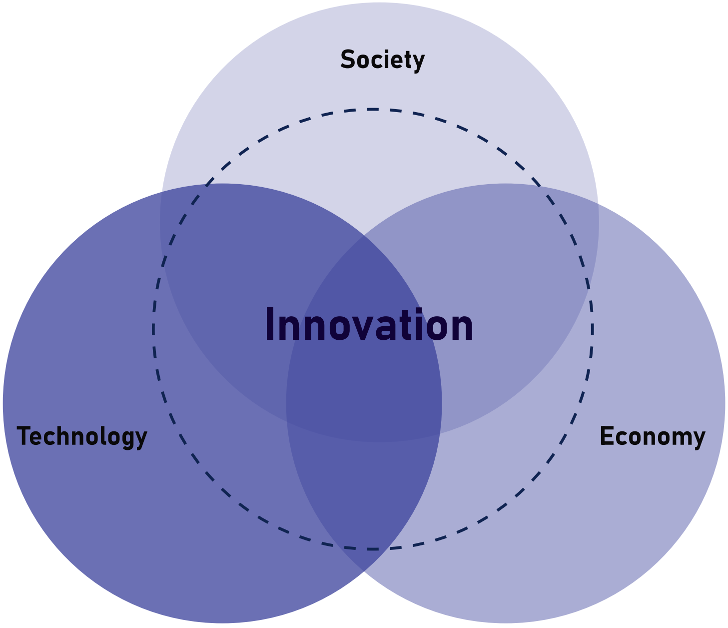
Understanding the contexts



04.2. The contexts contributing to the wave of bankruptcies

To understand the context in which firms develop plastic innovations and the phenomenon in this research referred to as 'the wave of bankruptcies among Dutch pioneering companies in the field of technological advancements in plastic waste management,' I examine the context from technological, economic, and societal perspectives (see Figure 12).

Figure 12
Venn Diagram. The dimensions of an innovation.



Note. Author's own conceptualisation based on literature on innovation.

04.2.1. The role of plastics as a material and recycling advances

The most widely used polymer, classified as a thermoplastic, is polyethene terephthalate (PET), which is predominantly used in textiles, packaging, and, for example, bottles (McNeeley & Liu, 2024). Most can be classified as single-use plastics, as approximately 60 per cent of all polymers are produced for single-use purposes (Franz et al., 2024). Furthermore, most polymers are neither readily biodegradable nor stable; when disposed of in the environment or in landfills, they persist for centuries and can emit harmful substances (Franz et al., 2024). When transitioning towards a circular economy, it is necessary to develop methods for recycling this material (McNeeley & Liu, 2024).

This may not be as simple as it seems, as plastics can contain unknown contaminants, such as dyes and softening agents, which pose challenges to the recyclability of the polymers (López de Dicastillo et al., 2020). These contaminations can lead to a lower quality of the recycled plastics, and eventually, they often find their resting place, after being recycled a few times, in the incinerator or landfill (Geyer et al., 2017).

When plastics are burned, and the heat is used as an energy source, significant amounts of greenhouse gases are released, as plastics are an intermediate product of crude oil (European Environmental Agency, 2022). Incineration can also produce harmful substances that remain in the bottom or fly ash (European Environmental Agency, 2022). Hence, to transition to our circular economy with the aim of a healthy living environment, incineration, even with energy recovery, is not the answer.

To recover plastics, five recycling techniques can be distinguished: primary recycling (reextrusion), secondary recycling (mechanical recycling), tertiary recycling (chemical recycling), quaternary recycling (energy recovery) (Schyns & Shaver, 2021).

The current and most common method for recycling is mechanical recycling (Mamun & Ahmed, 2025). This waste management approach consists of the steps: collection, sorting, shredding, melting, and conversion into secondary raw materials. As stated by Shamsuyeva and Endres (2021), the major advantage is that mechanical recycling is suitable for a decentralised implementation, as the plants are inexpensive and straightforward (p. 3). Mechanical recycling is more ecologically friendly than chemical recycling (Makhija et al., 2024), and it has a relatively low demand on energy resources compared to plants in chemical recycling (Shamsuyeva & Endres, 2021). Nonetheless, since the melting and conversion process occurs at high temperatures, damage to the polymer chain's integrity is not uncommon, resulting in a lower product quality (Schade et al., 2024). Also, recycled polymers must be pure and clean to produce high-quality regranulates (Schade et al., 2024). This leads to mechanical recycling being mainly post-industrial, not for post-consumer waste, such as food packaging (Schade et al., 2024). Thus, to transition to the ideal of a closed-loop recycling system, where waste is fully recovered and does not accumulate in the environment, it is necessary to look beyond mechanical recycling toward chemical recycling.

Chemical recycling breaks the polymer chains to retain monomers, or at least molecules with a low molecular weight (Schade et al., 2024). With chemical recycling, the quality of the polymers is maintained, and degradation and the accumulation of additives can be avoided by purifying the low-molecular-weight recycling products (McNeeley & Liu, 2024). Nevertheless, the use of chemical recycling is not entirely without negative externalities: the process requires substantial energy to break polymer chains, necessitates the cleaning and sorting of raw materials, and not all polymer types are suitable for chemical recycling (Schade et al., 2024).

Another possible solution is to substitute current feedstock plastics with bio-based plastics. However, biodegradable plastics may not, at least in their current usage, provide the complete answer, as the label ''biodegradable'' can encourage consumers to dispose of waste carelessly, neglecting recycling efforts, and ultimately ignoring the high energy content of polymers (de Jong et al., 2025). Furthermore, in the absence of a robust waste management system, bio-based plastics are often landfilled (Elias, 2016). The traditional recycling system remains challenging with developing novel bio-based plastics, as the existing recycling infrastructure is primarily designed for high-volume, fossil-based plastics (de Jong et al., 2025). Also, costs remain a critical factor in determining the competitiveness of biobased polymers (de Jong et al., 2025).

Two types of biobased plastics exist: drop-ins and novel biobased polymers (de Jong et al., 2025). Unlike novel polymers, drop-ins have properties similar to those of polymers derived from fossil-based feedstock (de Jong et al., 2025). The drop-ins can therefore utilise the existing infrastructure of their fossil-based counterparts. This highlights the importance of price parity, as these bio-based materials do not inherently offer performance advantages. Large-scale production from the outset is required to achieve this cost competitiveness, which demands high capital expenditure (CAPEX) to utilise existing industrial infrastructure and mature processing technologies (Murcia Valderrama et al., 2020, as cited in de Jong, 2022). Conversely, bio-based polymers with superior or unique performance characteristics must enter the market at smaller production scales due to the absence of an established market, as this allows for lower initial CAPEX and a more incremental market introduction (de Jong et al., 2025). The transition from the first demonstration plant to plants that enable more standardised, cost-effective production often leads to an enormous price gap of tens of millions of euros per kiloton of product. As explained by de Jonge et al (2025), this disparity is driven by technical and regulatory uncertainties, lack of economies of scale, immature supply chains, and the steep learning curve associated with early-stage deployment (de Jong et al., 2025). Consequently, the initial investment barrier is significant and poses hindrances for the emerging bio-based solutions (Murcia Valderrama et al., 2020, as cited in de Jong, 2022). For these reasons, biodegradable polymers do not appear to offer a universal solution to the plastic waste problem yet.

04.2.2. The role of policy and regulations

A common misperception is that companies developing technologies aimed at reducing environmental impact, referred to as cleantech, are still in their infancy (Croce et al., 2025). This is not the case, as 60 per cent of European cleantech firms were founded before 2000 and are already embedded in industrial value chains, exhibiting high technological readiness (Croce et al., 2025). Thus, companies in cleantech are not just emerging; they are ready to scale; the real challenge lies not in the complexity of the invention, but rather in deployment at scale (Croce et al., 2025). This phase of commercialisation is difficult as cheap imports of virgin plastics from Asia and the United States of America reduce the profitability of recycled plastics, as Marc den Hartog (CEO of Renewi and chair of DWMA recycling sector) states in the article, resulting in stagnating revenues, mounting plastic stocks and recycling companies winding down production (Dutch Waste Management Association, 2024). These market imbalances are leading to lower demand for European-made recycled materials. They also pose environmental and safety risks because of inconsistent compliance with regulations designed to protect the environment and human health. Other constraints include the large amounts of paperwork, long delays in obtaining and renewing permits (Furfari, 2025), and regulations that prohibit direct food contact with recycled PET (Circle economy et al., 2025).

This trend is troubling, as the European Commission has implemented the new Waste Shipments Regulation, which will restrict, and by 2026 may even prohibit, waste exports to non-OECD countries. Hence, the European demand and need for a domestic recycling system is expected to increase (European Commission, 2024).

The key regulations regarding plastics and safeguarding human health and the environment include the Single-Use Plastics Directive (SUPD) and the Packaging and Packaging Waste Directive (PPWD) (Wagemakers et al., 2024). These directives aim to unify how member states manage packaging and waste, explicitly targeting the reduction of plastic waste disposal (Directive (EU) 2018/852 of the European Parliament and of the Council of 30 May 2018 Amending Directive 94/62/EC on Packaging and Packaging Waste, 2018). Waste is also regulated through the Waste Framework Directive (WFD), which formalises waste management and promotes the efficient use of materials by establishing a waste hierarchy, recycling targets, and principles such as the “polluter pays” and “extended producer responsibility” (EPR) (Chandran et al., 2020). Although key laws, such as the PPWR and the SUP Directive, aim to enhance plastics circularity, they do not fully address the competitiveness challenges faced by the European industry (Furfari, 2025).

Besides regulations, the EU is also implementing sustainability reporting and due diligence mechanisms, such as the Corporate Sustainability Reporting Directive (CSRD) (European Commission, n.d.-b).

All member states have implemented various collection and recycling schemes to comply with the European Union’s and national targets (Picuno et al., 2021). However, the different schemes strongly deviate between the member states (Picuno et al., 2021).

The Netherlands has implemented a landfill ban since 1995 on 35 waste streams, including biodegradable waste. Currently, the ban spans over 60 waste streams (European Environment Agency, 2025). Moreover, the government has implemented the Waste Disposal Tax to further regulate the waste management system. This tax is adjusted annually, with an increase, and levied on all waste incinerated, landfilled, or exported to other countries (Netherlands Enterprise Agency, n.d.). Additionally, in non-urban municipalities, a 'pay-as-you-throw' system is implemented to encourage citizens to make a greater effort in separating their waste at the source (European Environment Agency, 2022).

The EPR scheme of the Netherlands applies to all packaging and has only one producer responsibility organisation (PRO), called 'Afvalfonds Verpakkingen or Verpact' (Verpact, n.d.). This organisation, consisting of companies active in the Dutch plastic industry, applies fee modulation between material groups and according to plastic type. Each rate is based on the costs for collecting and recycling the respective packaging material (Verpact, n.d.). Additionally, Verpact applies a fixed amount of general system costs for each material type. Hence, the rates for the waste management contribution are based on the total cost per material complying with producer responsibility (European Environment Agency, 2022).

In addition to financially contributing to the collection and recycling of plastics through the EPR and Verpact, there is a gate fee that needs to be paid to the recyclers (Circle Economy et al., 2025). For non-food plastics, the cost of this gate fee for recyclers to process the material was minus 500 EUR/ton; the market price in 2022 was minus 200 EUR/ton. In comparison, for plastics suitable for food contact (thus excluding recycled plastics), the gate fee for recyclers was plus 700 EUR/ton, with a market price of plus 1,400 EUR/ton, which later that year even rose to plus 2,000 EUR/ton (Circle Economy et al., 2025). This contributes to the uneven playing field (Circle economy et al., 2025).

To support firms active in this industry, the Dutch government has increased the mandatory use of recycled plastics in plastic products to 40 per cent by 2030 (CE Delft, 2022). It aims to introduce a levy of 800 EUR/ ton of plastic (Oerlemans, 2024). Furthermore, the government plans to introduce the blending obligation in 2027, three years ahead of the European regulations (CE Delft, 2022). Solely relying on legislation and regulations may, however, not be sufficient and could potentially even lead to a bounce effect as the imposed levies and the 25-30 per cent recycled plastic blending requirement might disproportionately burden Dutch companies in the plastic recycling even more, consequently further weakening the international competitiveness of the firms internationally as these measures could lead to a 45 per cent decline in sales of plastic products (CE Delft, 2022). As a result, a significant portion of production could be replaced by imported plastic products from abroad (CE Delft, 2022). Next to the expected market shrinkage when these instruments are implemented, there is the effect on environmental waste. The study showed that these policies and regulations are unlikely to have a significant effect on plastics that end up in the environment.

04.2.4. The role of the economic and investment environment

Companies, primarily startups and scaleups, depend heavily on funding to finance the high investment costs and lengthy research and development periods. With the Netherlands among Europe's leaders in venture capital, ranking among the top venture capital investors per capita (Bollen, Hers, et al., 2025), this might not pose challenges at first glance. This might, unfortunately, be further from the current truth than we would like; the Netherlands lags other European countries in its share of venture capital investment in deep tech (Bollen, Kerssens, et al., 2025).

Furthermore, the Netherlands is falling behind in scaling innovations, which hampers the growth and scale-ups of startups (Bollen, Kerssens, et al., 2025). This is evident in the sales from new-to-market and new-to-firm innovations, which are notably below the EU average (67.5%) and have decreased further since 2018 (13.9%), highlighting difficulties in commercialising innovation outputs (Pasimeni et al., 2025b). This trend is not exclusive to the Netherlands, as the current investment climate in the whole European Union is regarded as challenging; market data for 2025 show that the capital raised by European VC funds to date is at a decade low, less than half the amount for the same period last year (Kolodziej et al., 2025). The main constraints for scale-up financing are the availability of capital for portfolio companies, difficulties in fundraising and the exit environment (Kolodziej et al., 2025).

Additionally, geopolitical uncertainty is regarded as the primary challenge for investors in later-growth companies. According to the European Investment Bank's report, the main barriers to scaling companies within the EU are its fragmented markets, access to capital, and investors' risk tolerance (Kolodziej et al., 2025). The shallow capital markets are mainly driven by the development of national markets in silos, with idiosyncratic national rules and practices that hinder cross-border investments (Arampatzi et al., 2025). This fragmentation would eventually hamper the development of these markets, as most are too small and shallow to compete internationally (Arampatzi et al., 2025).

Furthermore, the EIB report (2025) identified the exit and scale-up environment as one of the weakest elements of the European Equity ecosystem (Kolodziej et al., 2025). For companies aiming to scale their invention, banks, pension funds, insurance companies, and asset managers are key investors ranking behind family offices (Kolodziej et al., 2025).

Furthermore, regulatory fragmentation leads to overregulation, bureaucratic complexity, and higher compliance and reporting burdens for companies. These regulatory hurdles and the shallower market often make it simpler and more attractive for companies to expand into the USA than to cross EU borders (Kolodziej et al., 2025; Steinbach, 2018).

04.2.5. The role of labour

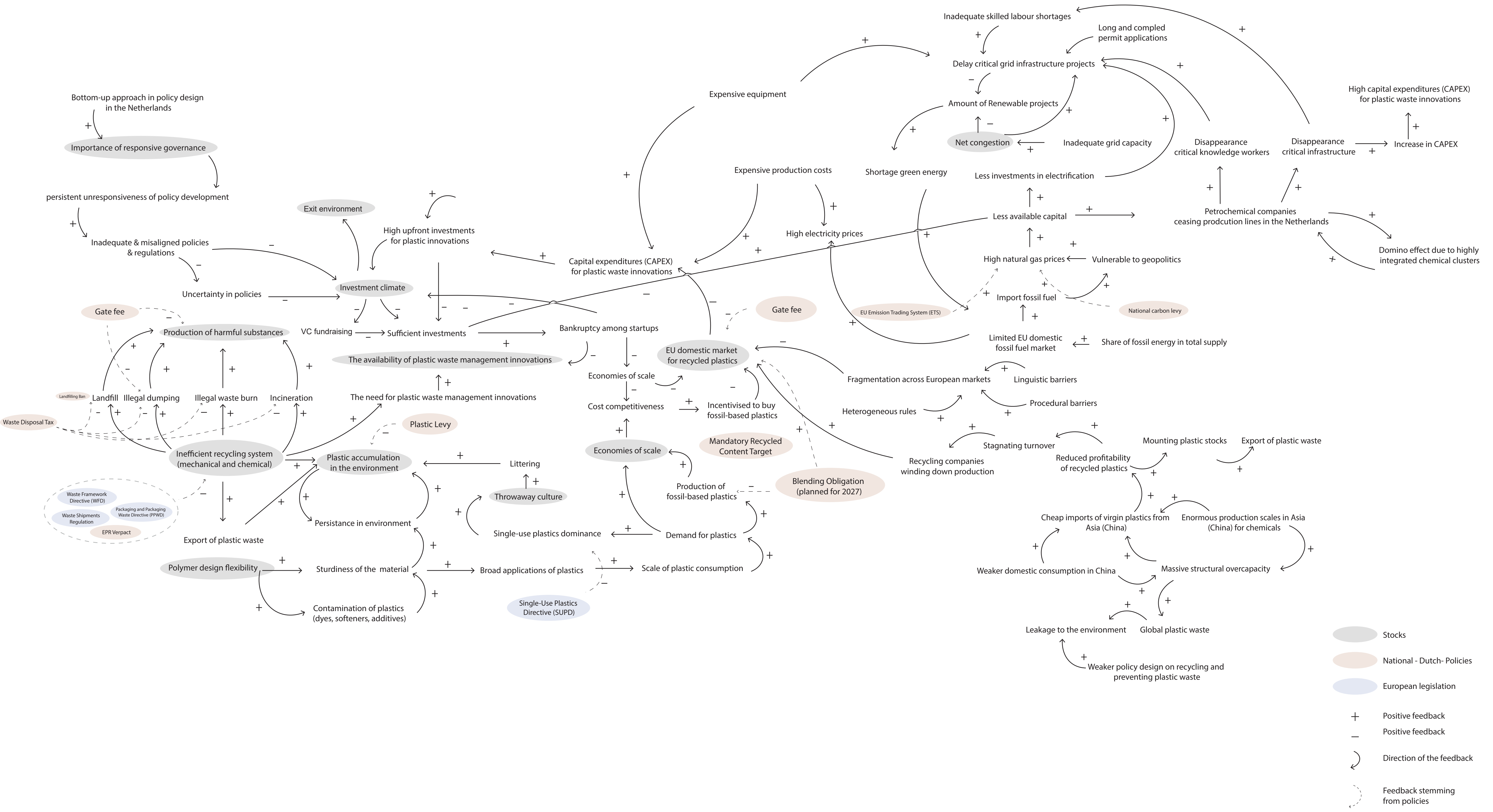
For innovation, not only investments but also a workforce equipped with the skills to implement and adapt to new technologies and digital tools are essential (OECD, 2025b). However, in the Netherlands, labour shortages are, as stated by the OECD (2023), particularly severe (p. 59), especially in STEM (OECD, 2023b, 2025b). This has resulted in smaller firms falling behind larger ones, and initiatives like the 'Accelerating Digitalisation of SMEs', launched in 2018 to help small businesses with the tools needed to succeed in global markets, being held back by the labour shortages (OECD, 2025b).

04.2.6. The causal loop diagram

To grasp how the different causes and effects interact, the underlying drivers and their outcomes, as discussed above, are brought together in a causal diagram (Figure 13). This visualisation does not claim to capture the full complexity of the system, but it makes the interrelations visible in a way that linear text cannot (Haraldsson, 2004). By isolating the principal elements and mapping how they reinforce or counteract one another, the diagram clarifies the depth of the phenomenon and the extent to which these dynamics are intertwined. It serves as a structured entry point into a problem that is otherwise diffuse, fragmented, and difficult to hold in mind all at once (Haraldsson, 2004).

Figure 13

Causal Loop Diagram.



Note. Author's own causal-loop diagram based on the method described in Haraldsson (2004), with adjustments to components and feedback representation.

04.3. The contexts at the macro scale

In this section, I examine the second phenomenon, 'the uneven development of innovation activity within the identified cross-border region'. The analysis centres on the contextual factors shaping this region. Because the region spans both the Netherlands and Germany, two firms, one from each country, serve as the analytical entry points. The contextual analysis starts with an overview of the national contexts in which these firms operate, including their history and a brief overview of the chemical industry.

04.3.1. Brief overview of the chemical industry and its historical context

As quoted by the Executive Vice-President for Prosperity and Industrial Strategy, the chemical industry can be considered as 'the mother of all industries' or as the handmaiden, with over 96 per cent of manufactured goods relying on chemicals (European Commission, 2025b). The modern chemical industry grew in the 1940s and 1950s, as the world wars drove rapid expansion with chemistry discoveries in government, industrial and academic research labs, and collaborations between them laying the foundations for the growing industry (Tickner et al., 2021). Additionally, using oil as a substitute for coal provided the chemical industry with abundant, cheap and easily transportable raw material (Aftalion, 2012). The world wars pushed governments to invest heavily in R&D and manufacturing capacity, in addition to providing a guaranteed market for their products (Smith, 1988). This led to, in solely three years, an output of 1.4 billion pounds annually, which is impressive when considering the initial output of the industry being barely any synthetic rubber (Smith, 1988; Tickner et al., 2021). Alongside government investments and regulation, the 1952 breakup of the conglomerate IG Farben, one of Germany's most innovative companies, caused a disruption in the chemical industry (Poege, 2022). This separation exposed its innovative technologies and resulted in the formation of three major successors (BASF, Bayer, and Hoechst) as well as about a dozen smaller companies (Boon, 2014).

Strategic government interventions, such as the confiscation and distribution of German patents after WO2, and major private-sector investments in highways, pipelines, ports, and other critical infrastructure for the industry's growth, enabled extensive industry growth in the United States (Tickner et al., 2021). After the Second World War, the plant capacity and aviation fuel were transferred to private companies, creating the basis for the growth of petrochemicals (Tickner et al., 2021). Since World War II, the chemical industry has been highly self-reliant, able to manage industrial relations and make strategic planning decisions ith little or no state involvement (Ilgen, 1983). Ilgen (1983) states that the marketplace, not the hand of government, has shaped the future in chemicals (p. 659). This, with a side note, as the government created the marketplace, and even when it did not create the whole future, it did influence the creation of its strong foundation. Due to the industry's commitment to free trade and the benefits of its international activities, it experienced low political visibility (Ilgen, 1983).

After World War II, the world chemical trade expanded more rapidly than chemical production (Ilgen, 1983). By the end of the 1950s, the chemical industry was a major contributor to economic growth, as strong patent protections and a prevailing antitrust climate enabled the rise of new engineering firms that helped perfect chemical processes (Smith, 1998). Additionally, collaboration and licensing helped innovations from the lab to commercialisation and scale (Tickner et al., 2021). According to Ilgen (1983), the chemical industry has been both highly concentrated and highly competitive throughout its history. This is remarkable, as these two things are normally incompatible (Ilgen, 1983). Alfred Kahn, in Adams's (1950) dissertation, argued that both could occur due to the vast capital requirements of the modern chemical industry firm, which pushed the industry towards oligopoly; enormous investment programs demanded healthy profit margins, which could be better assured through market-sharing and pricing agreements (p. 206). He further emphasises a pattern he describes as a ‘bewildering and paradoxical’ cycle of conflict, competition, diplomacy, and cooperation (p. 206). Central to this is an inelastic demand that continues to grow steadily, strengthening friendly or even collusive market relations. In this intrinsic tendency towards cooperation, several forms have been used, including joint ventures, non-invasion of rival giants, preemptive holdings, patent pooling, and the purchase and sale of chemical raw materials among the giants (Adams, 1950). As described by Kahn in Adams’s dissertation (1950), mid-twentieth-century chemical companies often avoided encroaching on each other’s dominant product areas unless they possessed a genuinely novel process or product, producing market relations that were ‘friendly, if not collusive’ (pp. 197–198). However, as Ilgen (1983) shows, the vast diversity of chemical product lines and the continuous flow of innovation make such arrangements unstable. Large firms frequently rely on and defend small, innovation-driven companies as important sources of technological change and essential intermediates (p. 625).

By the end of 1973, the chemical industry appeared to be in a mature phase, lacking rapid internal growth driven by innovation. In this phase, the strategy of leaders in the chemical industry often involved refocusing or diversifying their portfolios of activities across enterprises, akin to a game of Monopoly, without creating genuinely new activities (Aftalion, 2012). In the early 90s, a crisis was gripping the European Chemical industry due to the considerable cost disadvantages that European producers of mass products experienced compared to producers outside Europe (Albach et al., 1996). As further stated by Albach et al. (1996), these cost disadvantages stemmed from higher costs for raw materials, labour, and environmental protection, as well as the global geographical shift in the production of chemicals toward closer proximity to major customers (p. 35). Consequently, companies experienced unprofitable production, and, as emphasised by Albach et al. (1996), it became even more important to concentrate on more refined, more R&D-intensive products (p. 37).

