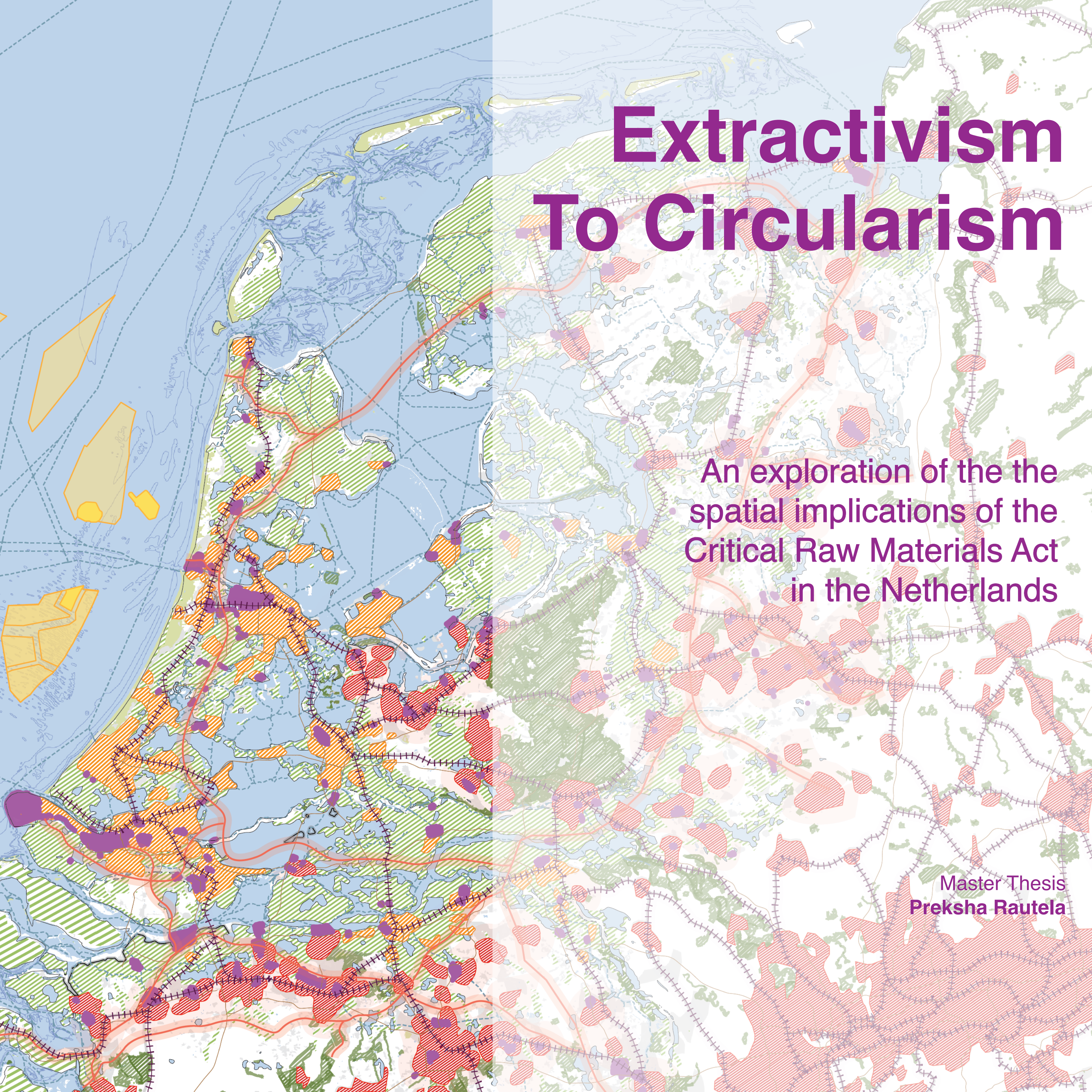

Extractivism To Circularism

An exploration of the the spatial implications of the Critical Raw Materials Act in the Netherlands

Master Thesis
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Colofon

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Lastly, to my Mom and Dad, your unconditional love and support made this journey possible. Thank you.

Extractivism

"Extractivism involves appropriation of natural and human resource wealth, producing a drain that damages or depletes its source in a potentially irreversible way. Extractivism is a modality of capital accumulation in current global capitalist development that conditions, constrains, and pressures lives of virtually all humans and other-than-humans." - Chagnon et al, 2022

Circularism

This thesis explores a transformative shift towards 'circularism'. An alternate approach envisioning a future where resource management and consumption prioritizes sustainability and regeneration.

Abstract

The European Union's Critical Raw Materials Act (CRMA) aims to address the growing demand and the supply chain disruptions of critical raw materials essential for energy and digital transitions. While the Act emphasizes enhancing processing, recycling, and extraction activities within Europe, it does not address the significant spatial and environmental impacts of establishing these facilities. This issue is further complicated by our consumption patterns, which drive increased material use for a better quality of life, thus necessitating more extraction and processing activities.

This thesis examines these implications by focusing on neodymium, a rare earth element, and develops a circular supply chain for neodymium magnets in the Netherlands. Beyond addressing supply chain disruptions, the research critiques the current economic system by exploring different processing capacities within alternative growth paradigms using scenario building.

The findings indicate that the CRMA, which follows the green growth model, may lead to spatial and economic lock-ins, proving unsustainable in the long term under the current socio-economic framework. This study highlights the need for a holistic approach that integrates environmental and spatial considerations, along with long-term planning, into policy-making to ensure socio-ecologically resilient supply chains for critical raw materials.

Keywords: circularity, critical raw materials, growth paradigm, socio ecological resilience, scenario building

Contents

Introduction

In the globalized world we live in today, the most significant advantage lies in the access it provides nations and regions to resources, knowledge, and commodities that are beyond their domestic production capabilities. While it facilitates exchanges and free trade, it also creates interdependence among nations, even for essential commodities, the most apparent example being oil and electricity. This interdependence in the supply chain of commodities makes nations vulnerable to geopolitical uncertainties. This vulnerability becomes challenging when specific countries, having established dominance over critical commodities, strategically manipulate access to these resources for geopolitical influence.

This challenge is aggravated by the capitalist approach that underpins globalization, which promotes economic growth at the expense of increasing resource consumption for a better quality of life. Despite the ever-growing alarm over the climate crisis and widespread environmental degradation, the fact that extractive industries remain central to powering economies and societies has not changed. (Ciccantell, 2000)

Currently, Europe faces similar challenges with bottlenecks in the supply of certain essential raw materials (European Union, 2023). In response, there are growing initiatives to develop a European-centric supply chain to mitigate these vulnerabilities.

- Africa
- Central Asia
- Asia Pacific
- South America, Caribbean
- European Union
- Other Europe

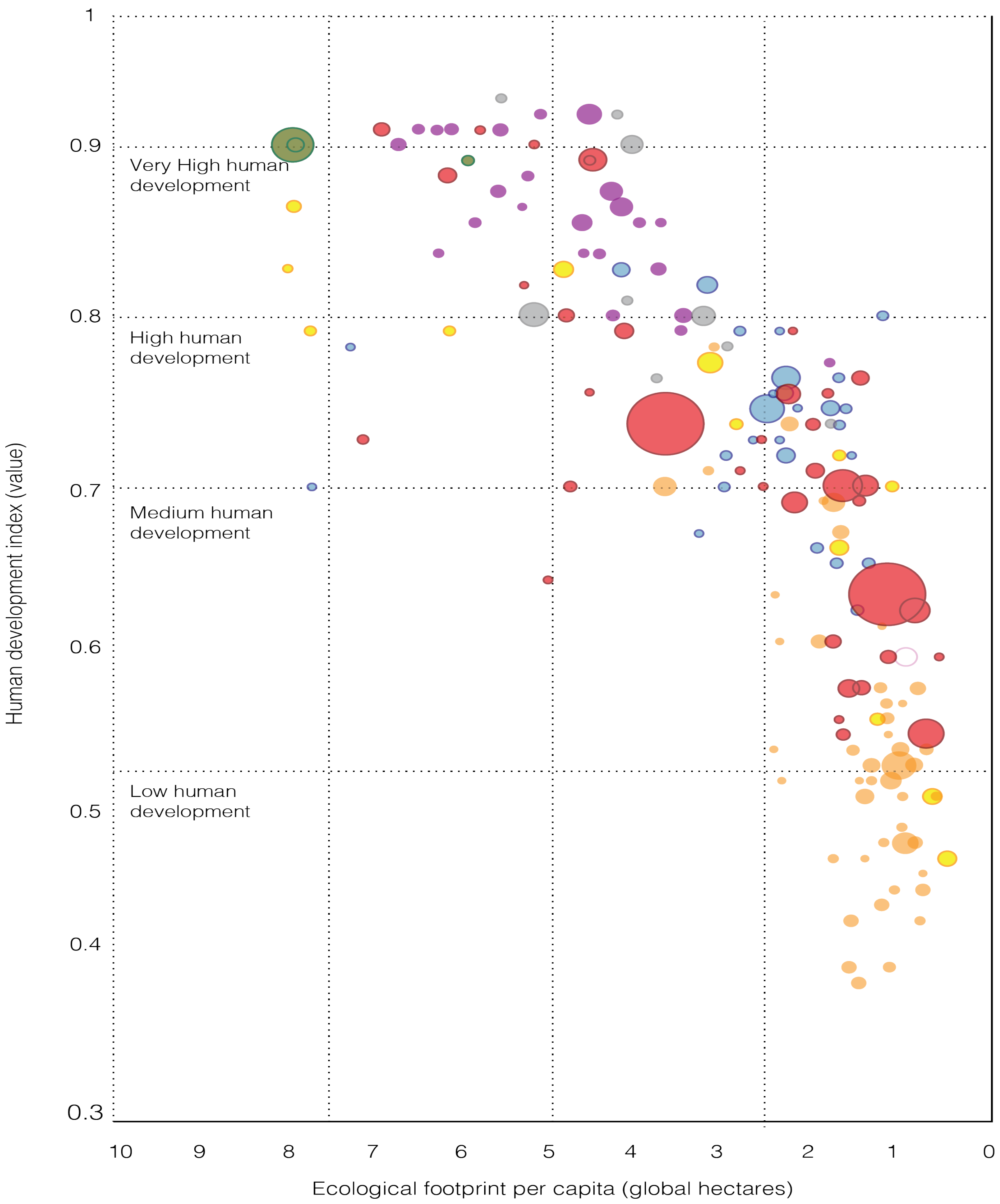


Fig 1.1: Graph showing that as HDI increases ecological footprint also increases.

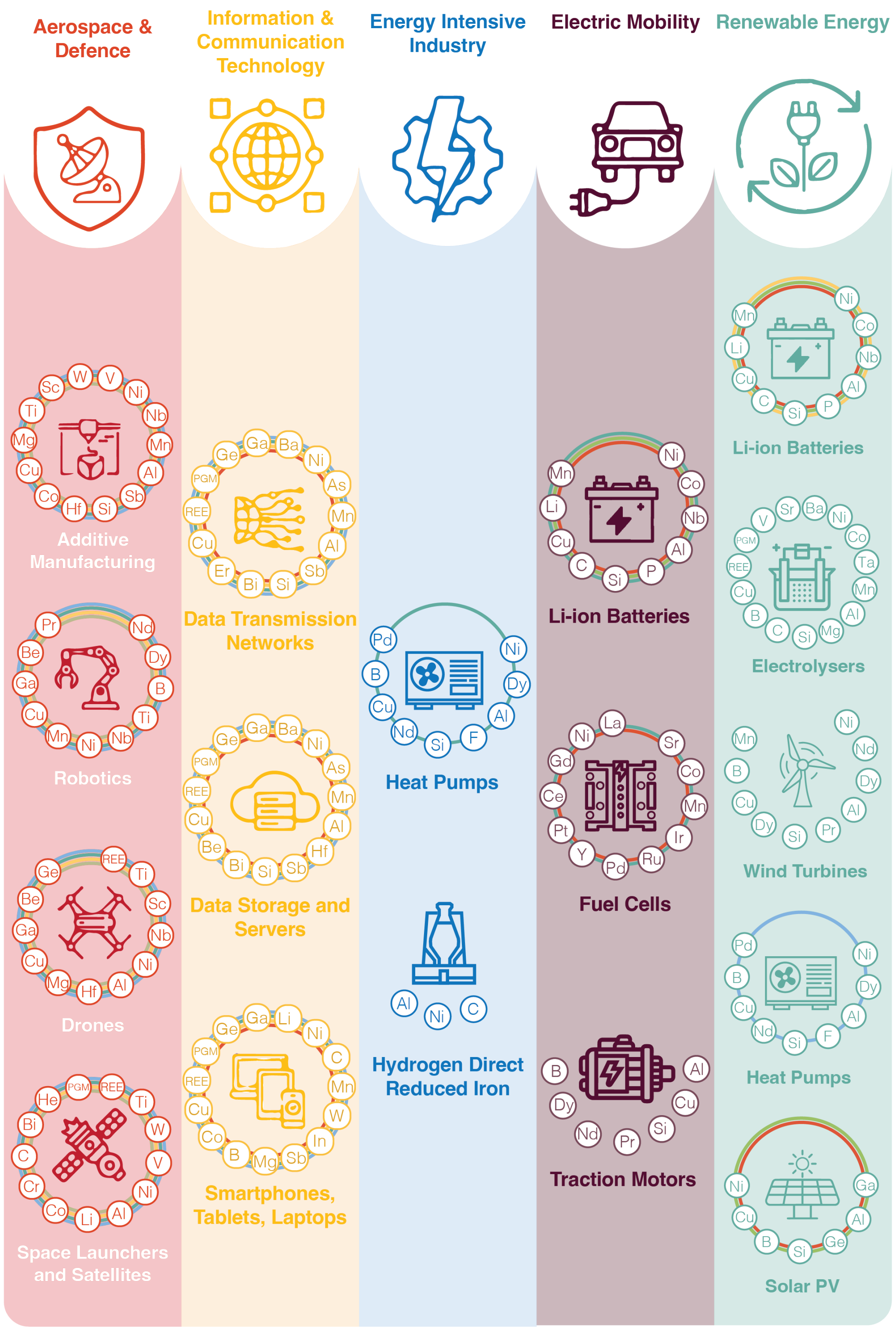
Source: UNDP(2009)

The Role of Critical Raw Materials

The European Green Deals aims to achieve climate neutrality by 2050 (European Commission, 2021). The green energy and the digital transitions are at the heart of this Green Deal. However, a clean energy system is much more mineral and metal-intensive than a conventional fossil fuel system. The technologies we need, like solar panels, wind turbines, Li-ion batteries, and heat pumps, are manufactured from a complex mix of many materials like cobalt, lithium, graphite, nickel, and rare earth elements. The demand for these materials is predicted to grow unprecedently in the coming years as countries race to deliver their climate commitments (European Union, 2023). However, the EU heavily relies on other countries to supply raw materials to build these technologies. Thirty of these materials are coined as critical raw materials by the European Union.

Fig 1.2: Sectors and technologies that depend on critical materials

Source: European Union, 2023



The European Union defines critical raw materials as highly economically important for Europe while also being highly vulnerable to supply chain disruptions (European Union, 2023). To ensure EU access to a secure and sustainable supply of critical materials, the European Commission has formulated the Critical Raw Materials Act (CRMA), enabling Europe to meet its 2030 climate and digital objectives.

While the CRMA is an incredible initial move, it comes along with multiple challenges that are currently not stated within the act. The most profound ones are the implications that it would cause on space and on territory within the borders of the European Union. This is the particular gap addressed in this research.

The starting point of this research is an exploration of how to spatially bridge the gap between the geopolitical uncertainties in a globalized chain by creating a domestic supply chain. The study primarily aims to devise a spatial strategy to establish a resilient supply chain for Neodymium magnets in the Netherlands. However, the scope of this research extends beyond the immediate logistical challenge and delves into critiquing the current capitalistic approach to economic growth and consumption patterns.

This study focuses on neodymium, specifically used in Neodymium-Iron-Boron (NdFeB) magnets, as an exemplary material to understand the spatial implication of the CRM act. This research will focus on the Netherlands as a case study for developing a more profound, spatial understanding of the CRMA.

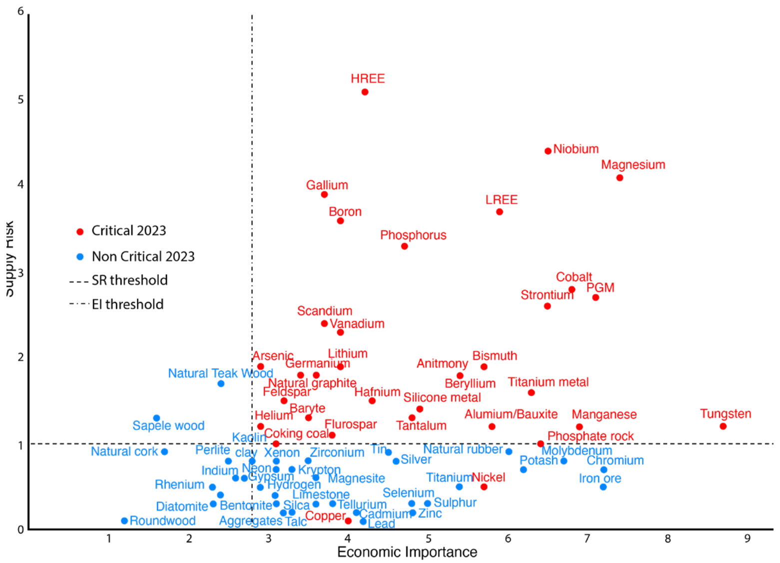


Fig 1.3: Critical Raw Materials list 2023

Source: European Union, 2023

Fig 1.4: A drone photo of the Tata Steel IJmuiden steel factory

Source: ANP

Problem Fields

In this chapter, the problem field is described. The chapter begins by describing the issues at the global scale. This sets the stage for a more detailed discussion of the implications within Europe, where we delve into the unique challenges and considerations specific to the Dutch context.

Demand - Supply Disparity

The current supply chain for neodymium used in producing permanent magnets is complex and dominated by certain nations, leading to a significant disparity between demand and supply within the European Union (EU). According to a report by the Joint Research Centre, the projected demand for neodymium across various sectors within the EU is estimated to range between 317,120 to 455,269 tonnes by the year 2050 (European Union, 2023). In stark contrast, the European Union's production capacity currently stands at approximately 1,000 tonnes annually. This figure is vastly overshadowed by the staggering 16,000 tonnes of magnets imported yearly, underscoring a profound dependency on external sources (JRC analysis, 2023).

The geographical location of the various stages in this supply chain is predominantly influenced by factors such as cost-effective labor, established industrial ecosystems, and variable degrees of regulatory compliance. These factors collectively enable the production of these magnets at minimal costs. However, this competitive edge in the global market is often achieved at the expense of labor and environmental standards, further exacerbating the disparity between the EU's domestic supply and the material's growing demand.

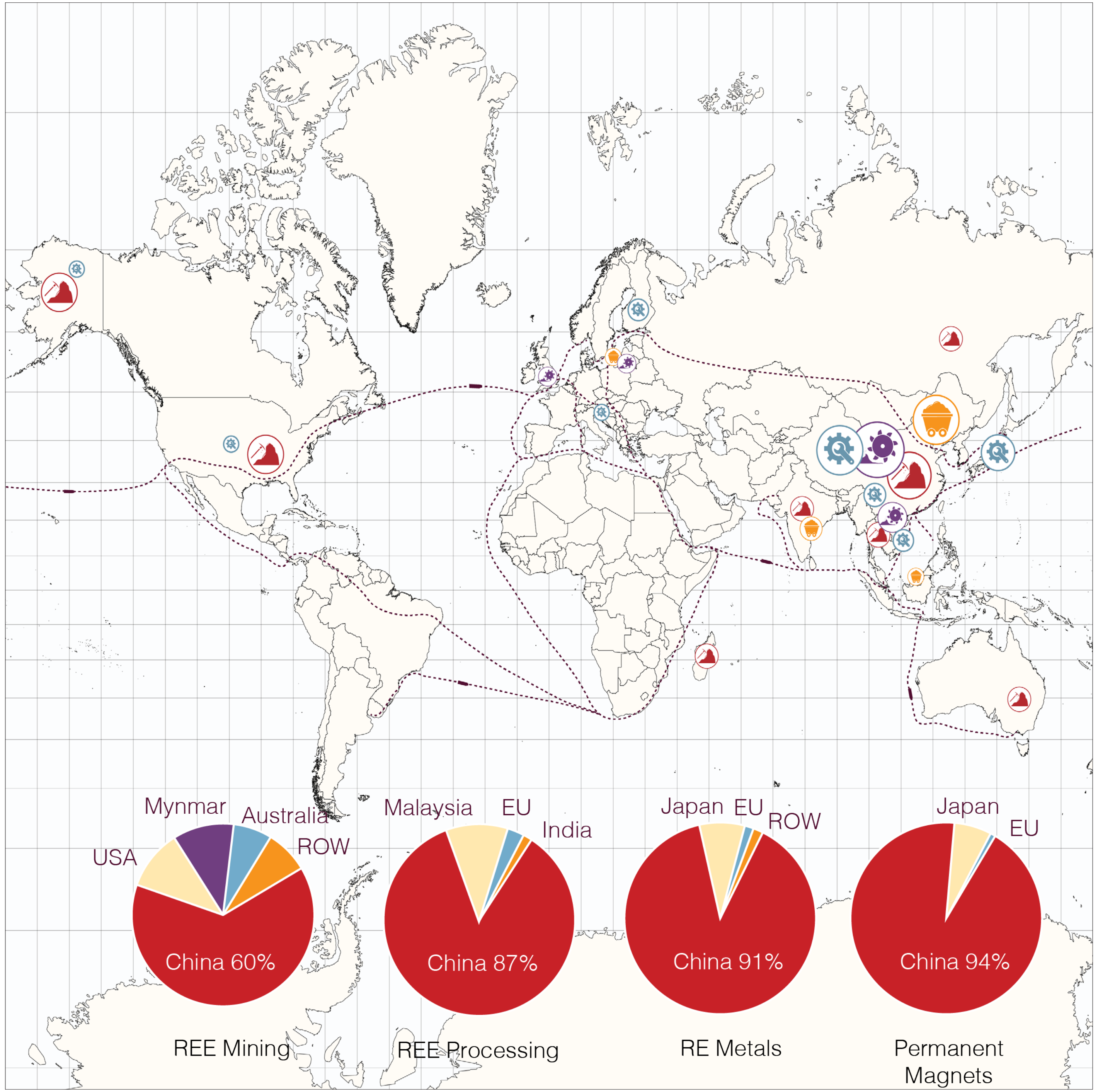
Fig 2.2: Geographic concentration of processes in the supply chain of NdFeB magnets

Source: Author
Data: Buchan & Stacey, 2022

Fig 2.3: World rare earth supply chain market share

Source: ERMA, 2021

Mine production
Oxide seperation
Metal refining
Magnet manufacturing
100%
10%
Size based on percentage



Atrocities of a Globalized World

Currently, the European Union is dependent on other countries to import raw materials. While this globalized supply chain makes Europe's supply of critical raw materials and hence the Green Deal vulnerable to geopolitical uncertainties, it also has associated problems.