04.3.2. Brief overview of the current European chemical industry

The European chemical industry, which includes petrochemicals, is a fundamental and integral part of the European Economy, given its contributions to production, trade, employment, and investment (Boyanov, 2020). The importance of the industry is demonstrated by the use of its products by both large industrial plants and individual customers in the production of everyday consumer goods, in agriculture, and in production and service activities that produce materials such as fuels, plastics, cosmetics, fertilisers, and crop protection (Lenort et al., 2019). This importance is also reflected in the European economy being largely supplied by the European chemical industry (Cefic, 2025), which has resulted in the chemical industry currently being Europe’s fourth-largest manufacturing sector. Furthermore, the chemical industry is a leading exporter (Eurostat, 2025), and a key contributor to Europe’s trade balance (European commission, 2025b). The main building blocks, such as petrochemicals, ammonia, and chlorine, form the basis of numerous value chains, which leads to the industry being highly interconnected with other industries (European Commission, 2025b).

Nowadays, the largest producers of chemical industry products in Europe are Germany (28.7 per cent), France (13.9 per cent), Italy (10 per cent) and the Netherlands (9.1 per cent) (Lenort et al., 2019). Firms in the European chemical industry have been among the most successful worldwide, composed of all companies that produce their products exclusively or primarily by converting substances (Albach et al., 1996).

Many top companies within the chemical industry are recognisable oil and gas names, including ExxonMobil, Chevron, Shell and state-owned Saudi Arabian SABIC (Tickner et al., 2021). This heterogeneity in products makes the chemical industry distinctive from other industries, which translates, within the chemical industry, to completely different technical/scientific conditions and R&D situations and a high degree of vertical integration within the industry itself; the major raw materials of chemical manufacture are products from themselves, as the chemical industry is its own most important market (European Union, 1996, referenced by Albach et al., 1996).

The large-scale production of chemical products, especially in a (meta-) cluster such as ARRRA, requires a broad range of inputs, with energy being one of the most vital. The industry uses approximately 25-50 per cent of the natural gas it purchases as raw material; the remaining is utilised for generating steam and power for plants and processes (Cefic, 2025), resulting in the primary energy source still being non-renewables (Lenort et al., 2019). The chemical industry is therefore highly dependent on gas prices (Cefic, 2025). One of the reasons why the industry is highly energy-intensive is that the steam crackers, an essential component in chemical production, cannot operate technically below 60 per cent of their capacity (Aftalion, 2012; Lenort et al., 2019). Also, key upstream basic organic and inorganic chemicals, such as ethylene, chlorine, and propylene, are based on energy-intensive processes (Cefic, 2025). Transporting these inputs is important, which has led to an advanced and large-scale cross-border European gas network compared to other regions around the globe, such as China (Lipiäinen et al., 2023; Zhang et al., 2022).

The profitability of producing low-value basic commodity chemicals and materials is only possible through economies of scale, as many key chemicals and materials require extensive, expensive processing facilities (Clomburg et al., 2017). On top of that, many operations require extremely high temperatures and pressures, yielding high operating costs (Tickner et al., 2021). The current state of the chemical industry spans multiple countries and continents, resulting in significant interdependencies and extended supply chains (Tickner et al., 2021). If one country or major supplier starts curtailing production or experiences a disruption, the risk of a shockwave affecting the entire global industry can be expected (Tickner et al., 2021). With the global chemical industry still expected to grow (Lorbeer et al., 2024), the most growth is expected in regions with the least developed policy frameworks and infrastructure, due to bans on certain chemicals and consumer attitudes towards chemicals in products in high-consumption countries (Tickner et al., 2021).

In 2007, 12 of the 30 leading chemical companies in the world were headquartered in Europe (Das & Icart, 2016). Reflecting Europe as a significant, if not the primary, global player in the chemical industry. However, recently, the European chemical industry has shrunk by over 50 per cent since 2003, due to high energy and feedstock costs, lack of domestic demand, high labour costs, environmental regulation, geopolitical tensions, and low market demand (Cefic, 2025; Das & Icart, 2016). This has resulted in the closure of more than 20 major production sites within the European Union, including steam crackers and other upstream facilities used for producing fundamental building blocks (European Commission, 2025c). The closure of crackers and other production sites may ripple through the entire chemical ecosystem, putting over 200,000 direct jobs at risk (European Commission, 2025c). On top of that, the industry is facing intense competition from emerging economies, especially from Asia and the Middle East (Das & Icart, 2016). European countries face the decline of the chemical industry differently; in the Netherlands, the decline was the largest, at 6.8 per cent, France registered a decrease of 5.2 per cent, and Germany registered a decrease of 2.6 per cent (Cefic, 2025).

Currently, most chemical companies are concentrated in six EU countries: Germany, France, Italy, the Netherlands, Spain, and Belgium. Germany has the highest number of companies, with over 140,000, followed by France and Italy (Das & Icart, 2016).

04.3.3. The Chemical Industry in the Dutch Economy

(Socio-)Economical context

Amid the global pandemic, the energy crisis, and current geopolitical turmoil, the Dutch economy has faced challenging periods. Nevertheless, according to the OECD Economic Survey (2025c), the Netherlands weathered these global crises well, as evidenced by the fact that the money received from international transactions exceeded that sent out, thereby demonstrating strong trade competitiveness (p. 12). Contributing to the competitiveness is its advanced infrastructure, highly skilled workforce, and one of Europe's most developed digital networks, characterised by strong connectivity, robust data centre capacity, and extensive broadband coverage (Bollen, Kerssens, et al., 2025). Furthermore, the country's open trade regime, strategic geographic position, and efficient logistics have made it a key European gateway economy (OECD, 2025c). Yet, as mentioned, this same openness also creates vulnerability to global shocks, geopolitical fragmentation, and supply chain disruptions, particularly given the country's dependence on imported energy (OECD, 2025c).

Currently, the Dutch industry is concentrated in five major industrial clusters, structured around shared infrastructure and supply chains (International Energy Agency, 2025). This cluster model supports cost-efficient decarbonisation by internalising economies of scale and promoting knowledge spillovers, for example, through shared energy infrastructure and innovation networks (OECD, 2021a). However, it may also lock in geographic and sectoral resource allocation, reducing flexibility and adaptability in the long run, which is seen as a potential constraint for achieving carbon neutrality by 2050 (OECD, 2021a).

Collaboration is deeply embedded in the Dutch innovation system. The traditional polder model of consensus and cooperation encourages extensive public-private partnerships, particularly in the chemical industry, where SMEs, multinationals, research institutions, and universities collaborate closely in research and development (R&D) (Stankiewicz & Jongsma, 2012).

The focus on trade also applies to energy commodities. Following the closure of the Groningen gas field, the country shifted from being a major producer and exporter to a net importer (International Energy Agency, 2025b). However, it continues to play a central role in the European gas trade through LNG terminals in Rotterdam and Eemshaven, with the government planning to expand these facilities to enable the import of green hydrogen via Eemshaven (International Energy Agency, 2025b). Hydrogen already plays an increasingly significant role in the Dutch energy landscape, making the Netherlands the second-largest hydrogen consumer in Europe and the largest per capita, with roughly one-third of hydrogen currently produced from natural gas in industrial processes (International Energy Agency, 2025), which is noteworthy, as the European Commission (2025c) has emphasised hydrogen as necessary for staying cost-efficient and key for the decarbonisation of various chemical products (p. 8).

Industrial policy

As the Netherlands is a member state of the European Union, it has, beyond national laws and regulations, laws and legislation that transcend borders (Ministerie van Algemene Zaken, 2012). Consequently, the European directives are obliged to be implemented into national policies and regulation (Leiden University, n.d.). This may sound easy, yet the European policy landscape is evolving rapidly, with the European Green Deal a notable example. The European Green Deal aims to transform the EU into a resource-efficient and competitive economy with no net GHG emissions by 2050 (European Commission, n.d.). It is notable for aiming to revise the EU's climate and energy legislation by June 2021, including the European Energy Tax Directive and

the EU ETS Directive (European Commission, n.d.).
Policies in the Netherlands are primarily based on a bottom-up approach, informed by detailed information provided by large firms, sectors, and clusters (OECD, 2021). In May 2019, the Dutch Parliament passed a new Climate Act, mandating a reduction in domestic greenhouse gas emissions by 49 per cent by 2030 compared to 1990 levels, and 95 per cent by 2050 (OECD, 2021). In particular, the chemical industry must cut its emissions by 59 per cent by 2030, as it is the heaviest emitter in the country, representing 44 per cent of all industrial emissions (European Commission, 2025c). This is also seen in the regional clusters in the Netherlands that are the heaviest emitters: Rotterdam-Moerdijk, Smart Delta Resources (Zeeland), Chemelot (South-Limburg), Noord Nederland (Eemshaven, Delfzijl, and Emmen), and Noordzeekanaalgebied (Amsterdam-IJmuiden) (OECD, 2021).

As mentioned, electrification is important towards a more sustainable paradigm. However, the main challenges in transitioning to renewables stem from capacity constraints in the Dutch grid (OECD, 2025b). Beyond the elevated network charges, the lack of compensating measures in national policy frameworks significantly contributes to the overall cost burden (Bollen, Hers, et al., 2025). The Netherlands is consequently classified among the countries offering the least energy-cost support and is currently experiencing end-user electricity prices, resulting in energy costs of roughly €95/MWh (Bollen, Hers, et al., 2025). High energy prices are not new for the country, which has long faced structurally higher costs than, for example, the United States (OECD, 2021). What is different today is the scale of the divergence, widening an already persistent transatlantic cost gap (OECD, 2021). According to Bollen, Kerssens et al. (2025), Dutch industrial gas prices are also higher than in neighbouring countries. They identify the national carbon tax as an important factor. Although it was introduced to stimulate cleaner production, it now functions largely as a revenue-generating tax, thereby contributing to higher gas prices (p. 301). The lack of cost offsets made energy production relatively expensive compared with neighbouring countries, especially in energy-intensive industries such as the chemical sector.

To relieve pressure on large energy consumers, the Dutch government has justified granting extensive preferential treatment to energy-intensive users, such as parts of the chemical sector, on the grounds of maintaining industrial competitiveness (OECD, 2021). This preferential treatment takes the form of energy tax exemptions, lower tax rates for large consumers, and generous free allocations of emission allowances. However, these benefits are unevenly distributed across firms and sectors (OECD, 2021). They are granted primarily on the basis of energy intensity and scale, rather than on a careful assessment of each sector’s exposure to international competition or its actual carbon intensity (OECD, 2021). As a result, small firms typically face much higher energy and carbon prices than large incumbents. In practice, this means that large energy users benefit from lower tax rates simply because of their size, while smaller producers pay a proportionally higher tax rate.

Another constraint in the current design of the energy tax is that the tax is applied uniformly per unit of electricity consumed, without differentiating by the carbon content of the energy source (OECD, 2021). Consequently, the tax increases the cost of both renewable and fossil-based electricity without encouraging a shift toward cleaner generation or providing direct incentives for decarbonising the power sector. This design makes continued reliance on fossil-fuel-based electricity financially more attractive than it should be from a climate-policy perspective (OECD, 2021). On top of this, the revenues stemming from the energy tax usually go into the Dutch government budget (Bollen, Hers, et al., 2025). The generous exceptions for certain industries and the low tax rates for large energy consumers contribute to energy-intensive industries

paying less tax (OECD, 2021). Subsequently, contributed less to the Dutch green tax efforts.
A significant energy tax was the ODE, implemented as of 1 January 2013, to stimulate the transition from fossil fuels to sustainable energy (OECD, 2021). The ODE was a separate levy on natural gas and electricity, in addition to the energy tax (OECD, 2021). The central policy objective of the ODE is to fund payments to renewable energy projects under the Sustainable Energy Production Scheme (SDE++) (de Vries et al., 2024). From 2023 onwards, the Dutch government has simplified the energy taxation and ODE levy by incorporating the ODE surcharge rates into the energy tax (Vattenfall, n.d.). Consequently, all the ODE rates for 2023 were zero and will be abolished from 2024 onwards (Vattenfall, n.d.). The revenues from the Energy Tax are used to finance the SDE++ subsidies (de Vries et al., 2024).

Lastly, another noteworthy scheme is the EU ETS, which is based on a 'cap and trade' principle, with the cap reduced annually in line with the EU's climate target (European Commission, n.d.-a). This policy is expressed in emissions allowances, with one allowance entitling the holder to emit 1 tonne of CO2 eq (European Commission, n.d.-a). Companies pay a direct fee for their emissions (the 'polluter pays' principle). The ETS creates a financial incentive to reduce emissions, as investing in cleaner production can eventually become cheaper than continuously purchasing emission allowances (de Vries et al., 2024). However, this is only part of the picture. At the same time, the ETS encourage incremental improvements; the incentives for large-scale technological shifts are lowered when clean technologies receive fewer or no free allowances (Flues & Dender, 2017). Additionally, neighbouring countries use ETS revenues to offset energy-related electricity costs in industry; however, this is not the case in the Netherlands, where the revenues are directed to the national budget (TNO, 2025).

Even with tax exemptions for large energy consumers, energy prices remain high, as shown by the struggles of the Dutch and European chemical industries (Bollen, Hers, et al., 2025). This is reflected in LyondellBasell and Tronox stopping chemical production in Rotterdam, citing high energy costs as the main reason (Bollen, Hers, et al., 2025). Shortly after LyondellBasell and Tronox announced their plans, chemical giant SABIC also announced it was exploring whether to continue its operations in the Netherlands, citing high energy prices as the main reason (Bollen, Hers, et al., 2025). This trend will ultimately result in a structural loss of productivity, earning power, and GDP since the loss of industrial value cannot be compensated by less energy-intensive sectors such as the service sector (Bollen, Kerssens, et al., 2025), which might be troubling as the Netherlands might lose its strategic chains with the chemicals in the Rhine-Ruhr in Germany (Bollen, Kerssens, et al., 2025). The Dutch industry accounts for about 20 per cent of total corporate income tax revenues, with the chemical industry contributing around three billion euros (Bollen, Hers, et al., 2025).

Innovation and deployment policies

Despite the OECD's critical eye on industrial energy policies, it also recognises the Netherlands as a leading nation in terms of green tax expenditures, which increased from 0.31% to 0.46% of GDP between 2019 and 2022 (OECD, 2025b). This primarily stems from the transition of the SDE+ subsidy to the SDE++ scheme, which encompasses climate-mitigation technologies across varying sectors (OECD, 2025b). Furthermore, subsidies to encourage renewable energy generation and the adoption of net-zero technologies increased from 0.46% to 0.81% of GDP during the same period (OECD, 2025b). However, despite the rising trend in grants and subsidies, tax expenditures remain the main method of industrial policy used by the Dutch government (OECD, 2025b).

The Dutch support policy for low-carbon technologies prioritises the cost-efficient deployment of relatively mature technologies through several subsidy programmes, with the SDE++ as the central instrument. This is shown in the Netherlands, where the focus is more on deployment and demonstration than on the early research and development (R&D) phase (OECD, 2021). However, the total funding available for demonstration projects is not proportional to the investment scale required in the industry: for example, a single 100 MW electrolyser costs around EUR 50–75 million, while total national funding for demonstration amounts to less than EUR 300 million per year (OECD, 2021). Furthermore, the Dutch government is reducing the Research and Science Fund by 125 million euros (Baarsma, 2024). Additionally, it aims to gradually phase out the National Growth Fund, removing the 6.8 billion euros in unallocated funds reserved for future investments (Baarsma, 2024).

The main support instruments in the Netherlands, the abatement payment SDE++, the corporate tax allowances, energy investment allowances (EIA) and MIA) (Nederland (RVO), n.d.), rely on an updated list based on firms' suggestions (OECD, 2021). This bottom-up approach enables the government to fine-tune support at a granular level, ensuring it aligns with the specific needs of individual firms. Nevertheless, as stated by the OECD (2021), this also highlights the need for good governance, making it even more acute and necessitating flexibility and responsiveness in policy-making (OECD, 2021). Furthermore, in 2023, the Netherlands ended the temporary cost compensation (IKC-ETS), a discount on electricity costs for large consumers (TNO, 2025).

For the earlier stages of technology development, the Netherlands implements instruments that apply broadly across sectors (such as R&D tax credits), which benefit technologies already close to market rather than early-stage, high-risk innovations (OECD, 2021b). For SME innovation, the Netherlands relies mainly on the WBSO and MIT schemes, which offer tax deductions and regional innovation grants, comparable in purpose to Germany's ZIM and IGF programmes (OECD, 2021b).

04.3.4. The Chemical Industry in the German Economy

(Socio-)Economical context

In the immediate post-war period, the German economy was described as Wirtschaftswunder (economic miracle) (Naudé & Nagler, 2021). The growth was driven by institutional factors, including the country's reconstruction under the Marshall Plan, the introduction of social-market policies, and the success of SMEs, or the so-called Mittelstand, in expanding their exports to global markets (Naudé & Nagler, 2021). By the end of 1900, Germany had become Europe's largest economy and the second largest worldwide, establishing itself as one of the world's leaders in science (Naudé & Nagler, 2021; OECD, 2025b). The remarkable rise of German industrialisation and socio-economic development was likely driven by advances in education and scientific establishments, the entrepreneurship and business community, and government support. In other words, it exemplifies the triple-helix model of innovation and development (Mroczkowski, 2014).

Another contributor to this triple helix was the establishment of the Fraunhofer Society in 1949, which comprises many research laboratories conducting applied research on industrial innovation to improve industry competitiveness (Beise & Stahl, 1999). With Max-Planck Institutes, designed to complement research at universities and often located close to each other, the Fraunhofer Institute established itself as the leading contract institution for industrial innovations in Germany (Beise & Stahl, 1999). Furthermore, Germany has a well-functioning higher education system, with mature, institutionalised public-private coordination and cooperation that supply skills suited to the needs of the innovation system (OECD, 2022).

According to OECD (2022), this was mainly caused by ‘The Humboldtian’ university model, which has historically emphasised research, knowledge generation and intellectual inquiry, together with the country’s well-regarded technical universities, which focus on engineering and applied sciences, have contributed to Germany’s rich supply of well-educated labour-market entrants (p.34). Furthermore, the OECD (2022) notes that Germany’s strong innovation performance is partly driven by the close collaboration between universities and industry, which ensures that people develop the skills needed in the workforce (p. 34). In addition, Germany’s well-developed vocational education and training (VET) system, which focuses on practical, occupation-specific skills, is highlighted as a key factor supporting the country’s capacity to adopt and apply innovations (OECD, 2022).

The close collaboration between universities, which also serve as research institutes, and entrepreneurs enabled inventions to be quickly adopted and commercially applied. This growth was especially evident in the chemical and pharmaceutical sectors, as major companies like BASF, Bayer, and Höchst established private industrial research laboratories in the 19th century, primarily to invent and commercially utilise innovations (Mroczkowski, 2014). The rapid increase in innovations and inventions was notable, with many companies tracing their origins to this period. Collaboration between research institutions and universities was crucial, and government efforts significantly contributed to the rapid growth in innovation (Mroczkowski, 2014).

Beyond supporting education, the government promoted the railway system, facilitating the transportation of heavy machinery and enabling trade with neighbouring countries, which expanded further afield (Kopsidis & Bromley, 2014). Only in two decades, from 1871 to the present, did Germany experience negative GDP growth during the 1910s and 1940s, both due to war (Mroczkowski, 2014). In that period, many scientists and their knowledge fled the country, ultimately ending up in the United States. This exodus notably boosted patent activity in the United States, especially in the chemical and pharmaceutical industries, leading to a rise in patent filings in this field (Mroczkowski, 2014).

Nowadays, the rise in globalisation and the restructuring of companies and industries has led to a new business model in Germany, bringing together raw material suppliers, chemical manufacturers, intermediates, speciality-chemicals producers, infrastructure, and service providers at a single site: the industrial chemical site (AIChE, 2011). In recent years, large conglomerates have become smaller businesses, focusing on core competencies, and high-performing speciality chemicals have consequently emerged in Germany (AIChE, 2011). While large firms are in Germany among the most significant business-sector players in innovation, they are the minority, as 99 per cent of German firms have fewer than 500 employees, which is referred to as the Mittelstand (OECD, 2022).

Industrial policies

Germany’s Climate Ac tion Plan 2050, adopted in 2016, reaffirmed the Paris Agreement target of achieving carbon neutrality by mid-century and set a 2030 milestone requiring a 49–51 per cent reduction in industrial GHG emissions from 1990 levels (OECD, 2025a).

The 2021 energy shock hit Germany particularly hard due to its large manufacturing base. Between late 2021 and early 2025, production in energy-intensive industries declined by roughly 15 per cent, and overall investment fell 6.3 per cent compared to 2019 (European Commission, 2025a). The economic slowdown coincided with a structural shift in trade relations: China moved from being a key export market to a direct competitor, notably in machinery, automotive, and green technologies (European Commission, 2025a). While declining wholesale energy prices helped contain inflation, they also compressed producer margins and delayed investment in renewables, storage, and industrial decarbonisation (European Commission, Directorate-General for Economic and Financial Affairs, 2025).

The COVID-19 pandemic and Russia's war of aggression against Ukraine exposed several vulnerabilities in Germany's export-oriented economy, particularly its heavy reliance on Russian energy imports and its exposure to global supply chain disruptions (OECD, 2025a). The war also forced Germany to rapidly diversify its energy imports away from Russia, shifting towards suppliers such as Norway, the Netherlands, Belgium and the United States (OECD, 2025a). Alongside these shocks, Germany's economic resilience is also affected by pre-existing structural issues, such as slow digitalisation and concentrated supply chains (OECD, 2025a).

Between 2019 and 2022, Germany's industrial policy shifted from emphasising energy-cost relief and R&D to prioritising decarbonisation technologies, while keeping R&D a constant pillar (OECD, 2025). Furthermore, the 2022 energy-price crisis led to broad, non-industrial fiscal measures, such as general energy-tax reductions and price caps, rather than targeted industrial interventions. These were complemented by federal efficiency programmes, including SME energy audits and the KfW Energy Efficiency Programme, as well as a growing portfolio of funds supporting large-scale deployment of low-carbon technologies.

Nevertheless, as the OECD (2021) notes, funding remains concentrated on CAPEX, with insufficient OPEX support to close the cost gap between fossil-based and low-carbon processes. Furthermore, Germany is promoting energy research and development in its energy transition strategy, as the government allocated 1.5 billion euros to energy transition research funding (International Energy Agency, 2025a).

Industrial energy-cost support in Germany predominantly benefits manufacturing, as horizontal relief schemes and energy tax reductions largely favour high-consumption sectors (European Commission, 2025). The government also expanded green finance: green loans increased from 0.3 to 0.4 per cent of GDP between 2019 and 2022, driven by the KfW Renewable Energy Program Standard 1 and the BEG Non-Residential Buildings loan scheme. The BEG Non-Residential Buildings subsidy accounted for approximately 0.17 per cent of GDP in 2022, and regional programs, such as the NRW Bank Universal Credit, added further capacity (European Commission, 2025). In sum, Germany relies more heavily on subsidies, which are often sector-specific and partnership-based, especially compared to the Netherlands, which uses a broader mix of tax allowances and loans.

Furthermore, Germany does not impose a national cap when compensating for industrial electricity costs; instead, compensation is directly linked to ETS revenues (TNO, 2025). Moreover, the focus is on the installation level rather than individual companies (TNO, 2025), leading to reduced electricity costs and more targeted compensation.

Regarding skills and human capital, the STEM Action Plan 2.0 promotes education and retraining in fields vital to the energy transition, such as heat-pump installation and other technologies crucial for decarbonisation (International Energy Agency, 2025a).

Innovation and deployment policies

Germany's innovation ecosystem is decentralised and comprises over 1,000 publicly funded research institutions (OECD, 2025a). This decentralisation and regional autonomy allow German innovation policies to align more closely with local industrial priorities (OECD, 2022). However, as Naudé and Nagler (2021) point out, Germany is currently facing a slowdown in innovation, reflected in entrenched institutions, diluted incentives for science and entrepreneurship, and limited diffusion of digital technologies across firms. Germany's innovation model focuses heavily on internal, incremental development within established industries rather than on radical innovation or new-firm creation (Pasimeni et al., 2025a). Moreover, German policies place greater emphasis on R&D projects and fundamental research than those in the neighbouring countries, such as the Netherlands. Despite the innovation slowdown, Germany continues to outperform the EU average: it ranks highest in high-tech imports and employment within innovative enterprises, and the European Commission identifies business R&D expenditure per employee as a key strength (Pasimeni et al., 2025a).

In addition, knowledge transfer from public research to commercial applications remains weak, constraining the creation of new products and services (Naudé & Nagler, 2021; OECD, 2025b). Germany has a targeted grant funding system as one of its main policy instruments supporting SMEs in their innovation endeavours, thereby providing direct funding (Naudé & Nagler, 2021; OECD, 2022, 2025a).

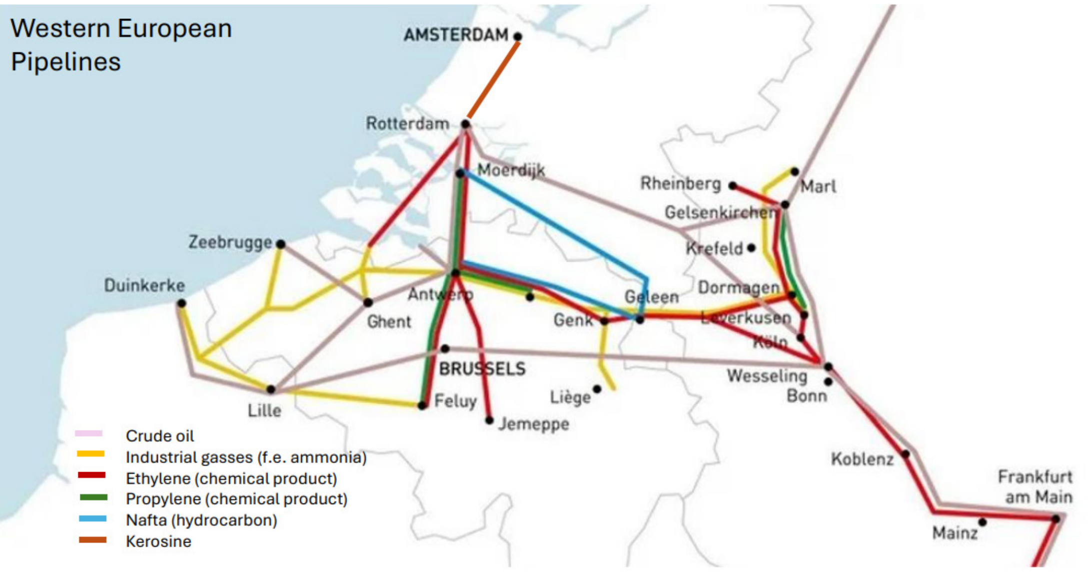
The impact of weakening innovation dynamics has been offset by Germany's export-led growth model (OECD, 2025a). However, the economy now faces stagnation in GDP and declining exports, signalling a gradual loss of market share, particularly in China and the United States (European Commission. Directorate General for Economic and Financial Affairs., 2025). Employment growth has also slowed, especially in manufacturing. At the same time, job creation has been partly offset by gains in public services, education, and healthcare (European Commission, Directorate-General for Economic and Financial Affairs, 2025). The chemical industry, one of Germany's most significant globally and the second-largest industrial energy consumer, remains a cornerstone of this transition and a significant focus of decarbonisation policy (International Energy Agency, 2025a).

04.4. The context at the meso scale

The ARRRA cluster is the most highly industrialised and integrated (petro-)chemical cluster in Europe (Patrahau et al., 2022). Within the ARRRA, Antwerp is the largest European chemical hub, as 90 per cent of the 720 km of pipelines in the port is used to transport chemicals and petrochemicals (Patrahau et al., 2022). Figure 14 shows the ARRRA cluster with its extensive pipeline system. Even though Germany is one of the largest producers of chemicals in Europe, the chemical hubs are mainly situated near the Netherlands and Belgium (Patrahau et al., 2022). As a result, most chemicals are also stored in these countries (Patrahau et al., 2022)

Figure 14

Pipeline infrastructure ARRRA cluster. From Ports of Rotterdam & Antwerp-Bruges (2025).



Note. Adapted from Ports of Rotterdam & Antwerp-Bruges (2025), Value creation for Europe (Ports of Rotterdam and Antwerp-Bruges).

The clustering of companies in this cluster generates synergies and economic advantages by offering shared networks, suppliers, distributors, markets, resources, and support systems (Heikkilä et al., 2010). Furthermore, it provides increased networking opportunities between businesses and the surrounding community, enhances economies of scale through diverse stakeholders, improves connectivity among stakeholders, and boosts capacity in resources and skills base (Heikkilä et al., 2010). Especially in the chemical industry, where many input factors are used to produce many bulky and costly outputs, co-location, leading to clustering, is a frequently occurring phenomenon (Ketels, 2007). One of the most important drivers for chemical companies to co-locate is transportation costs and risks, creating an environment in which companies naturally tend to cluster across different stages. This is especially true since the geographic locations of key feedstock inputs do not match those of key markets for chemical products (Ketels, 2007). The extensive 1,600 km pipeline network plays a critical role in transportation, enabling products to be easily moved to chemical sites. In addition to transporting raw materials such as naphtha, hydrogen, liquid hydrocarbons, ethylene, propylene, fuel oil, and crude oil, the pipeline network connects important assets, including refineries.

When domestically produced feedstock is insufficient to meet the chemical industry's needs, plants can obtain supplies directly from import terminals at ports (Patrahau et al., 2022). This highlights the benefit of clustering import and storage terminals with industrial facilities. Next to the pipeline network is the transportation over inland waterways, for example, via the Rhine River (Patrahau et al., 2022). Proximity to a seaport, which facilitates sea freight, is therefore a factor in selecting a chemical site location (Kimm, 2008). The largest ports in Europe are the Netherlands (Rotterdam) and Belgium (Antwerp). The high level of integration among ports within the clusters enables them to mitigate operational disruptions (such as steam cracker outages) and facilitate the efficient exchange of key intermediates, such as ethylene and propylene (van der Reijden et al., 2021).

As a result, chemical production facilities are often situated near transportation and logistics hubs and tank storage companies, as the chemical industry is directly supported by these storage companies, considering that about half of all naphtha produced in Europe comes from the ARRRA cluster, and the meta-cluster is largely reliant on it (Ketels, 2007; Patrahau et al., 2022). In the production of naphtha, the Netherlands plays a key role, supplying most of the critical raw material to the meta-cluster (Patrahau et al., 2022).

In addition to strategic co-location to improve proximity, it does more than just facilitate material movement; it also underpins comprehensive research and design efforts. Chemistry research often requires costly equipment, collaboration among large teams, and considerable time to turn ideas into commercial products (Adams, 1950). Furthermore, the commercial development and use of new products tend to be costly, making larger investments more efficient than smaller ones and thereby encouraging cooperation and co-location (Adams, 1950).

Next to cooperation, competitive dynamics are a crucial force in cluster formation and, thereby, in the evolution of the chemical industry meta-cluster. The relationships between chemical producers and their suppliers are often highly complex and varied due to vertical integration between producers and suppliers, which can even involve operating within the same corporate entity (Patrahau et al., 2022). While in a purely market-driven context, product substitution would typically be based on straightforward trade-offs between cost and performance. This is not the whole picture within the ARRRA cluster. Here, the influence of spatial clustering and governmental frameworks means that firms do not make portfolio decisions based solely on market logic (Meijering & Jabbe, 2021). Instead, their choices are also guided by shared infrastructure, policy incentives and regional interdependencies (Heikkilä et al., 2010; Kimm, 2008; Meijering & Jabbe, 2021). As a result, the industry's direction is shaped by more than just competition; it reflects the combined pressures of cooperation, co-location and public governance. Thus, the strategic choices in the meta-cluster cannot be seen in isolation from the surrounding industries and market conditions, as well as global and regional governance and politics.

In short, the chemical parks in the Rhine-Ruhr can be considered clusters in their own right, integrated into the energy and material flows (Schneider et al., 2025). The geographical location of the chemical sites is strategically chosen with two aspects in mind: first, the availability of feedstock, and second, the ability to transport sales products (Kimm, 2008).

To enhance cooperation in the cluster, stakeholders initiated the Trilateral Chemical Region.
The success of this initiative is complex, as the region spans three countries, making strategic policy alignment difficult (Meijering, 2022). Institutional governance adds further complexity, as numerous departments oversee the meta-cluster, each responsible for specific elements of the system, often with divergent or conflicting mandates stemming from regional, national, European, or international legislation (Meijering, 2022). Furthermore, cross-border cooperation continues to face regulatory, financial, and administrative hurdles that companies and research institutions encounter due to cross-border financing or differing regulations regarding energy, climate, or waste (Trilateral Chemical Strategy | STIP Compass, n.d.).

04.5. The context of the clusters at the micro scale

04.5.1. Chemelot in Geleen (Avantium)

The cluster in Geleen, called Chemelot, is a well-known industrial complex in Limburg, near Geleen, Figure 15 (van Bree et al., 2020). Its focus is on producing basic chemicals, biomedical and sustainable materials, serving various applications and markets (van Bree et al., 2020). The site is energy- and feedstock-intensive, relying primarily on electricity, fuel, and naphtha (Oliveira & van Dril, 2021). On top of that, the cluster maintains strong collaborative ties with neighbouring areas outside the Netherlands, notably the industrial clusters in Germany, Belgium and France (van der Reijden et al., 2021).

Figure 15

Location of Chemelot, Geleen.

From the beginning, Geleen has experienced strong government influence, with many key industrial breakthroughs during the first half of the 20th century being significantly supported by state initiatives (Meijering & Jabbe, 2021). The government's role in the development of the chemical industry is evident in its management of the closure of mines in Limburg, with part of the deal involving the same company that would, with government backing, invest in expanding (petro-)chemicals production in Limburg to offset the loss of mining activities and preserve jobs (Meijering & Jabbe, 2021). This demonstrates the national authority's ability to shape markets and establish the entire chemical industry in Geleen from scratch (Meijering & Jabbe, 2021).

Chemelot comprises approximately 150 closely interconnected firms, including major incumbents such as DSM-Firmenich, OCI Nitrogen, Arlanxeo and SABIC (Oliveira & van Dril, 2021). Rather than a fragmented collection of industrial zones, Chemelot constitutes an integrated site, hosting 60 production facilities across 800 hectares (van Bree et al., 2020).

Additionally, the site is strategically connected via pipelines for natural gas, naphtha, and ethylene to Antwerp, Rotterdam, and the Rhine-Ruhr region, forming part of the broader ARRRA cluster (van Bree et al., 2020). As further stated, it also benefits from a 150 MW combined heat and power facility, extensive steam and gas networks, and a district heating system for the nearby city of Sittard, which is currently under development. (van Bree et al., 2020, p. 50). Moreover, according to this TNO report, the industrial zone employs around 8,000 individuals, while 16,000 work in related services such as logistics, maintenance, security, and catering (p. 51). Additionally, 150 companies and 850 students are located within the cluster (van der Reijden et al., 2021).

With the site's extensive steam and gas network, the companies operating there are committed to maintaining high cooperation and integration. This cohesion enables the site to function as a highly coordinated system (van Bree et al., 2020). However, such tight interdependence comes with significant vulnerabilities. A change within one company may have direct consequences for others. For instance, due to the site's power infrastructure's cascading and optimised design, removing a single process may disrupt the power supply to other facilities (van Bree et al., 2020). This interconnectedness presents a substantial barrier to energy-related sustainability transitions, as the report further highlights that removing a single unit may eliminate a critical link in the utility or resource chain (van Bree et al., 2020). Moreover, the companies operating at Chemelot are susceptible to economic cycles and can suffer significant financial losses during economic downturns (van Bree et al., 2020).

Chemelot also hosts a dedicated campus for education and research in the chemical sciences. Through this initiative, the chemical cluster seeks to create space to develop new technologies and applications (Brightlands | Chemelot Campus, n.d.). This focus on education, research, and technological advancements has led to the development of an openly accessible demonstration facility. Here, organisations and universities affiliated with Chemelot, such as TNO and Maastricht University, are actively working to bring together all relevant stakeholders (Brightlands Circular Space, n.d.). This large-scale site, comparable in size to several football fields, will showcase innovative technologies designed to accelerate the transition to a circular plastics economy (Brightlands Circular Space, n.d.). In doing so, the sub-cluster embraces open innovation as one of its central strategic principles. Open innovation refers to the purposeful inflows and outflows of knowledge that accelerate innovation (Chesbrough, 2002). Traditionally, large firms have relied heavily on internal research and development to create new products. This inward orientation has created barriers for potential collaborators and competitors (van de Vrande et al., 2009). With this strategic move by Chemelot, the cluster intends to make a more substantial contribution to innovations through collaboration and knowledge spillovers (Brightlands Circular Space, n.d.). An example of such innovation is the plant planned by SABIC and Plastic Energy, which will chemically recycle plastic waste into pyrolysis oil, a feedstock that can be reprocessed into new plastics (Chemelot, 2020). The broader objective of these initiatives is to substitute fossil-based raw materials with sustainable alternatives and to electrify chemical production processes (Chemelot, 2020). This transition is essential because the industrial cluster currently consumes around 4 million cubic meters of natural gas and approximately 93,000 barrels of naphtha daily (Chemelot, 2020). The electrification demand of the Chemelot site is expected to grow from 250 MW in 2020 to a maximum of 2,500 MW in 2050 (Provincie Limburg et al., 2025).

The governance of industrial clusters involves multiple levels, including municipalities, provinces, the national government, and the European Union (van der Reijden et al., 2021). In many industrial clusters, large-scale industrial installations are part of the Emission Trading Scheme (ETS), which the European Union also oversees. In the Netherlands, the Nederlandse Emissieautoriteit (NEa) monitors ETS-covered installations; however, in Chemelot, ETS entries are centrally organised by the Officer Emission Trading at Sitech Services BV for all GHG-emitting installations (van der Reijden et al., 2021). Even with the companies' cooperation on joint infrastructure and technological developments in Chemelot, each company still sets its strategic direction from its headquarters in the country where it is based (van Bree et al., 2020). In the cluster, they participate collectively through a central coordinating body, represented by designated representatives, and consequently, major strategic decisions of the individual companies are not made at the Chemelot site, but rather at the international headquarters of the parent companies, such as SABIC in Riyadh, OCI in London, Fibrant in China, and Borealis in Vienna (van Bree et al., 2020). This results in local executives based in Geleen having limited influence over long-term strategic planning

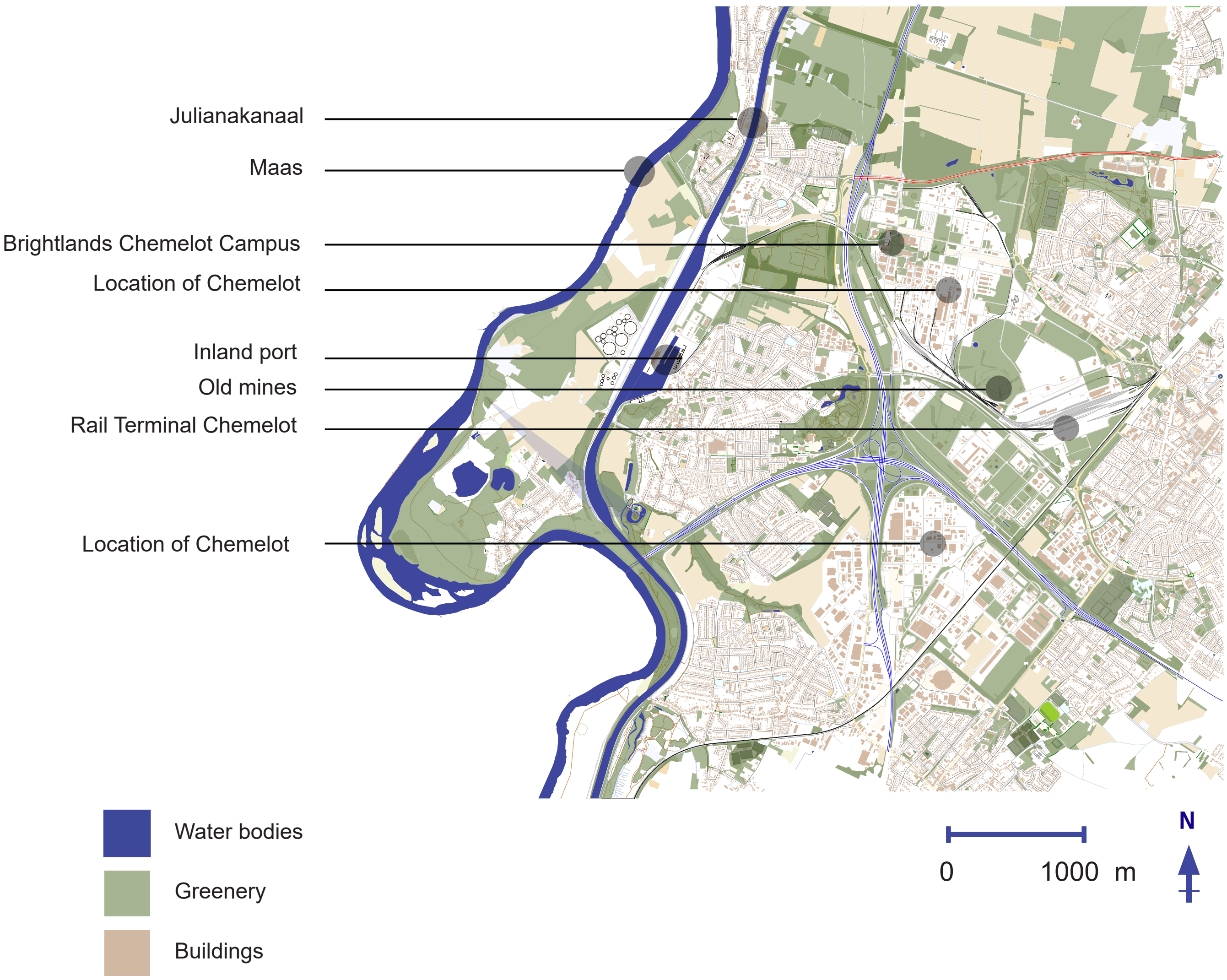
The current landowner of Chemelot is DSM-Firmenich, a member of the industrial cluster. However, this might change as two representatives, two municipalities, and the province want to buy the land from the company (Westerveld, 2025). They have also asked the national government to support this decision with €2 billion. This will result in the Chemelot site becoming publicly owned (Westerveld, 2025).

In recent years, large players at the site have received increasing requests from brand owners, such as Coca-Cola, Unilever and IKEA, for more sustainable alternatives to existing plastic products (van Bree et al., 2020). This rising demand became particularly evident when the announcement of a pyrolysis plant was immediately followed by increased market interest, which may highlight the growing need for a circular plastics economy driven by environmental concerns and policy and regulatory pressures (van Bree et al., 2020).

Below (Figure 16) is the map of Chemelot, showing how the chemical site is embedded in the situation.

Figure 16

Location of Chemelot in situation. Adapted from MilvusMap (2025–, data © OpenStreetMap contributors).



Note. Map data © OpenStreetMap contributors, retrieved via MilvusMap (milvusmap.eu), 2025.

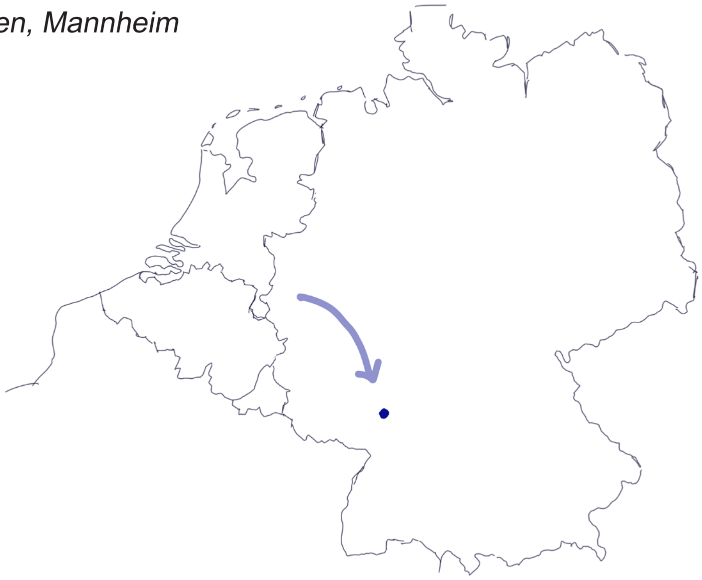
04.5.2. Ludwigshafen in Rhein-Neckar

Germany hosts approximately 60 chemical parks, covering over 2,000 hectares (AIChE, 2011), with many of these concentrated in five major chemical regions. The largest German sites are located along the West European ethylene pipeline, including ChemSite in North Rhine-Westphalia (Marl, Gelsenkirchen), Bayer in Leverkusen, Hoechst near Frankfurt, and BASF in Ludwigshafen (Kimm, 2008). Within North Rhine-Westphalia, the chemical parks are essentially part of the ARRRA cluster and form the basis of two major centres: the Ruhr region (ChemSite cluster) in the north and the Rhine area (ChemCologne) in the south.

Most chemical parks are situated along the Rhine River, benefiting from direct access to Europe's major seaports, Rotterdam and Antwerp (AIChE, 2011). This is also the case for the industrial cluster in Ludwigshafen (Figure 13). The Rhine is equipped with modern docks tailored to the operational requirements of the chemical industry along its course (AIChE, 2011). West Germany's chemical region hosts two major international airports: Cologne/Bonn and Düsseldorf, and Duisburg's largest inland European port (AIChE, 2011). The industrial clusters have strong connections to the international railway network, linking chemical sites in northern Germany, such as those around Hamburg, often called the "North Sea" region. The rise of the chemical industry in the Rhine area was historically tied to the Ruhr coal reserves (Van Wassenhove et al., 2007). Like Antwerp and Rotterdam, industrial growth surged after World War II when the break-up of the former IG Farben conglomerate led to the establishment of refineries and steam crackers by petrochemical companies within the cluster (Van Wassenhove et al., 2007).

Figure 13

Location of Ludwigshafen, Mannheim



Traditionally, German chemical sites operated as single-user, self-contained facilities with internally connected structures (AIChE, 2011). Today, these sites are open to multiple companies that benefit from shared infrastructure and material flows (Van Wassenhove et al., 2007). Site management is typically carried out by the site's original operator, who provides essential services such as transport, maintenance, waste disposal, and wastewater treatment. This arrangement enables chemical producers to focus on core activities (research, development, and production) while relying on the site operator for support services (AIChE, 2011).

At Ludwigshafen itself, the industrial cluster exports goods to a diverse range of sectors, including automotive, machinery and plant engineering, chemicals, information technology, biotechnology and life sciences, energy, and the cultural and creative sector (BASF, n.d.-b).

Given that the approximately ten square-kilometre cluster is the largest integrated chemical complex in the world, it is not surprising that the chemical site can serve such a broad array of industries. The site's backbone is the Verbund, a dense network of around 200 production plants interconnected by over 2,850 kilometres of pipelines and more than 230 kilometres of rail track (Otto, 2011). Additionally, 40 per cent of the transport is via daily ship, 32 per cent via trucks, and 38 per cent via rail cars (BASF, n.d.-e). The Verbund idea was developed in Ludwigshafen, from where it has been further developed and exported worldwide. The whole infrastructure, logistics, and production plant system is intelligently connected at such a site, in which chemical processes can run in a resource-efficient way with lower energy consumption and higher yields (BASF, n.d.-f). Thereby limiting waste and optimising energy usage.

At the heart of the Ludwigshafen site lie two steam crackers, comprising 13 soccer pitches (BASF, n.d.-f). These plants are frequently the beginning of supply chains. The raw materials for the production are delivered via pipeline or ship, arriving at the designated plants via three ports, two tank farms and an extensive piping network (BASF, n.d.-c). Next to BASF, the largest company on the site and the operator, the Ludwigshafen industrial cluster also hosts companies such as LyondellBasell, INEOS Styrolution, and Air Liquide SA (Otto, 2011). Also, spin-offs from BASF can still be located at the site, such as TrinamiX, a startup developing solar cells (Otto, 2011).