- Outsourcing mining activities have resulted in an 'unequal ecological exchange' between high-consumption economies that have profited from the appropriation of land, labor, and raw materials from producer economies, leading to both human rights violations and severe environmental repercussions (Fernández & Ferreira).

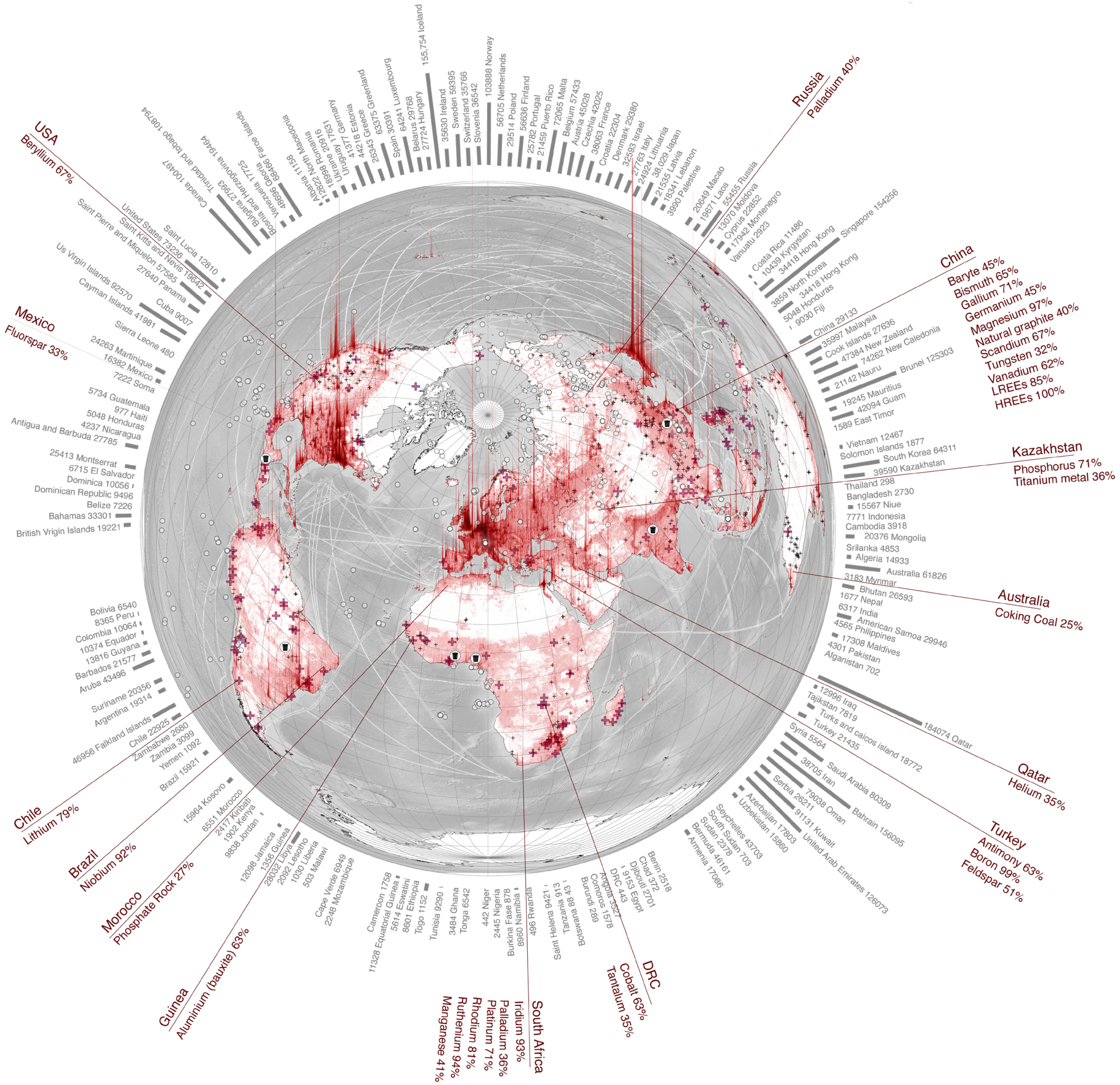
- Another challenge is that these technologies generate vast amounts of e-waste. Much more material will accumulate during the following decades due to these transitions. However, unlike fossil fuels, these materials can be recycled. While the current recovery rates of these materials in general are low, to reduce the dependence on the extraction of more materials in the future, recycling offers excellent potential.

- The third problem is that studies have shown that as our prosperity increases (shown as GDP per capita in Fig 2.1), our consumption of resources also increases. Our current patterns of living are driving us to more and more material accumulation and consumption for a better quality of life at the cost of the work done by nature. So, instead of simply swapping existing dependencies from fossils to materials, the challenge is how to strike a balance between reducing the dependency on these materials while also improving the livability of the people.

Fig 2.1: Unequal Exchange: Disparities in Global Production and Consumption

Source: Author
Data Source: European Union, Usgs, World Economic Data

Closed mines
Active mines
Conflicts
Waste Dumpsites
GDP per capita
Energy consumption
EU CRM Dependancy



Current Linear Supply Chain of NdFeB Magnets

Despite the critical nature and extensive utilization of neodymium magnets, their recycling rates within the European Union are meager, estimated at less than 1% (Binnemans, 2013). This inefficiency in recycling can be attributed to the existing practices in metal recovery, which are usually designed to primarily recover Fe from the magnet, leading to loss of Neodymium in the process (Kumar, 2022). Neodymium recovery is not considered a priority within the EU as there is no processing capacity to process the recovered material. Another reason for a linear chain is that recyclers' flowsheets do not include recovery of Neodymium due to the lack of recycling technologies and the absence of economies of scale (Crowk, 2016).

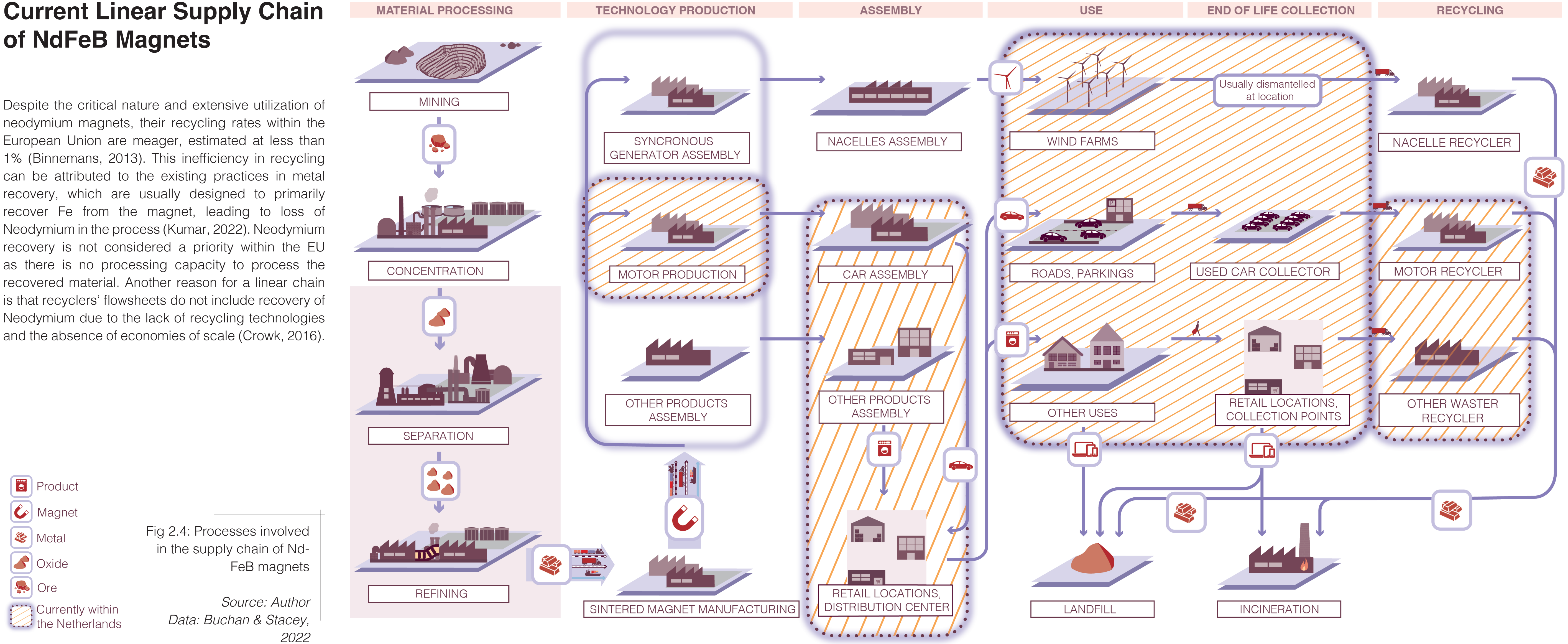


Fig 2.4: Processes involved in the supply chain of Nd-FeB magnets

Source: Author
Data: Buchan & Stacey, 2022

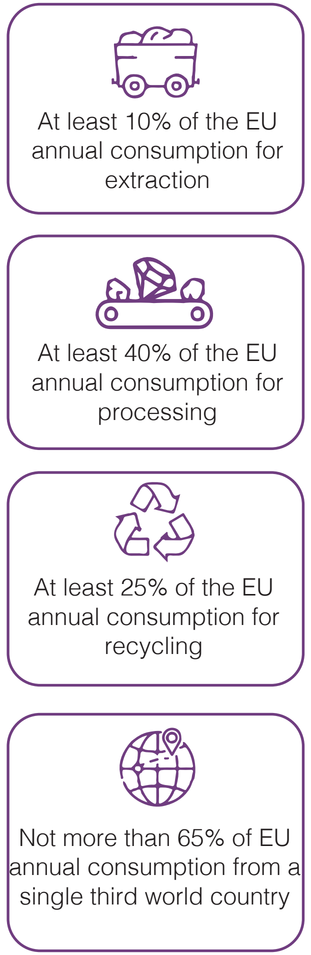
EU and Dutch response

Critical Raw Materials Act
As a reaction to these problems, the European Union has formulated the Critical Raw Materials Act, which states that 10% of the global production of critical raw materials needs to be done domestically, and 40% of the processing should be done domestically (European Union, 2023). This act is a part of the Green Deal industrial plan. The Green Industry Act addresses technologies that will make a significant contribution to decarbonization (European Union, 2023). It supports, in particular, strategic net-zero technologies that are commercially available and have a good potential for rapid scale. Such technologies strengthen the EU's industrial competitiveness and energy system's resilience while allowing the clean energy transition (JRC analysis, 2023). The European Raw Materials Alliance report suggests a potential for developing a Europe-wide supply chain of raw materials. However, this scheme does not include the Netherlands (ERMA, 2021).

Dutch response to the problem
The Netherlands is not included in the plans even though Neodymium is one of the most needed metals for the Dutch economy. Also, the Netherlands has major ports, which are the main inlets of primary materials in the EU. Enhanced capabilities in processing Neodymium would boost the Dutch economy by creating a new industrial sector, and increasing exports. By securing its own supply of processed, the Netherlands and the broader EU can reduce reliance on non-EU countries, enhancing economic and geopolitical stability.

The Netherlands has also formulated a national strategy for raw materials. However, since it does not have mineral deposits, it wants to support the EU by building up processing and industrial capacities (Rijksoverheid, 2022).

While both the European Act and the national strategy are incredible first moves, there is currently no roadmap for their implementation, and due to their recent introduction, they do not discuss their impact on space and territory. This is specifically the problem addressed in this thesis since the processing, refinement, and assembly of these technologies have substantial spatial claims and would lead to significant territorial transformations.



Critical Raw Materials act
Benchmarks for 2030

Source: European Union(2023)

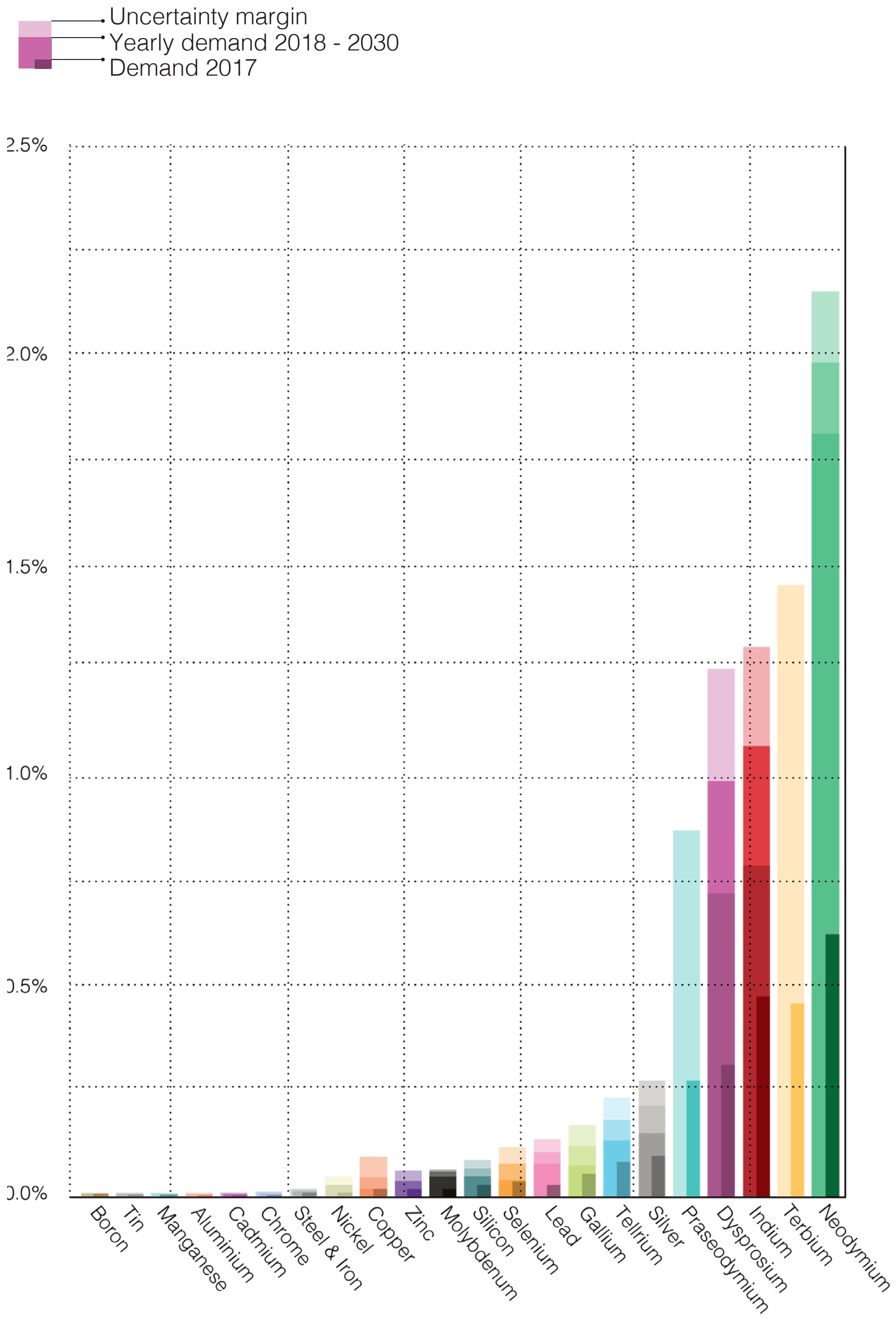


Fig 2.5 : Metal demand for Dutch renewable electricity production

Source: Metabollic

Theories and Concepts

This chapter articulates the theoretical framework suitable for the problem. This exploration serves as a lens through which the issue is examined and understood in greater depth.

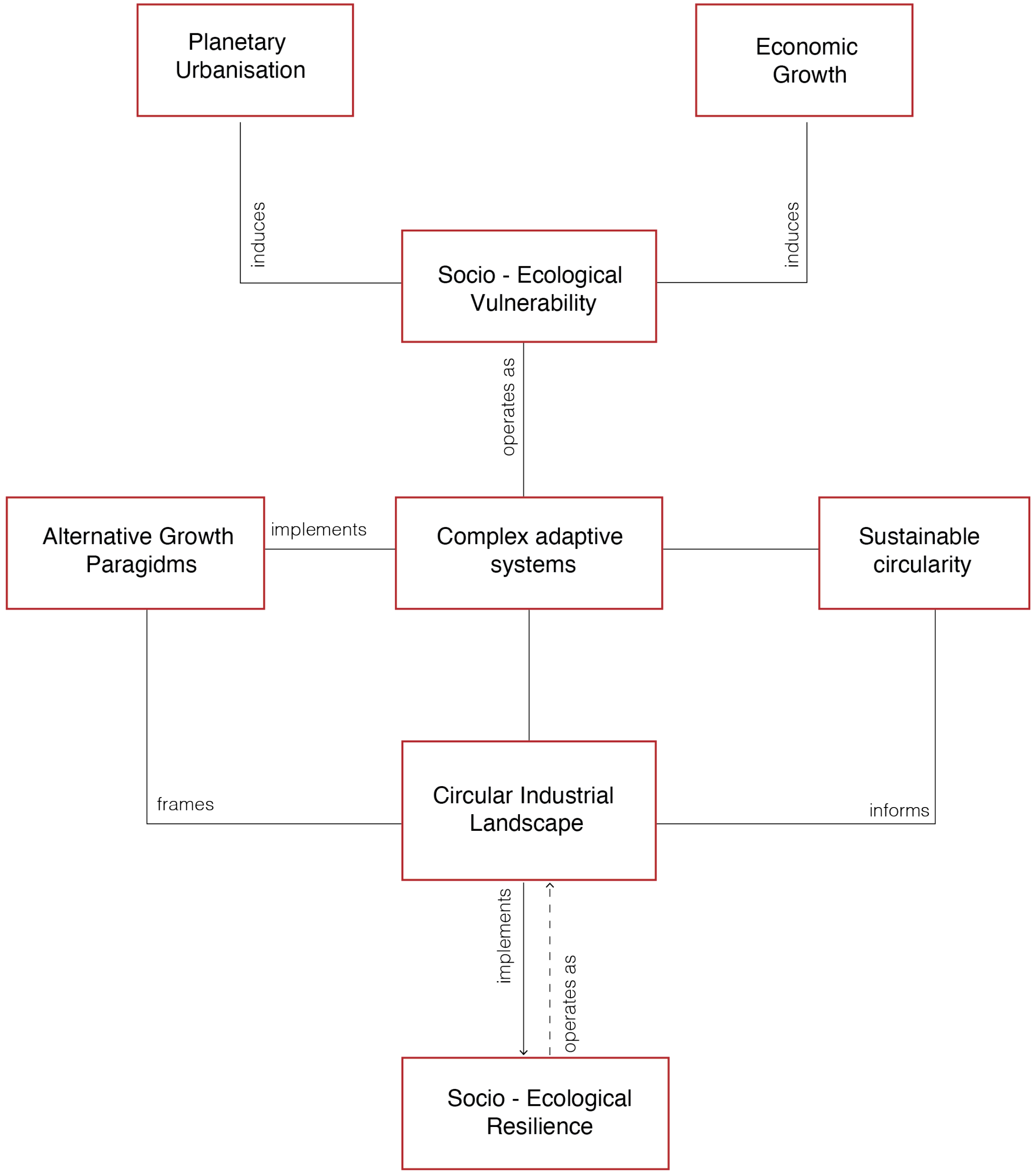
Theoretical Framework

Theory is primarily used to translate the finding from the problem fields chapter into spatial issues that are relevant to urbanism.

Theories from urban planning, environmental sustainability, and industrial ecology, offering a holistic perspective. The three main concepts are socio ecological resilience, circular economy and alternative growth paradigms. The theoretical framwork illustrates the reltionship between these concepts.

Fig 3.1 : Theoretical Framework

Source: Author



Planetary Urbanisation

Globalization of commodity production has caused local hinterlands to become export-oriented, specialized, and mechanized landscapes (Brenner & Katsikis, 2020). Most of these territories have lost geographical relations with their adjacent city and export their outputs to metropolitan areas worldwide. These operational landscapes result from unequal global exchanges between the consumption and production regions (Brenner & Katsikis, 2020).

The global circulation of commodities and loss of connection to specific areas of consumption leads to a need for more awareness about the negative impact of consumption behaviors on the environment. Consequently, humans often become unaware of the exhaustive toll their actions have on these territories and extra-human nature. Capitalism ingrains the pursuit of profit and growth, leading to a culture of normalized exploitation, often prioritizing economic objectives over equitable and sustainable development.

Industrial processes like mining cause ecological devastation and deplete land's capacity to sustain ecological surpluses. This results in a metabolic rift that destabilizes accumulation processes and leads to two significant problems.

Firstly, the established hinterland becomes obsolete, rendering parts of the countryside sacrifice zones for capitalism's extractivist motives (Brenner & Katsikis, 2020). Secondly, it forces society to seek alternative resources to depend on. We are undergoing a noticeable shift in this dependency as we are moving from a reliance on fossil fuels to metals and minerals. This transition is not merely shifting the source but also reconfiguring power dynamics and resource control in the global economy. However, it is often overlooked in a capitalistic paradigm that the environmental impact of these mining and processing practices is so significant that it is impossible to keep doing it in the long run.

Socio Ecological Resilience

The changes that cities have undergone due to the dominance of the neoliberal agenda have eroded their resilience (Hudson, 2010). Deregulation of the movement of products, capital, and people has decreased the protection that local economies used to have from external influences (Eraydin et al., 2013). Concurrently, fluctuations in the global economy have exposed the fragility of urban systems. This has exposed cities and individuals to increasing risks and uncertainties due to global resource control. Resilience is the capacity of a system to absorb disturbance without shifting to another regime (Holling, 1973; Walker et al., 2004). A resilient social-ecological system is more equipped to prevent unwelcome surprises (regime changes) in the face of external disturbances and, therefore, more capable of providing us with the commodities and services that support our quality of life. (Walker & Salt, 2006).

For a resilient regional supply chain, this would imply having minimal environmental implications, a higher level of self-reliance, less dependence on external decisions, and the capacity to handle external shocks. This strategy moves away from extending inter-regional networks for sourcing resources from far-off areas. Instead, it focuses on a selective withdrawal and enhancing local independence by developing regional resources. This would imply a more place-based production through a more materially aware understanding of what drives development (Hudson, 2010).

The demand for Neodymium needed for permanent magnets is expected to rise drastically, necessitating a substantial expansion of production capacity, particularly in Europe. The challenge lies in establishing these industrial facilities to ensure ecological resilience. Failure to integrate ecological concerns in industrial development can have significant environmental consequences, including pollution, degradation of natural resources, and loss of biodiversity.

Nonetheless, all economic activities have an unavoidable environmental impact, and it is unreasonable to anticipate total closure or that all regions can be self-sufficient or even equally robust, particularly concerning issues such as raw material processing. Therefore, balancing industrial growth and environmental protection is crucial to ensure a sustainable future.

However, how far is it possible to "create more self-contained regional economies, while securing the successful transition to ecologically sustainable and socially just forms of the regional organization, economy, and society" (Hudson 2010). This is still an important question.

Complex Adaptive System

Resilience thinking provides an approach for observing a socio-ecological system as a single system working across several time and geographical scales (Hudson, 2010). Researchers have found that most systems go through repeated cycles consisting of four phases: fast expansion, conservation, release, and reconfiguration, known as the adaptive cycle (Gunderson & Holling, 2002).