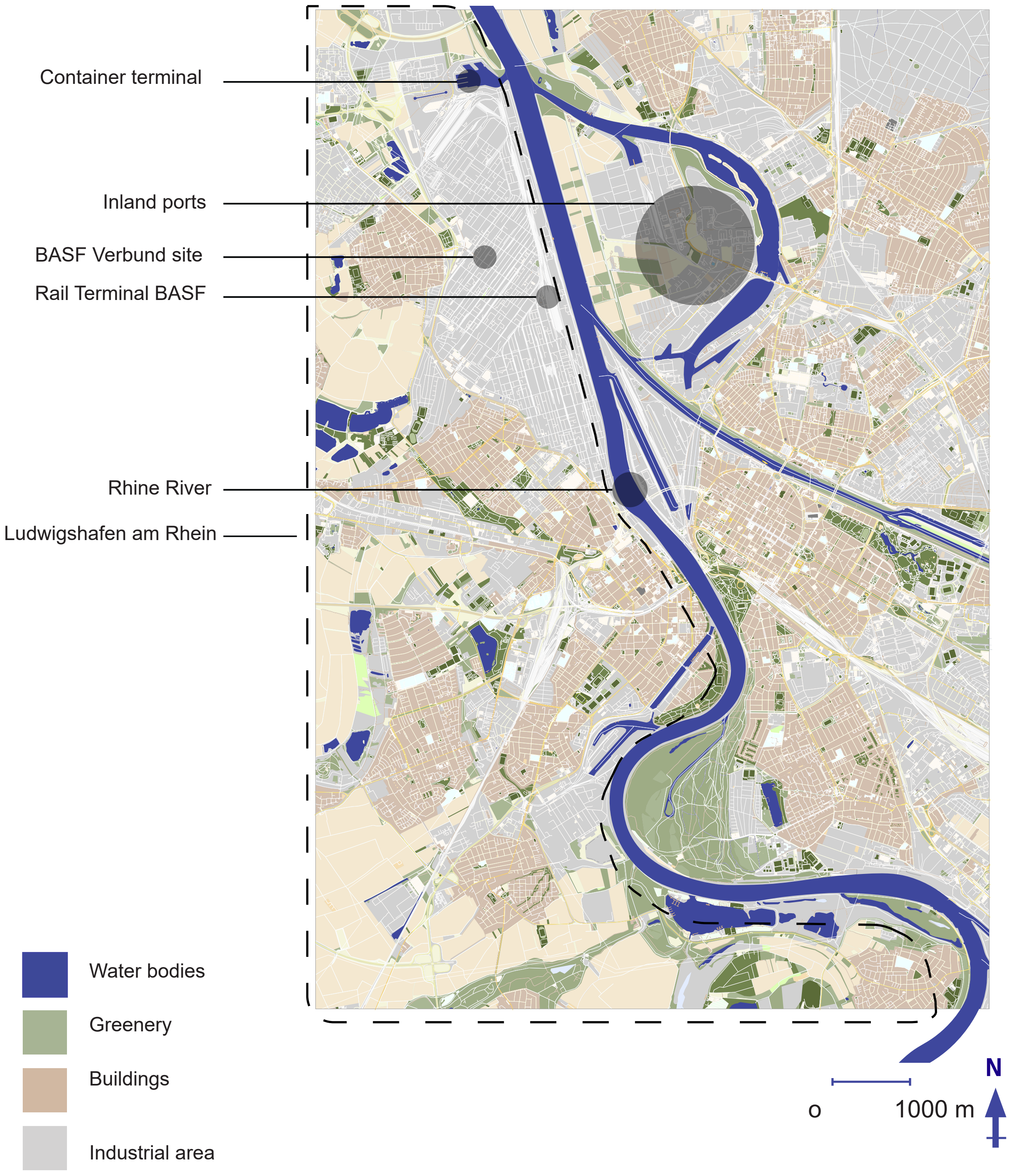
The Ludwigshafen site is in the Rhein-Neckar metropolitan area, spanning three German federal states. Although it is the smallest among Germany's metropolitan regions, it ranks second in population density and has the second-largest proportion of land dedicated to settlement and transportation (OECD, 2023a). Additionally, the region hosts around 160,000 companies, with the three largest being in Mannheim-Ludwigshafen and Heidelberg. Key sectors include automotive, biotechnology, chemicals, energy, health and life sciences, and information technology (OECD, 2023a). As further stated by the OECD (2023a) report, education plays a crucial role in the region by facilitating networking and knowledge transfer, enhancing the development of specialised skills, and promoting digitalisation (p. 29). Moreover, it provides a shared framework for the region, supporting constructive collaboration among various actors (p. 29).

The Rhine–Neckar Metropolitan Region operates under a unique public–private governance model in Germany, established through a treaty between the states of Baden-Württemberg, Rhineland-Palatinate, and Hesse (Yan & Growe, 2022). This treaty assigns the region legally binding responsibilities for cross-border coordination and spatial planning across three states, seven districts, and 290 municipalities. The governance structure consists of three interconnected bodies: the Verband Region Rhein-Neckar (the public-law regional authority), Metropolregion Rhein-Neckar GmbH (a public–private development company), and Zukunft Metropolregion Rhein-Neckar (a stakeholder association) (Yan & Growe, 2022). Together, these institutions form the governance framework of the officially designated European Metropolitan Region (EMR), a status granted by the Conference of Federal and State Ministers for Regional Planning (MKRO) to strengthen the region's national and international competitiveness (Yan & Growe, 2022). In essence, the EMR concept in Germany is a strategic effort to consolidate and coordinate the strengths of its major urban areas, extending beyond administrative boundaries to create more powerful, coherent, and globally competitive "motors" of development (OECD, 2023a).

Additionally, by reorganising Germany's spatial economy along relational lines, this concept sees borders as more than just fixed lines on a map. Instead, they are defined by the more flexible boundaries of metropolitan form and function, rather than merely political, administrative, or territorial boundaries (Yan & Growe, 2022). Below (Figure 17) is the map of Ludwigshafen, showing how the chemical site is embedded in the situation.

Figure 17

Location of Ludwigshafen in situation. Adapted from MilvusMap (2025–, data © OpenStreetMap contributors).



Note. Map data © OpenStreetMap contributors, retrieved via MilvusMap (milvusmap.eu), 2025.

04.6. The context of the firms and their inventions

04.6.1. Avantium and Releaf ®

About Avantium

Avantium is a Dutch chemical and technology company specialised in renewable chemistry (de Jong et al., 2022). The company, initially part of Shell but spun off in February 2000 (Avantium, 2025d), is nowadays headquartered in Amsterdam and has three pilot plants (one in Geleen and two in Delfzijl), and R&D laboratories in Amsterdam (Avantium, 2024; de Jong et al., 2022). These R&D Laboratories in Amsterdam are situated in Matrix innovation centres, as the centre offers a customised workspace in a high-grade scientific environment where collaboration and interaction are stimulated (‘About Us’, 2025).

Avantium’s most important business strategies involve licensing and divesting its patents to third parties (Avantium, 2024). As de Jong et al. (2022) state, IP rights are among the company’s most valuable assets and its technologies are covered by 137 patent families (2020), which are listed under different entities, including Avantium, Avantium Knowledge Centre, Furanix and Synvina. (p. 5). As further stated by de Jong et al. (2022, p. 5), especially the markets of Europe, the United States and Asia are important, since their approvals are seen as leading in the fields in which Avantium is active. In more detail, they strategically file their patents in the countries where they are most relevant; for example, bio-feedstock conversion technologies are filed in countries with abundant biomass, and basic end-use application patents are filed in the countries where those products are produced or consumed. Nonetheless, Avantium’s primary downstream development strategy is to establish an open innovation platform for FDCA and PEF applications, in which the company collaborates closely with partners and customers to ensure the applications integrate into their systems (de Jong et al., 2022). These partnerships, for example, are expected to construct production facilities (Avantium, 2024).

About the invention

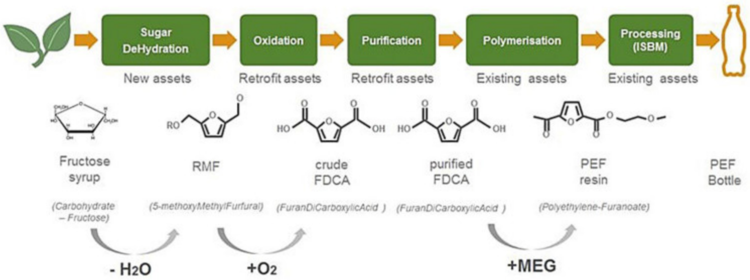
As mentioned, polymers are organic materials composed of large macromolecules made up of smaller units (monomers) of the same kind (Muralidhara et al., 2022). These polymers can be categorised into two main types: natural and synthetic polymers. Natural polymers occur naturally in the environment, unlike synthetic polymers, which are manufactured from petroleum-based resources (Muralidhara et al., 2022). One of the most widely used polymer materials in the current market is PET, which accounts for more than 70 million tons of production per year (Alaraby et al., 2025), accounting for roughly 9 per cent of the total plastic consumption and 12 per cent of global solid waste (Alaraby et al., 2025). Even though PET is predominantly used in synthetic fibres, a substantial portion is dedicated to plastic bottles (Alaraby et al., 2025). These plastic bottles can persist in landfills for up to 500 years (Lundell & Thomas, 2020). The environmental accumulation of plastics and widespread compounding of microplastics stemming from these bottles, in combination with the seedy plastic exports due to mismanagement of plastic waste (Alaraby et al., 2025; Lobelle et al., 2024; Lundell & Thomas, 2020), highlights the need for a better waste system and more sustainable materials. Avantium addresses these issues by producing a fully biodegradable alternative to PET, called PEF (Avantium, 2019).

The technology, also known as YXY Technology, converts plant-based sugars into FDCA, one of the main building blocks of PEF, together with plantMEG (Avantium, 2021), see Figure 18.The PEF bottle is marketed under the name Releaf®.

Since most PET bottles are not entirely made from this type of plastic, as they often have an extra layer of nylon in applications requiring a strong gas barrier, the advantage of PEF is that such a layer is unnecessary, as this bioplastic naturally has adequate barrier properties (Avantium, 2019). Additionally, the extra layers found in some PET bottles complicate the recycling process

Figure 18

Conversion steps to transform fructose into FDCA and subsequently PEF. From de Jong (2022)



Note. de Jong, E., Visser, H. A., Sousa Dias, A., Harvey, C., & Gruter, G.-J. M. (2022). The Road to Bring FDCA and PEF to the Market. Polymers, 14(943). https://doi.org/10.3390/polym14050943

(Avantium, 2019). (de Jong et al., 2022). Nevertheless, it must be noted that, even with this technological advantage, an inflow of virgin resin would always be needed, whether minor or not (de Jong et al., 2022). In other words, it is not possible to create an infinite mechanical recycling loop without adding some new, clean polymer to compensate for losses and impurities.

04.6.2. The innovation ecosystem

Avantium has R&D labs located at the Matrix Innovation Centre in Amsterdam's Science Park (Avantium, 2025). After this phase of highly specialised research, the invented technology was demonstrated in Geleen at their pilot plant (de Jong et al., 2022). Currently, Avantium has started its FCDA plant in Delfzijl, where FDCA is synthesised from RMF (5-(methoxymethyl furfural) via HMF (5-hydroxymethyl furfural), as a step forward towards commercialisation (VNCI, 2025). HMF is an organic compound produced by the hydration of reducing sugars such as fructose and glucose (de Jong et al., 2022).

The U.S. Department identified FDCA as one of the twelve sugar-based building blocks holding the most significant potential for producing biobased chemicals and materials (Eerhart et al., 2012). FDCA can be produced via a chemical reaction of 5,5-hydroxymethylfurfural (HMF) (de Jong et al., 2022). Producing HMF to gain FDCA on a larger scale has been challenging, as HMF undergoes further reactions to form a reactive, bio-based organic chemical compound, primarily used in applications such as pharmaceuticals and cosmetics (Eerhart et al., 2012). Avantium has been pioneering in this area, creating a method that makes HMF more stable (Eerhart et al., 2012). This is notable, as it allows for the production of biobased plastics on a large scale (de Jong et al., 2022).

The path towards commercialisation

Avantium is part of a consortium that realises larger-scale HMF production (Schipper, 2025). In the consortium, twelve European partners, managed by Michelin Engineered Polymers, primarily aim to build a plant to demonstrate the applications of HMF (Avantium, 2025c). The current plants producing HMF are primarily in Asia, with China dominating the market (Schipper, 2025). The consortium has received 20 million euros in EU Horizon funding (Schipper, 2025), of which Avantium has been awarded a 200,000 euros grant to participate (Avantium, 2025c). Next to large companies, four research centres and four academic partners are part of the consortium (Public documents – Cerisea, 2025). The plant will be built in Peage-de-Roussillon in France (Cerisea – Produce a high-performance bio-based intermediate to serve the sustainable industry!, 2025). Other noteworthy memberships, as Avantium refers to them, are the Renewable Carbon Initiative, Bio-based Industries Consortia, MVO Nederland, and VNCI ('Partnerships and Collective Action', n.d.).

Fructose can be derived from various biomass sources to produce HMF and FDCA, including sucrose (from sugar beets or sugarcane), starch (from wheat, maize, or potatoes), and cellulose (from second-generation biomass such as wood pulp or wood chips) (de Jong et al., 2025). The choice of feedstock depends on availability and cost considerations. This is the result of the chemical industry's narrow focus on increasing production scale and yields, and reducing costs, making the commercialisation of the same product from a different feedstock difficult, as it will have to compete on cost from day one (Stichnothe et al., 2020). Moreover, partners in the value chain's willingness to pay an initially higher price (also known as the green premium) is limited (Stichnothe et al., 2020). As further stated, the lack of acknowledgement of this, along with no plan to overcome this gap, has led to the failure of pioneering biobased businesses (Stichnothe et al., 2020, p. 9).

Avantium has a strategic supply agreement with Tereos, under which Avantium will purchase fructose syrup made from European wheat as feedstock for the planned FDCA at its plant in Delfzijl (Avantium & Tereos, 2021). As stated, the agreement spans multiple years and secures 100 per cent bio-based, local feedstock (p. 9). The Tereos Fructose Syrup plant, located in Aalst, Belgium, has an R&D team specialising in plant-based technologies and biomass production (Avantium & Tereos, 2021). Additionally, Avantium has partnered with the Industrial Sustainable Chemistry group at the University of Amsterdam to develop and patent a technology to break down cotton in polycotton fabric into glucose (Avantium, 2025). This cotton glucose can also be utilised as an industrial sugar for the feedstock of PEF and FDCA (Avantium, 2025).

Another important monomer for PET and PEF is plantMEG. PlantMEG can be used in textiles and plastic packaging (Avantium, 2021). Avantium produces this glycol in its plant in Delfzijl. On top of that, Avantium converts its non-food lignocellulosic feedstock into industrial sugars in its pilot plant in Delfzijl, which can be used to produce FDCA and PEF.

Furthermore, Avantium partners with Cosun Beet Company in a joint venture to utilise its beet sugar as the renewable feedstock for plantMEG (Avantium, 2021b; VNCI, 2021).

Strategy in navigating the market

To accelerate the process and navigate the market barriers faced by inventions in plastic waste management, Avantium signed a collaboration agreement with Cargill's subsidiary, NatureWorks, in 2008 to develop FDCA-based polyesters (NatureWorks and Avantium to Collaborate on Biobased Polymers, n.d.). NatureWorks was one of the few companies that managed to commercialise a novel and biobased polymer and, as a result, genuinely understood the process of bringing new polymers to market (de Jong et al., 2022). As part of Avantium's strategy to bring its new polymer, PEF, to market, they chose partners capable of producing polymer at scales ranging from tens of kilograms to meet the required specifications so that they could test the quality in Avantium's bottles themselves (de Jong et al., 2022). As further stated by de Jong et al. (2022), the rationale was that companies could experience PEF's superior properties firsthand, thereby convincing them to adopt it (p. 4).

In 2009, the climate convention in Copenhagen brought together companies that manufacture fossil-based plastics with Avantium, which was attempting to scale up production of biodegradable plastic (de Jong et al., 2022). This really enabled the company to expand its network and acquire new clients. Since Avantium's strategy for landing new partnerships was straightforward, with no fancy words, it was simply a matter of seeing it for yourself; they managed to secure a material transfer agreement with a company, enabling it to evaluate the PEF properties independently (de Jong et al., 2022). Once the outstanding properties of PEF were confirmed, they signed a multi-year joint development agreement (JDA) with Coca-Cola to develop PEF for bottles

(The Coca-Cola Company, 2011). A few years later, joint development agreements were also signed with Danone and ALPLA (Avantium, 2013). Avantium refers to these partners as the 'bottle consortium', providing the company with insights into regulatory expertise and guidance on obtaining food contact approval for PEF and on toxicity testing of the FDCA monomer (de Jong et al., 2022). These partnerships also provided Avantium with the technical expertise and financial support to complete two pilot plants for its FDCA production (de Jong et al., 2022).
Nowadays, the company delivers PEF to companies such as Refresco, Albert Heijn, AmBEv, Coca-Cola, Henkel, Carlsberg, Louis Vuitton, and PANGAIA, as these partners are the channels that ensure Avantium's products reach the market (Pals, 2024a).
Another important partnership is with tolling partner Selenis in Portugal, which polymerises the delivered FDCA from Avantium into PEF (Avantium, 2025b).

Towards a commercially FDCA plant

Avantium aims to completely integrate the FDCA factories into the site's energy system in Delfzijl. This is an important step in the commercialisation of the invention, as it is the first commercial plant for FDCA (VNCI, 2025). The establishment of the plant is in cooperation with AkzoNobel, Chemport Europe, RWE and Staatsbosbeheer, and with additional help from the province of Groningen (Chemie park Delfzijl, 2017). The CEO of AkzoNobel Nederland stated in the interview that Avantium's technology complements the biobased projects at the site and contributes to the sustainable development of AkzoNobel's Specialty Chemicals division (Chemie Park Delfzijl, 2017). However, the construction of the new plant was not without difficulties. The projected investment stood at €150 million, with an additional contingency of roughly 20 per cent to cover unforeseen costs, mainly driven by elevated construction and material prices, potentially pushing the total expenditure above the initial estimate (Wagenaar, 2023). The facility represents a scaled-up version of the existing plant operated in Chemelot (Wagenaar, 2023).

For the current plant, the initial energy system is stated as simple, with electricity and heat as the primary energy sources (Kamperman, 2021). The most essential input is electricity and heat from the existing grid and networks, with a total installed thermal and electrical capacity of approximately 20 MW throughout the plant (Kamperman, 2021). Furthermore, as stated in the Witteveen & Bos report by Kamperman (2021), North Water supplies processes and demineralised water based on surface water to Avantium from its plants in Delfzijl (p. 14). The water as input stems from the new project Duurzame Watervoorziening Delfzijl (DWD). This joint venture will also collect wastewater from Avantium for purification in the future. Due to the subsidies from VEKI, Versnelde Klimaatinvesteringen Industrie, Nationaal Programma Groningen, and JustTransitionFund, North Water was capable of realising the DWD project ('Koninklijke opening Avantium ook een bijzondere mijlpaal voor North Water', n.d.).
The byproducts produced are used by others outside the site for energy (Kamperman, 2021). North Water (Kamperman, 2021) disregards byproducts that do not align with the standards.

As the CEO of Avantium mentioned in an interview, financing its operations and attracting the right people remain among the company's biggest challenges (Pals, 2024b). In the initial phase, funding was provided by Shell, Akzo, GSK, and Pfizer, which served as initial customers (Petram & Co, n.d.). Nowadays, investors, such as InvestNL, and institutions, such as ABN AMRO Bank, ASN Bank, ING Bank, and Rabobank (together with InvestNL forming a consortium of lenders), as well as entrepreneurs like Pieter Kooij and the province of Groningen, provided Avantium with capital, in total a 90 million euros debt financing package, to build its FDCA plants (InvestNL, 2021).
In 2011, as part of the initial financing round, Sofinnova Partners, Aster Capital, and De Hoge

Dennen led the round, along with existing investors Aescap Venture, Capricorn Cleantech Fund, ING Corporate Investments, and Navitas Capital (Kolodny, 2011). Also, the government awarded Avantium with a subsidy and an innovation credit of 5 million euros from the Dutch Ministry of Economy, Agriculture and Innovation (Kolodny, 2011). Part of the round was used to buy out the shares held by DFJ Esprit, AlpInvest, Eastman, EDBI, and Pfizer (Kolodny, 2011).

Quite recently, the Dutch government reinvested 10 million euros via InvestNL in the company. This funding served as a short-term debt and is expected to be repaid. Earlier, the company received 10 million euros from the province of Groningen and the aforementioned consortium of lenders (Avantium, 2025a).

04.6.2. BASF And Ecovio®

BASF is one of the world’s largest chemical companies, founded in 1865 (Kimm, 2008). Integration is one of BASF’s core strengths, as the company holds the fundamental belief that integrated chemical sites are necessary to manage chemical production and reduce financial vulnerability (Kimm, 2008). The company aims to physically integrate production chains, thereby ensuring the lowest production costs for bulk chemicals. This leads to advantages in downstream products (Kimm, 2008). The company’s leading production site is located in Ludwigshafen, the world’s largest single-company integrated production site (Kimm, 2008).
Plastics are a key component of BASF’s production portfolio, utilised in various industries, including automotive engineering, medical technology, electronics, electrical engineering, and building insulation (Franz et al., 2024).

BASF currently operates in 92 countries in 2024 and has 235 operating production sites worldwide (BASF, 2025a). On top of that, the company has eleven operating divisions, grouped in the following segments:

- Chemicals: Petrochemicals, Intermediates
- Materials: Performance Materials, Monomers
- Industrial solutions: Dispersions & Resins, Performance Chemicals
- Nutrition and Care: Care Chemicals, Nutrition & Health
- Surface technologies: Catalysts, Coatings
- Agriculture solutions: Agricultural Solutions

According to BASF’s annual report, the cornerstones of the operating divisions are the service unit, research and development, and the Corporate Centre (BASF, 2024, p. 11). Additionally, BASF is one of the largest publicly owned companies with a high free float, meaning that a significant portion of the company’s shares can be publicly traded (BASF, 2025; ‘Free Float’, n.d.). This has led to the company having over 900,000 shareholders(BASF, 2025).

In its belief that integration is crucial, BASF has developed a concept known as The Verbund. This concept of ‘The Verbund’ has become a core competency of the chemical company (Brüggemann et al., 2008). At all major sites, production plants are interconnected in a highly complex manner, forming a network that links basic chemicals to specialities along value-adding chains (Brüggemann et al., 2008). The backbone of the production Verbund is a mesh of approximately 200 production plants connected by 2,850 kilometres of pipelines and over 230 kilometres of rail track (Otto, 2011). At a Production Verbund site, by-products are reused within the chain as secondary fuel sources or raw materials for other plants (Brüggemann et al., 2008). This synergy-driven management approach enables BASF to produce more sustainably, requiring less energy and fewer raw materials while reducing logistical costs. A drawback, however, is that establishing such an integrated and efficient system involves immense amounts of data, as well as hidden layers of complexity and interdependencies (Rizvi et al., 2025). The largest Verbund site is in Ludwigshafen, although BASF also operates other Verbund sites worldwide, most of which are significantly smaller (BASF, n.d.-c). The second largest Verbund site is in Antwerp (BASF, n.d.-a). Furthermore, on each site, every plant has its own cost structure, whereby the cheapest plants are the most resistant to price drops. As stated in the Interview with the Vice President by the Energie Gasten ‘The expensive factories are the first to go (Melis, 2025).

The invention

Ecovio® is BASF's certified-compostable bioplastic, consisting of polylactic acid (PLA) and the biodegradable polyester PBAT (Ecoflex®). PLA is produced from renewable raw materials such as sugar- or starch-based feedstocks, whereas PBAT is traditionally fossil-based. Recently, BASF has introduced a biomass-balanced PBAT variant in which a share of the fossil feedstock is replaced with renewable waste- and residue-based raw materials via an ISCC-certified mass-balance approach. The applications of Ecovio ® include shopping and waste bags, mulch films, paper coatings, shrink films, thermoformed packaging, injection moulding, and transport packaging (BASF, 2018). The polymer serves as a drop-in replacement in conventional plastic production, requiring no blending. It consists of biodegradable Ecoflex® from BASF and a biodegradable, bio-based thermoplastic polyester derived from renewable resources, giving it properties equivalent to standard non-biodegradable plastics (Ecovio® – Biobased and Compostable Polymer, 2025).

04.6.3. Its innovation ecosystem

The invention originated at BASF's Ludwigshafen headquarters, the company's central site for polymer and packaging R&D (Siegenthaler et al., 2012).

Central to this system are two steam crackers, the synthesis gas plant, and the acrylic acid plants, which initiate numerous value chains (The Mass Balance Approach, n.d.). BASF argues that creating new infrastructure for renewable feedstocks would itself carry a significant environmental burden. The mass balance approach, in their opinion, is thus a more sustainable option whilst reducing fossil use by introducing alternatives at suitable points in the existing system (The Mass Balance Approach, n.d.). Furthermore, another benefit of this approach is that the petrochemical crackers operate effectively with biobased feedstocks (The Tricky Task of Marketing Biomass-Balanced Plastics, 2025).

BASF expanded its biodegradable plastics footprint through several partnerships. In Spain and Portugal, the company collaborated with WPO Polymers to enhance distribution, service, and delivery flexibility for its biodegradable polymer portfolio (Biernat, 2021). In the United States, BASF partnered with Heritage in Mississippi to support the conversion and supply of biodegradable films, strengthening the regional availability of BASF's compostable materials (Russell, 2013).

In Germany, the company has also conducted several pilots, mainly in Berlin, such as with the municipal waste management company Berliner Stadtreinigung (BSR), and in the district of Bad Dürkheim, to test the product on consumers (Biernat, 2019).

Biodegradable packaging must be certified under local standards within an international framework (Siegenthaler et al., 2012). Certification bodies include DIN CERTCO in Germany, Vincotte in Belgium, the Netherlands, Luxembourg, and the Biodegradable Products Institute in the United States (Siegenthaler et al., 2012).