In the reorganization phase, uncertainty rules and all alternatives are open. In the case of this research, consider the need to transition away from fossil fuels; the development of renewable technology is a result of this phase, and it is driving up demand for energy generation. In the exploitation phase, the system is engaged in a period of rapid growth, as we are currently experiencing with the shift in dependence on critical materials. The transition to the conservation phase proceeds incrementally. During this phase, energy gets stored, and materials slowly accumulate. It can be constructed capital (machines and buildings) or human capital (management and marketing skills and acquired knowledge). The pace of growth decreases as connectedness grows, the system becomes more inflexible, and resilience falls. The system becomes more vulnerable to disruption as its reliance on existing structures and procedures increases.

The loss of structure continues as linkages are broken, and natural, social, and economic capital leaks out of the system. Rapid growth to mid-conservation is a stage of capital accumulation and high to moderate resilience. A significant backloop is unavoidable unless there is an organized effort to reduce the complexity, release some potential, and return to the rapid growth phase or create a very rapid, minimal conservation-to-reorganization transition (Gunderson and Holling, 2002). In the case of critical materials, this can be accomplished by recycling and reusing the stock materials. It is advisable to proactively plan for the necessary industrial capacities to maximize the postponement of the release period. This planning should aim to retain materials within the ecosystem for the most prolonged possible duration.

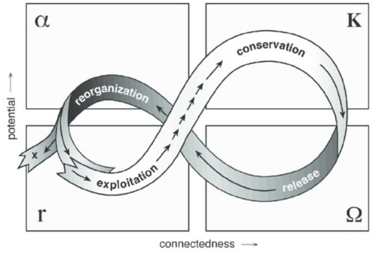


Fig 3.2 : Adaptive cycles

Source: Gunderson and Holling (2002)

Sustainable Circular Economy

This research aims to create a resilient supply chain for NdFeB magnets by implementing circular economy principles. However, contemporary spatial policy needs to be clearer about the relationship between circularity and sustainability. While these terms are related, they represent distinct objectives.

A Circular economy is “a closed-loop system that employs circular processes such as reuse, refurbishing, remanufacturing, and recycling to convert waste into resources” (Kirchherr et al., 2017). On the other hand, the most commonly accepted definition of sustainability is provided by the Brundtland Commission, which is “development that meets the needs of the present without compromising the ability of future generations to meet their own needs.” (Brundtland Commission, 1987). Most authors agree that the Circular Economy (CE) aims to create a closed-loop system to eliminate resource inputs and reduce waste and emissions. In contrast, sustainability goals are broader and more fluid, encompassing a range of environmental, economic, and social objectives (Geissdoefer et al., 2017). In contrast, CE mainly benefits economic actors through better resource use and, in the process, indirectly aids the environment and society, but not as its primary focus.

Different authors have varying opinions on the relationship between circular economy and sustainability. The one that resonates most with this research is given by Bocken et al. (2014) as recognizing circularity as just one of several archetypes within sustainable business models. In this view, circularity is a valuable strategy among various options to achieve systemic sustainability.

However, there are negatives to this relationship as well. A circular economy does not always lead to sustainability, as in some situations where the impact of closing the loop is higher than producing new material. For this research, a circular economy is not merely viewed as a system dedicated to closing resource loops as an end. Instead, the primary objective of establishing circular resource flows is to attain sustainability.

Territorial Circularity

The current research on the relationship between CE and industrial facilities is mainly focused on a material flow perspective based on technical and entrepreneurial advancements (Palm et al., 2021), which mostly translates to just recycling and reuse (Marin & De Meulder, 2018a; Moreno et al., 2016). This way of thinking has its roots in industrial ecology, which examines circularity and material flows from a top-down and technocratic approach (Ghisellini et al., 2016; Marin & De Meulder, 2018). This makes it crucial to realize that circularity is a multifaceted problem across scales and sectors. (Williams, 2019). The role of land and territories is limited within the current knowledge of CE. The initial attempts to incorporate CE principles in spatial planning remain primarily at a theoretical level (Furlan et al., 2022) However, territories play a crucial role in transitioning to CE, as territory is an essential link between circular development strategies to ecosystems, landscapes, or territorial assets, and it allows different international, national, regional, and local goals to be linked in spatial organization (Forster et al., 2021).

CE and Economic Growth

Despite extensive research on the CE, many CE theories and practices overlook the importance of social equity and material use reduction (Kirchherr et al., 2017), often favoring recycling within economies focused on growth. Current CE frameworks typically consider only the resources entering the system (Marin & De Meulder, 2018), unintentionally supporting extractive practices by insufficiently reducing overall resource consumption. A genuinely circular economy should move beyond the economic growth paradigm, concentrating instead on systemic resource use reduction. The key challenge lies in achieving a regenerative eco-industrial development, which goes beyond merely advocating for 'green' technologies. This development requires a holistic approach that examines the interactions between CE processes, the environment, and the economy they operate within (Ghisellini et al., 2016). Therefore, the goal of regeneration should encompass not just material or energy recovery but a comprehensive improvement of the entire living and economic model, surpassing the conventional capitalistic, business-as-usual approach to resource management.

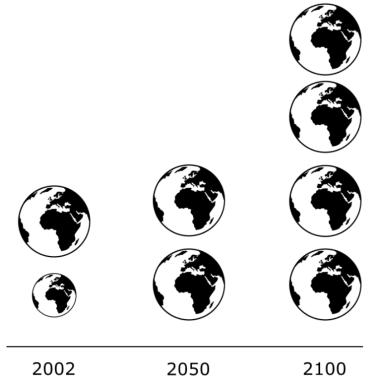


Fig 3.3 : Earths needed if current production and consumption patterns continue

Source: Footprint Network

Alternate growth paradigms like Degrowth and Post Growth have been developed on this perspective to find alternative ways to look at development. However, these paradigms are rooted in economic studies, and research about their implications in urban planning is similar to theories relating it to mainly resource consumption centered around cities and urban areas, not clearly stating the impacts on industrial processes.

Problem statement

[problem] Currently, Europe faces significant bottlenecks in the supply chain of its critical technology, making its ambition to deliver the green deal by 2050 vulnerable to geopolitical uncertainties (JRC analysis, 2023). Therefore, the EU and the Dutch national government have formulated the CRMA and the Dutch raw material strategy to build strategic autonomy by creating domestic supply chains. Despite the policies being an incredible initial move, there is currently no roadmap for their implementation. Moreover, they overlook the territorial transformation, the spatial and environmental implications of these facilities.

The primary focus of these initiatives is to build a closed-loop system through green industries, but they need to acknowledge the ecological limits of the system, which are challenged by our current overconsumption patterns.

[vision] In order to build socio-ecological resilience from global supply chain disruptions through a circular approach, it is important to understand the territorial perspective on circularity and look for alternate growth models to maintain the ecological limits of the system.

[Knowledge gap]
[A] The current research on the relationship between CE and industrial facilities is mainly focused on a material flow perspective based on technical and entrepreneurial advancements (Cornell et al., 2021; Palm et al., 2021), rooted in industrial ecology (Ghisellini et al., 2016; Marin & De Meulder, 2018b). However, territories play a crucial role in transitioning to CE, as territory is an important link between circular development strategies and ecosystems and landscapes (Forster et al., 2021). CE concepts are integrated within urban planning primarily at the theoretical level. However, the amount of space needed, the spatial conditions for circular activities, and the implications of these activities on territory and the environment are not clearly known.
[B] The current literature on alternative growth models has been developed from an economist's point of view and lacks detailed spatial implications. The relationship between growth paradigms and urban planning is limited. While there is some research on the reorganization of urban areas and their consumption within these paradigms, they usually overlook industrial production capacities.

The knowledge gap addressed in this research is the need for a territorial perspective on circularity and how it can be operationalized to formulate a regional strategy for future circular industries. It also involves the gap in the existing knowledge of growth paradigms in relation to industrial capacities.

[aim] The study aims to exlore the spatial implications of the CRMA by devising a strategy to establish a resilient, circular supply chain in the Netherlands for Neodymium magnets. However, the scope of this research extends beyond the immediate logistical challenge and delves into critiquing the current approach to growth and consumption patterns by exploring the extent of processing and manufacturing capacities in alternative growth paradigms.

Societal Relevance

This thesis addresses the challenge that EU currently faces due to supply chain bottlenecks and aims to protect people from the potential consequences of resource scarcity due to geopolitical uncertainties. The societal relevance of this project also arises from the pressing issues around existing extractive and refining industries. Currently, there exists an evident disparity between consumer and producer regions, with the latter experiencing appropriation of land, resources, and labour. Moreover, there is the global issue of electronic waste, a considerable portion of which currently is outsourced by Europe to other nations, thereby exacerbating the environmental crises in those regions. By developing domestic production capacities and a circular chain the project tries to reduce this imbalance. Additionally, the project highlights that our current way of living, which promotes material accumulation and consumption in the search of higher standards of living, has a significant environmental cost. It is important to move beyond predictions of rising consumption and consider alternative futures that prioritize minimizing resource consumption. This shift not only aligns with circularity frameworks but also offers potentials to reduce ecological pressures associated with resource extraction and overconsumption.

Scientific Relevance

Existing research on Critical Raw Materials (CRMs) primarily focuses on evaluating their criticality and projecting their future consumption trends. This focus often centres on quantifying the required quantities of these materials. However, there is a notable gap in understanding such transitions' spatial and environmental impacts.
While numerous studies on critical materials concentrate on the vulnerabilities of supply chains, this project adopts a socio-ecological resilience framework. This approach addresses the spatial creation of a robust supply chain within the ecological limits of the system.
This thesis also addresses the gap in understanding the Circular Economy's relation to spatial and territorial aspects by quantifying the spatial requirements and conditions necessary for circular activities.

Ethical Paragraph

This thesis often extends beyond urbanism's traditional boundaries, which could lead to underestimation or misinterpretation. To address this, the ongoing development of the thesis is mindful of these limitations, and feedback from experienced professionals in the field is actively sought through interviews to inform and refine the research, ensuring a more comprehensive and accurate perspective.

Research and Design Methods

This chapter explains the methods used in this thesis project. The chapter also describes the research questions, aims, and the extected outcomes.

Research questions and objectives

Main research question

What could be the potential spatial impacts of the European CRMA on the Netherlands based on different economic paradigms ?

Aim

Identify the spatial implications of the CRMA by devising a spatial strategy to establish a resilient, circular supply chain in the Netherlands for Neodymium magnets. Exploration of the different processing capacities in alternative growth paradigms.

SRQ1

What could the future circular supply chain of NdFeB magnets look like?

Aim

To understand the preconditions, processes, interdependancies, spatial claims and environmental impacts of the circular supply chain of Neodymium used in NdFeB magnets.

SRQ2

How could spatial requirements for a ciruclar suppply chain of NdFeB magnets differ depending on time and economic development?

Aim

To project the potential spatial requirements of a local, circular supply chain of NdFeB magnets based on different possible actions and decisions

Understanding how a circular supply chain can adapt to and integrate with varying economic landscapes.

SRQ3

What could be the suitable spatial conditions for setting up a circular supply chain for NdFeB magnets in the Netherlands?

Aim

To identify the spatial conditions within the Netherlands for establishing the various stages of a circular supply chain for NdFeB magnets based on the spatial scenarios

SRQ4

What could be the impact of a future circular supply chain of Neodymium on territory, ecology, landuse and energy landscape in the Netherlands?

Aim

To evaluate the impacts that a future circular supply chain for neodymium would have on the territorial and ecology, land use, and the energy landscape.

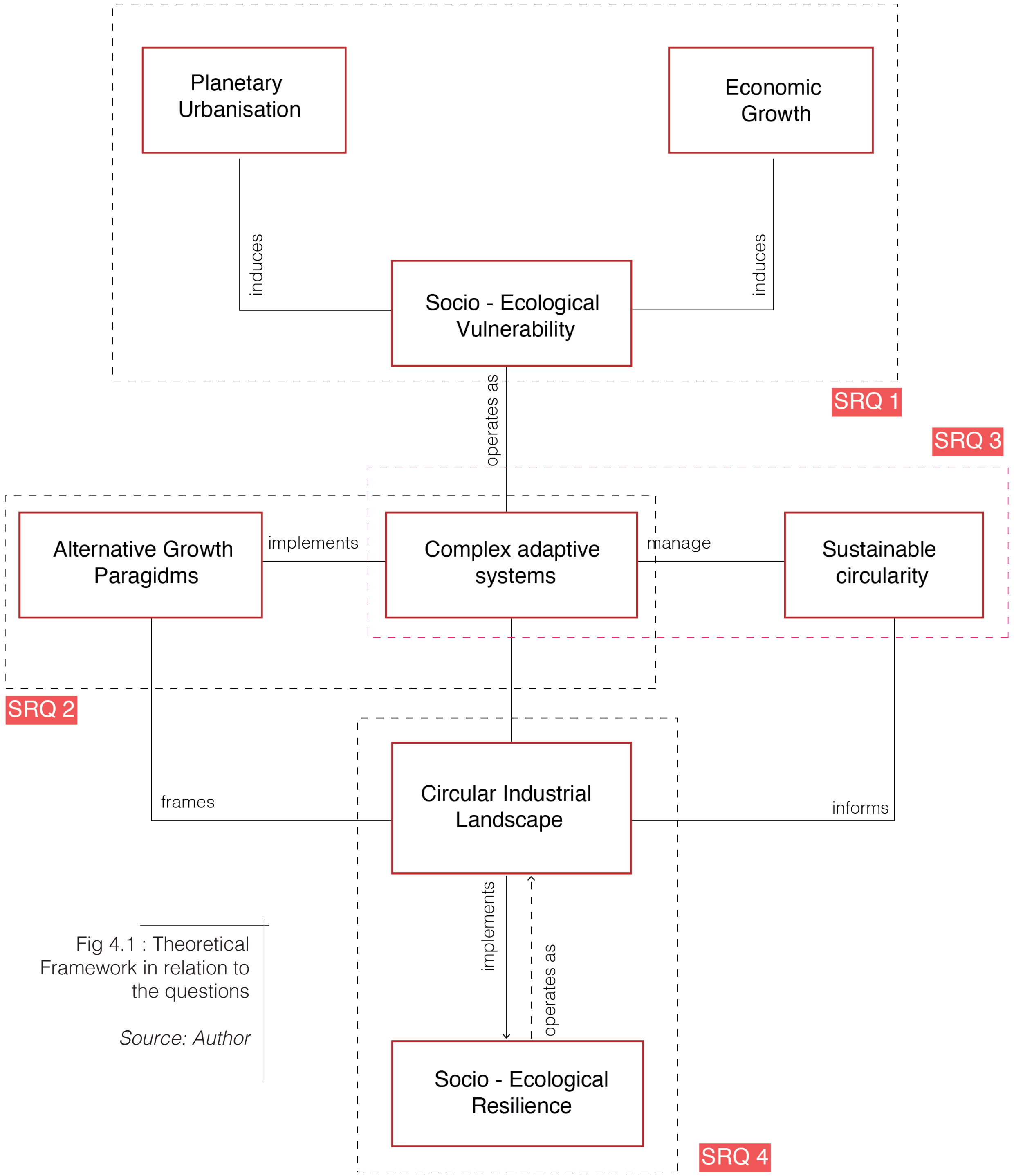


Fig 4.1 : Theoretical Framework in relation to the questions

Source: Author

Research framework

The research framework illustrates the different methods used to answer the sub-research questions, the connections between different research questions and how the outcome serve as the basis to answer other questions. Since multiple methods are used to collect and analyse data, it is crucial to integrate them to draw conclusions and reach the intended outcomes.

Main research question

What could be the potential spatial impacts of the European CRMA on the Netherlands based on different economic paradigms ?

LR Literature review
- PA Policy analysis
- SA Suitability analysis
- SB Scenario building
- M Mapping
- ES Evaluation of the Scenarios
- DA Diachronic Analysis

To understand

SRQ 1: What could the future circular supply chain of NdFeB magnets look like?

LR

To project

SRQ 2: How could spatial requirements for a circlular supply chain of NdFeB magnets differ depending on economic development?

SB M DA

To identify

SRQ 3: What could be the suitable spatial conditions for setting up a circular supply chain for NdFeB magnets in the Netherlands?

M DA SA PA

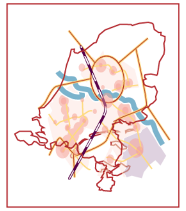
To evaluate

SRQ 4: What could be the impact of a future circular supply chain of neodymium on territory, ecology, landuse and energy landscape in the Netherlands?

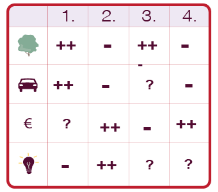
ES M

Intermediate Outcomes

Scenario framework



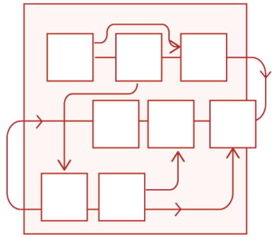
Spatial suitability map



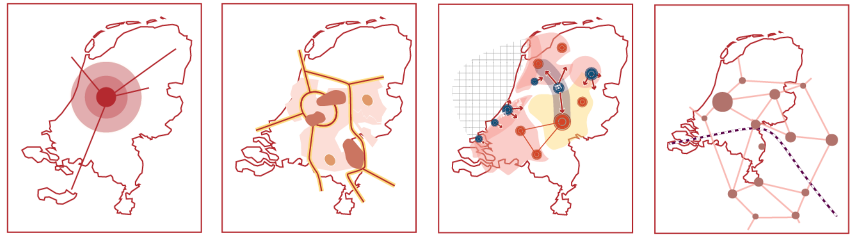
Evaluation framework

Expected Outcomes

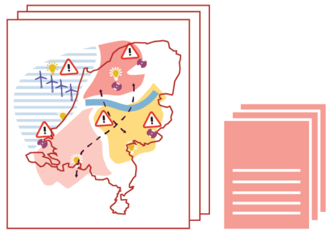
1: An understanding of the potential supply chain



2: Four possible futures



3: Structural national vision, Policy recomendations



4: Exemplary Design

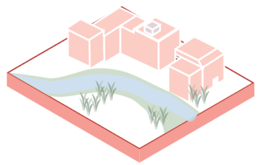


Fig 4.2 : Research Framework

Source: Author

Research methods

Policy analysis

This method involves reviewing policy documents and reports to align the research with the government's strategies and visions (Yanow, 2007). These are critically reviewed to understand the direction of development and existing limitations and conflicts of the European and Dutch governments. This process was done to understand the direction of development policies, formulate the problem, and identify existing limitations and conflicts at the national and EU levels.

SRQ 3: To understand the suitability of potential locations of a circular supply chain.

Literature review

A literature review involves a review of relevant scholarly articles, books, and other sources to synthesize the existing body of knowledge on a particular topic (Snyder,2019). A literature review was done to formulate the problem statement, identify the gaps in existing research, and formulate the conceptual and theoretical foundations of the project.
Databases: Google Scholar, Scorpus, TU Delft Library

SRQ 1: To understand in detail the processes and environmental impacts of a future circular supply chain of NdFeB magnets.

SRQ 2: To understand the future demand forecast for NdFeB magnets for the Netherlands and the European Union.
To understand the economic development paradigms, their consequences, and their impacts.

SRQ 4: To understand the procedure involved in formulating an assessment framework.

Diachronic Analysis

A diachronic study is an analytical approach that explores phenomena across different periods of time, focusing on their evolution, development, and historical changes (Widdersheim, 2018). In this research, a comprehensive diachronic analysis of the industrialization process in the Netherlands, with a specific focus on the metal industry, is done. The aim is to understand the spatial patterns and distribution of the industries and to explore their relationship with the economic structure and socio-ecological dynamics over time.

SRQ 3: To understand historically the spatial distribution of the industries in relation to the economic structure.

Suitability analysis

Suitability spatial analysis is a geographical and analytical method used to determine the potential and feasibility of a given area for a specific purpose or use (Yang, 2007). In this research, Geographic Information Systems (GIS) is used to evaluate characteristics like soil type, proximity, and the symbiotic relationships among land uses to determine the most optimal locations for different processes in the future circular supply chain of NdFeB magnets.

SRQ 3: To understand the spatial distribution of industrial areas and circular activities under different scenarios.

Mapping

Mapping is used as a research method for analyzing spatial relationships and phenomena and effectively translating complex data into visually understandable formats (James, 2016). In this research, Geographic Information Systems (GIS) is used for spatial analysis, which facilitates an understanding of existing conditions, identifies spatial patterns, and enables the geographic representation and contextualization of problems. Thus, the relationships and patterns across multiple scales, from local to global, provide an in-depth perspective on the topic's spatial dimensions.

SRQ 1: To understand the spatial claims and infrastructural requirements for different facilities within the supply chain and geographical locations and flow relations in the supply chain at the global scale.

SRQ 3: Analyse existing and potential geographical locations, find suitable locations for a circular supply chain at the national scale, and spatially depict the scenarios.

SRQ 4: To visualize the integrated national vision.

Scenario building

Scenario planning is a method to respond to the uncertainties and complexities in future material demand, socio-economic trends, and political decisions (Durance & Godet, 2010). It is based on recognizing multiple potential futures rather than a single predetermined outcome. This method facilitates the exploration of different possible options to speculate on future developments while also generating valuable insights about the present.

SRQ 2 & 3: To illustrate and understand how a circular supply chain can adapt to and integrate with varying economic landscapes over different periods.

Evaluation of the Scenarios

Evaluating scenarios is used to analyze the scenario outcomes based on different parameters. A vital component of this approach is developing an evaluation framework, which allows for systematically comparing scenarios according to specific criteria, revealing their strengths and weaknesses (Venable et al.,2012). This research compares scenarios based on spatial, social, economic, environmental, technical, and political factors.

SRQ 4: To compare and evaluate the different scenario outcomes.

Potential Circular Supply Chain

In this chapter, the future circular supply chain is described and the spatial and environmental repecussions are highlighted. Also the current geographical locations of the processes within the supply chain are mapped.

Neodymium's Contribution in Sustainable Technology

To understand the potential supply chain of Neodymium processing for manufacturing NdFeB magnets, it is essential to gain a foundational understanding of the material itself.

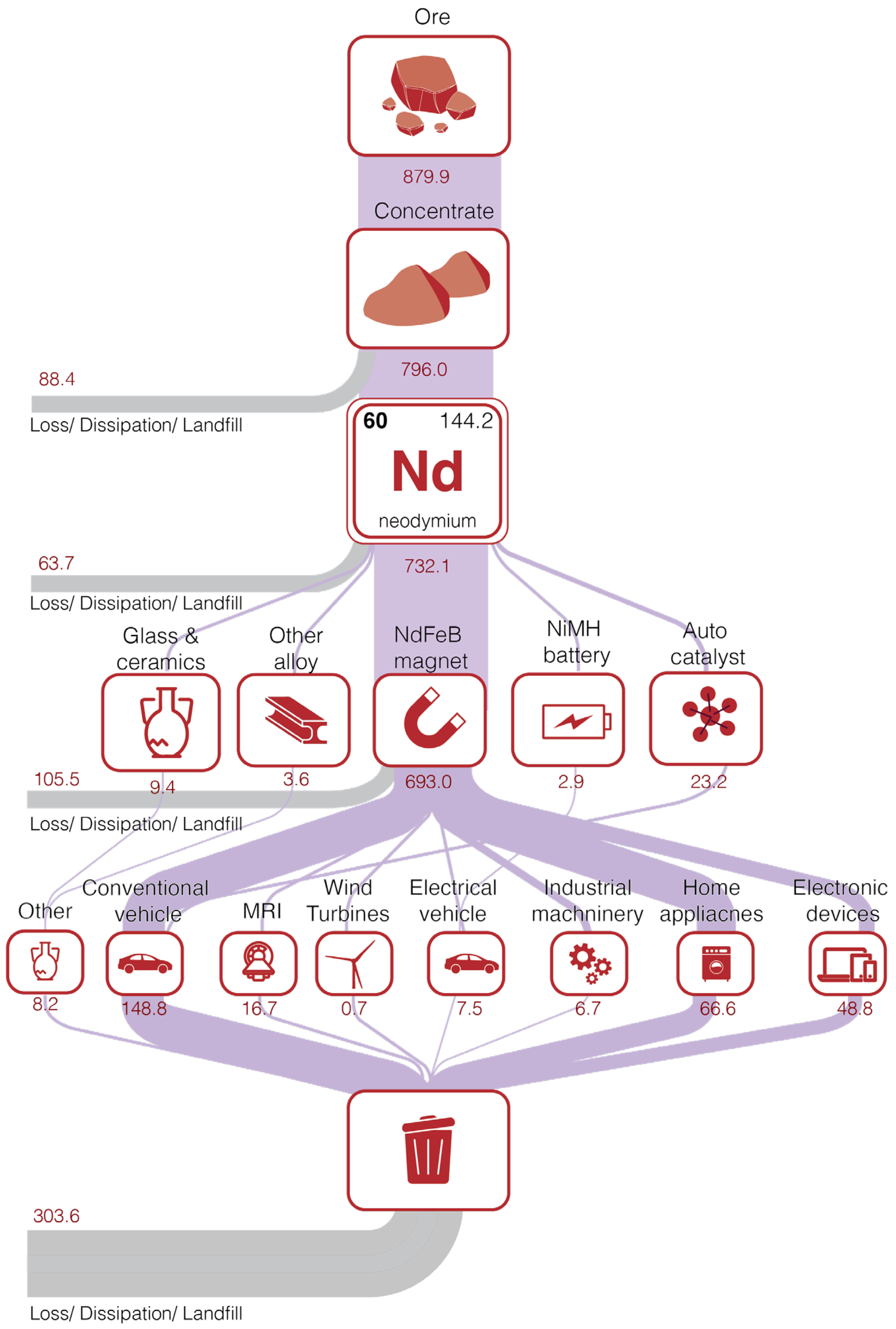
Neodymium is a Rare Earth Element (REE). REE is an often misunderstood group of 17 unique elements. They are rare because of their poor concentration in ore deposits, but their abundance in the earth's crust is quite large. This makes their mining and extraction not to be profitable and highly exhaustive (Liu et al, 2022). Several rare earths are essential for decarbonizing the energy sector, and China dominates their processing.

It is a crucial element for green energy as it manufactures permanent magnets of neodymium–iron–boron (NdFeB). NdFeB permanent magnets are used as components in generators for wind turbines and traction motors for electric vehicles and are thus crucial for the green transition. Although the amount of Neodymium required for these magnets is relatively small, the complexity of the supply chain behind them is significant. This intricate process makes it interesting to examine the spatial claims and environmental impacts that even a minimal quantity of this material can have.

While it is essential for green and digital transitions, it also has applications for other uses like industrial motors and our daily electronic devices as shown in Figure 6.1.

Fig 5.1 : Global Nd cycles with accumulated stocks and flows in kt, 1990–2020

Source: Liu et al., 2022



Relevance for the Dutch Economy

This research focuses on the Netherlands as a case study for developing a more profound, spatial understanding of the CRMA. The Netherlands is an important contributor to the energy transition in Europe and, hence, a significant consumer of technology produced by Neodymium. Major Dutch companies like Airbus, ASML, and Hardt Hyperloop depend on a resilient supply of neodymium magnets. Moreover, the nation's significant ports serve as a gateway for European imports and provide a strategic advantage in potentially processing these materials, thereby enhancing their value.

Furthermore, the Netherlands has been at the forefront of Circular Economy (CE) initiatives (Tsui, 2023). This commitment is particularly relevant in securing a resilient supply chain for materials like Neodymium, as the primary processing and extraction of these materials are financially heavy and pose significant environmental challenges. By situating this supply chain within the Netherlands, there is an opportunity to ensure adherence to CE principles, thereby aligning economic activities with sustainable and environmentally conscious practices.

In her speech addressing export restrictions at ITC, Universiteit Twente, the Dutch Minister for Foreign Trade and Development Cooperation, Liesje Schreinemacher, mentioned that

"In 2040.....The Netherlands alone will need up to 15% of current global production of neodymium – a rare earth metal used in magnets."

(Ministerie van Buitenlandse Zaken, 2023). She also mentioned that by positioning the Netherlands as a crucial strategic element in key supply chains, efforts can be directed to areas of significant impact. And that the strengths of the country lie in its vast knowledge, expertise in logistics, and strong industrial capabilities (Ministerie van Buitenlandse Zaken, 2023).

Future Circular supply chain of NdFeB magnets

For a circular NdFeB magnet supply chain it is essential to have processing in the Netherlands.

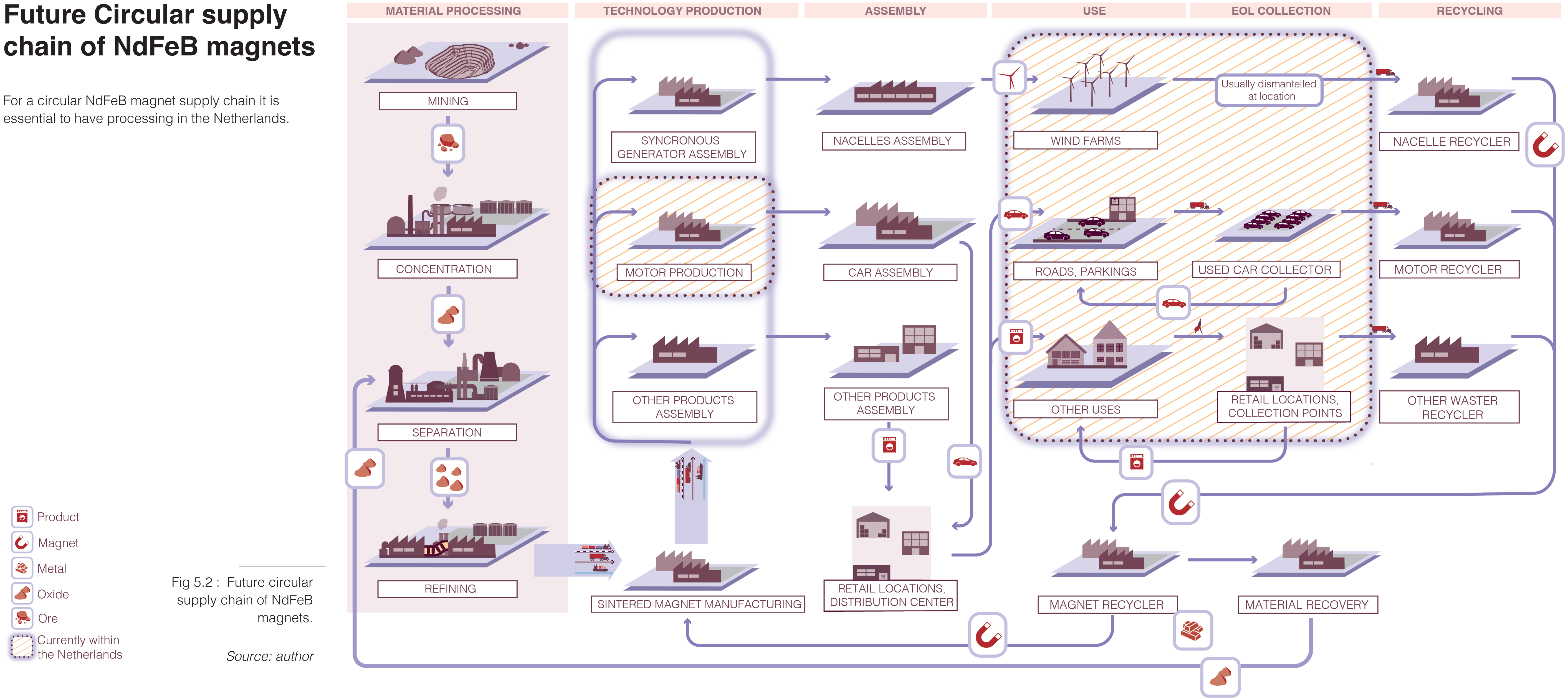


Fig 5.2 : Future circular supply chain of NdFeB magnets.

Source: author

Spatial and Environmental implications

The figure shows the organisation of the activities involved in the supply chain with their infrastructural requirement and their space claim.

The Rijkswaterstraat (Ministry of Infrastructure and Water Management) has set zones for different business and industrial activities to prevent nuisance. There are 6 catergories with different distances from living locations. The ministry also mentions a which activity belongs to which category. These are the categories shown in the figure.

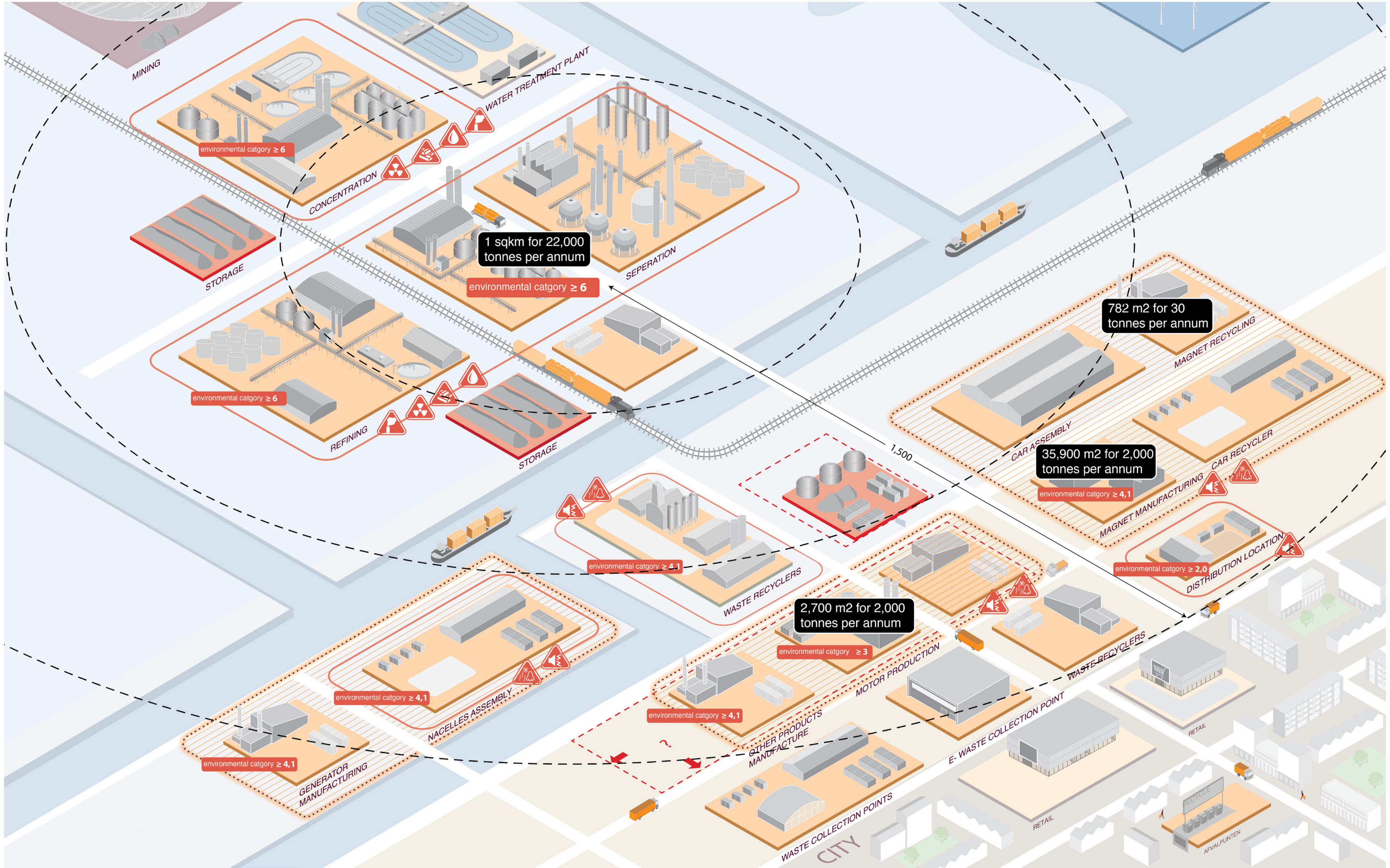


Fig 5.3 : Spatial and environmental implications of a circular supply chain

Source: author

Data source: Rijkswaterstaat Ministry of Infrastructure and water management

Existing Assembly and Manufacturing location

The map shows how different assembly and manufacture companies in the Netherlands are located in the supply chain. Eindhoven is a key spot for its many magnet companies and factories. Besides manufacturing, Eindhoven is also an important location for research and tech companies.

- Electric Motor Producer
- Car Assembly
- Other Vehicle Assembly

- Generator Producer
- Wind Turbine Assembler

- NdFeB Magnet Producer

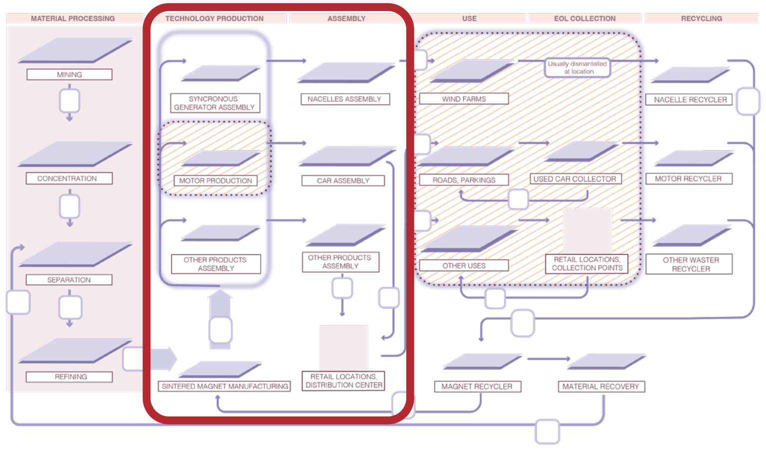
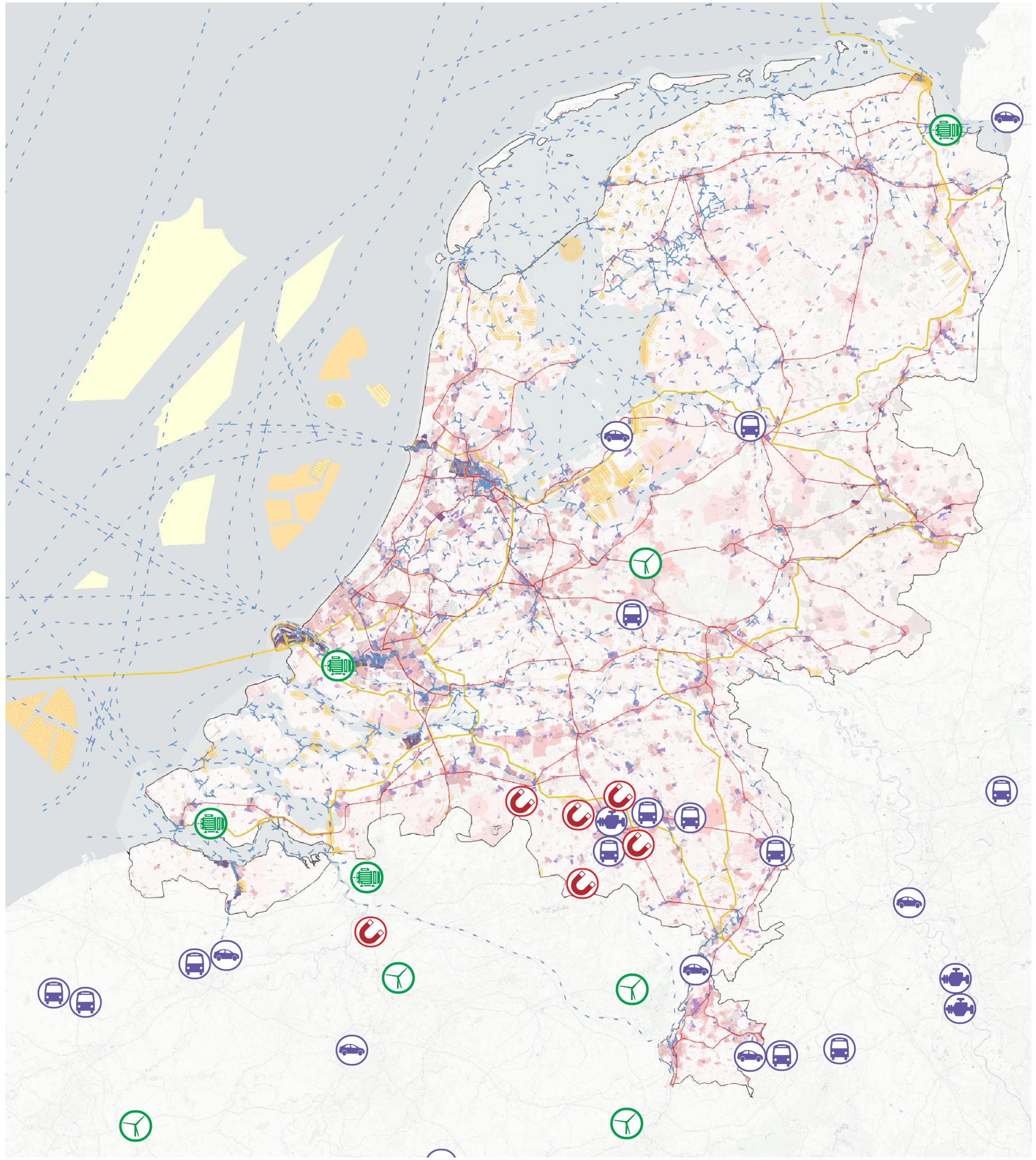


Fig 5.4 : Manufacturing and assembly companies

Source: Author
Data: Google maps, OSM, Wind Europe, ACEA



Current Stock of Neodymium

This map illustrates the existing stocks of Neodymium magnets, highlighting a correlation where higher population densities are associated with greater potential stocks. The map includes the geographical distribution of wind turbines which also account for the current stock of Neodymium.

- Wind Turbine locations
- Population density
- Roads

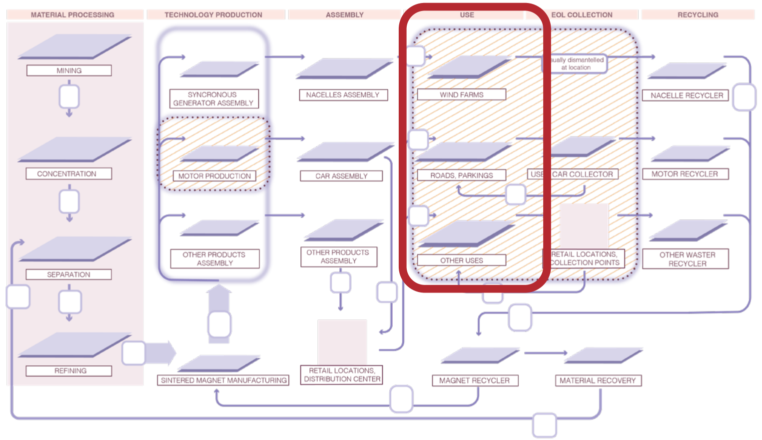
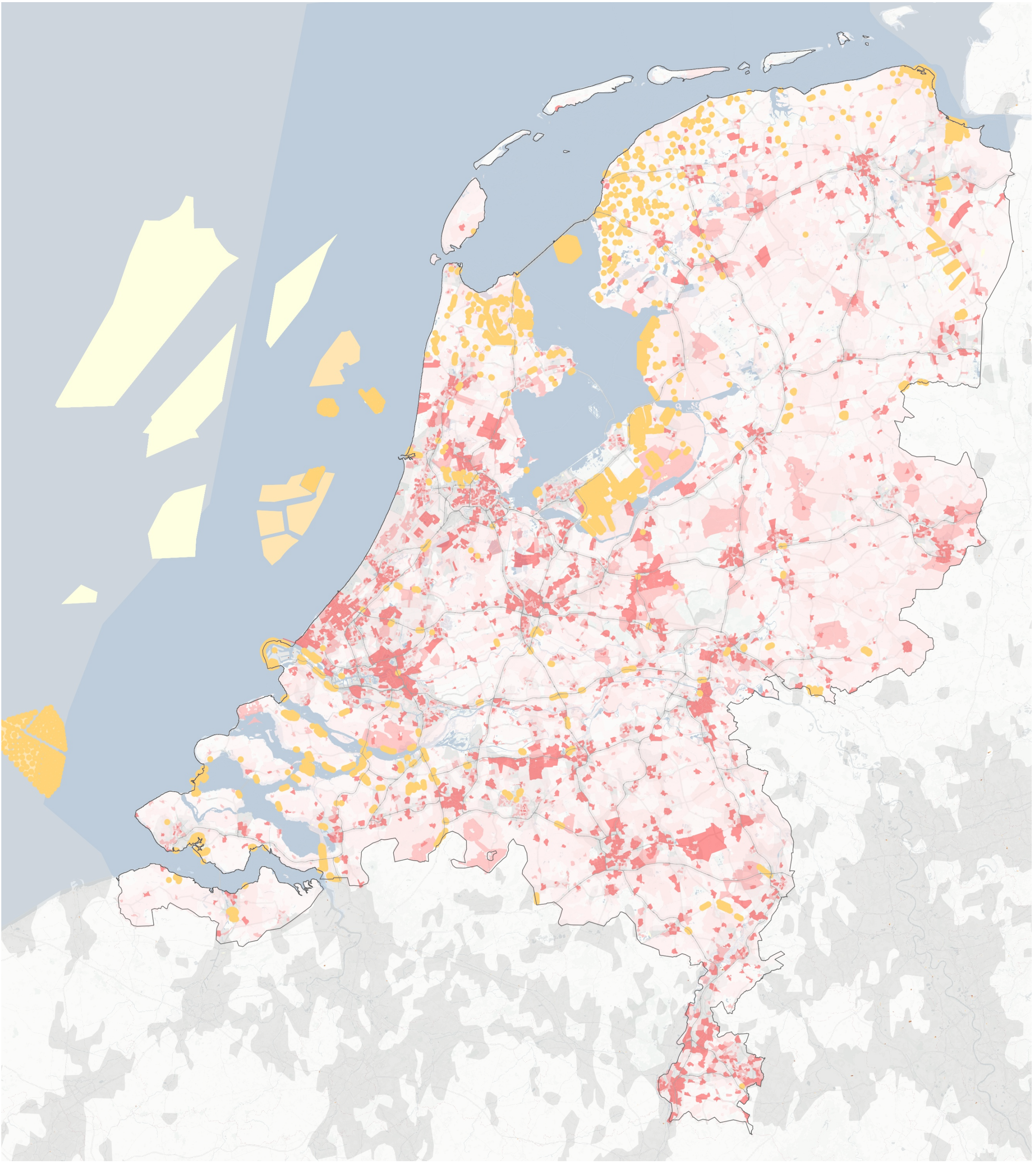


Fig 5.5 : Current stock of Neodymium

Source: Author
Data: CBS, Open Infra-structure map



Existing End Of Life (EOL) Functions

This map illustrates the existing locations of the Eol functions involved with the NdFeB magnet supply chain.