In addition, BASF has established a platform known as the Network for European Open Innovation to co-create technologies with external partners (BASF, n.d.-d). Moreover, BASF maintains eight Academic Research Alliances, including BELLA, CaRLa, BasCat, JONAS, and BARI, and collaborates with approximately 260 universities and research institutes (BASF, n.d.-b). In 2024, the company invested €2,061 million in R&D and employed approximately 10,000 staff members (BASF, 2024).

BASF in Ludwigshafen requires approximately 15 million metric tons of steam annually, 12 million MWh from fossil fuel power plants, and 4.5 million MWh from electricity (BASF, n.d.-b). Approximately half of this comes from the three power plants on the site, which, unlike

conventional power plants, which only generate electricity, also produce steam (BASF, n.d.-b). Besides electricity, steam is an essential component of BASF's energy system.
BASF recently received funding from the German Federal Ministry for Economic Affairs and Climate Action to construct the world's largest industrial heat pump in Ludwigshafen (BASF, 2024). The heat pump will be powered by renewable energy, utilising waste heat generated during the cooling and cleaning of process gases at the Ludwigshafen site (Hedley, 2024). For the realisation of the heat pump production, the company is working together with MAN Energy Solutions (Fabian, 2022).

Electrification is a crucial pillar for the company, as a significant portion of production is still based on fossil fuels (BASF, 2024). To be able to electrify, the company is developing CO2-free technologies (BASF, 2024). To achieve this, the company is considering, for example, electrically heated steam cracker furnaces used to produce petrochemicals (BASF, 2024). On top of that, BASF envisions a project that will implement an offshore wind farm with a capacity of 1.5 gigawatts (GW) and produce CO2-free hydrogen, providing Ludwigshafen with green electricity (Nonnast, 2021b, 2024).

Furthermore, BASF has signed a letter of intent with RWE to realise a wind farm along the Dutch coast (Nonnast, 2021a). In this endeavour, BASF has acquired 49.5 per cent of Vattenfall's shares (Nonnast, 2021a). Additionally, BASF partnered with ENGIE for a 25-year Power Purchase Agreement (PPA) in Europe (Roßkopf & Wettberg, 2021b). Under this PPA (power-purchase agreement), ENGIE will provide BASF with up to 20.7 terawatt hours of renewable electricity (Roßkopf & Wettberg, 2021b). BASF later reduced its investments by selling shares to a financial co-investor: Allianz(Roßkopf & Wettberg, 2021a).

In addition to a collaboration on the wind farm in the Dutch coastal area, BASF is also collaborating with Vattenfall on wind farms located in the German North Sea, specifically the Nordlicht sites (Nonnast, 2024). These sites have a capacity of 1.6 gigawatts. BASF will use the wind farm to mainly supply the site in Ludwigshafen (Nonnast, 2024). The windfarm Nordlicht 1 has a capacity of approximately 980 megawatts; the other site, Nordlicht 2, will have a capacity of roughly 630 megawatts (Nonnast, 2024). The total electricity produced, once fully operational, is expected to be approximately six terawatt-hours (TWh) (Nonnast, 2024).
Furthermore, the company partners with natural gas suppliers, as BASF collaborates with Equinor, in Norway, to deliver up to 23 terawatt hours of natural gas annually over ten years (Schabacker, 2025). This is not their first partnership, as Equinor has supplied gas and liquids to BASF for several years (Schabacker, 2025).

Lastly, the Rhine Valley region has enormous geothermal potential due to the presence of the Upper Rhine Graben (Dornstadter et al., 2019). One idea for utilising this heat source is to supply the Ludwigshafen site with CO2-free steam, for which the company Vulcan would be the partner with the technical expertise to exploit geothermal heat (Fabian, 2024).
Moreover, BASF is working with Siemens Energy to establish water electrolysis at the Ludwigshafen site (Fabian, 2023). Most hydrogen produced and consumed still occurs at the same site (Lipiäinen et al., 2023), which supports BASF's rationale for enabling this at its Ludwigshafen site. The German Federal Ministry for Economic Affairs and Climate Action and the State of Rhineland-Palatinate provided funding up to 124.3 million euros, and up to 37.3 million euros will be financed by the government of Rhineland-Palatinate (Fabian, 2023) . The electrolyser will be one of the largest in Germany once it is operational, with an output of 54 megawatts (MW) and a capacity of 8,000 metric tons of hydrogen per year (Fabian, 2023). Once

it is operational, the company will supply the metropolitan region of Rhine-Neckar with hydrogen to enable a hydrogen-based economy (Fabian, 2023).

BASF uses water as a coolant, solvent, cleaning agent, and component in its products (BASF, 2024). To promote sustainable water management, the company cooperates with the European Water Partnership (Dittrich-Krämer & Stögbauer, 2014). The purpose of this cooperation is to reduce environmental risks associated with water shortages (Ottewell, 2025). At its Ludwigshafen site, BASF operates one of Europe's largest wastewater treatment plants and the largest on the Rhine(BASF, n.d.-g). The facility purifies BASF's wastewater and treats wastewater from nearby municipalities such as Bobenheim Roxheim, Ludwigshafen and Frankenthal (BASF, n.d.-g). This indicates close cooperation with these municipalities. The resulting sewage sludge is incinerated, and the generated steam is used to produce electricity stored in the district heating network. In this process, BASF works with Technische Werke Ludwigshafen (TWL) and Stadtwerke Frankenthal (Stephan, 2024).

The Rhine River is essential for BASF, serving as a source of intake, a recipient of treated water and a transportation route. In 2005, at Ludwigshafen, 98.3 per cent of water consumption came from surface water, supplied by freshwater from the Rhine River and lakes (Völker et al., 2007). Water no longer usable in production processes is discharged back into the river or other water bodies after treatment (Völker et al., 2007). At the Ludwigshafen site, the Rhine thus serves as a vital lifeline, forming the interface where the chemical industry and the natural environment intersect (Völker et al., 2007).

04.7. How to analyse the observations

As the mechanisms defined by Yeung (1997, 2005, 2019) are still rather broad due to their foundational character, I use the framework from Van den Berghe (2018) to operationalise a more concrete understanding of these mechanisms. In operationalising these, the mechanisms in the Van den Berghe framework can couple into several relational types (Van den Berghe, 2018). However, after examining the different contexts of the plastic innovations, the relational types listed by Van den Berghe (2018) do not entirely encompass the innovation ecosystem of the plastic innovations studied here. Therefore, I am revising them into additional relational types and using them as a basis for understanding the differences and similarities across contexts, as well as the differences in coupling forms and mechanisms.

- Commercial flows. (e.g., IP licensing royalties, sales, marketing)
- Resource flows. (raw) Materials, energetic (used as input for the su pport of production/ manufacturing of the innovation, water (used as input for the support of production/ manufacturing of the innovation)
- Capital flows. Shareholder/ investments/ subsidies (Full or partial ownership of shares or companies/ angel investors/ institutions investing in innovation for or without ownership)
- Knowledge flows. Intended knowledge & research spillovers

Below are the relational types mapped for Avantium and BASF, Figures 19 and 20. To visualise the role of specific actors and regions in the innovation ecosystems surrounding each invention, every relationship with an economic agent has been assigned a ring and colour. Each ring corresponds to a relational type listed above and indicates the dominant role of a region within the innovation ecosystem. Key drivers that shape these relations, such as pipeline and freight transport and the importance of the Rhine and its tributaries, are also represented.

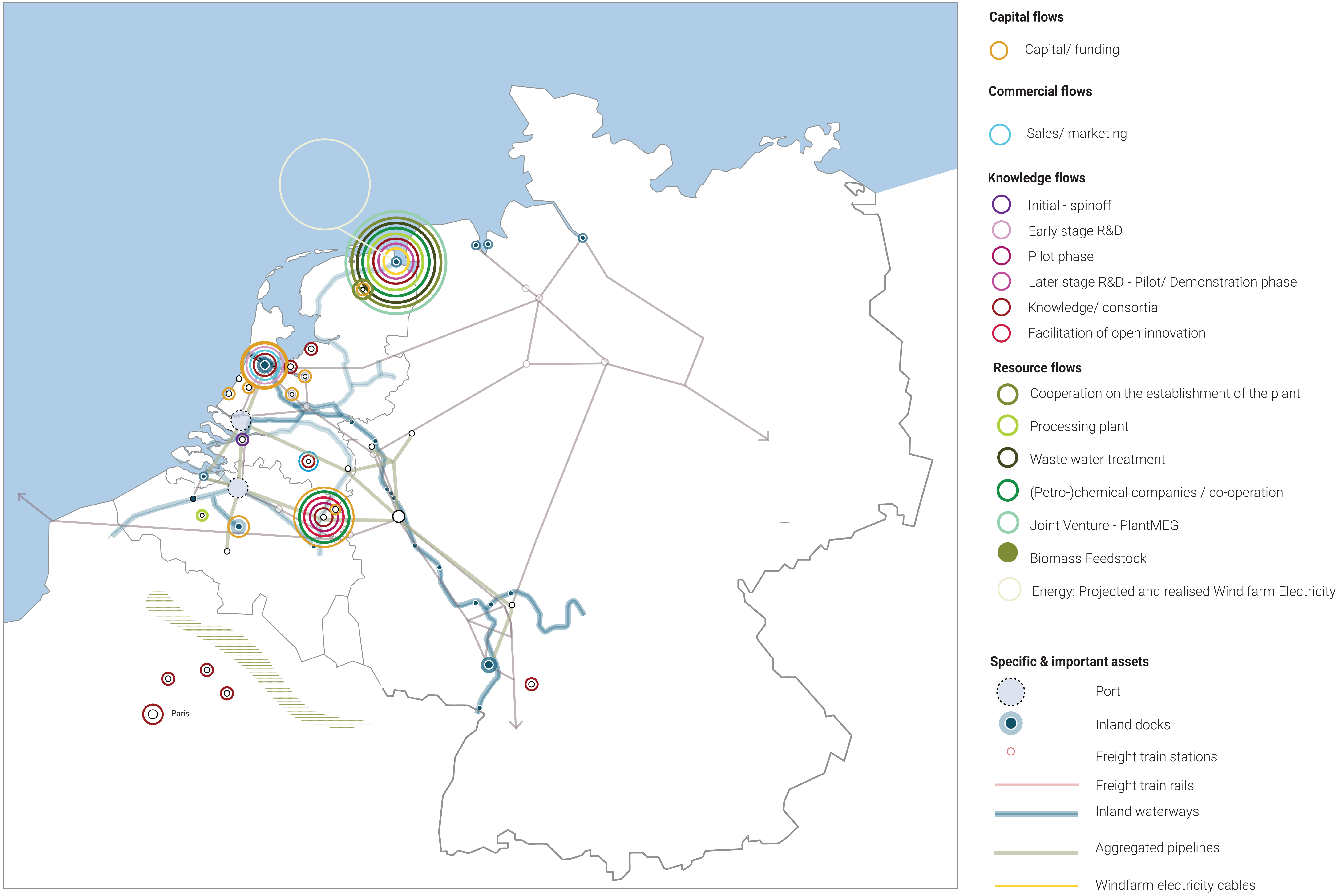
Relational roles are allocated according to location. For example, in the case of Avantium, multiple organisations contributing to scale-up may be situated in Amsterdam, yet this appears as a single ring because they collectively fulfil the same relational function. Where relevant, ring thickness is increased to reflect greater intensity, as in the case of the capital ring around Amsterdam due to the concentration of investors there. If an economic agent operates in multiple locations and the leading site for the invention is unclear, the headquarters has been selected (e.g., Vattenfall in the BASF ecosystem).

These maps intentionally focus on the local innovation ecosystem; overseas partners are therefore not shown. This does not imply that commercialisation is purely local or that international supply chains are absent, particularly in the case of BASF, but rather that the local ecosystem is most relevant for the analytical scope.

In summary, the more a region contributes to the innovation ecosystem of the company, the more relational rings it receives and the more prominently it appears on the map.

Figure 19

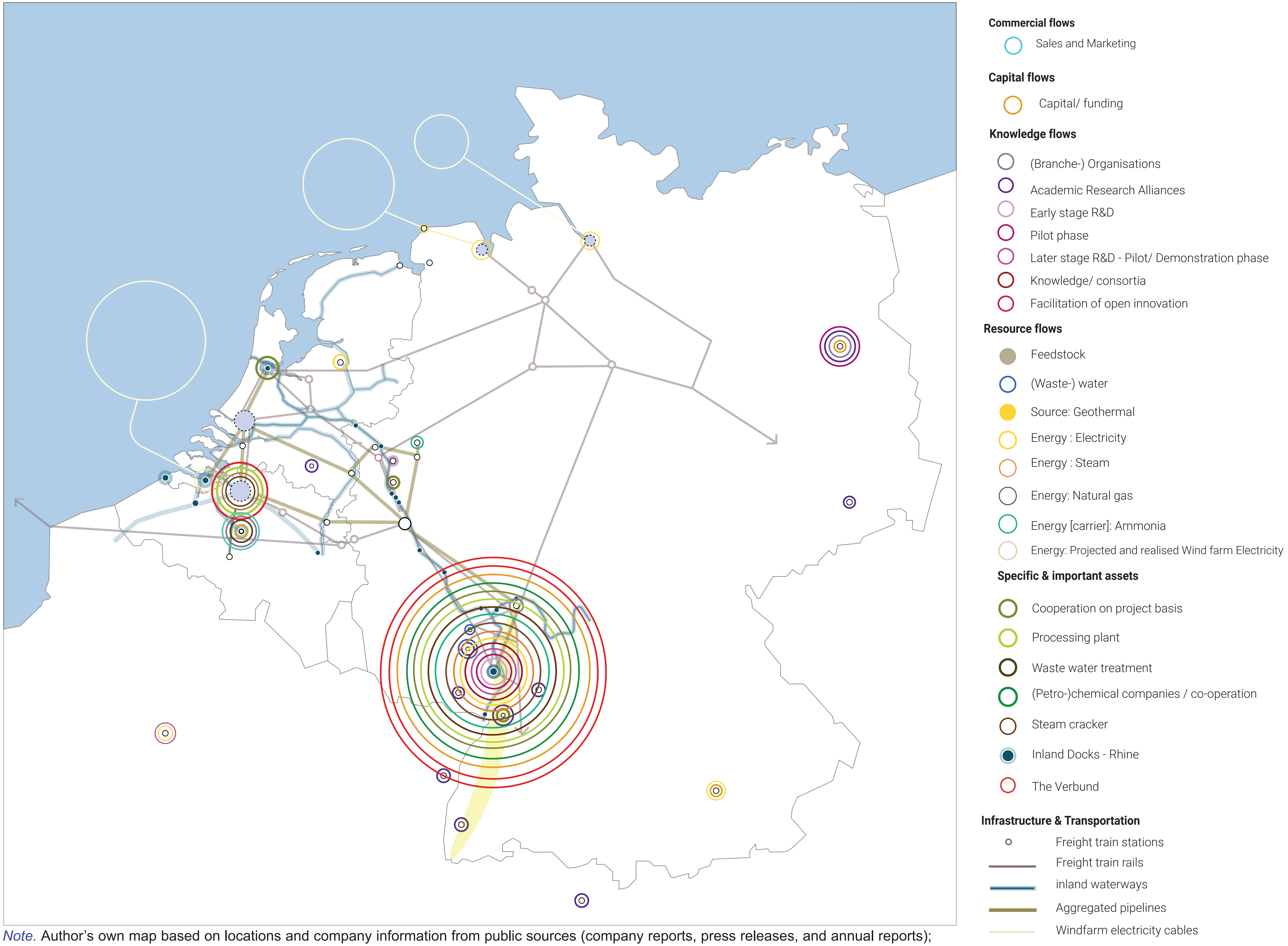
Innovation Ecosystem of Avantium.



Note. Author's own map based on locations and company information from public sources (company reports, press releases, and annual reports); conceptual inspiration from Van den Berghe (2018).

Figure 20

Innovation Ecosystem of BASF.



Note. Author's own map based on locations and company information from public sources (company reports, press releases, and annual reports); conceptual inspiration from Van den Berghe (2018).

05. Discussion

From the results, it became apparent that innovation still occurs in specific, specialised regions, where the inventions are often used and improved. This clustering in Europe seems to stem from incremental innovation, mainly carried out in operational plants. Moreover, research and development (R&D) is concentrated in large companies that also dominate patent activity. This trend is also seen in the inventions in the field of plastic waste management studied here. Regions with high patent activity, therefore, reflect mainly the presence of a few large firms rather than the clustering of an abundance of smaller, more radical startups. This does not necessarily mean that the system's technological advances in this field are flawed or that a more monopolistic market is a 'bad' thing. In addition, I would argue that it certainly does not mean that the smaller, mostly startups/scale-ups that pioneer in plastic waste management and go bankrupt are not well-equipped to survive. Rather, it reflects the difficulties in commercialising inventions in the chemical industry, like with plastics, and, more importantly, the systemic mismatch between the Netherlands and the needs of these companies.

At first glance, it appears to be a simple, straightforward answer, pointing to the larger companies in the United States and China and their disruption of the European plastic domestic market, especially since the Netherlands ranks among the top venture capital investors per capita (Bollen et al., 2025), which suggests that capital - one of the key drivers for developing technologies - might not be the main issue here and that the answers must lie elsewhere, outside the Netherlands or solely in addressing external factors with policies, such as the blending obligation. However, the Netherlands seems to be more flawed for commercialising these inventions than all the news articles reporting on the plastics industry appear to admit. The most noteworthy could be the mismatch between the neoliberal mindset the Netherlands has adopted, prioritising free trade with little to no government interference, whilst government interventions and clear steering in industrial strategy and policies are still very much needed.

What started as an attempt to understand two separate situations: failure of innovative technologies in plastic waste management, and the setting in which they do succeed in commercialising, proved to be way more connected than I initially thought they would be. Not only did it become clear that the companies in both phenomena are part of the same logic, but, more importantly, they partly share the same innovation ecosystem to commercialise their inventions.

Where are the inventions?

After mapping the patent data and the literature review, it showed that the region with the most patent activity is Germany, and more granular, the Antwerp, Rotterdam, Rhine-Ruhr Area meta cluster (ARRRA). When taking into consideration the report of the patent office EPO on technological innovations in plastic waste management (2025), and their analysis of BASF, Evonik and Bayer, as one of the principal patent applicants, it is not surprising that the geographical distribution of technological advances in plastic waste management is located in the same area, even within the petrochemical industry. This implies that, since patents across technology classes capture innovation activity (Breschi, 2000), innovation in plastic waste management exhibits patterns similar to, and even identical to, those in the petrochemical industry.

Considering that the patent data showed many startups and companies originating from collaborations, such as consortia, spin-offs, or subsidiaries of larger companies, the similarities in patterns might not be as unexpected. Subsequently, the data indicated that infrastructure, rather than administrative borders, defines the region's spatial form in which patent activity occurs.

Moreover, this could indicate that the Netherlands does possess the conditions needed for these inventions to reach market acceptance. On the other side, it also indicates that the Netherlands holds part of the answer as the ARRRA meta-cluster spans several borders. Thus, for the commercialisation of the inventions, the Netherlands should look beyond its borders to its neighbouring countries.

Furthermore, the limitation that arose from the patent data, in addition to the aforementioned limitation in the methodology, was the imperfect comparison between innovation and inventions. In this research, I used high patent activity as a proxy for innovation activity. However, the filing of patents signals the potential of the invention for commercialisation rather than that it has actually reached this phase of market acceptance. This poses a potential mismatch, as I treated the innovation activity and high invention activity as the same. Secondly, the categorisation of firms as start-up/scale-up, SME or multinational in the tables reflects my own interpretation of their characteristics and stage of development. These classifications may differ from how the firms identify themselves, and should therefore be viewed as indicative rather than definitive.

The patterns observed

Historical path dependency

Shaped by post-World War II industrial reorganisation, a pattern that kept emerging was the close partnership between government, research institutions, and industry- also called the triple helix- as an important condition in the success of the modern chemical industry. Strategic mechanisms and institutional coupling forms, such as government investments in infrastructure for raw-material transport, laid the foundations for today's industrial clusters to benefit. Interestingly, not all developments were intentional. The disbanding of IG Farben, for example, unintentionally promoted industrial growth and the formation of material relational structures, including refineries, steam crackers, and interconnected pipelines in the region that would later be known for the ARRRA meta-cluster. Furthermore, the release of the company's research to the public led to knowledge spillovers that accelerated technological advancements.

The companies that have their roots in these post–Second World War expansion of the sector, nowadays considered conglomerates, such as BASF, continue to dominate the European chemical industry in our modern petrochemical industry. Industries dominated by conglomerates are typically considered mature. In classical industrial life-cycle terms, a mature phase is usually followed by decline. However, the current dominance of incumbents, combined with this industry's wide array of submarkets and the persistent entry of pioneering new firms, points not to a decline but rather to a structural transition within the (petro)chemical industry itself. With plastics remaining integral to society and demand continuing to rise, the shift is unlikely to be away from plastics altogether, but rather toward a different feedstock base: biobased inputs and post-use plastics, instead of fossil fuels. This suggests an internal shift within the chemical industry that happens simultaneously with the partial external energy transition. However, for this internal transition to occur, the energy transition is not just important; it appears to be decisive.

The energy lock-in effect

Energy, both as a feedstock and a source of power, is one of the primary conditions for the commercialisation of these inventions and a driver for these companies to co-locate. This is due to the high-energy-intensive operations required to produce the products: energy and resource sharing result in lower overall costs and reduced risks. This creates an environment in which companies naturally tend to cluster across different stages. Subsequently, the companies can produce more efficiently, as the output from one supply chain can serve as an input to another. In addition, it reduces waste and makes operations energy-efficient. These economies of scale are thus essential for the commercial viability of their operations and products.

Fascinatingly, Avantium, although based in Chemelot during its pilot phase, located its first commercial plant in Delfzijl, a chemical cluster outside the ARRRA meta-cluster. Given that its PEF feedstock is biobased and that the shift from pipeline-based transport to trucked biobased feedstock is underway, the regional requirements seem to change accordingly as the emphasis moves away from underground infrastructure and inland waterways towards roads, highways, and access to energy sources, preferably renewable. This may also explain the rationale for Delfzijl: in addition to access to other chemical firms, the cluster offers proximity to renewable energy sources such as offshore wind, and the region's hydrogen plans are likely an additional pull factor.

The initial choice for Chemelot as a pilot location thus suggests that it is less about infrastructure availability, such as pipelines and inland waterways, and more about proximity to major (petro-)chemical firms, enabling expertise exchange, knowledge spillovers, and access to a broader network of potential customers. At the same time, the Delfzijl plant is fully embedded in the local energy system and resource base, benefiting from the integrated structure of that chemical cluster. BASF, in contrast, strategically collaborates with multiple partners to develop and expand renewable energy capacity, consequently contributing to structural changes in the German and Dutch energy landscapes. BASF, therefore, appears to be developing and promoting energy projects. In contrast, by being part of a smaller Dutch chemical cluster near the North Sea wind farms, Avantium follows an operational path that focuses on utilising available renewable inputs rather than shaping its production.

However, sharing resources and maintaining integrated supply chains for energy and feedstocks also introduces inherent risks. If major (petro-)chemical firms withdraw from an industrial cluster, the consequences extend far beyond a single supply chain. Chemical production is only profitable at vast scales, in highly capital-intensive facilities, and is characterised by strong vertical integration. This means that once a key producer stops operating, the economics of the entire system start to unravel. Subsequently, since material and energy flows are tightly interconnected within and across sites and borders, the shutdown of one plant can trigger immediate disruptions throughout the network. The high degree of vertical integration reinforces this vulnerability: the chemical industry is its own most important market. When core firms shift or cease production, the shock reverberates through the entire cluster.

Energy Taxation and offsets

Energy taxation significantly influences the (petro-)chemical industry due to its structural dependence on substantial, continuous energy inputs. Given the centrality of (energy) costs to firms' success, the chemical industry is narrowly focused on scaling production and reducing costs. This makes the commercialisation of the same product from a different feedstock even more challenging, as it must compete on cost from day one. In other words, reducing energy costs through effective offset mechanisms is essential.

At the same time, firms in this sector operate with long R&D horizons and capital-intensive investment cycles, which explains the dominance of CAPEX over OPEX in their financial models. This preference is mirrored in policy design: although sustainability instruments are presented as technology-neutral, they structurally advantage incumbents with established infrastructure. The SDE++ is a clear example of such misaligned support.

The Netherlands' bottom-up policy revision allows the state to tailor support to firm-specific needs, yet, as the OECD (2021) notes, such decentralisation requires responsive governance. The persistent gap between industry warnings and a lack of governmental response suggests that this requirement is not being met. This has likely contributed to a structural misalignment between financial instruments and industrial needs.

Furthermore, Dutch industrial policy remains liberal and market-led, relying heavily on horizontal tax exemptions that neither target strategic sectors nor steer investment flows. This approach favours large energy users without recognising their role in the sustainability transition or in maintaining European competitiveness. The Dutch implementation of the EU ETS adds to this imbalance: revenues are absorbed into the general budget, turning the ETS into a stick without a corresponding carrot. Germany, by contrast, recycles ETS revenues back into the industrial base to offset electricity costs and deploys large state-backed instruments, particularly KfW loans, to actively direct capital towards strategic sectors such as manufacturing, energy, and transport.

The misalignment between Dutch industrial policy and cluster logic is reflected in the absence of robust energy-offset mechanisms, the non-aligned SDE++, and the fragmented tax exemption system. For firms operating in the Netherlands, this translates into an uneven playing field within the EU, exposing them to competitive disadvantages relative to firms in countries with more coherent industrial strategies. The situation is particularly acute for smaller pioneering companies, which are excluded from most exemptions and therefore face a harsher investment climate, while being perceived as riskier due to the lack of supportive infrastructure. High electricity prices make cleaner production so expensive that it effectively prevents firms from transitioning, slowing down the very sustainability shift that policy rhetoric claims to prioritise.

Taken together, the green transition is often framed as market-driven and innovation-led; yet history shows that state intervention played a decisive role in building the industrial base we rely on today. What began as a state–industry–science alliance has since been privatised, while its structural advantages remain firmly in place. Startups and scaleups still depend on public funding and political steering, which exposes the myth of a self-regulating market. It also reveals the mutual dependency between decarbonisation and the shift towards bio-based feedstocks, both of which require industrial reconfiguration, investment direction, and policy coherence. Misalignment between these transitions appears to create constraints on innovation and scaling.

Governance steering and alignment

Furthermore, the cross-border nature of the ARRRA region also shows a misalignment in governmental steering; although the infrastructure functions as an integrated system, the institutional landscape does not. Regulatory, financial and administrative barriers stemming from different national rules on energy, climate, financing and waste complicate cross-border cooperation and slow down cluster-wide coordination. The result is an industry governed as if it were national, while, in reality, it needs to function as a transnational system. Also at Chemelot, this fragmentation is evident: the companies' headquarters on the site are not in the cluster, yet they make significant contributions to it. Moreover, the land is still owned by a company, with the municipality and the government having little or no influence over it.

This poses challenges, as analysis of Ludwigshafen indicates that aligning policies across multiple governance scales, effective and close cooperation with industry, and responsiveness to the needs of companies in the area are important conditions for making regions capable of maturing these inventions.

Innovation

Due to the highly complex, cost- and time-intensive nature of technological advances in the chemical industry, the setting in which commercialisation of inventions can be realised has been a core challenge for the chemical industry from the outset. Subsequently, this led to the need for stabilised markets rather than competitive ones, and created a tendency towards collaborative efforts such as joint ventures, patent pooling, cross-licensing, and resource sharing. Not solely the complexity of the products, but also the costs of transporting resources and the high vertical integration of companies in the chemical industry have created a collaborative market structure. The industry's complexity in products, specialised labour, and the need for dense research networks are reflected in both BASF's and Avantium's strategies. Subsequently, BASF engages with 260 universities, several research alliances, and its own venture capital arm. Also, Avantium seems to follow a similar path on a smaller scale, partnering with the University of Amsterdam's Sustainable Chemistry Group to build its HMF plant and locating at the Matrix Innovation Centre. Having these research institutes in its proximity proved beneficial for both firms, as well as the proximity of other research areas (via universities, for example, or the Matrix Innovation Centre). Additionally, knowledge spillovers via open innovation, for example, have a role in the chemical clusters, albeit in different ways. Avantium has access to an environment that promotes open innovation through Chemelot's facilities.

Both cases have a notable difference: BASF keeps its open value creation system near a single site, whereas Avantium has spread it across three locations. Amsterdam hosts the initial R&D stages, followed by pilot phases in Chemelot, with Delfzijl serving as the link to commercialisation. Moreover, these cooperative rather than solely competitive market dynamics have also emerged in the strategies of Avantium and BASF. Avantium utilises patent licensing and divestment (i.e., patent transfer to a third party) to access specialised facilities, expertise, and labour within the broader chemical networks. Also, BASF is employing a sub-licensing strategy, allowing other industry players to utilise the patented invention.

Taken together, this would mean that the petrochemical companies, widely regarded as the problem, are in fact another critical condition. Besides, inventions and knowledge are created through extensive learning processes and ongoing development. Without the inventions that can phase out fossil fuels, such as ecovio® from BASF, it would be less likely that future inventions would not need this raw material.

Discourse and framing

Furthermore, a notable mechanism that emerged was the tendency of public and policy debates to oversimplify complex industrial systems by reducing them to a few convenient 'actors', such as Furthermore, a notable mechanism that emerged was the tendency of public and policy debates to oversimplify complex industrial systems by reducing them to a few convenient "actors", such as the "market" or "the petrochemical industry". This simplification hides the web of interdependent decisions, infrastructures, and institutions that actually shape outcomes. It turns structural problems into stories of blame; in this regard, it focuses on cheap imports and the lack of policies, while leaving the underlying mechanisms untouched. When policy is built on these simplified stories, it targets symptoms rather than causes, and the gap between the problem and the proper response continues to grow.

In total, the very infrastructure and configuration of the petrochemical system, often framed as the problem, appeared to be one of the most recurring conditions for scaling plastic-waste inventions. Without this system, these types of technologies cannot move beyond the pilot stage. This indicates that the transition, therefore, depends not on bypassing petrochemicals but on repurposing them. That is, the transition towards a circular plastics system does not readily replace the petrochemical system in the ARRRA; it evolves through it.

05.2. Reflections on relational economic geography

Relational economic geography provided the primary theoretical framework for this research. Understanding how to apply this theory to inform policy-making in real-world settings, however, is in its infancy, as academics have primarily provided frameworks, guidelines, and considerations for its use. Hence, the steps in the methodology in this research have been my own attempt at a possible sequence of methodological steps to ground this theory, using the guidelines provided by Yeung (1997) and Gong and Hassink (2020).

Subsequently, the analysis was built around a multi-scalar contextual approach, using two contrasting phenomena: one in which commercialisation seems to succeed, and the other in which the same type of inventions fails to commercialise. What proved especially useful was beginning inductively from the situation in which this type of invention fails to commercialise, identifying relevant perspectives, and using these lenses deductively to analyse the second phenomenon. Later, I employed an inductive approach, analysing inventions and how their applicants have developed the systems around them to commercialise them. This back-and-forth made it possible to see which themes and patterns consistently resurfaced and which did not. It also enhanced the understanding of the overall setting by examining recurring themes from various angles and scales. The methodology (Figure 18) is included in Appendix E. Notably, Avantium proved particularly informative in this process. Although initially intended to feature only in the region where the inventions are commercialised, the company sits at its periphery, only partially embedded in the ARRRA meta-cluster. This position at the intersection of the two phenomena helped to clarify which mechanisms were intrinsic to the ARRRA system and which operated independently of it.

Since this research started with the phenomenon, referred to as the wave of bankruptcies and is part of a broader system, the Netherlands, the initial phase of the study was deliberately exploratory. The selection of reports, news articles, and open data sources was guided by the first phenomenon itself, rather than by predefined theoretical frameworks. This approach aligns with Gong and Hassink's (2020) view that theorising starts with theory-laden social observation, where researchers engage with empirical material through pre-existing questions and conceptual intuitions. Although this breadth occasionally made the process overwhelming, and the lack of a clear scope risks needless meandering, it turned out to be an important methodological function. By not fixing the analytical frame too early, the approach reduced the risk of what Gong and Hassink, drawing on Bhaskar (2013), identify as the epistemic fallacy: the false mixture of reality with knowledge (ontology) and our conception of what exists (epistemology) that occurs when surface observations are mistaken for underlying structures due to mistakenly confusing what exists with what we know about it. Allowing the phenomenon to guide early observational choices, therefore, helped maintain openness to deeper causal mechanisms rather than prematurely imposing an explanatory mindset.

Throughout the contextual analysis, it became clear that tracing and understanding the hidden mechanisms at play in our current society requires more time than a thesis can provide. The amount of complexity we have built into our society makes the task almost endless. Thus, if this is the reality, the question is how far we should continue to scrape back the layers. I agree with Yeung (1997) that a theoretical saturation point can eventually be reached. However, I would argue that this point does not occur uniformly across all parts of a contextual analysis. In my research, the theme that emerged around infrastructure reached theoretical saturation, but the historical and policy layers did not. This was due to the policy and historical contexts being more selective, opinionated, and therefore more abundant, whereas the infrastructure contexts were more straightforward and less contested. With this, I do not mean that saturation cannot be reached, but rather that it may require narrowing the scope and accepting that some

mechanisms will remain hidden, or a more comprehensive, in-depth investigation is needed.
Moving from description to explanation is central in relational economic geography, which requires tracing the mechanisms that connect causes to outcomes. In this, Gong and Hassink emphasised using differences, serving as a warning against ‘chaotic conceptions’ that rely on classifications of attributes rather than understanding the reasons behind the events. I purposively deviated from this approach, as I also analysed the similarities across the cases. This decision was informed by the shared regional context of the inventions, which made it relevant to investigate what aspects are occurring in both cases and why. In my opinion, this enhanced a more in-depth understanding of the context and which causes had trans-contextual relevance.

In this research, mechanisms were initially derived from open data sources and then triangulated with academic work. Relying solely on open sources introduced a limitation as the causal links present are already shaped by the authors’ interpretations of the data. This resulted in two types of mechanisms in the research. Some were selective and held more biased narratives. Others were more neutral and less distorted in their interpretation. The latter were mainly focused on the infrastructure, production systems, and energy flows.

I would argue that distinguishing between these is essential in contextual analysis; therefore, triangulation with multiple perspectives, such as through interviews, is advisable to separate interpretive noise from the events/ actions and thus the relation that connects them to a specific outcome. However, it is worth noting that a pure state or unbiased information about the context cannot be directly obtained from interviews, as some situations may seem so normal or natural to a participant that the underlying mechanisms remain hidden (Yeung, 1997). Thus, the same situation applies as with open data sources; the researchers must ‘elevate’ themselves above the data to gain a broader and clearer picture (Yeung, 1997). In this research, I sought to reduce subjectivity in open data sources via reliance on policy reports with a relatively neutral orientation, such as those from the OECD, to make the data less susceptible to interpretation.

At the same time, as Yeung (2019) notes, mechanisms cannot be treated as pure ideas detached from reality. Even when attempting to reduce subjectivity, some distortion inevitably remains, as not everything can be abstracted into a ‘pure’ form.

The steps I undertook in the theory-development phase, which formed the basis for understanding the patterns and conditions, required moving continuously between what Gong and Hassink (2020) describe as theory-laden observation and theory development. Each pass through the collected data allowed me to refine emerging concepts and to identify mechanisms that were not visible at first glance. Naming, categorising and refining the patterns, therefore, involved constant movement between the open data sources and the contextual analysis that served as rational abstraction that formed the results section of this research. This iterative back-and-forth was essential for bringing underlying mechanisms to the surface.

Combining different analytical techniques (visualisations, Excel sheets, and text-based coding) also proved useful. These tools forced me to re-engage the data from different angles and helped reveal relations that would not have emerged through a single mode of analysis. Based on the experience in this research, I would argue that even if the methodological steps are analytically distinct, the phases themselves often occur simultaneously, and there is value in allowing this overlap; as understanding of the underlying dynamics deepens, gaps in the observed data also become more visible. Addressing these gaps is crucial for developing a more complete picture of the mechanisms at work. In the theory-development phase (narrowly defined), a set of recurring patterns emerged, forming the basis for constructing the concepts. However, because this research also aims to formulate practical recommendations, I found that the framework of Gong and Hassink (2020) does not specify when a mechanism can be considered derived, nor does it offer concrete guidance on how to operationalise the concept-development stage. For that reason, I added the sequential stages used in grounded theory, as outlined by Yeung (1997), who draws on the work of Turner (1981, 1994) (p. 61). This provided a more explicit and workable structure for developing concepts from empirical material. However, grounded theory is heavily inductive, whereas a critical-realist approach requires reasoning that engages both induction and deduction, as an overly inductive analysis risks merely reproducing what appears in the data rather than identifying the mechanisms that produce the observed outcomes (Yeung, 1997). To counter this, the use of rational abstractions becomes essential. Abstracting from descriptive data emphasises the need for iteration: repeatedly stepping back, comparing patterns and relations between events/actions with their outcomes across different scales and perspectives, and avoiding the trap of mistaking description for explanation.

Since concepts form the foundation of middle-range theory, this research has focused on developing the constituent components of those concepts, referred to as conditions in this research. Nevertheless, when a single researcher examines, interprets, and abstracts from the data, the resulting concepts are inevitably partial. They must therefore be tested, criticised and, if necessary, reconfigured by others to arrive at more complete and less partial concepts and, eventually, a more robust middle-range theory. As Hassink (2019) warns, “halfway de-contextualisation” must be avoided. For that reason, claiming that this thesis delivers a full theory-development phase would dilute the meaning of theorisation. I cannot, on my own, produce a theory with generalisability beyond the context from which it was derived.

Lastly, a consideration worth noting is the meaning of the word ‘relational’ in relational economic geography and how it was used in this research, as economic geography, as discussed by Gong and Hassink (2020), is not synonymous with relational economic geography (Sunley, 2008). In this research, the focus was on distinguishing between specific forms of relationships, using the framework proposed by Van den Berghe (2018) as guidance. The relational dimension became more pronounced in the latter part of the research, where the case study helped uncover the relations between the firm holding the invention and the ties it had built to support the commercialisation of its invention.

However, when using the filed patent as a guide to understand what is needed for the invention to be successful, this imposes limitations on the types of relations analysed. Relational elements such as trust, culture and values are not captured in the patent and hard to grasp in open data sources. Some relations examined in this research do suggest the crystallisation of these socio-cultural dimensions, for example, when a partnership repeatedly appears in the data as a ‘trusted partner’ in news articles, but this still does not reveal what that trust actually means for these actors. Understanding this type of relation would, for example, require interviews.

Moreover, relationality also refers to moving beyond binary thinking (Yeung, 2005). When categories are used from the outset during data collection, there is a risk of creating such binaries or forcing relations into predefined boxes. I would therefore suggest that, when using the sequence of steps provided in this research, researchers either avoid relying too rigidly on their identified categories or actively explore how the connections between them challenge or cross these boundaries.

In this research, I attempted to articulate a clearer, step-by-step approach to the theory-development phase (narrowly defined, as highlighted by Gong and Hassink (2020)) and to provide insight into how its methodological steps can be distinguished in practice. In doing so, the intention is not to offer a complete theory, but to contribute to the ongoing discussion on how theorising in economic geography can be made more transparent and methodologically grounded.

05.1. Further research, implications and limitations

In this thesis, I aimed to clarify the stages of theorising by developing a sequence of methods and steps. Relational economic geography is a field in which these distinctions are often implicit and, when aimed at providing these steps, the iterative nature of theorising is frequently overlooked (Gong & Hassink, 2020). By operationalising their framework and complementing it with guidelines from Yeung (1997), I attempted to offer an initial, structured interpretation of how this theory can be developed and applied for real-world settings.

At the same time, the inherent non-linearity and iterative character of theorising mean that the conceptual development presented here should be regarded as a narrow and preliminary stage rather than a fully elaborated theoretical contribution. Specific mechanisms or contextual dynamics may not have been captured, particularly because parts of the empirical field fall outside my primary disciplinary background. This emphasises the need for triangulation with domain experts and for broader engagement with scholars approaching these questions from different perspectives.

Subsequently, the sequence of methods proposed in this thesis has not been applied elsewhere. Its validity and usefulness, therefore, remain untested, and future research should assess, refine and possibly extend it through comparative cases. A further limitation concerns the lack of clarity surrounding what constitutes a good theory and what makes the distinction between process and mechanism sufficiently clear. Although Yeung (1997) provides a precise account of what a causal mechanism must entail (a necessary relation, identified through rational abstraction and iterative critique), applying this distinction in practice proved far less straightforward.

Having a clearer grasp of these, I would argue, is essential to developing a workable, distinct sequence of steps for grounding relational economic geography. Without such clarity, there remains a risk of either over-abstraction that slips into ‘chaotic conception’ (Sayer, 1992, in Yeung 1997) or risks failing to identify actual causal mechanisms at all.

Lastly, this research analysed two firms and their national contexts in depth, with a primary focus on the Netherlands. To examine innovation, an imperfect but useful proxy, patents, was employed. That is, to understand whether these conditions are relevant beyond these cases, it makes sense to analyse other firms and the regions in which they are active, examining them across scales. In other words, further refinement of these methodological steps by other researchers, using different cases and contexts, is therefore necessary to strengthen their methodological reliability and their relevance for critical-realist theorising.

06. Conclusion

The research question of this thesis was:

> *Which conditions within innovation ecosystems enable the commercialisation of inventions in plastic waste management?*

The findings showed that commercialisation depends primarily on cluster embeddedness, with regional specialisation being more critical than industrial diversity. Most inventions are concentrated in the ARRRA meta-cluster spanning the Netherlands, Belgium, and Germany. In Germany, patent activity is centred in major innovation hubs in the west, whereas the Dutch pattern mirrors the industrial clusters at Rotterdam and Chemelot. Furthermore, patent activity is highly concentrated in a small number of applicants, and most inventions relate to the chemical sector rather than pure recyclers.

Compared with Germany, the Netherlands hosts more start-ups. However, the Dutch environment limits its pioneering companies through EU ETS incentives that promote incremental rather than breakthrough innovations, tax exemptions favouring large incumbents, subsidies that do not meet the needs of this type of invention, and high energy prices without offsets; the Dutch industrial policy relies primarily on taxation rather than targeted support, resulting in pioneering firms exposed to (energy) high costs. This, combined with persistent labour shortages in STEM, long and complex food-approval permit applicants, and even more notably, the lack of renewable energy infrastructure, further constrains the conditions under which these inventions can mature.

On the other side, the findings indicated that commercialisation requires economies of scale, as the analysed chemical inventions are capital- and energy-intensive. Co-location enables strategic couplings among firms, infrastructure, and feedstock supply, creating more efficient resource and energy use, less waste, and lower costs. Without this, achieving cost parity with fossil-based plastics is hardly possible. In addition, companies rely on consistent and predictable policy and industrial strategy that encourage, rather than solely rely on, taxes, especially since financing the gap between pilot and commercial plants demands long-term, high-risk investments. With the low-risk appetite in Europe and no clear pathway in industrial strategy and policies, these investments are less likely to materialise. The findings show that inventions do not progress to commercialisation unless these conditions, namely co-location, economies of scale, and clear steering in industrial policies, are aligned.

The ARRRA meta-cluster was historically enhanced by the disbanding of IG Farben, which laid the basis for the infrastructural co-location (pipelines, ports, steam crackers, and advanced energy systems) and large-scale production capacity that current companies now benefit from. On top of that, the Rhine River is more than a river; it functions as a core logistical artery that shapes the chemical industry and the spatial form of the ARRRA cluster. Topped with the Verbund logic, targeted subsidies and skill and training programmes in Germany create the right conditions for these inventions to reach the market.

Moreover, firms in these clusters combine competition with collaboration through licensing, joint ventures, shared production and energy facilities, and open-innovation networks. Furthermore, the vertical integration of chemical companies internalises demand, as the chemical industry is its own biggest market, resulting in a market that is not purely competitive but also driven by collaboration and government steering. This is driven mainly by the complexity of such inventions, which enhances the need for knowledge sharing. Moreover, due to this complexity, another essential enabler is the triple helix, in which companies, government, and academia collaborate to lay the proper foundation for these companies to develop and scale their invention.

The innovation ecosystem created by intentionally the involved actors stem from the need to scale within existing chemical clusters, where the expertise, energy systems, and other necessary infrastructure developed by large (petro)chemical firms can be leveraged. Smaller companies need access to this infrastructure, large amounts of energy, and expertise that such clusters can provide. The commercialisation of inventions, therefore, requires alignment with the larger companies present on the site or on other sites through licensing, joint ventures, resource sharing, and/ or shared facilities.

This explains why scaling remains uneven across regions. The tactical couplings, concerning short-term or temporary alignments, are evident in project-based collaborations, open innovation initiatives located in Chemelot and at the Ludwigshafen site, and in temporary funding, such as loans and subsidies. In the case of Avantium, the province of Groningen also plays a significant role by providing the company with capital, as does the government-backed investment fund Invest-NL. For the commercialisation of the invention of Avantium, not a single investment, subsidy, or loan is sufficient, but instead recurring investments over more extended periods of time. BASF obtains its subsidies directly from the German Federal Ministry for Economic Affairs and Climate Action and the State of Rhineland-Palatinate.

In sum, the commercialisation is not the result of one single cause, but instead the sum of structural (energy-infrastructure), strategic (cluster–incumbent integration), and tactical (temporary support) mechanisms across scale. If this alignment does not occur, as is now seen in the Netherlands, it becomes vastly challenging to commercialise plastic waste management inventions.

07. Recommendations

The recommendations outlined below follow the multi-scalar structure of this study. The innovation maps (Figures 17 and 18) show that Avantium operates within a relatively polycentric national system in which regions fulfil distinct roles that collectively form the innovation ecosystem. By contrast, BASF's ecosystem is more centralised, with a strong concentration of functions within a single region. Consequently, the conditions for commercialisation differ between the Dutch and German contexts.

Despite these differences, the analysis identified common patterns and conditions, including infrastructure, energy availability, resource flows, market structure, and access to highly skilled labour. The proximity of major ports, existing petrochemical assets and potential for renewable energy make the Netherlands strategically positioned to develop chemical recycling and related technologies. This applies to both emerging firms and large (petro-)chemical companies that rely on port-based infrastructure and international feedstock flows.

At the same time, one of the main conditions identified in this research was the (petro-)chemical industry. Not only does it offer benefits for startups/scaleups that can leverage the efficiency of integrated energy and supply chains, but many inventions also occur in the (petro-)chemical industry. Subsequently, if the Netherlands wants to maintain innovations in plastic waste management and thereby improve the conditions needed for the inventions to mature into these innovations, it would be advisable to look beyond the startups themselves and towards the (petro-)chemical companies. Rather than asking whether the petrochemical industry should remain in the Netherlands, the relevant question for commercialisation is how the system surrounding these companies can be reconfigured more sustainably.

In this reconfiguration, energy is one of the leading enablers; thus, the energy transition, energy prices, and the energy market become important drivers. In addition, the redirection of petrochemicals, driven by the shift towards biobased and renewable energy, demands a rethink and a clear strategy, for which the government needs to set the path.

Below, the recommendations are outlined according to scale.

National level

- *Strengthen high-voltage grid capacity* (including 380 kV) to enable industrial electrification and renewable integration in key clusters, especially Delfzijl and Chemelot.
- *Align energy prices, tariffs, and network costs* with neighbouring countries to reduce competitive disadvantages for energy-intensive operations.
- *Reassess the SDE++* in view of chemical-sector requirements.
- Improve the *transportation connectivity* with Chemelot and Delfzijl.
- Implement *targeted tax and compensations* instruments that are tailored rather than uniform.
- Treat compensation mechanisms not as subsidies but as *(temporary) insurance* against carbon leakage and deindustrialisation until energy infrastructure and renewable supply become sufficient.
- Streamline *approval procedures for food-contact* use of recycled plastics.

As discussed, the data showed that these companies heavily depend on R&D, intellectual property, and skilled employees to create value, thereby establishing ecosystems that enable close cooperation, resource sharing, and encourage innovation. The collaboration among involved actors (e.g., universities, public research institutions, the private sector, public authorities, the triple helix) extends thus beyond sharing resources to include sharing ideas and best practices, which may result in more complex or sophisticated solutions that would not have been achieved individually. This reflects, among other things, the need for human capital, not only highly specialised employees but also people able to work in the plants. This has led to the following recommendations:

- *Strengthen linkages with universities and research institutes*, particularly between Amsterdam, Eindhoven and Chemelot.
- *Improve mobility connections* between Chemelot and key research centres (e.g., Eindhoven, Amsterdam).
- *Improve liveability and housing in industrial regions* to attract and retain specialised labour.
- *Enhance, and motivate people for, vocational (MBO) training* in chemical operations and process engineering to meet skill requirements in decarbonising industries.

As the ARRRA meta-cluster spans borders, designing effective, integrated cross-border governance and cooperation is important. However, the energy market remains national and thus fragmented, as does transportation, two important pillars of the ARRRA meta-cluster (Raudla & Spendzharova, 2022). A condition for the chemical industry is better-aligned cooperation between countries in energy, infrastructure, and ports.

Currently, the European (petro-)chemical industry, in its current form, is competing globally with powerhouses such as China and the US. This challenge is worsened by the mergers and acquisitions (M&A) in Europe being more heavily regulated than in China or the US, where industry consolidation has created larger, more competitive players (Lumpe et al., 2025). These consolidated structures enable economies of scale in key sectors such as plastics and base chemicals, giving those regions a significant competitive advantage. Together with better cooperation and alignment compared to at the European level, this leads to a shift in thinking about the current European petrochemical sector and its role in the global debate, especially moving away from volume-based approaches to value-based ones. That is, even with all the conditions in place, there remains the risk that overseas competitors will disrupt the chemical market, as reported (Baumgartner et al., 2025; Lumpe et al., 2025).