- Large Waste Collection Points
- Car Recycler
- Recycling of waste metale
- Wind Turbine Decomissioning

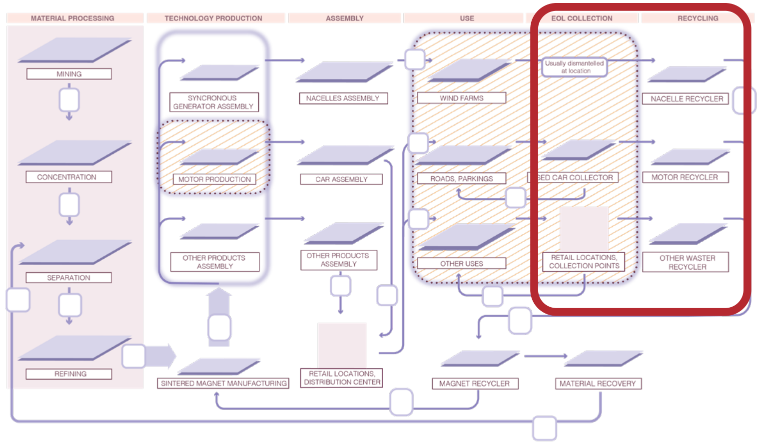
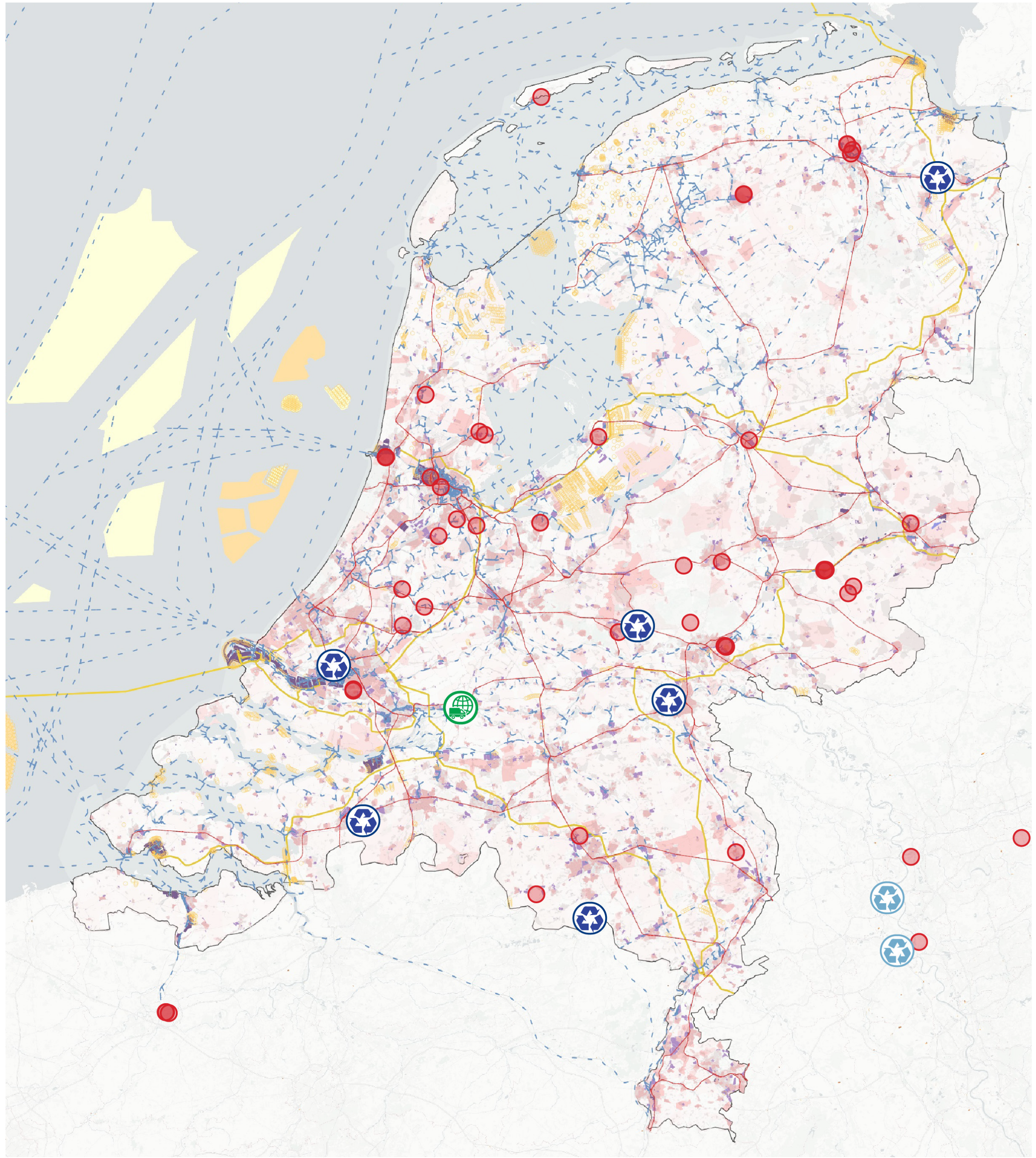


Fig 5.6 : Current stock of Neodymium

Source: Author

Data: Google maps, OSM, Wind Europe, ACEA



Existing Metal Processing Industry

This map displays the geographic locations of metal industries in the Netherlands and the pollution they cause.

- Manufacturing
- Mining or quarrying
- Processing or Production
- Recycling of waste metale
- Treatmentt or coating
- Air pollution
- Water pollution

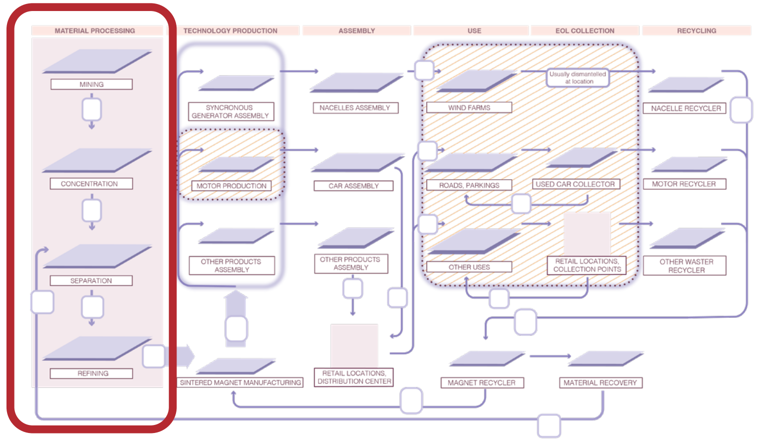
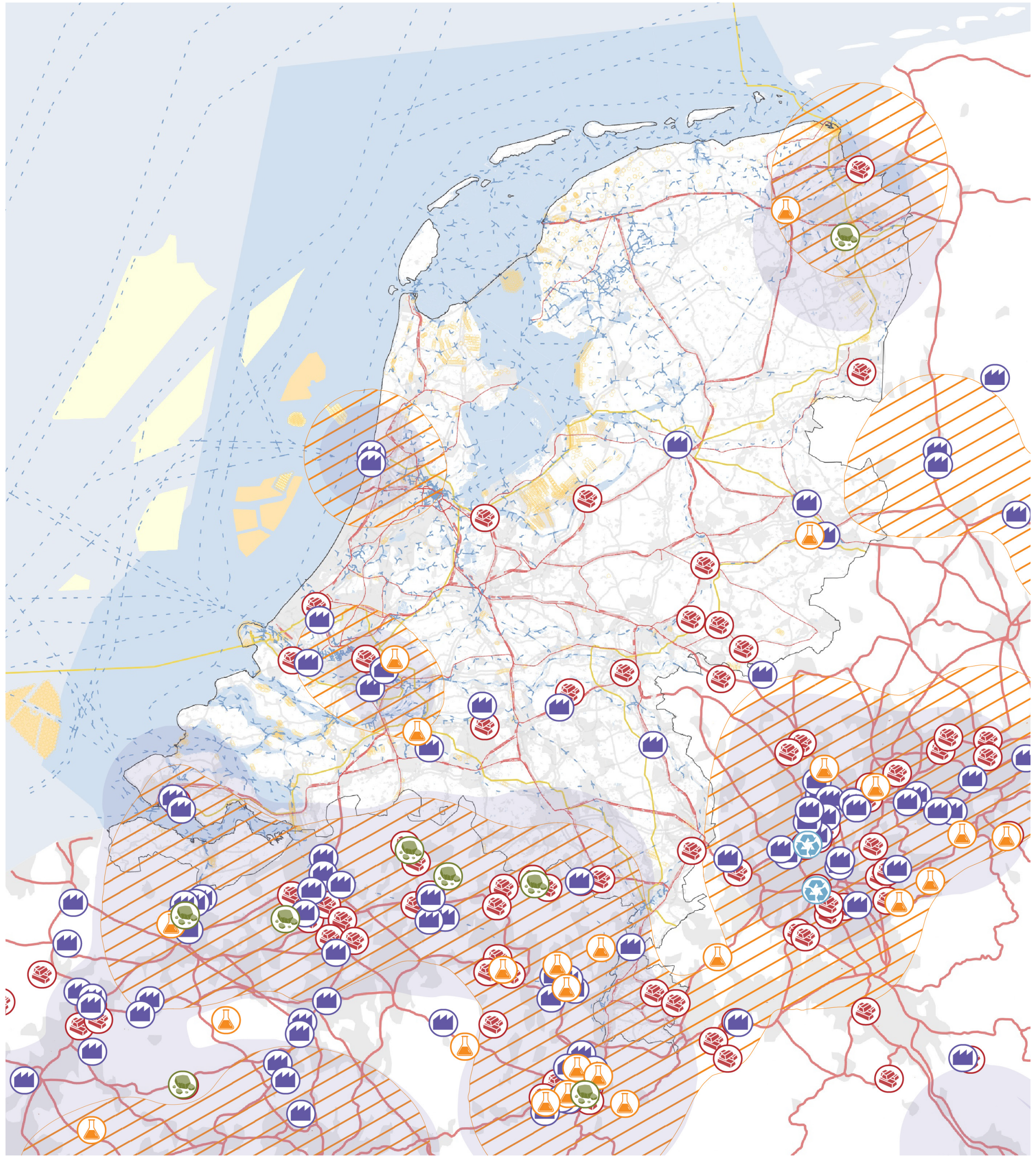


Fig 5.6 : Metal Processing locations

Source: Author

Data: E-PRTR



Diachronic Analysis

A diachronic analysis was done to understand the impacts of the Industrial Revolution on the Netherlands, placing it in a global context. This analysis specifically explored the relationship between the economic structure of that era, the materials utilized, the scale of industrial production and consumption, and their spatial organization.

The main focus was on three materials- iron, steel, and aluminum, within the Dutch context. The analysis seeks to understand how the use and production of these materials influenced the Netherlands' industrial landscape.

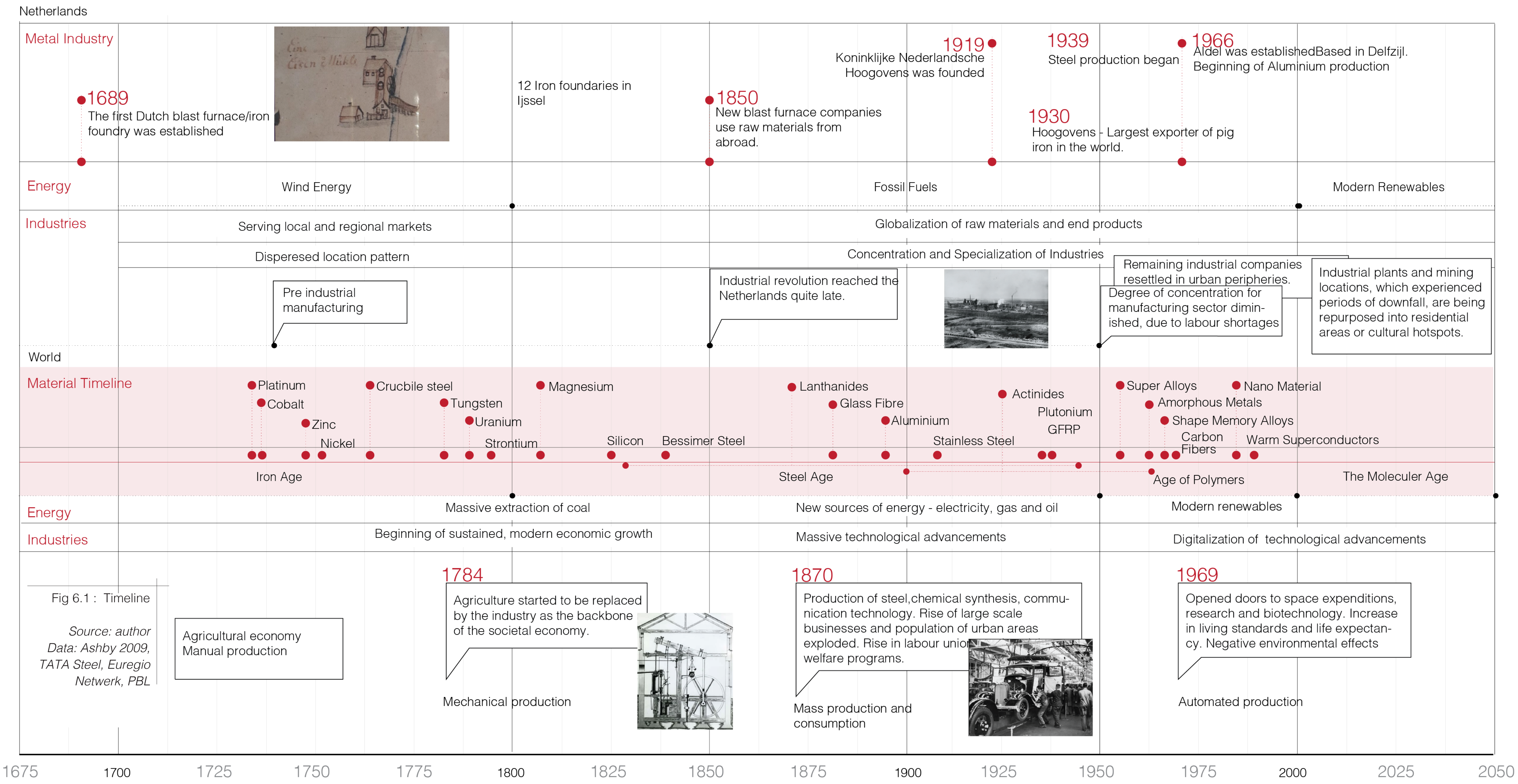


Fig 6.1 : Timeline

Source: author
Data: Ashby 2009, TATA Steel, Euregio Netwerk, PBL

Iron Foundaries

The Ijssel region in the Netherlands is referred as being the birthplace of the Dutch iron industry. In the 17th century, the local smelting of iron ore began in small blast furnaces. The first Dutch blast furnace was established in 1689, and cannon balls and bombs were made (Energio Network, n.d.). Eventually, everywhere in the Netherlands small foundries started coming up producing products based on the local demand. The iron ore needed for production was located locally in the soil and charcoal came from the region. The water wheel was used to produce energy and river also served as a crucial transport route for finished products.

By 1850, the Dutch iron industry expanded, with new blast furnace companies importing raw materials from abroad. This period saw a surge in demand for cast iron, leading to the establishment of numerous foundries across the Netherlands. These foundries produced a variety of products, including cookware, windows, stoves, lampposts, and grave crosses, primarily catering to local markets (Energio Network, n.d.).

As the industry evolved, Dutch foundries began manufacturing automotive parts, such as brake drums. Today, the majority of production is still geared towards the automotive and tractor industries, with consumption extending beyond local markets (Energio Network, n.d.). In 1918, the founding of Koninklijke Nederlandsche Hoogovens marked a significant milestone, and by 1950, it had become the world's largest exporter of pig iron (TATA Steel, n.d.).

Historically, many smaller foundries were scattered throughout the Netherlands, often located along rivers to utilize water power, and facilitate easy transport of iron. These industries often coupled with related sectors like shipbuilding. As the production capacities grew, the size of the industries grew and the size of the urban settlement around also grew.

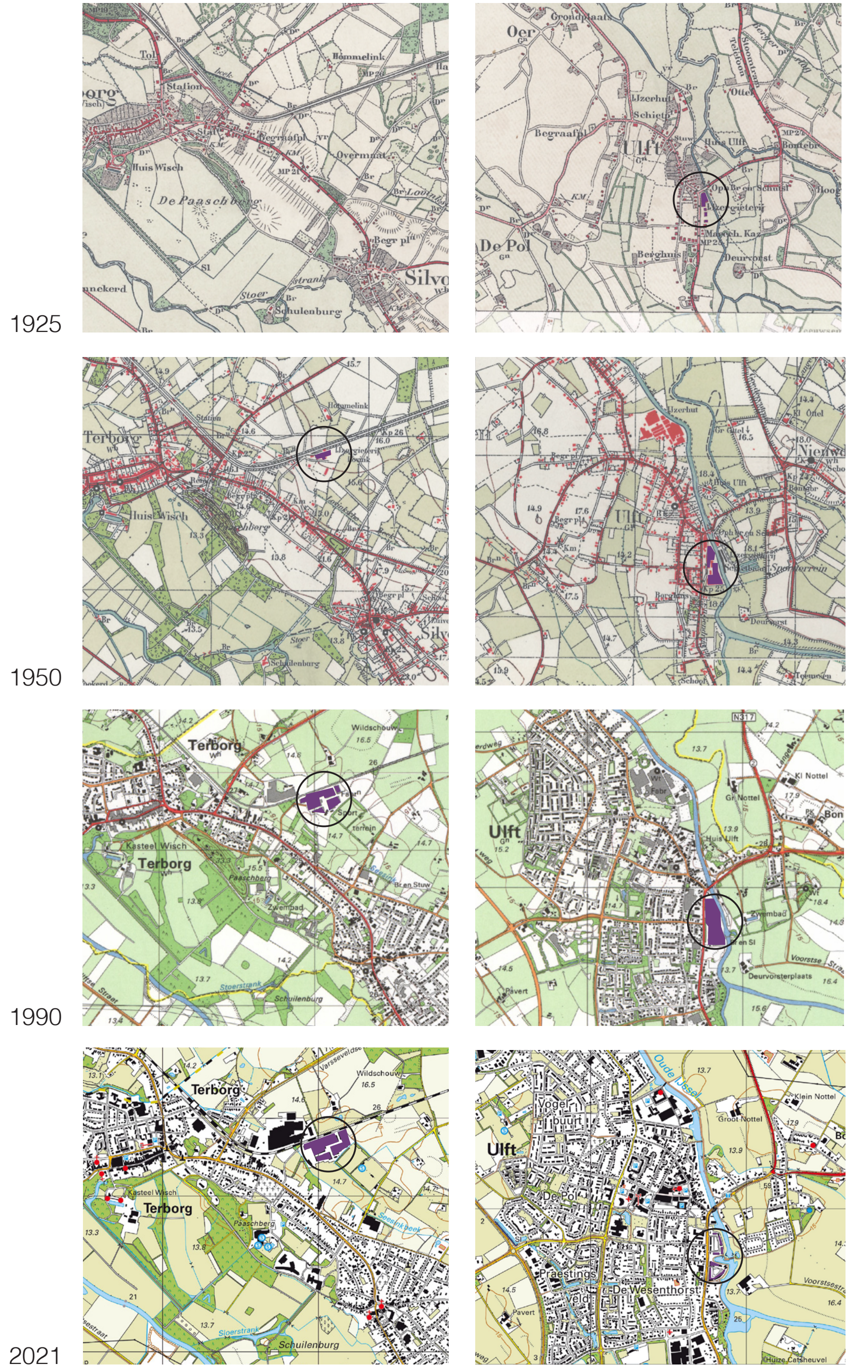


Fig 6.2 : Growth around the iron foundary

Source: Topotijdreis

Steel Production

Ijmuiden, once known as “Dutch Arcadia,” transformed drastically with the construction of the North Sea Canal (Saskia, kgnl). The canal’s creation made the area attractive for heavy industry. Today it is one of our most polluting industrial areas in the Netherlands.

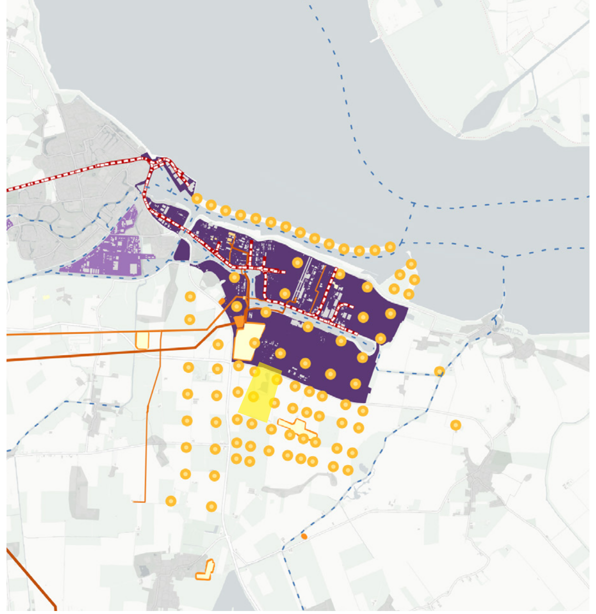
Koninklijke Nederlandsche Hoogovens, established in The Hague, aimed to to make the Dutch industry less dependant on imports (Tata Steel, n.d.). The geographical location of the Netherlands was ideal for the establishment of an iron and steel company, with its excellent access to the sea for the supply of raw materials and the export of finished products. Alternative sites near Rotterdam and Moerdijk were dismissed due to poor structure of the local soil (Muntjewerff & Bläsing, n.d.).

Today, Tata Steel Ijmuiden stands as Europe’s largest steel factory. However, its environmental impact is significant, being the Netherlands’ top emitter of CO_2 (8% of national emissions), nitrogen, lead, and mercury (EJAtlas, n.d.).