A strategy could be for the ARRRA petrochemical cluster to focus more on innovative and specialised inventions rather than on commodities. This shift in thinking could be an important driver of technological development, such as in the commercialisation of plastic waste management. A similar strategic shift happened during the petrochemical crisis of the 1990s, when European producers moved from competing on bulk commodities to specialising in higher-value segments. This shift ultimately improved resilience and competitiveness. This historical example indicates that a renewed emphasis on value-driven innovation could once again be an effective response to global market pressures.

This has led to the recommendations, seen on the next page.

European Level

- *Prioritise coordination of energy markets and infrastructure* between the Netherlands, Belgium and Germany
- *Strengthen cooperation between the ports of Rotterdam and Antwerp f*or feedstock logistics and circular-chemistry development.
- *Improve liveability and housing in industrial regions* to attract and retain specialised labour.
- *Develop joint industrial strategies* focusing on technological upgrading and high-value segments rather than volume-based petrochemicals.
  Or, reconsider the role of market consolidation in enabling scale and competitiveness.
- *Expand pipeline infrastructure* for hydrogen and alternative feedstocks as part of the developing hydrogen backbone.

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Appendix A

From patent data into text. Adjusted per country and patent dataset.

```
from pdf2image import convert_from_path
import pytesseract
import os

# The settings
pdf_path = r"G:\Mijn Drive\Thesis\Research proposal\Thesis
map\0.START\Databases for Patents\Python\patent.pdf" #
Update this if needed
output_folder = "ocr_output"  # Folder to store page text files

# The folder
os.makedirs(output_folder, exist_ok=True)

import os
print(os.path.exists(pdf_path))     # Should print True
print(repr(pdf_path))               # Shows exact path string

# converting the PDF to images
print("Converting PDF pages to images...")
pages = convert_from_path(pdf_path, dpi=200, poppler_
path=r"C:\\Users\\Gebruiker\\Release-24.08.0-0\\
poppler-24.08.0\\Library\\bin")

# Run OCR and to save the text
all_texts = []
for i, page_img in enumerate(pages):
    text = pytesseract.image_to_string(page_img,
lang="eng+deu+nld")
    all_texts.append(text)
    # Save each page's OCR to a text file
    txt_file = os.path.join(output_folder, f"page_{i+1}.txt")
    with open(txt_file, "w", encoding="utf-8") as f:
        f.write(text)
    print(f"OCR for page {i+1} saved to {txt_file}")

print("All pages processed.")
```

Appendix B

From a text into an Excel sheet

```
import re
import pandas as pd
import os

# 1. Read lines from OCR file
ocr_file = r"C:\Users\Gebruiker\Documents\Python\BE_patents.csv"

if not os.path.exists(ocr_file):
    raise FileNotFoundError(f"OCR file not found: {ocr_file}")

with open(ocr_file, "r", encoding="utf-8") as f:
    ocr_text = f.read()

# Split into lines, remove empty lines
lines = [line.strip() for line in ocr_text.split('\n') if line.strip()]

# 2. Regex: Find Dutch postcode + city (+ country)
postcode_pattern = re.compile(
    r'(?P<postcode>\d{4}\s?[A-Z]{2})\s*,?\s*(?P<city>[A-Za-z\- ]+)?\s*\(?(?P<country>[A-Z]{2})?\)?',
    re.IGNORECASE
)

matched = []
unmatched = []

window_size = 3
for i in range(len(lines)):
    block = " ".join(lines[i:i+window_size])
    pc_match = postcode_pattern.search(block)
    if pc_match:
        matched.append({
            "postcode": (pc_match.group("postcode") or "").replace(" ", ""),
            "city": (pc_match.group("city") or "").strip(" ,;.-") if pc_match.group("city") else "",
            "country": (pc_match.group("country") or "").strip(" ,;.-") if pc_match.group("country") else "NL"
        })
    else:

# 3. Export to Excel
df_matched = pd.DataFrame(matched).drop_duplicates()
df_unmatched = pd.DataFrame(unmatched)
df_matched.to_excel("postcode_matches.xlsx", index=False)
df_unmatched.to_excel("postcode_unmatched.xlsx", index=False)

print(f"Extraction (postcode-only) complete! Matched: {len(df_matched)} | Unmatched: {len(df_unmatched)}")
```

Appendix C

From Excel sheet to matched postal codes.

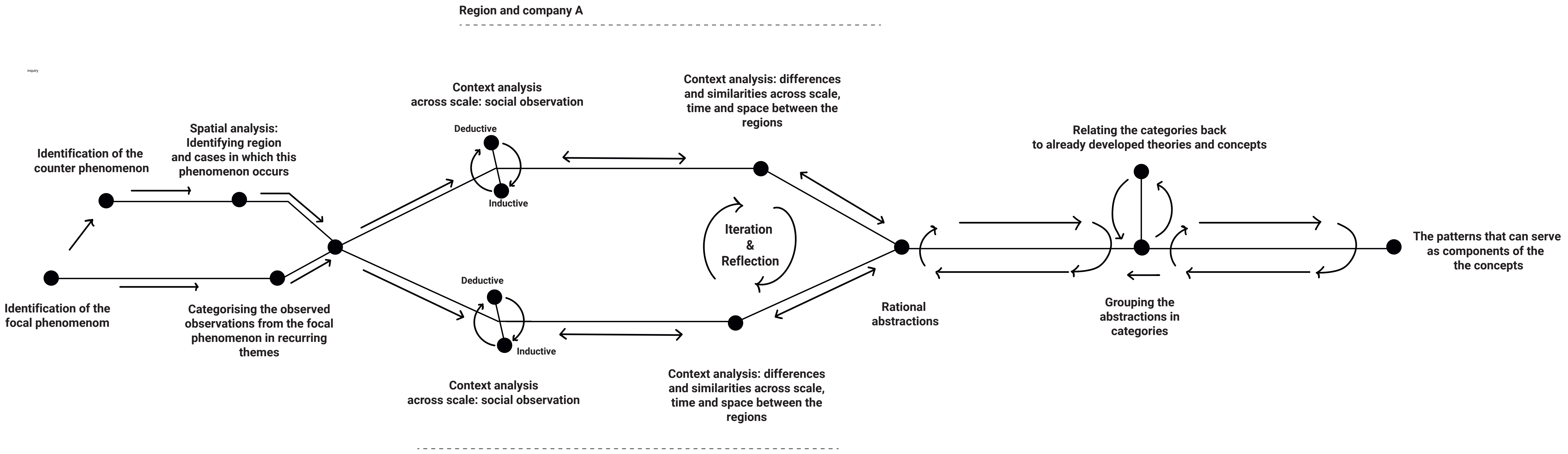
```
import pandas as pd
import re

# The settings
txt_file = r"C:\Users\Gebruiker\OneDrive\ocr_output\BE_all_pages.txt"
georef_csv = r"C:\Users\Gebruiker\Downloads\georef-belgium-postal-codes.csv"

# 1. Extract only real postcodes – adapt per country
with open(txt_file, encoding='utf-8') as f:
    text = f.read()
postcodes = re.findall(r'(?<!\d)([1-9]\d{3})(?!\d)', text)
print(f'Extracted postcodes: {postcodes[:10]} ... ({len(postcodes)} found)')
df_postcodes = pd.DataFrame(postcodes, columns=['Post code'])
df_postcodes['count'] = 1
df_counts = df_postcodes.groupby('Post code').count().reset_index()

# 2. Georeferencing – adapt per country
df_geo = pd.read_csv(georef_csv, sep=';', encoding='utf-8')
df_geo.columns = [col.strip() for col in df_geo.columns]
df_geo['Post code'] = df_geo['Post code'].astype(str).str.strip().str.extract(r'([1-9]\d{3})')[0]

# 3. Merge on postal code
df_merged = df_counts.merge(df_geo, on='Post code', how='left')
df_merged.to_csv('The name of the document.csv', index=False)
print('Merged output saved to The name of the document_patents_postcode_georef.csv')

# 4. Unmatched ones
unmatched = df_merged[df_merged['Geo Point'].isna()]
print(f"Unmatched postcodes: {len(unmatched)} out of {len(df_merged)}")
if not unmatched.empty:
    print(unmatched[['Post code', 'count']].head(10))
```

Appendix D

From postal codes to heatmaps

```
import pandas as pd
import folium
from folium.plugins import HeatMap

# 1. Patent data
patent_file = r”C:\Users\Gebruiker\OneDrive\BE_patents_postcode_georef.csv”
df_patent = pd.read_csv(patent_file, delimiter=’;’)
df_patent.columns = [c.strip() for c in df_patent.columns]

print(“Kolommen in patent-bestand:”, df_patent.columns.tolist())

postcode_col = ‘Post code’ if ‘Post code’ in df_patent.columns else df_patent.columns[0]
df_patent[postcode_col] = df_patent[postcode_col].astype(str).str.replace(‘ ‘, ‘’).str.upper()
df_patent[‘pc4’] = df_patent[postcode_col].str[:4]  # mag evt pc4 heten, is 4cijferig BE

# 2. Georef
georef_file = r”C:\Users\Gebruiker\Downloads\georef-belgium-postal-codes.csv”
tried = False
for delim in [‘,’, ‘;’, ‘\t’]:
    try:
        df_geo = pd.read_csv(georef_file, delimiter=delim, usecols=[0,2], low_memory=False)
        tried = True
        print(f”Succesvol ingelezen met delimiter ‘{delim}’.”)
        break
    except Exception as e:
        print(f”Delimiter ‘{delim}’ gaf een fout: {e}”)

if not tried:
    raise Exception(“Kon de georef CSV niet goed inlezen. Check bestand/delimiter.”)

df_geo.columns = [c.strip().lower() for c in df_geo.columns]
df_geo = df_geo.rename(columns={“geo point”:”geo_point”, “post code”:”pc4”})
df_geo[‘pc4’] = df_geo[‘pc4’].astype(str).str.replace(‘.0’,’’)

print(“Patent PC4 voorbeelden:”, df_patent[‘pc4’].unique()[:5])
print(“Georef PC4 voorbeelden:”, df_geo[‘pc4’].unique()[:5])

# 3. Merge op PC4
df_merged = pd.merge(df_patent, df_geo, on=’pc4’, how=’left’)

# 4. Split in lat/lon
df_merged = df_merged.dropna(subset=[‘geo_point’])
df_merged[[‘lat’, ‘lon’]] = df_merged[‘geo_point’].str.split(‘,’, expand=True)
df_merged[‘lat’] = df_merged[‘lat’].astype(float)
df_merged[‘lon’] = df_merged[‘lon’].astype(float)

# 5. Group by PC4 for Heatmap (after lat/lon exist!)
pc4_counts = df_merged.groupby([‘pc4’, ‘lat’, ‘lon’]).size().reset_index(name=’count’)

# 6. Prepare heatmap data:
[lat, lon, count]
heat_data = [
    [row[‘lat’], row[‘lon’], row[‘count’]]
    for _, row in pc4_counts.iterrows()
    if pd.notnull(row[‘lat’]) and pd.notnull(row[‘lon’])
]

# 7. Create a heatmap
m = folium.Map(location=[50.85, 4.35], zoom_start=8, tiles=’cartodbpositron’)  # BE-centered
HeatMap(heat_data, radius=14, blur=24, max_zoom=1).add_to(m)
m.save(“patent_BE_heatmap.html”)
print(“Heatmap saved as patent_BE_heatmap.html”)

# 8. Log unmapped PC4s
unmapped = df_patent[~df_patent[‘pc4’].isin(df_geo[‘pc4’])]
print(“Niet-gematchte PC4’s:”, unmapped[‘pc4’].unique())
unmapped.to_csv(“unmapped_patent_BE.csv”, index=False)
```

Appendix E *Methodology outlined*



Appendix F

Tracking emerging patterns

	Context	Emerging / Summarised Pattern
History	History: WWII expansion and cross-sector collaboration (government, academia, industry).	Early state–industry–academia collaboration laid the foundation for long-term institutional coupling (Triple Helix).
History	History: Shift from coal to oil as primary feedstock.	Resource substitution created cheap, abundant, and easily transportable inputs, enhancing fossil-based path dependence.
History	History: Government investment in R&D and manufacturing with guaranteed markets.	State intervention accelerated industrialisation and created dependence on public market formation.
History	History: Government investment in infrastructure (pipelines, ports, highways).	Public infrastructure shaped the spatial and logistical backbone of the industry.
History	History: Post-war industry self-reliance with limited state involvement.	Transition from state dependence to private oligopolistic self-governance.
History	History: Oligopolistic market structure in chemicals.	Market concentration produced stability but limited competition.
History	History: "Community of interest" among few dominant firms.	Cross-ownership and joint ventures cemented inter-firm coordination.
History	History: Economies of scale in production and research.	Scale effects extended from production to innovation, reinforcing dominance of large firms.
History	History: Break-up of IG Farben created BASF, Bayer, Hoechst.	Structural reorganisation spurred innovation and global corporate emergence.
History	Maturity stage of the industry (Chen, 2022; Audretsch & Feldman, 1996).	Mature stage marked by consolidation, R&D centrality, and geographic dispersion of innovation.
Macro	EU dependence on chemical sector for inputs and trade.	The chemical industry underpins other sectors and drives EU trade performance.
Macro	Chemicals as own key input source.	Vertical integration—industry as its own primary supplier and market.
Macro	High energy intensity (steam crackers, ethylene, propylene, etc.).	Structural energy dependence and operational inflexibility due to technical and thermal constraints.
Netherlands	Netherlands: R&D collaboration among firms and universities.	Institutionalised collaboration enhances innovation spillovers.
Netherlands	Netherlands: Clustered industrial structure and strong infrastructure.	Spatial concentration and integration facilitate cooperation and efficiency.
Netherlands	Netherlands: Growing hydrogen use, largely from natural gas.	Hydrogen transition still fossil-linked—emerging dependency pathway.
Netherlands	Netherlands: Open trade economy, strong exports but exposure to shocks.	Trade openness enhances competitiveness but heightens vulnerability to global disruptions.
Netherlands	Netherlands: Dependence on foreign energy imports.	Structural exposure to geopolitical and supply-chain risks.
Netherlands	Netherlands: High network and energy costs; production halts.	Domestic energy pricing undermines industrial competitiveness.
Netherlands	Netherlands: Site integration and systemic vulnerability.	Inter-firm interdependence creates cascading risk within clusters.
Germany	Germany: Marshall Plan, social-market economy, SME export growth.	Institutional foundations of industrial growth and export orientation.
Germany	Germany: Government–science–industry collaboration.	Triple-Helix institutional model driving applied industrial innovation.
Germany	Germany: Fraunhofer and Max-Planck research ecosystem.	Publicly funded applied research as a long-term innovation engine.
Germany	Germany: Infrastructure (railways) for industrial transport.	State infrastructure policies enabled trade and regional integration.
Germany	Germany: Emergence of integrated industrial sites.	Co-location of full value chain increased efficiency and interdependence.
Germany	Germany: Decentralised innovation governance.	Regional autonomy enhances policy alignment with industrial needs.
ARRRA	ARRRA: Cluster synergies and shared infrastructure.	Spatial clustering generates economies of scope and network effects.
ARRRA	ARRRA: Location near transport hubs and ports.	Co-location driven by logistics rather than market proximity.
ARRRA	ARRRA: Complex producer–supplier relations.	Vertical and horizontal integration across production stages.
ARRRA	ARRRA: Antwerp and Rotterdam as core hubs.	Centralised infrastructure nodes anchor the meta-cluster.
ARRRA	ARRRA: Extensive pipeline system linking sites.	Physical interconnectivity underpins resource and feedstock flows.
ARRRA	ARRRA: Feedstock import via ports and inland waterways.	Strategic siting near ports ensures continuous raw-material supply.
ARRRA	ARRRA: Netherlands as key naphtha supplier.	National specialisation within meta-cluster production chain.
ARRRA	ARRRA: Firms guided by shared infrastructure and policy incentives.	Governance and spatial coupling shape strategic decisions beyond pure market logic.
ARRRA	ARRRA: Trilateral Chemical Region across NL-BE-DE.	Cross-border governance complexity limits policy alignment.
ARRRA	Market dominance of large firms.	Oligopolistic coordination concentrates innovation power in major companies.
ARRRA	Netherlands: Startup activity and entrepreneurship.	Favourable business environment fosters small-firm dynamism.
ARRRA	Research institutes and patent activity.	Strong role of research organisations in knowledge creation.
Geleen	Geleen: Historic state support for industrial development.	State-driven industrialisation and market formation.
Geleen	Geleen: Integrated site and pipeline connections.	Infrastructural interdependence facilitates efficiency and risk sharing.
Geleen	Geleen: Cluster scale (150 companies, 850 students).	Dense innovation and production ecosystem.
Geleen	Geleen: Exposure to economic cycles.	High cyclicality and vulnerability to global market shifts.
Geleen	Geleen: Infrastructural interdependence and energy transition barriers.	Systemic lock-in hampers decarbonisation and process flexibility.
Geleen	Geleen: Open innovation strategy (Brightlands).	Knowledge inflows/outflows institutionalised to stimulate innovation.
Geleen	Geleen: High natural gas and naphtha use; rising electrification demand.	Energy-intensive production with growing electricity dependency.
Geleen	Geleen: Multi-level cluster governance.	Overlapping governance levels complicate strategic coordination.
Geleen	Geleen: Strategic decisions by foreign HQs.	Limited local agency within global corporate networks.
Ludwigshafen	Ludwigshafen: Location along Rhine with port access.	Inland waterway linkage optimises logistics and trade.
Ludwigshafen	Ludwigshafen: Post-WWII growth after IG Farben break-up.	Corporate restructuring and investment enabled cluster expansion.
Ludwigshafen	Ludwigshafen: Site management by main operator.	Centralised site governance enables service efficiency.
Ludwigshafen	Ludwigshafen: Verbund system linking 200+ plants.	Dense infrastructural network ensures circularity and resource optimisation.
Ludwigshafen	Ludwigshafen: Waste-to-feedstock loops.	Internal resource reuse minimises waste and energy loss.
Ludwigshafen	Germany (EMR concept): Cross-regional strategic coordination.	Regional governance fosters coherent industrial development.

Appendix G *- patent dataset and assigned category Netherlands*

Applicants	Type company
GET2GREEN LOGISTICS B V [NL]	MKB
CURE TECH B V [NL]	Startup/Scale up
NOVOCHEM GREEN ADDITIVES 4 B V [NL]	MKB
NOVOCHEM GREEN ADDITIVES B V [NL]	
CURE TECH B V [NL]	Startup/Scale up
ARAPAHA B V [NL]	Startup/Scale up
SPEX TECH B V [NL]	Startup/Scale up
QCP HOLDING B V [NL]	Startup/Scale up
CURE TECH B V [NL]	Startup/Scale up
ARKEMA FRANCE [FR]	MKB
HEATHLAND B V [NL]	
SABIC GLOBAL TECHNOLOGIES BV [NL]	Multinational
DAKIP B V [NL]	MKB
NUTRICIA NV [NL]	MKB
SABIC GLOBAL TECHNOLOGIES BV [NL]	Multinational
ASCEM B V [NL]	Research institute
OERLEMANS PACKAGING B V [NL]	MKB
SHELL INT RESEARCH [NL]	Multinational
LUTGENDORF PIETER HENDRIK [NL] WAVIN BV [NL]	multinational
SABIC GLOBAL TECHNOLOGIES BV [NL]	Multinational
WASTE PAPER TRADE C V [NL]	MKB
OBM RECYCLING MACHINERY B V [NL]	
TRIOWORLD APELDOORN B V [NL]	Multinational
SABIC GLOBAL TECHNOLOGIES BV [NL]	Multinational
SHPP GLOBAL TECH BV [NL]	Multinational
UNILEVER IP HOLDINGS B V [NL]	Multinational
IONIQA TECH B V [NL]	Startup/Scale up
NOURYON CHEMICALS INT BV [NL]	Multinational
WIT INT B V [NL]	Startup/Scale up
PROBO SIGN B V [NL]	MKB
INTERFACE INTERNAT B V [NL]	Multinational
SOLENIS TECHNOLOGIES CAYMAN LP [KY]	
FELDMANN LENNART [NL] FELDMANN MARC [ES]	Individual
ROODENBURG MICHAEL [NL]	Individual
ALBRECHT HUIJSMANS ANTONIA MAR [NL]	Individual
TNO [NL]	Research institute
TNO [NL]	Research institute
HENDERICKX MATHIAS WILHELMUS MARIA [NL]	Individual
MACHF BOLLEGRAAF APPINGEDAM B [NL] MACHF BOLLEGRAAF APPINGEDAM B V [NL]	Individual
CRAMWINCKEL MICHIEL [NL]	Individual
ECO HABITAT B V [NL]	MKB
QUINLYTE HOLDING B V [NL]	Startup/Scale up
RENES AGF SERVICES B V [NL]	MKB
SABIC GLOBAL TECHNOLOGIES BV [NL]	multinational
SABIC GLOBAL TECHNOLOGIES BV [NL]	multinational
SABIC GLOBAL TECHNOLOGIES BV [NL]	Multinational
QCP HOLDING B V [NL]	Startup/Scale up
AVANTIUM KNOWLEDGE CENTRE BV [NL]	Startup/Scale up
CUYPERS JEAN MARIE WILHELMUS [NL]	Multinational
ROCKWELL INTERNAT A S [DK]	
AVANTIUM KNOWLEDGE CENTRE BV [NL]	Startup/Scale up
DAKLAPACK EUROPE B V [NL]	MKB
ROCKWOOL INT [DK] CUYPERS JEAN-MARIE WILHELMUS [NL] LAMBIE STUART [GB] SMEETS GERARDUS	Multinational
Fibrant	Multinational
Fibrant	Multinational
WASTE PAPER TRADE C V [NL]	MKB
OSO FIBER UK LTD [GB]	
ARKEMA FRANCE [FR] JAPAN STEEL WORKS EUROPE GMBH [DE] HEATHLAND B V [NL]	MKB
IONIQA TECH B V [NL]	Startup/Scale up
STICHTING IMEC NEDERLAND [NL]	Research institute
ECO HABITAT B V [NL]	MKB
JAMES HARDIE RESEACH PTY LTD [AU]	Multinational
JAMES HARDIE RESEACH PTY LTD [NL]	
GEN ELECTRIC [NL]	Multinational
IONIQA TECH B V [NL]	Startup/Scale up
TNO [NL]	Research institute
ELSINGA BELEIDSPLANNING EN INNOVATIE B V [NL]	MKB
TRISOPLAST INTERNAT BV [NL]	MKB

- patent dataset and assigned category Germany

No	Applicants	Type company
1	VON DEYM CARL LUDWIG GRAF [DE] STREUBER FRITZ MICHAEL [DE]	Individual
2	MAEURER ANDREAS [DE] SCHLUMMER MARTIN [DE] BECK OTTO [DE] FRAUNHOFER GES FORSCHUNG [DE]	Research institute
3	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
4	ZIMMERMANN TOBIAS J [DE]	Individual
5	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
6	KBG KUNSTSTOFF BETEILIGUNGEN GMBH [DE]	Mittelstand
7	CVP CLEAN VALUE PLASTICS GMBH [DE] HOFMANN MICHAEL [DE] GERCKE ALEXANDER [DE]	Multinational
8	GRANNEX GMBH & CO KG [DE]	Multinational
9	KUNSTSTOFF RECYCLING GRUENSTADT GMBH [DE]	Multinational
10	CONTINENTAL REIFEN DEUTSCHLAND GMBH [DE]	Multinational
11	POIESZ MATTHEUS J [DE]	Individual
12	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
13	UNIV DRESDEN TECH [DE]	University
14	CONTINENTAL REIFEN DEUTSCHLAND GMBH [DE]	Multinational
15	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
16	KBG KUNSTSTOFF BETEILIGUNGEN GMBH [DE]	Mittelstand
17	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
18	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
19	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
20	FRAUNHOFER GES FORSCHUNG [DE] SCHLUMMER MARTIN [DE] MAEURER ANDREAS [DE]	Research institute
21	MANKIEWICZ GEBR & CO GMBH & CO KG [DE]	Multinational
22	KURARAY SPECIALITIES EUROPE [DE]	Multinational
23	GIESECKE & DEVRIENT MOBILE SECURITY GMBH [DE]	Multinational
24	MITRAS IND HOLDING GMBH [DE]	Mittelstand
25	VOLKSWAGEN AG [DE] BASF SE [DE]	Multinational
26	SAPERATEC GMBH [DE]	Startup/Scale up
27	CFK VALLEY STADE RECYCLING GMBH & CO KG [DE] MEIER LEIF OLE [DE]	Multinational
28	SAPERATEC GMBH [DE]	Startup/Scale up
29	MONDI CONSUMER PACKAGING TECHNOLOGIES GMBH [DE] MONDI AG [AT]	Multinational
30	SCHMID BAUKUNSTSTOFFE GMBH [DE]	Multinational
31	SGL CARBON SE [DE] SHOWA DENKO CARBON GERMANY GMBH [DE]	Multinational
32	APK AG [DE]	Multinational
33	NO CANARY GMBH [DE]	Startup/Scale up
34	REESE LARS [DE] HAASE ARNE [DE] PETERS NORBERT [DE] KRONES AG [DE]	Multinational
35	SISI WERKE GMBH [DE] HPX POLYMERS GMBH [DE]	Multinational
36	KRONES AG [DE]	Multinational
37	BASF SE [DE]	Multinational
39	WIETEK HOLDING GMBH [DE]	mittelstand
40	CONSTANTIA PIRK GMBH & CO KG [DE]	Multinational
41	SAPERATEC GMBH [DE]	Startup/Scale up
42	REIFENHÄUSER GMBH & CO KG MASCHINENFABRIK [DE]	Multinational
43	WESTDEUTSCHER DRAHTSEIL-VERKAUF DOLEZYCH GMBH & CO KG [DE]	Mittelstand
44	UHDE INVENTA FISCHER GMBH [DE] THYSSENKRUPP AG [DE]	Multinational
45	KUEGLER JOST ULRICH DIPL ING [DE]	Individual
46	NITSCHE MANFRED [DE] LORENZ ARNULF [DE]	Individual
47	ELG CARBON FIBRE INT GMBH [DE]	Multinational
48	RIEMER DETLEF [DE]	Individual
49	KOSLOW ALEXANDER [DE]	Individual
50	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
51	SAPERATEC GMBH [DE]	Startup/Scale up
52	OUTOTEC OYJ [FI] SCHAAF TANJA [DE] BINDER CHRISTIAN [DE] ANASTASIJEVIC NIKOLA [DE] SCHNEIDER GUENTER	Individual
53	HERBOLD MECKESHEIM GMBH [DE]	Multinational
54	KLEIDERLY UG HAFTUNGSBESCHRAENKT [DE] KLEIDERLY GMBH [DE] KLIEDERLY GMBH [DE]	Startup/Scale up
55	COPERION GMBH [DE]	Multinational
56	GANZ JOHANN [DE]	Individual
57	BASF SE [DE]	Multinational

58	DER GRUENE PUNKT DUALES SYST [DE] HECKERT UMWELTTECHNIK GMBH [DE] ARLETH FRANK [DE] KOCH THOMAS [DE] WINTER MIRKO [DE] HANDSCHICK BERT [DE] DIETRICH TROELTSCH ERNST PETER [DE]	Mittelstand
59	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
60	BASF SE [DE]	Multinational
61	BASF SE [DE]	Multinational
62	PUREN GMBH [DE]	Mittelstand
63	CONSTANTIA PIRK GMBH & CO KG [DE]	Multinational
64	BASF SE [DE]	Multinational
65	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
66	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
67	UNIV HANNOVER GOTTFRIED WILHELM LEIBNIZ [DE] ENDRES HANS JOSEF PROF DR ING [DE]	University
68	BASF SE [DE]	Multinational
69	KRONES AG [DE] HEIDELBERGER DRUCKMASCH AG [DE]	Multinational
70	BASF SE [DE]	Multinational
71	EVONIKOPERATIONS GMBH [DE]	Multinational
72	SAPERATEC GMBH [DE]	Startup/Scale up
73	CONTINENTAL REIFEN DEUTSCHLAND GMBH [DE]	Multinational
74	BASF SE [DE]	Multinational
75	BASF SE [DE] BASF CHINA CO LTD [CN]	Multinational
76	ELG CARBON FIBRE INTERNAT GMBH [DE] ELG CARBON FIBRE INT GMBH [DE]	Multinational
77	BASF SE [DE]	Multinational
78	MITSUBISHI POLYESTER FILM GMBH [DE]	Multinational
79	DER GRUENE PUNKT DUALES SYSTEM DEUTSCHLAND GMBH [DE] DER GRUENE PUNKT—DUALES SYSTEM DEUTSCHLAND GMBH [DE]	Mittelstand
80	EVONIKOPERATIONS GMBH [DE]	Multinational
81	BASF SE [DE]	Multinational
82	UNISENSOR SENSORSYSTEME GMBH [DE]	mittelstand
83	ASG AUTOMATEN SYSTEME GMBH [DE]	Multinational
84	SENSOR INSTR ENTWICKLUNGS UND VERTRIEBS GMBH [DE]	mittelstand
85	BASF SE [DE]	Multinational
86	APK AG [DE]	Multinational
87	COVESTRO DEUTSCHLAND AG [DE]	Multinational
88	BRANDSCH RAINER [DE]	Individual
89	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
90	YAMAMOTO MOTONORI [DE] KUENKEL ANDREAS [DE] SKUPIN GABRIEL [DE] BLUM RAINER [DE] BASF SE [DE]	Multinational
91	CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
92	KERNBAUM SEBASTIAN [DE] SEIBT HORST [DE] SAPERATEC GMBH [DE]	Startup/Scale up
94	RECOM PATENT & LICENSE GMBH [DE]	Multinational
95	HANS HERMANN TRAUTWEIN SB TECHNIK GMBH [DE]	mittelstand
96	SIEGENTHALER KAI OLIVER [DE] BLUM RAINER [DE] SKUPIN GABRIEL [DE] YAMAMOTO MOTONORI [DE] BASF SE [DE]	Multinational
97	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
98	FOSHAN KING WONDER HI TECH CO LTD [CN] JACK WOLFSKIN AUSRUESTUNG FUER DRAUSSEN GMBH & CO KGAA [DE] TOPGOLF CALLAWAY BRANDS CORP [US]	mittelstand
99	RITTEC UMWELTTECHNIK GMBH [DE]	Startup/Scale up
100	APK AG [DE]	Multinational
101	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
102	EVONIKOPERATIONS GMBH [DE]	Multinational
103	MEIER MEINHARD [DE] GRIMBERG EDELBERT [DE] REGENER PETER [DE] HORNUNG ANDREAS [DE]	Individual
104	REDUX RECYCLING GMBH [DE]	Startup/Scale up
105	DER GRUENE PUNKT DUALES SYST [DE] SIEMENS AXIVA GMBH & CO KG [DE]	Multinational
106	ECOENERGY GES FUER ENERGIE UND UMWELTTECHNIK GMBH [DE]	Mittelstand
107	RITTEC UMWELTTECHNIK GMBH [DE]	Startup/Scale up
108	DUESENFELD GMBH [DE]	Research institute
109	RECYPLAST GMBH [DE]	Multinational
110	BASF SE [DE]	Multinational

111	RECYCLING ZENTREN BRANDENBURG [DE]	Mittelstand
112	APK AG [DE]	Multinational
113	KRONES AG [DE]	Multinational
114	RITTER GMBH [DE]	Multinational
116	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
117	CVP CLEAN VALUE PLASTICS GMBH [DE] CVP CLEAN VALUE PLASTICS GMBH	Multinational
118	DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
119	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
120	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
121	HEIDELBERGCEMENT AG [DE]	Multinational
122	GRÖTSCHEL RALF [DE]	Individual
123	SMART COLORING GMBH [DE]	Startup/Scale up
124	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
125	BASF SE [DE]	Multinational
126	DKR DEUTSCHE GES FUER KUNSTSTO [DE] DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
127	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
128	SCHAEFER THILO [DE]	Individual
129	EVONIKOPERATIONS GMBH [DE]	Multinational
130	SAPERATEC GMBH [DE]	Startup/Scale up
131	SAINT-GOBAIN WEBER GMBH [DE] SAINT GOBAIN WEBER [FR]	Individual
132	KOELBL ENGINEERING UND CONSULT [DE]	Individual
133	SENSOR INSTR ENTWICKLUNGS UND VERTRIEBS GMBH [DE]	Mittelstand
134	POMMERSHEIM RAINER [DE]	Individual
135	DIAMAT MASCHB GMBH [DE]	Mittelstand
136	BASF SE [DE]	Multinational
137	FIBER ENG GMBH [DE]	mittelstand
138	LURGI ZIMMER GMBH [DE] TECHNIP ZIMMER GMBH [DE]	Multinational
139	ROTT HEINRICH [DE]	Individual
140	BASF SE [DE]	Multinational
141	BASF SE [DE]	Multinational
142	BRUECKNER MASCHBAU [DE]	Multinational
143	APK AG [DE]	Multinational
144	HASENPUSCH WOLFGANG [DE]	Individual
145	DETTER RUDOLF [DE] STENGEL PATRICE [FR]	Individual
146	RHEINISCH WESTFAELISCHE TECHNISCHE HOCHSCHULE AACHEN ABGEKUERZT RWTH AACHEN KOERPERSCHAFT	University
147	SMART MAT PRINTING B V [NL] BUERKLE CONSULTING GMBH [DE] LUTHE GREGOR [PT]	Multinational
148	VOITH PATENT GMBH [DE]	Multinational
149	DAIMLER CHRYSLER AG [DE]	Multinational
150	BASF SE [DE]	Multinational
151	LANGEN ROBERT [DE]	Individual
152	SARTORIUS STEDIM BIOTECH GMBH [DE]	Multinational
153	FISCHERWERKE GMBH & CO KG [DE]	Multinational
154	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
155	HOFMANN MICHAEL [DE] GERCKE ALEXANDER [DE] WERMTER CARSTEN [DE] CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
156	SORTIMO SPEEDWAVE GMBH [DE] ROSNER MICHAEL [DE]	Multinational
157	APK AG [DE]	Multinational
158	KRONES AG [DE]	Multinational
159	UHDE INVENTA FISCHER GMBH [DE] THYSSENKRUPP AG [DE]	Multinational
160	THICHY THOMAS [DE] LASSO FINANCIAL LTD [KN]	Individual
161	HOFMANN MICHAEL [DE] GERCKE ALEXANDER [DE] WERMTER CARSTEN [DE] CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
162	ADIDAS AG [DE]	Multinational
163	BOCK HANS-PETER [DE]	Individual
164	TECHNOCOMPOUND GMBH [DE]	Mittelstand
165	CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
166	CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational

167	CVP CLEAN VALUE PLASTIC GMBH [DE]	Multinational
168	KIEFEL GMBH [DE]	Multinational
169	MERCK PATENT GMBH [DE]	Mittelstand
170	TILS PETER [DE]	Individual
171	NIEDNER PETER [DE]	Individual
172	REIMERS H WERNER [DE] DEBUS DIETER [DE]	Individual
173	BASF SE [DE]	Multinational
174	RITTEC UMWELTTECHNIK GMBH [DE]	Startup/Scale up
175	MONDI CONSUMER PACKAGING TECH GMBH [DE]	Multinational
176	SCHOELLER ALLIBERT GMBH [DE]	Multinational
177	BASF SE [DE]	Multinational
178	LORENZ ARNULF [DE] NITSCHE MANFRED [DE]	Individual
179	BOETTCHER JOACHIM [DE]	Individual
180	BASF SE [DE]	Multinational
181	UNIV KONSTANZ [DE]	University

182	RAMPF HOLDING GMBH & CO KG [DE] RAMPF ADVANCED POLYMERS GMBH & CO KG [DE]	Multinational
183	TRENNTECHNIK ULM GMBH [DE] DOMO ENG PLASTICS GMBH [DE]	Multinational
184	KORYSZCZUK KURT [DE]	Individual
185	DUESENFELD GMBH [DE]	Research institute
186	KRONES AG [DE] FRIEDLAENDER THOMAS [DE] RIECKMANN THOMAS [DE] MARX FRANK [DE]	Multinational
187	EVONIKOPERATIONS GMBH [DE]	Multinational
188	NORDFOLIEN GMBH [DE]	Multinational
189	HAGEN RAINER [DE] UHDE INVENTA FISCHER GMBH [DE]	Multinational
190	BASF SE [DE]	Multinational
191	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
192	KRONES AG [DE]	Multinational
193	KRONES AG [DE]	Multinational
194	CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
195	BERNING MASCHINENFABRIK GMBH [DE]	Mittelstand
196	RAMPF ADVANCED POLYMERS GMBH & CO KG [DE]	Multinational
197	KOEHLER INNOVATION & TECH GMBH [DE]	Research institute
198	BASF SE [DE]	Multinational
199	BASF SE [DE]	Multinational
200	BASF SE [DE]	Multinational
201	BASF SE [DE]	Multinational
202	HILTL CHRISTOPH [DE] STORZ KARL GMBH & CO KG [DE]	Multinational
203	FRAUNHOFER GES FORSCHUNG [DE] HOEGL KOMPOST UND RECYCLING GM [DE]	Research institute
204	RPC BRAMLAGE GMBH [DE]	Multinational
205	DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
206	DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
207	TAILORLUX GMBH [DE]	Startup/Scale up
208	CHEN ZHEN [DE] FU HAO [DE] LUDWIG METIN ATILA [DE]	Individual
209	DIAMAT MASCHB GMBH [DE]	Mittelstand
210	BEHNSEN SILKE [DE]	Individual
211	KRONES AG [DE]	Multinational
212	EVONIKOPERATIONS GMBH [DE]	Multinational
213	BEHNSEN SILKE [DE]	Individual
214	CONTINENTAL REIFEN DEUTSCHLAND [DE] CONTINENTAL REIFEN DEUTSCHLAND GMBH [DE]	Multinational
215	HENKEL KGAA [DE] LAEIS & BUCHER GMBH [DE]	Multinational
216	CVP CLEAN VALUE PLASTICS GMBH [DE]	Multinational
217	HECKERT UMWELTTECHNIK GMBH [DE] DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
218	PHP FIBERS GMBH [DE]	Multinational
219	UNIV PADERBORN [DE]	University
220	REFRATECHNIK HOLDING GMBH [DE]	Multinational
221	FRIEDLAENDER THOMAS [DE] WASMUHT KLAUS-KARL [DE] ZACHARIAS JOERG [DE] MAYR STEPHAN [DE] KRONES AG [DE]	Multinational
222	OBERENDER ALFRED [DE] SCHNEIDER CHRISTA [DE]	Individual
223	PAPIER METTLER KG [DE]	Multinational
224	DER GRUENE PUNKT DUALES SYST [DE] AXIVA GMBH [DE]	Mittelstand
225	BASF SE [DE]	Multinational
226	OCE PRINTING SYSTEMS GMBH & CO KG [DE]	Multinational
227	KUNSTSTOFFRECYCLING CKT GMBH & CO KG [DE]	Mittelstand

228	BAYER AG [DE]	Multinational
229	APK AG [DE]	Multinational
230	APK AG [DE]	Multinational
231	PRECKEL KATRIN [DE] SCHACH MARTIN [DE] REINIGER MARKUS [DE] KHS GMBH [DE]	Multinational
232	ISIS GMBH SERVICEGESELLSCHAFT [DE]	Mittelstand
233	SMART COLORING GMBH [DE]	Startup/Scale up
234	TRIENEKENS AG [DE] STADLER ANLAGENBAU GMBH [DE]	Multinational
235	SAPERATEC GMBH [DE]	Startup/Scale up
236	SUN CHEMICAL CORP [US] GAUDI KAI-UWE W [DE] DIEKER JUERGEN [DE] JUREK MICHAEL J [US] KELLER LARS [DE]	Multinational
237	TRIENEKENS AG [DE] STADLER ANLAGENBAU GMBH [DE] RWE UMWELT AG [DE]	Multinational
238	KLEINEN KARL-HEINZ [DE] BUZGA HEINRICH [DE]	Individual
240	TOMRA SORTING GMBH [DE]	Multinational
241	BAUER JOERG R [DE]	Individual
242	WOLF ROMAN [DE]	Individual
244	AQUAFIL ENGINEERING GMBH [DE] AQUAFIL ENG GMBH [DE]	Multinational
245	TOMRA SORTING GMBH [DE]	Multinational
246	TOMRA SORTING GMBH [DE]	Multinational
247	BASF AG [DE]	Multinational
248	EGER RALF [DE]	Individual
249	RITTEC UMWELTTECHNIK GMBH [DE]	Startup/Scale up
250	FRIEDLAENDER THOMAS [DE] KRONES AG [DE]	Multinational
251	VOLKSWAGEN AG [DE] SICON GMBH [DE]	Multinational
252	AMTEC ANLAGEN UND MASCHINEN TECHNIK DÜREN GMBH [DE]	Mittelstand
253	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
254	MOSER JOSEF [DE]	Individual
255	BERGER ANDREAS [DE]	Individual
256	HESS HERMANN [DE]	Individual
257	BASF SE [DE]	Multinational
258	SPREERELAST GMBH [DE]	Mittelstand
259	ALD VACUUM TECHN AG [DE]	Multinational
260	BUECKMANN GMBH TECH GEWEBE UND [DE] TRIENEKENS AG [DE]	Mittelstand
261	PARAFFINWERK WEBAU GMBH [DE]	Mittelstand
262	HENKEL KGAA [DE]	Multinational
263	MAUSER WERKE GMBH [DE]	Multinational
264	BASF SE [DE]	Multinational
265	REPULPING TECH GMBH & CO KG [DE]	Mittelstand
266	FELDMANN MARC [DE] FELDMANN LENNART [DE]	Individual
267	BAM BUNDESANSTALT MATFORSCHUNG [DE]	Research institute
268	INFAN GMBH INGENIEURGESELLSCHA [DE] LRZ LANDHANDELS UND RECYCLING [DE] VARA UMWELTPRODUKTE GMBH [DE] MINERALOELHANDEL JOEDECKE [DE] AGRARGENOSSENSCHAFT PLANETAL E [DE] AUGUST FREBE GMBH [DE]	Mittelstand
269	QUARZWERKE GMBH [DE]	Multinational
270	RAUER LOTHAR [DE]	Individual
271	INEOS STYROLUTION GROUP GMBH [DE]	Multinational
272	XELLA TECHNOLOGIE UND FORSCHUN [DE] XELLA TECHNOLOGIE UND FORSCHUNGSGMBH [DE] XELLA TECH UN	Research institute
273	NEVEON GERMANY GMBH [DE]	Multinational
274	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
275	FRAUNHOFER GES FORSCHUNG [DE]	Research institute
276	DOMO ENG PLASTICS GMBH [DE]	Multinational
277	POLYSECURE GMBH [DE]	Research institute
279	RESCHNER KURT [DE]	Individual
280	ZECH UMWELT GMBH [DE] HERBOLD MECKESHEIM GMBH [DE]	Mittelstand
281	HOLZNER FABIAN [DE]	Individual
282	MTM PLASTICS GMBH [DE]	Multinational
283	MTM PLASTICS GMBH [DE]	Multinational
284	EVOXX TECH GMBH [DE]	Multinational
286	BASF SE [DE]	Multinational
287	SCHADE JANNO [DE]	Individual
288	OEZCAN ALI HASRET [DE]	Individual
290	RITTEC 8 0 UMWELTTECHNIK GMBH [DE]	Startup/Scale up

291	LANGEN ROBERT [DE]	Individual
292	KUJAT MARCUS [DE]	Multinational
	NORDENIA DEUTSCHLAND HALLE GMBH [DE]	
293	IFCO SYSTEMS GMBH [DE]	Multinational
	RINGLER WERNER [DE]	
294	HPX POLYMERS GMBH [DE]	Mittelstand
295	DER GRUENE PUNKT DUALES SYST [DE]	Mittelstand
297	HOPE TREE INT GMBH [DE]	Multinational
298	MTM PLASTICS GMBH [DE]	Multinational
299	CABKA GROUP GMBH [DE]	Multinational
300	HOJAJI HAMID [DE]	Individual
301	SAPERATEC GMBH [DE]	Startup/Scale up
302	SIEGWERK DRUCKFARBEN AG & CO KGAA [DE]	Multinational
303	UNIV HAMBURG [DE]	University
304	BASF SE [DE]	Multinational
305	SIEGWERK DRUCKFARBEN AG & CO KGAA [DE]	Multinational
306	UNIV HAMBURG [DE]	University
307	COVESTRO DEUTSCHLAND AG [DE]	Multinational
308	COVESTRO DEUTSCHLAND AG [DE]	Multinational
309	BASF SE [DE]	Multinational
	STUDIENGESELLSCHAFT KOHLE GGMBH [DE]	
310	BASF SE [DE]	Multinational
311	BASF SE [DE]	Multinational
312	ENBW ENERGIE BADEN WUERTTEMBERG AG [DE]	Multinational
313	ROCKWOOL INT [DK]	Individual
	CUYPERS JEAN-MARIE WILHELMUS [NL]	
	LAMBIE STUART [GB]	
	SMEETS GERARDUS ELISABETH MARIA REGINA MICHAEL [DE]	
	WIEGERS ROBERT BENNO [NL]	
314	COVESTRO DEUTSCHLAND AG [DE]	Multinational
315	UNIV MASSACHUSETTS [US]	Multinational
	BASF SE [DE]	
316	POLYTEX SPORTBELAEGE PRODUKTIONS GMBH [DE]	Mittelstand
	FORMATURF GMBH [DE]	
317	UNIV HAMBURG [DE]	University
318	FOSHAN KING WONDER HI TECH CO LTD [CN]	Mittelstand
	JACK WOLFSKIN AUSRUESTUNG FUER DRAUSSEN GMBH & CO KGAA [DE]	
	TOPGOLF CALLAWAY BRANDS CORP [US]	
319	U T G GES FUER UMWELTTECHNIK [DE] ISIS GMBH SERVICEGESELLSCHAFT [DE]	University
320	SMART COLORING GMBH [DE]	Startup/Scale up
321	BAYER AG [DE]	Multinational
322	KROENER ROMEO [DE]	Individual
323	SMART COLORING GMBH [DE]	Startup/Scale up
324	XPACK GREEN LOGISTICS GMBH & CO KG [DE]	Startup/Scale up
325	BASF SE [DE]	Multinational
326	BASF SE [DE]	Multinational
	BASF COATINGS GMBH [DE]	
327	ARKEMA FRANCE [FR]	Multinational
	JAPAN STEEL WORKS EUROPE GMBH [DE]	
	TRINSEO EUROPE GMBH [CH]	
328	PALLMANN MASCHF GMBH & CO KG [DE]	Individual
329	KROLK GMBH [DE]	Multinational
330	U & T UMWELT & TECHNIK CHEMNIT [DE]	University
	ANLAGENBAU UMWELT & TECHNIK CH [DE]	
331	U T G GES FUER UMWELTTECHNIK G [DE]	University
332	PAPIER METTLER KG [DE]	Multinational
333	LOEHRKE MICHAEL [DE]	Multinational
	SCHAEFER TIM [DE]	
	LI TEC BATTERY GMBH [DE]	
334	RUST HARALD [DE]	Mittelstand
	RUST & MITSCHKE ENTEX [DE]	
335	BOLTERSDORF HANS-JOACHIM [DE]	Individual
336	MERI ENV SOLUTIONS GMBH [DE]	Multinational
337	HANS HERMANN TRAUTWEIN SB TECH [DE]	Mittelstand
338	BASF SE [DE]	Multinational
339	ISKA GMBH [DE]	Mittelstand
340	CARBON CLEAN TECH GMBH [DE]	Multinational
341	KISTNER MARKUS [DE] TRAISSE ALEXANDER [DE]	Individual
342	SCHAELL PAUL [DE]	Individual
343	KORYSZCZUK KURT [DE]	Individual
344	W U R M GES ZUR WEITERVERARBEI [DE]	Multinational
345	ORAWETZ UTA [DE]	Individual
346	JOSEF KELLER GMBH [DE]	Individual

347	CIBA SC HOLDING AG [CH] ROTH MICHAEL [DE] PFAENDNER RUDOLF [DE] HERBST HEINZ [DE]	Multinational
348	FRANKEN MAXIT MAUERMÖRTEL GMBH & CO [DE] JOHANN BERGMANN GMBH & CO [DE]	Mittelstand
349	WIND PLUS SONNE GMBH [DE]	Mittelstand
352	ERNST HOMBACH GMBH & CO KG [DE]	Mittelstand
353	RINGWELSKI DANIEL [DE]	Individual
354	SANDER BIANCA [DE]	Individual
355	BASF SE [DE]	Multinational
356	GAMZA LEW [DE]	Individual
357	EVONIKDEGUSSA GMBH [DE]	Multinational
358	VOITH PAPER PATENT GMBH [DE]	Multinational
359	CONSTRUCTION RESEARCH & TECHNOLOGY GMBH [DE]	Research institute
361	BOLTERSDORF HANS-JOACHIM [DE]	Individual
362	ROUSE CHARLES GEORGE [DE]	Individual
363	FIBROLITH DAEMMSTOFFE GMBH [DE] QUICK MIX GRUPPE GMBH & CO KG [DE] FIBROLITH DÄMMSTOFFE GMBH	Multinational
364	CONSTR RES & TECH GMBH [DE]	Research institute
365	BASF AG [DE] BASF SE [DE]	Multinational

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