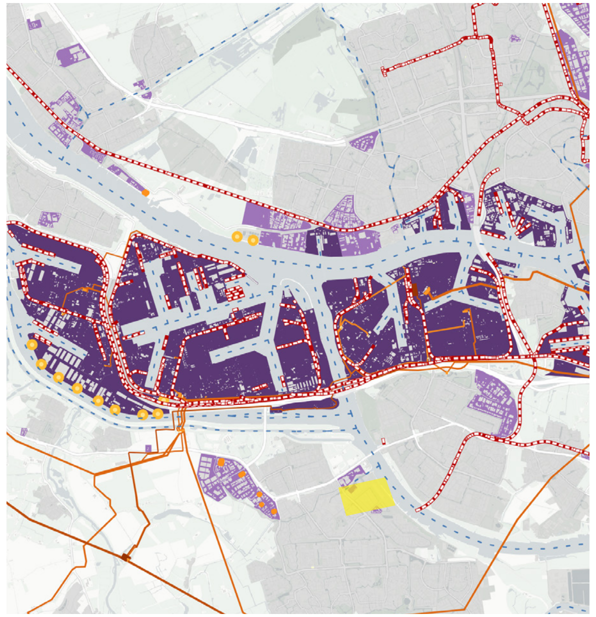
It also contributed to 88% of particulate matter emissions in the IJmond region in 2018, raising health concerns for nearby residents. Originally founded to build domestic capacity and reduce reliance on imports, this steel facility quickly expanded to enhance its competitiveness against foreign markets aiming to establish themselves as leaders in the steel sector.

Fig 6.3 : TATA Steel

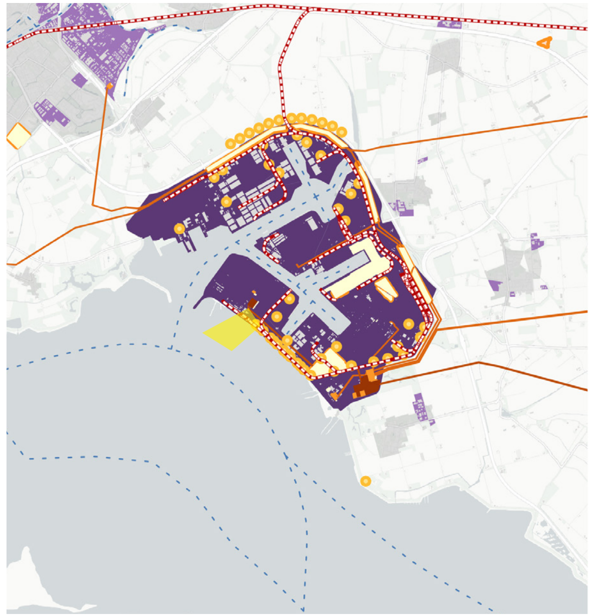
Source: Author



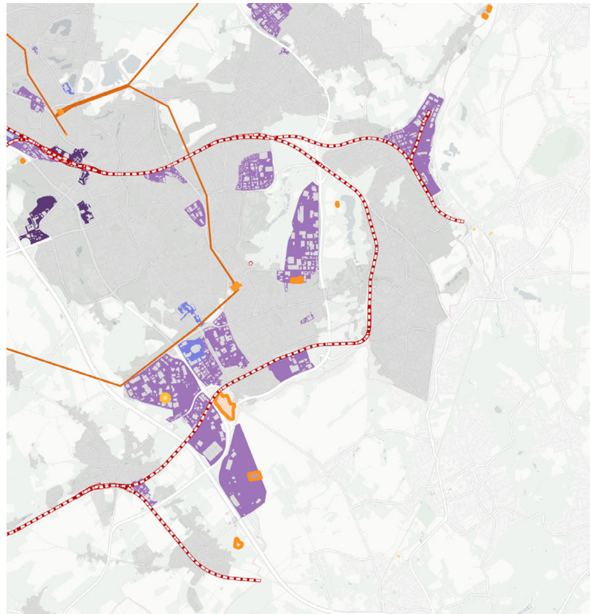
Aldel (1966)
Founded in Delfzijl, as the location was ideal for importing raw materials by sea. A crucial factor in choosing this site was the proximity to the Slochteren natural gas field, which provided an abundant and cheap electricity supply, essential for energy-intensive aluminum production.



Aluchenie (1966)
Founded in the port area of Rotterdam due to its proximity to the sea for the efficient export and import of various materials. Another point in choosing this location was that majority of dutch refineries are located in this port region.



Pechiney Nederland BV (1969)
Founded close to Vlissingen. The location was choosen based on the port, easy access to raw materials. Energy deal with a nuclear reactor located in Borssele, 3km away, so cheap electricity could be bought for the electric intensive electrolysis cells.



E-MAX Billets (1990)
Founded as a cast house for Alumax Europe, later taken over by Alcoa in 1997 and became part of plants in Drunen, Harderwijk and Roermond

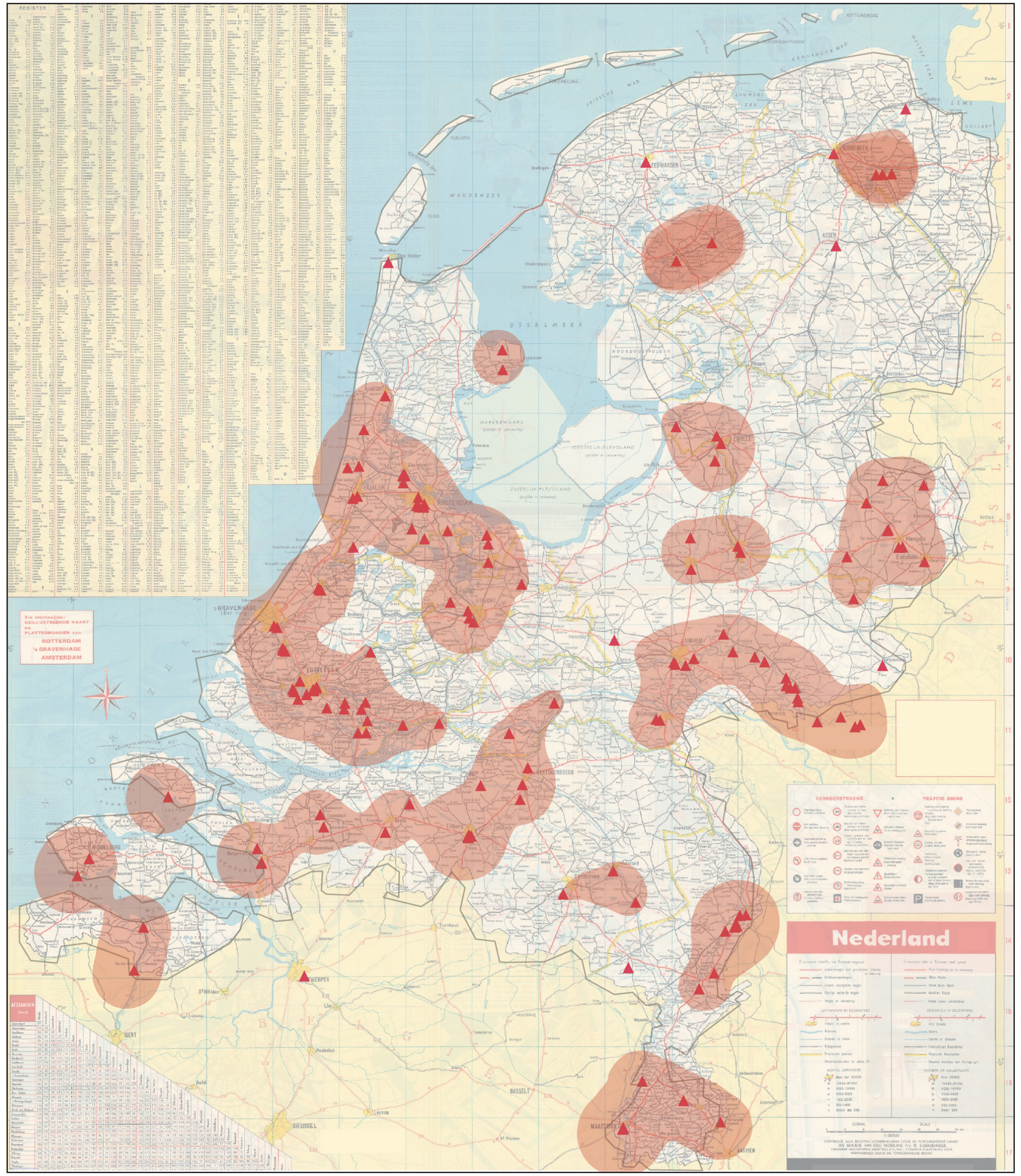
Aluminium Production

The developments in the Dutch aluminum industry were largely driven by the need for cost-effective energy sources, the strategic advantage of port locations for importing raw materials and exporting finished products, and the benefit of integrating into existing industrial hubs.

Fig 6.4 : Aluminium processing locations

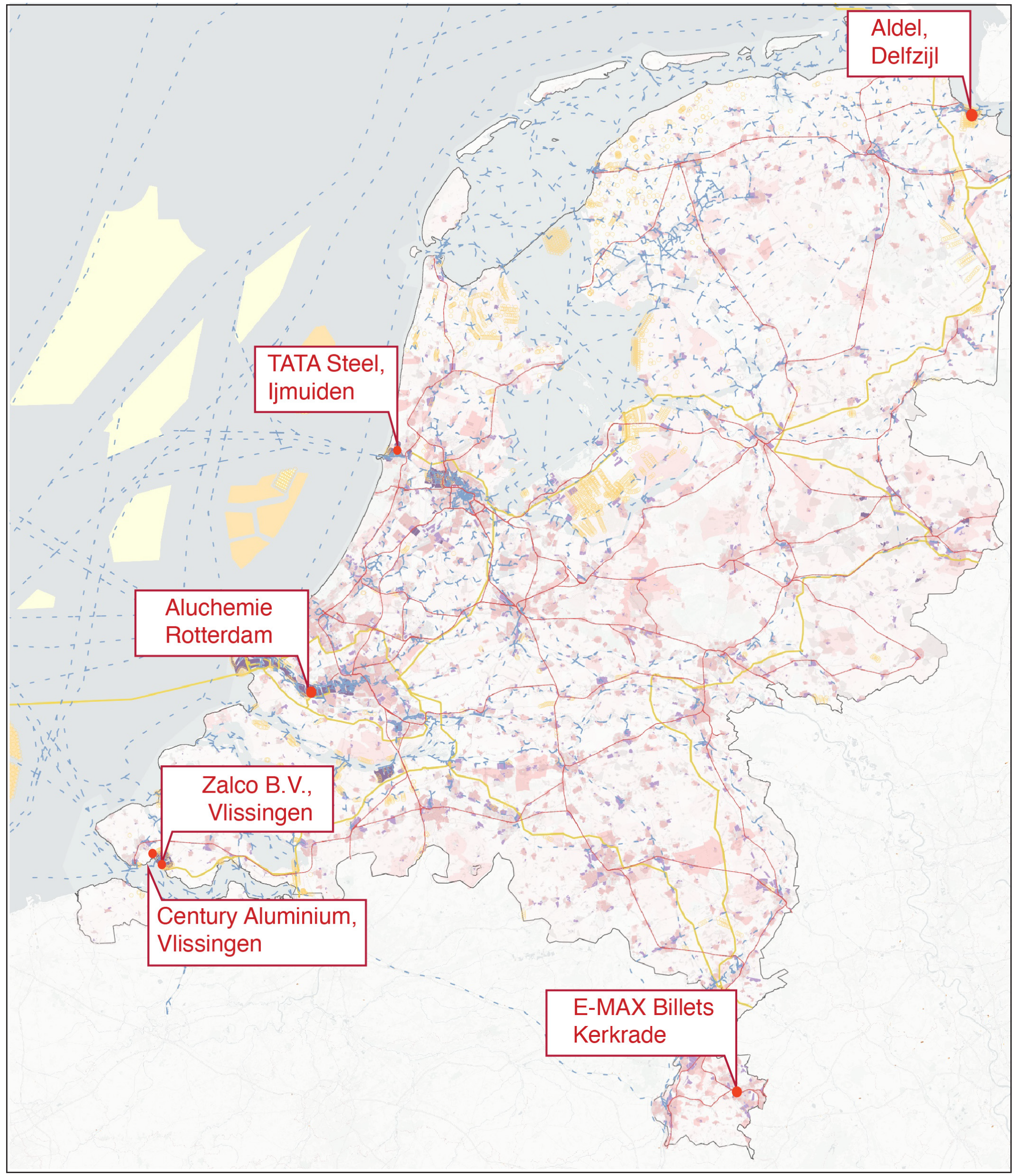
Source: Author

Bedrijven terreinen
Production plant
Train line
Electricity line
Wind Turbine



Overview of iron foundries in the Netherlands (1689-2012)
Data Source: Nederlands IJzermuseum (2020)

▲ Iron Foundaries



Overview of Steel and Aluminium Processing in the Netherlands (Current)
Data Source: PBL

Scenario Building

In this chapter, the method used to create the scenarios is outlined. Additionally, comprehensive narratives for the four created scenario is explained. After which the scenarios are evaluated.

(UNEP, 2002): *“Scenarios are descriptions of journeys to possible futures. They reflect different assumptions about how current trends will unfold, how critical uncertainties will play out, and what new factors will come into play.”*

Scenarios are based on assumptions and provide a focused glimpse into the future rather than complete descriptions. They are not scientific forecasts but tools for highlighting key future elements to drive development (Kosow & Gaßner, 2008). However, they are not just speculations but shaped by evidence and reasoning. While they have an exploratory function to widen our knowledge of the future, they also highlight its limitations.

A key metaphor in scenario planning is the funnel model. This model effectively illustrates the open-mindedness and diversity of future possibilities. The funnel’s narrow vertex represents the current situation with its inherent variables, while the widening shape of the funnel symbolizes the array of potential future paths (Kosow & Gaßner, 2008).

Among the many methods of scenario planning, this research uses the ideal-typical fashion as described by Kosow & Gaßner (2008, p. 25) through five phases: 1) identification of the scenario field; 2) iden¬tification of critical factors (or ‘descriptors’/ variables); 3) analysis of key factors; 4) scenario generation; 5) scenario transfer.

1) Identification of the scenario field

This project aims to establish a resilient and circular supply chain for neodymium-iron-boron (NdFeB) magnets by presenting various options for decision-making. This includes choosing between developing a domestic supply chain or regional collaboration. A critical decision in this context is determining the extent of processing capacity the Netherlands is prepared to accommodate within its borders.

Adding to this complexity is the variable demand for NdFeB magnets, influenced by societal behaviors and the emergence of alternative technologies. To address this complexity effectively, it is essential

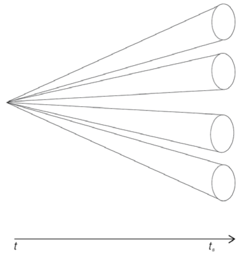


Fig 7.1: Scenarios funnel model

Source: Kosow & Gaßner (2008)

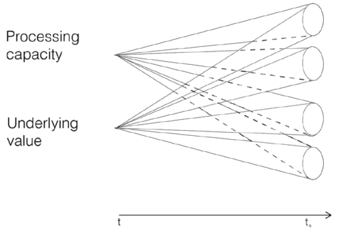


Fig 7.2 : Scenarios funnel model adapted for this research

Source: author

to understand the underlying value behind choosing a particular processing capacity, which also varies in each scenario.

Therefore, the research focuses on two key variables to frame the scenario analysis: the desired level of processing capacity within the Netherlands and the underlying value behind it. To systematically approach this analysis, the funnel model for this research is illustrated in Fig 5.2.

2 & 3) Identification and analysis of key factors

This research pinpoints critical factors like urban areas, infrastructure, industrial areas, energy, and ecology, as fundamental to this analysis. To construct scenario narratives, a comprehensive review of scholarly literature is done, which offers insights into future economic development paradigms. This narrative generation process is rooted in a literature-based approach, where synthesizing, interpreting, and articulating findings from various academic sources forms the backbone of the narrative structure. The process also includes the incorporation of quantitative analysis. Trend analysis and calculations are done to project future demands for the material and the spatail claim of the processes involved in the supply chain.

Scenario planning in this research operates as a bridge between evidence-based and imagination-driven methodologies. Through this balanced approach, the research aims to comprehensively understand the potential future landscapes of industrialization and economic development in the Netherlands.

4) Scenario generation

Four potential scenarios are identified in this research.
Each of the future scenarios has a different mix of strategies to achieve circularity and contribute to the raw materials strategy. Moreover, the future images also differ when it comes to the scale at which cycles close. This combined also has different effects on the development of the layout of cities and regions, business parks, work locations, and port and industrial areas. The sceanrios are individually exlpained in the next section of this report.

Introduction to the Scenarios

The scenarios are an exploration of the possible futures for the year 2050 based on different agendas and goals. It is assumed that to implement the Critical Raw Materials Act there can be different roadways that the Netherlands can take, which requires a fundamental change in the organization of the society and economy. **All of the scenarios adhere to circular economy principles in their own way by prioritizing certain principles over others. The difference lies in the processing capacities and the main agenda or value.**

	Knowledge Economy Business as usual	**Industrial Leaders** Green Growth	**Self - Sufficient** Degrowth	**Regenerative** Post growth
Processing capacity	0% processing	40% of EU consumption	100% of NL consumption	40% of NL consumption
Societal value and material consumption	Economic growth is necessary (Profit). Due to economic growth being the primary agenda material consumption increases.	Economic growth would lead to sustainable prosperity (Profit). Due to economic growth being the primary agenda material consumption increases.	Abandoning economic growth and prioritizing social equality and well-being. Due to economic growth not being the primary agenda material consumption decreases.	Emphasizing harmony with nature and prioritizing the well-being of the planet over relentless materialism Due to economic growth not being the primary agenda material consumption decreases.
Spatial organization	Urban growth concenrated around the Randstad. Processing centralized in the five main high environmental zones	Urban Growth concenrated around the Delta corridor. Processing centralized in the five main high environmental zones	Urban growth distributed throughout the country. Processing decentralized along inland rivers	Urban growth in high and dry areas. Processing in high and dry areas along inland rivers.
Infrastructure and energy	International network is made stronger. Logistical activities in the port of Rotterdam expand.Energy production concentrated in the North Sea	International network is priority, especially the Delta corridor.Energy production concentrated in the North Sea	National network is made stronger. Energy production is decentralized around major cities.	Stronger coorperation with Germany and Belgium. Energy production is decentralized aorund high and dry areas
Nature	The Netherlands Nature Network is completed. Dikes are higher for protection of the Randstad as it is the most important area.	The completion of the Netherlands' nature network has been compromised by the prioritization of space for large-scale industrial activities.	The Nature Network Netherlands has been successfully completed. A lot of measures are adopted to mitigate climate-related risks, like having ample space surrounding rivers to accommodate overflow	The Nature Network in the Netherlands has seen significant expansion to harmonize with natural processes rather than seeking to dominate them. Infrastructure such as dikes remains unaltered, allowing nature to reclaim land as it sees fit
Circular Priorities	**Slowing loops** Reuse, Repair, Refurbish, Remanufacture, Repurpose	**Closing loops** Recycle, Recover	**Narrowing loops** Refuse, Rethink, Reduce	**Regenerative loops** Restore, Renew, Revitalize

Processing capacity
Societal value and material consumption
Spatial organization
Infrastructure and energy
Nature
Circular Priorities

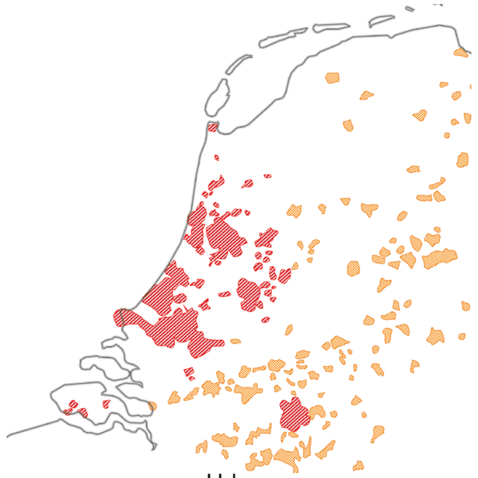
Scenario 1:
Knowledge Economy

This scenario is based on the argument that economic growth is necessary for benefits like fostering technological innovation and productivity. The world economy has grown to be highly interdependent, and heavily reliant on a complex global supply chain for resources.

Within this global system, the Netherlands stands out for its minimal efforts in material processing. The country has pivoted towards enhancing its technological capabilities, to compete and secure access. The Netherlands has emerged as an irreplaceable player through its cutting-edge technological innovations. Central to this advancement is ASML, a pioneer in the tech industry, whose exclusive technologies have positioned it as a crucial global entity. This strategic edge ensures access to products in exchange for technological knowledge.

This shift towards a knowledge-based economy disproportionately benefits the educated and skilled segment of the population, leading to wealth generation and improvement in the quality of life for these groups. This has led to an increase in the unequal ecological exchange among nations as well. There is remarkable growth in the technology and research sector, particularly among High-tech companies. People have developed a lot of confidence in technology and perceive it as the solution for sustainability. Due to this economic growth is pursued leading to an increased material consumption.

Industry



Urban

Infrastructure

Nature

Industry
Most high environmental category areas remain and continue to produce what they used to. Since there is no processing of rare earths in the Netherlands, no space is needed for processing, and there is no expansion of high environmental category zones. Business areas around the cities are dominated by High-tech and logistical companies. Manufacturing happens only for research and development purposes around the Eindhoven campus but does not happen in substantial amounts to cause an increase in the space needed. Production of final products does not increase in the Netherlands and they are mostly imported.

Logistics
Since most products are imported and the demand keeps on growing, container ports have expanded. Large warehouses are needed for temporary storage of these products, and find their place in the logistical corridor. Temporary storage warehouses are also needed for the export of EOL items for recycling.
Circular activities
EOL collection, for small electronics, happens in stores or shops. For large electronics, there are collection points in work locations (bedrijventerrein). Car collection and dismantling happens outside the cities in industrial areas with environmental category 3.

Repair, remanufacture, and reuse are prioritized in this scenario. For the repair of electronics, there are service stations in commercial areas. For the repair of cars, there are service stations in the work locations category 3. For major repairs, sorting, storage of parts, and repair of large electronics, there are repair hubs in the work locations category 3.

In this scenario, due to no processing capabilities for rare earths in the Netherlands, recycling of neodymium is not feasible locally. Consequently, most products that cannot be repaired after reaching EOL are exported to other countries to be recycled.

Urban
The Randstad keeps on growing. The most investment is towards educational and research institutions. Eindhoven being a key location for research and development on permanent magnets, also grows. There is expansion and densification both. Campuses have become high tech and cities have become smart.
Since a lot of manufacturing and processing companies leave or do not scale up, the environmental impact is not in the Netherlands. Consequently, it contributes to a healthier and safer living environment for its residents.
However, the high interdependence and specialization in high-tech sectors drive up the cost of living, exacerbating social inequalities and potentially leading to a higher rate of poverty among the less educated or skilled population. This becomes apparent as segregation becomes visible in the cities.

Mobility
A strong international network is needed to sustain this widespread global system. The port has become bigger and the incoming of ships has become more frequent. Freight trains are increased both in frequency and capacity. Delta corridor is completed and expanded. National infrastructure is also important for the circulation of goods throughout the country. People prefer using their own vehicle, which works well on the highways, but not as well in the city centers, where people still use active forms of transportation. Cars have become the quickest way of transportation for people.

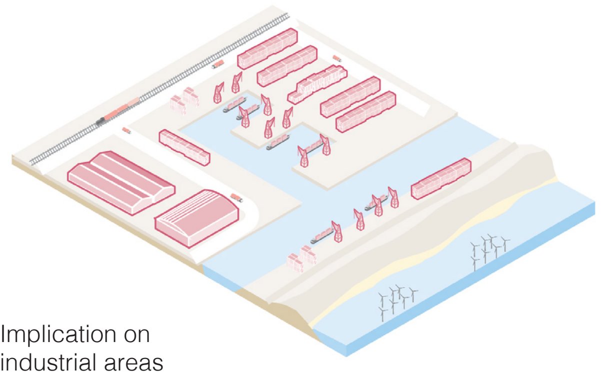
Energy
The energy demand has grown due to an increase in consumption of products like electric cars. Demand is partly covered by the North Sea and partly domestically around cities. A lot of energy can be easily imported so energy production does not have a very big spatial claim.

Nature
The Netherlands Nature Network has been completed. Dikes are higher for the protection of the Randstad as it is the most important area. Since there is no expansion of industrial areas for the incorporation of industrial processing and manufacturing, nature areas grow but are artificially managed (through dikes, polders, and canal systems).

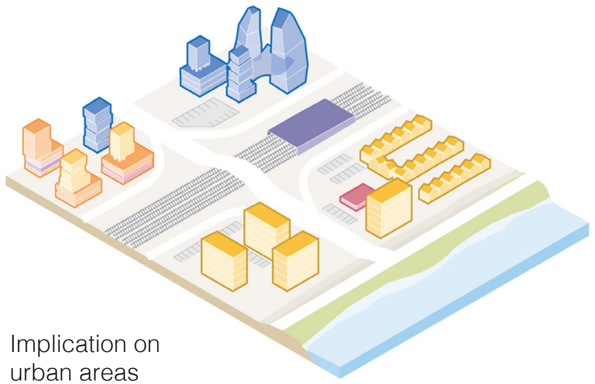
Map of the Netherlands 2050

This map illustrates the implication in the Netherlands if this scenario is realized.

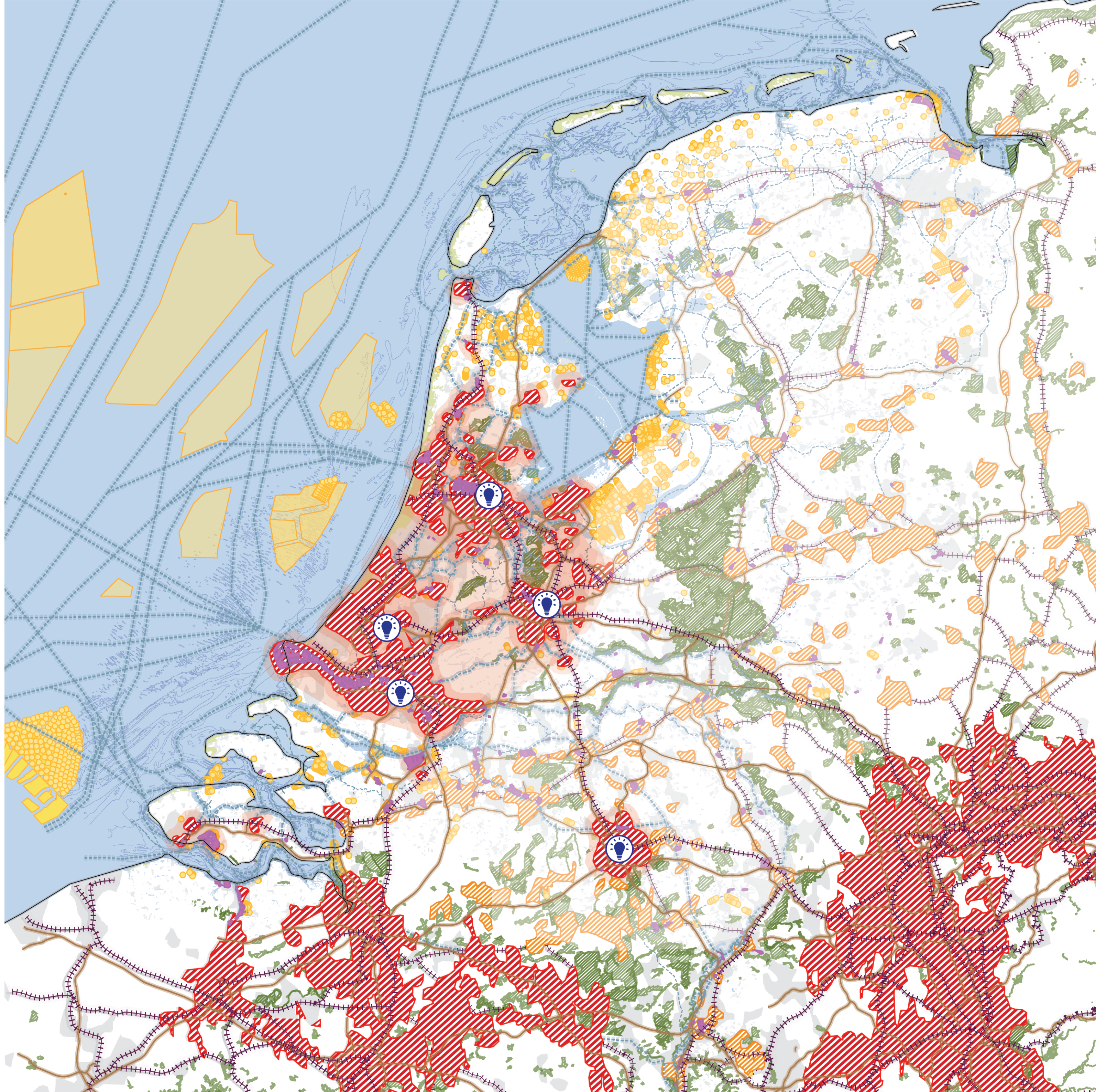
- Indusrtrial areas
- Urban areas (grow)
- Urban areas (do not grow)
- Natura 2000
- Railway
- Highway
- Waterway
- Research hotspots

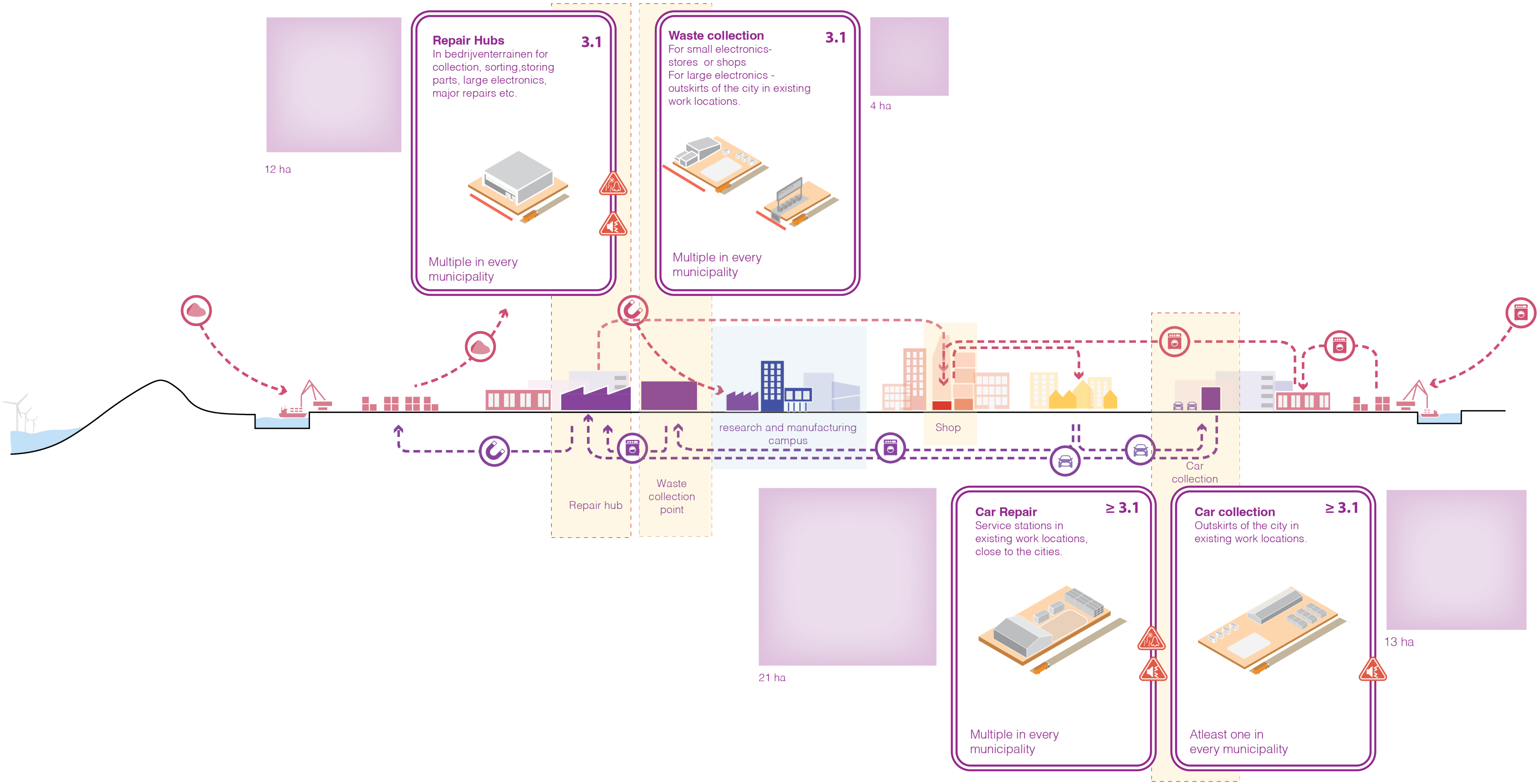


Implication on industrial areas



Implication on urban areas





12 ha
Repair Hubs
3.1
In bedrijventerrainen for collection, sorting,storing parts, large electronics, major repairs etc.
Multiple in every municipality
Waste collection
3.1
For small electronics- stores or shops
For large electronics - outskirts of the city in existing work locations.
Multiple in every municipality
4 ha
research and manufacturing campus
Shop
Repair hub
Waste collection point
Car collection
21 ha
Car Repair
≥ 3.1
Service stations in existing work locations, close to the cities.
Multiple in every municipality
Car collection
≥ 3.1
Outskirts of the city in existing work locations.
Atleast one in every municipality
13 ha

Scenario 2: Industry Leaders

In this scenario, opposing economic growth is seen as politically unviable. Economic growth is deeply ingrained in society's definition of a thriving economy. Technological developments are viewed positively, supported by the belief that technological advancements can lead to sustainable prosperity, termed green growth. According to the OECD, Green Growth is about achieving economic development while preserving natural resources and environmental services essential for well-being (Capozza et al., 2019). This perspective trusts that technological progress can solve environmental challenges. The focus is on advancing industrial processes and manufacturing, with the expectation that future technologies will mitigate environmental impacts.

This scenario prioritizes a thriving economy. This has led to two main outcomes. Firstly, there is an escalation in material consumption. Secondly, the Netherlands has become the industry leader in the processing of rare earths and built its capacity for processing 40% of Europe's total consumption.

The cooperation strategy exhibits a reliance on inter-European cooperation, with specific countries accounting for the processing of specific materials or processes within the supply chains. In terms of sustainability, profit dominates over people and the planet.

Industry

Industry

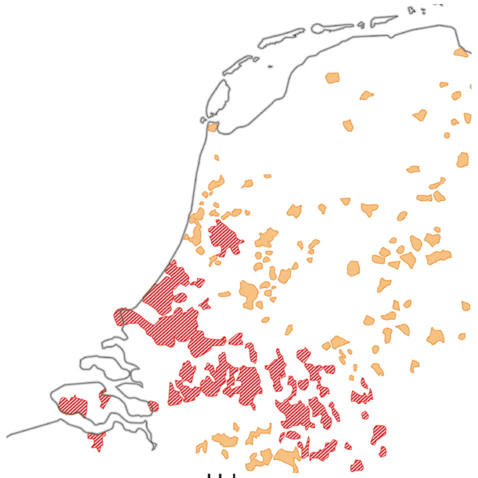
Following the manufacturing companies and large demand for the material, large material processing industries have also found a place in the five main high environmental category areas. Industrial activities are concentrated in specialized zones, designed to streamline manufacturing and processing operations. Production and assembly of final products happens in different locations within Europe.

The Delta corridor becomes important for sustaining European supply chains and consequently, industrial activities are concentrated along it. Processing of rare earths happens in high environmental category zone 6 i.e. 1,5 km away from living locations, mainly concentrated in the port of Rotterdam.

Since Eindhoven has existing manufacturing companies, it has become the hub for magnet manufacturing. Other locations include work locations in category 4.1 along the Delta corridor.

Logistics

Since most final products are imported and the demand keeps on growing, container ports have expanded along the Delta corridor. Large warehouses are needed for temporary storage of these products, and find their place in the corridor as well.



Urban

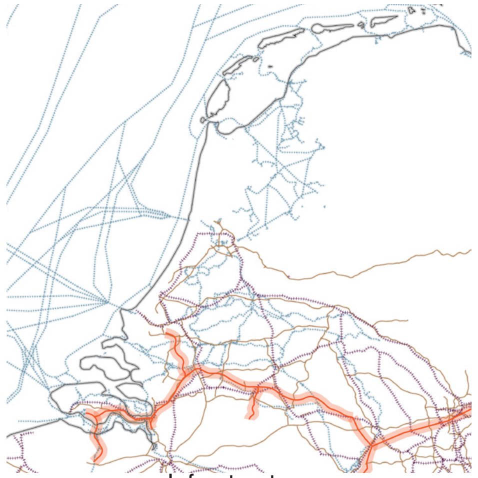
Circular activities

EOL collection, for small electronics, happens in stores or shops. For large electronics, there are collection points in work locations. Car collection and dismantling happens outside the cities in industrial areas with environmental category 3.

In this scenario recycling of magnets is prioritized and happens along with the processing facility in Rotterdam. For the repair of electronics, there are service stations in commercial areas. For the repair of cars, there are service stations in work locations category 3. There are circular hubs for major repairs, dismantling, sorting, and storage of parts in the work location category 3.

Urban

Urbanization is highly concentrated in the South, mainly around the Delta corridor and key cities like Rotterdam and Eindhoven, where land is optimized for economic gains. These areas experience densification due to extensive investments, on the other hand, the population in other urban areas shrinks. In highly urbanized areas, the priority is to maximize financial returns, leading to monofunctional zones such as luxurious offices, and large-scale residential areas, often situated away from the city cores, illustrating the emphasis on economic efficiency over mixed-use developments.



Infrastructure

Mobility

The international transportation network has been significantly strengthened and expanded, reflecting a deep reliance on European cooperation. With the completion of the Delta corridor, freight transport volumes have increased. Car use remains the preferred mode of transport. Specialized zoning, has led to longer travel distances. However, the shift towards zero-emission vehicles through electrification has marked a significant step towards sustainability but has increased the demand for electricity and raw materials.

Energy

Due to an increase in the heavy metal processing industry, the energy demand has increased. Also, since the population and prosperity have grown this demand is even more intensified. Intensive energy production happens at the Noord zee to support this. Rural areas are also rendered into large-scale monofunctional energy production areas. The energy network is still centralized. The hydrogen network is expanded along the delta corridor connecting the port of Rotterdam to the industries in the Ruhr area. This network expansion also fosters significant collaboration between industries located in Belgium and Germany.

Nature

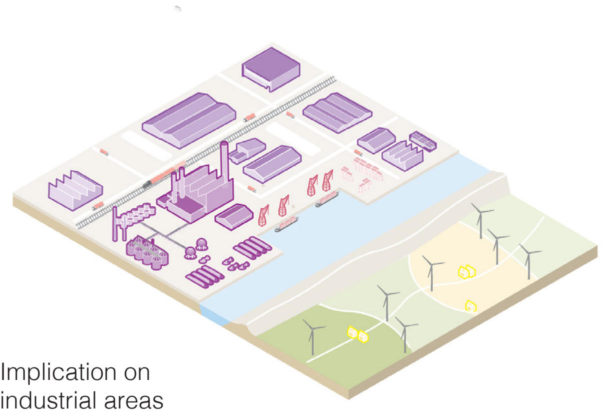
Nature

Towards nature, the attitude is that humans control nature. The completion of the Netherlands' nature network has been compromised by the prioritization of space for large-scale industrial activities. Nevertheless, the consolidation and expansion of urban and industrial areas in the western part of the country offer a potential for parts of the north to become natural. The dikes are strengthened further to secure the southwest of the country.

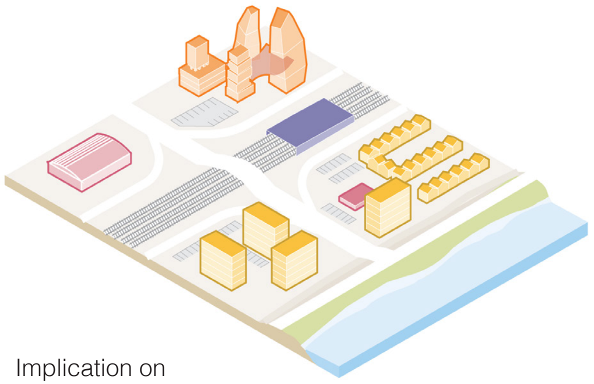
Map of the Netherlands 2050

This map illustrates the implication in the Netherlands if this scenario is realized.

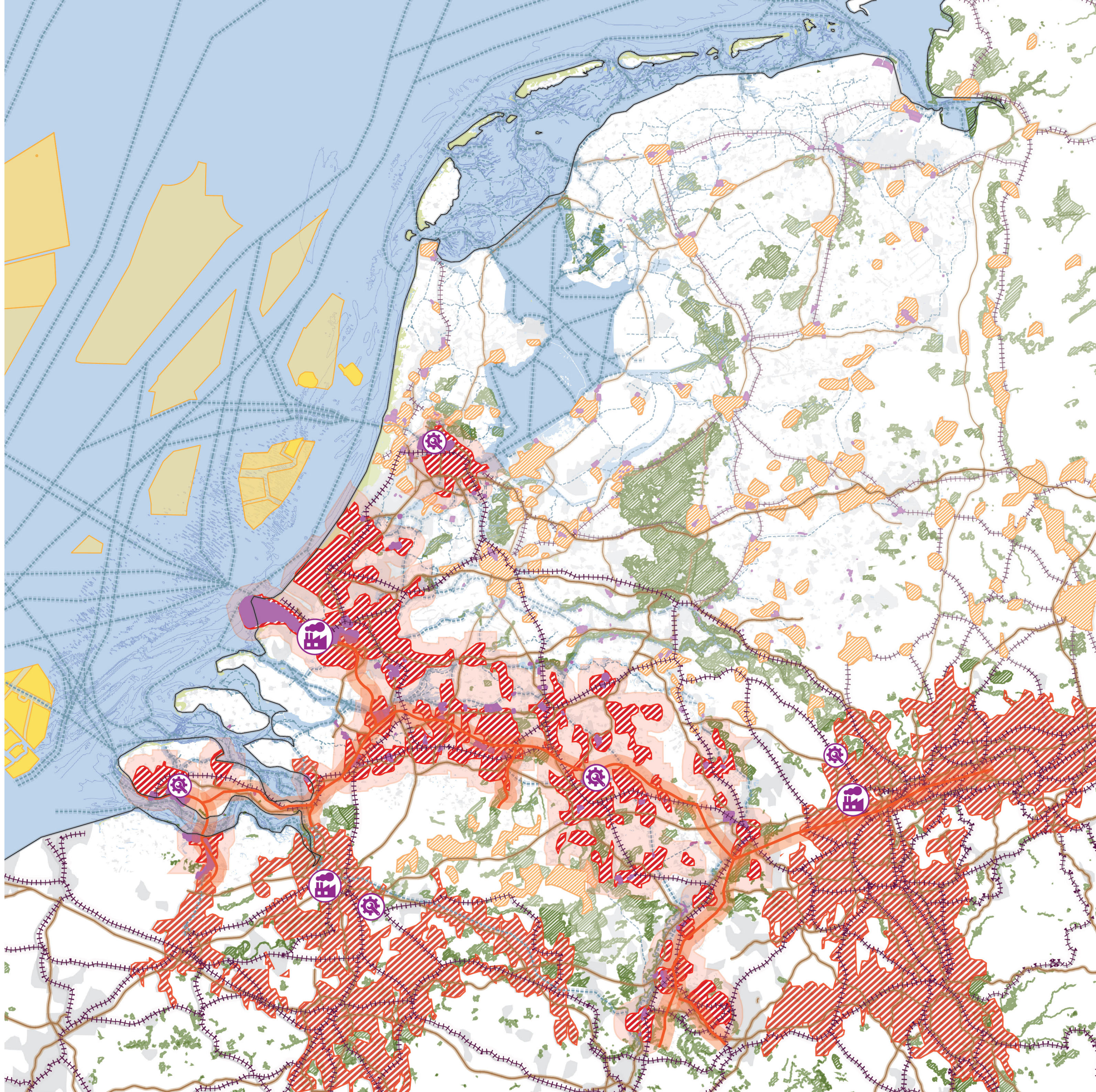
Indusrtrial areas
Urban areas (grow)
Urban areas (do not grow)
Natura 2000
Railway
Highway
Waterway
Hydrogen network
Processing locations
Manufacturing locations

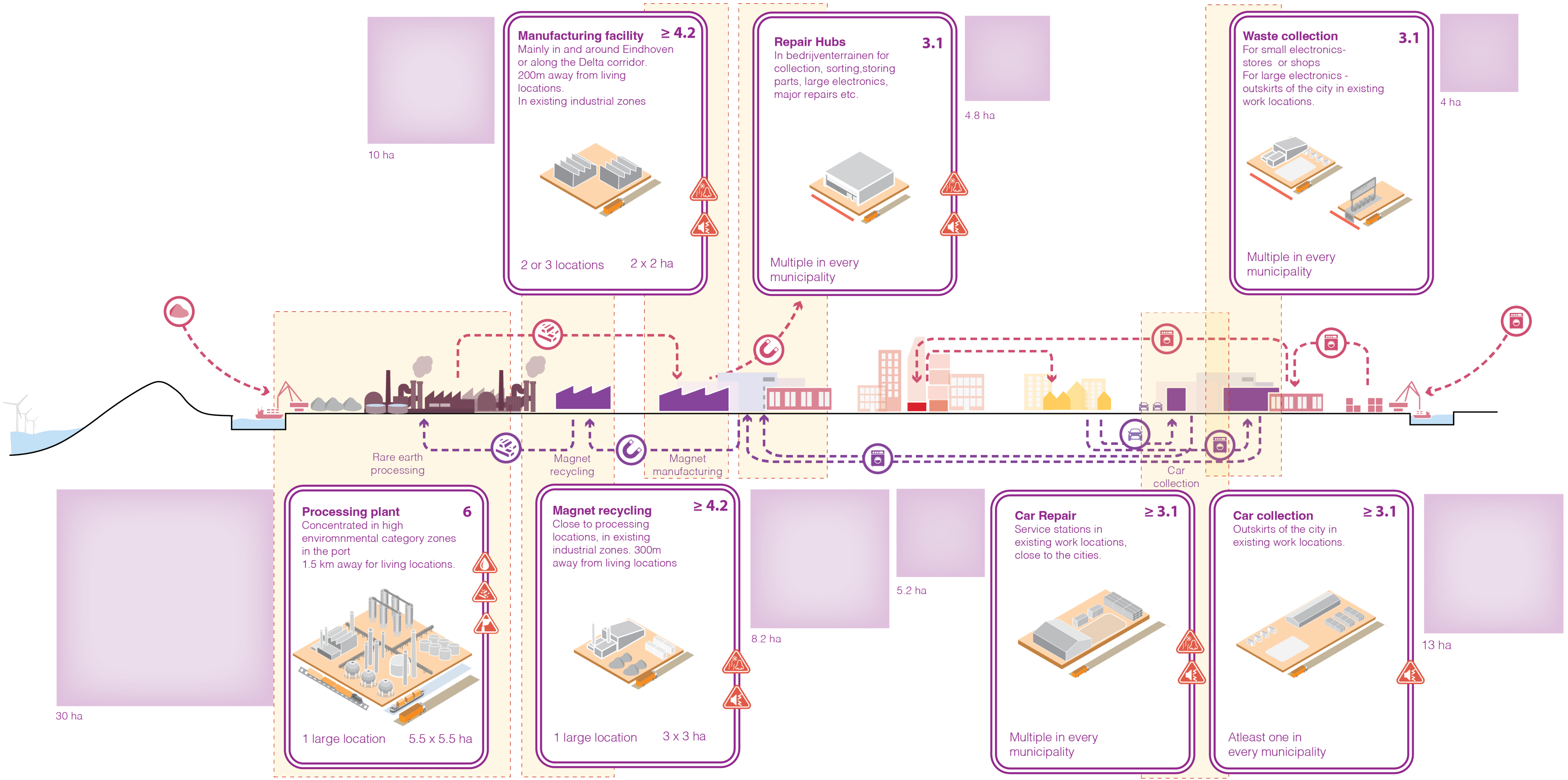


Implication on industrial areas



Implication on urban areas



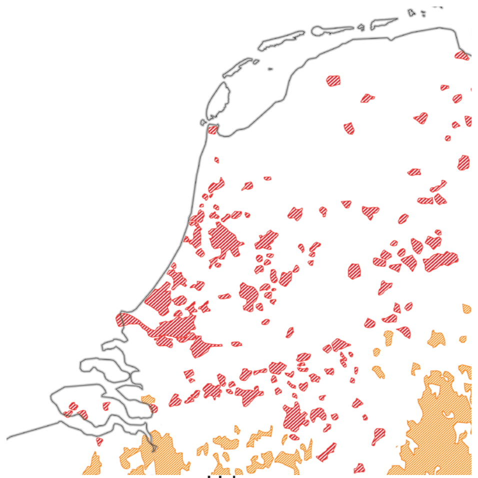

10 ha
Manufacturing facility
≥ 4.2
Mainly in and around Eindhoven or along the Delta corridor.
200m away from living locations.
In existing industrial zones
2 or 3 locations
2 x 2 ha
Repair Hubs
3.1
In bedrijventerrainen for collection, sorting,storing parts, large electronics, major repairs etc.
Multiple in every municipality
4.8 ha
Waste collection
3.1
For small electronics- stores or shops
For large electronics - outskirts of the city in existing work locations.
Multiple in every municipality
4 ha
Rare earth processing
Magnet recycling
Magnet manufacturing
Car collection
30 ha
Processing plant
6
Concentrated in high enviromnmental category zones in the port
1.5 km away for living locations.
1 large location
5.5 x 5.5 ha
Magnet recycling
≥ 4.2
Close to processing locations, in existing industrial zones. 300m away from living locations
1 large location
3 x 3 ha
8.2 ha
5.2 ha
Car Repair
≥ 3.1
Service stations in existing work locations, close to the cities.
Multiple in every municipality
Car collection
≥ 3.1
Outskirts of the city in existing work locations.
Atleast one in every municipality
13 ha

Scenario 3: Self Sufficient

This scenario argues for abandoning economic growth to respect environmental limits and achieve social equality and well-being (Likaj et al., 2022). It emphasizes reducing trade, decentralizing, and shifting away from materialism to defend ecosystems. It promotes cohousing and repurposing urban spaces for communal living to achieve a smaller footprint (Likaj et al., 2022). This fosters a culture where sharing is more valued than owning, aligning with a broader goal to place people and community before the planet and profit. While bottom-up initiatives are the primary way to make this happen, national-scale spatial reorganization like the mobility system could also steer these changes. However, a major behavioral shift is necessary for this scenario.

This manifests in a responsible approach to consumption and production. As a result of shared amenities, there is a reduction in material consumption. The Netherlands is committed to processing its own rare earth materials and is therefore building the domestic capacity to handle 100% of its consumption. This effort not only reduces dependency on international sources but also aligns with the Netherlands' aspiration for limited material prosperity growth, emphasizing a commitment to sustainability and self-reliance.

Industry



Urban

Infrastructure

Nature

Industry
High environmental category zones are no longer needed due to lower scale and greener techniques. Reduction in material consumption allows for downscaling of industrial operations. Therefore, smaller-scale processing can be decentralized and located along the inland rivers. They are located in medium-sized cities to create opportunities there for densification. Since the scale is much smaller the facilities can be 200 meters from living locations Manufacturing happens in existing bedrijventerreinen, in a decentralized way along the national hydrogen network. Production and assembly of final products also happen in the Netherlands and it spread over the country. This does not require an expansion of industrial areas; rather, it focuses on making existing spaces more efficient and denser. The reduced emphasis on the Netherlands as a logistical hub means less space is required for functions like storage, and transhipment.

Logistics
Large warehouses are needed for temporary storage of final products, and find their place close to production areas.

Circular activities
EOL collection, for small electronics, happens in stores or shops. For large electronics, there are collection points in transition zones (living + industry). Car collection and dismantling happen on the outskirts of the city.
For the repair of electronics, there are service stations in mixed-use areas (living + commercial). For the repair of cars, there are service stations in transition zones. For major repairs, sorting, storage of parts, and repair of large electronics, there are repair locations in transition zones.
Magnet recycling happens along with processing facilities. Sharing hubs for mobility and other facilities has become very common.

Urban
On a larger scale, the focus is on limiting urban expansion through densification and compact city policies (Wachter, 2013; Xue, 2014; 2018a). The decentralization of industrial activities makes urbanization distributed throughout the country. The historical dominance of certain regions over others was reduced. This equitable spread of urban development ensures a more balanced economic and social landscape, where no single area holds disproportionate influence or resources. Mixed-use environments flourish, where residential and commercial spaces coexist. This model promotes the concept of co-living and co-working spaces, which are complemented by shared facilities, fostering a sense of community and shared responsibility among residents. The organization of various industrial functions within proximity allows for synergetic benefits.

Mobility
The national transport infrastructure is strengthened, prioritizing public and freight transit systems to meet the needs of a more self-sufficient and interconnected society. Public transportation has become the backbone of mobility, offering accessible, frequent, and reliable services across the country. In this paradigm, the role of private vehicles is greatly diminished, aligning with a societal shift towards shared mobility solutions. This reflects a conscious choice to prioritize environmental and community welfare over individual convenience. There are mobility hubs for sharing and renting cars at central stations and major nodes.

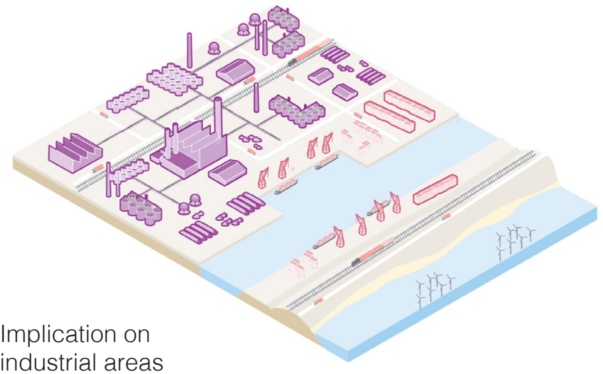
Energy
Since material consumption reduces, the energy demand also reduces. The number of wind farms in the North Sea is kept to a minimum. In parallel, a shift towards small-scale, community-based energy production has flourished. Neighborhoods become self-sufficient and interconnect by generating their own renewable energy. This also significantly reduces dependency on large-scale power plants.

Nature
The Nature Network Netherlands has been successfully implemented. A lot of measures are adopted to mitigate climate-related risks, ensuring the nation's preparedness for future challenges. A significant part of this strategy involves having ample space surrounding rivers to accommodate overflow during flood events. This not only protects communities and infrastructure from water-related disasters but also supports biodiversity by creating more habitable environments for various species. The main aim is to harmonize the natural world with human habitation, creating a resilient landscape that can mitigate the impacts of climate change.

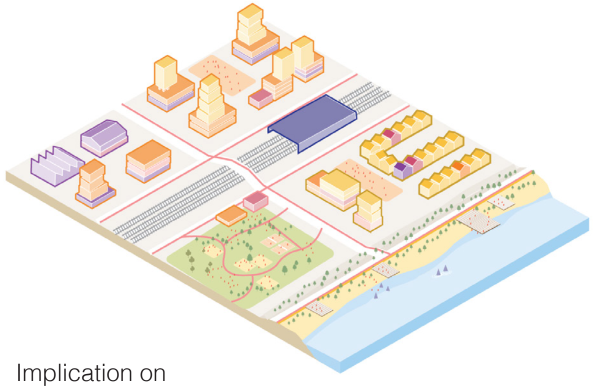
Map of the Netherlands 2050

This map illustrates the implication in the Netherlands if this scenario is realized.

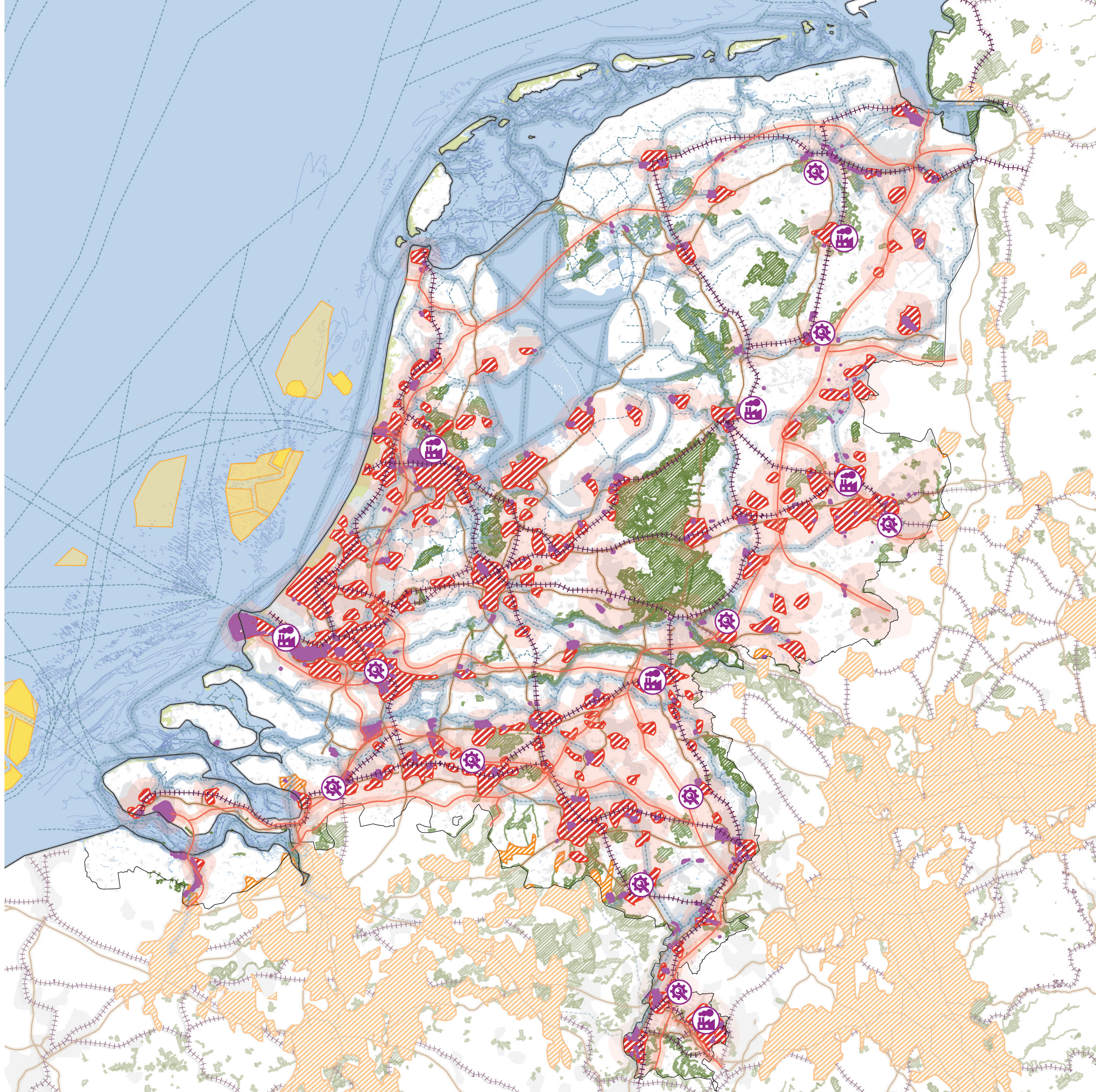
- Indusrtrial areas
- Urban areas (grow)
- Urban areas (do not grow)
- Natura 2000
- Railway
- Highway
- Waterway
- Hydrogen network
- Processing locations
- Manufacturing locations

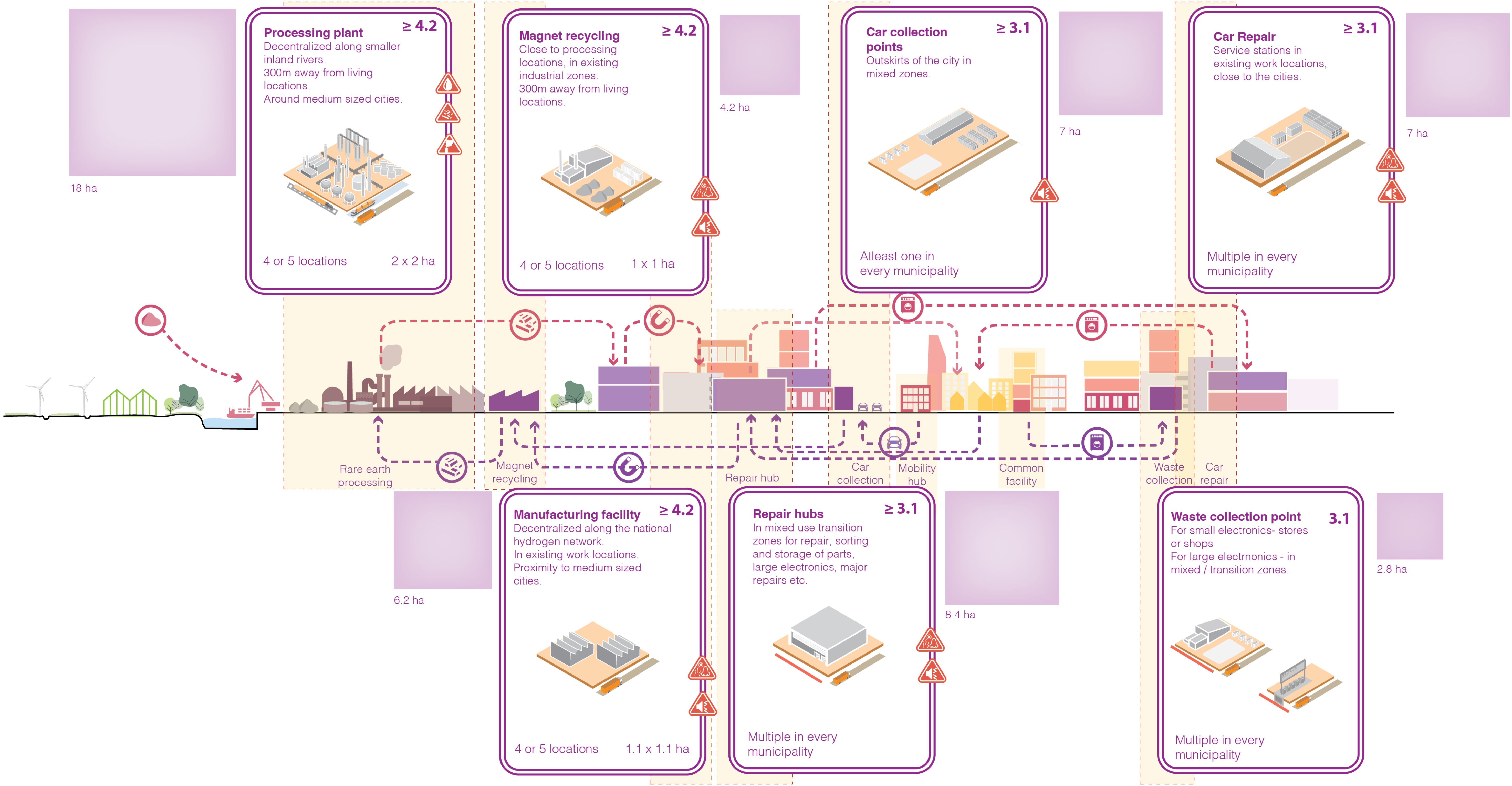


Implication on industrial areas



Implication on urban areas





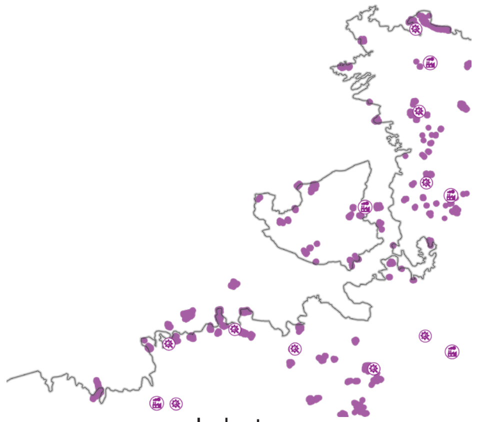
18 ha
Processing plant
≥ 4.2
Decentralized along smaller inland rivers.
300m away from living locations.
Around medium sized cities.
4 or 5 locations
2 x 2 ha
Magnet recycling
≥ 4.2
Close to processing locations, in existing industrial zones.
300m away from living locations.
4 or 5 locations
1 x 1 ha
4.2 ha
Car collection points
≥ 3.1
Outskirts of the city in mixed zones.
Atleast one in every municipality
7 ha
Car Repair
≥ 3.1
Service stations in existing work locations, close to the cities.
Multiple in every municipality
7 ha
Rare earth processing
Magnet recycling
Repair hub
Car collection
Mobility hub
Common facility
Waste collection
Car repair
6.2 ha
Manufacturing facility
≥ 4.2
Decentralized along the national hydrogen network.
In existing work locations.
Proximity to medium sized cities.
4 or 5 locations
1.1 x 1.1 ha
Repair hubs
≥ 3.1
In mixed use transition zones for repair, sorting and storage of parts, large electronics, major repairs etc.
Multiple in every municipality
8.4 ha
Waste collection point
3.1
For small electronics- stores or shops
For large electrtonics - in mixed / transition zones.
Multiple in every municipality
2.8 ha

Scenario 4:
Regenerative Scenario

Society embraces a paradigm shift, recognizing that decoupling urban growth from socio-ecological impacts is ineffective, as highlighted by Xue (2015). The narrative shifts from never-ending economic expansion to sustainable living, emphasizing harmony with nature and prioritizing the well-being of the planet over relentless materialism. This society redefines success, moving away from GDP metrics to holistic measures of happiness, environmental health, and social equity.

Since in this scenario, there is a motivation to balance development and socio-ecological impacts the Netherlands does 40% of the processing of its consumption. And since the main agenda is not economic development there is a reduction in material consumption.

People view themselves as components of the natural world, engaging with and benefiting from its services while also nurturing it. This attitude prioritizes the preservation of biodiversity and the maintenance of ecological balance through careful interaction with natural systems (Erisman et al. 2017). There is a collective preference for nature-based solutions over technological interventions, steering the economy towards a state of post-growth. However, there is regional cooperation required since the Netherlands does not aim to be self-sufficient.

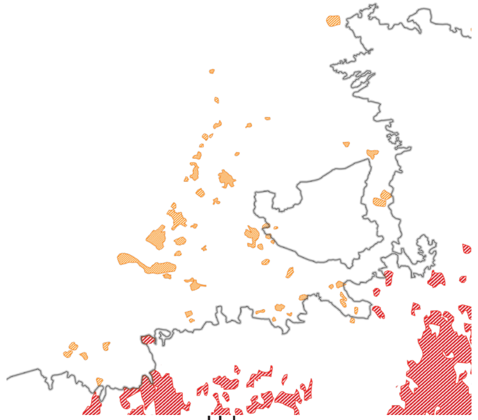


Industry

Industry
The shift towards decentralization allows processing to occur in inland industrial regions, including areas along small rivers, effectively integrating it back into the urban fabric. Processing facilities are located in high and dry areas along inland rivers, just outside of city limits. Manufacturing occurs within city limits, specifically in mixed-use transition zones, along the hydrogen network. Production and assembly of final products happen in the region. This does not require an expansion of industrial areas; rather, it focuses on making existing spaces more efficient and denser.

Logistics
Large warehouses are needed for temporary storage of final products, and find their place close to production areas. Since most final products are imported but the demand is lower space needed in container ports remains the same.

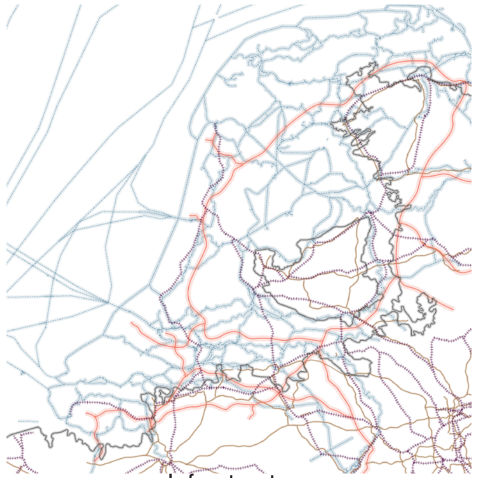
Circular activities
With reduced material consumption, the necessity for designated circular hubs diminishes, leading to the integration of circular functions within the city structure.



Urban

EOL collection, for small electronics, happens in stores or shops. For large electronics, there are collection points in transition zones (living + industry). Car collection and dismantling happen on the outskirts of the city.
Small thrift and repair stores are common in the city centers. For the repair of electronics, there are service stations in mixed-use areas (living + commercial). For the repair of cars, there are service stations in transition zones. For major repairs, sorting, storage of parts, and repair of large electronics, there are repair locations in transition zones.
Magnet recycling happens along with processing facilities.
Sharing hubs for mobility and other facilities has become very common.

Urban
The former dominance of certain regions over others was reduced as they were vulnerable to rising water levels, reflecting a withdrawal from mechanization. Development shifts focus to high and dry areas, aiming to lessen human control on nature. The concept of specialized zones for living, production, and work dissolves, giving way to integrated, mixed-use spaces. People adopt a lifestyle where they work



Infrastructure

close to or at their places of residence, fostering a closer connection between living and working spaces.

Mobility
Environmental quality takes precedence over travel time and driving speed, leading to a national public transport system complemented by a stronger emphasis on active transportation modes over cars. National road and rail infrastructures are maintained at the minimum capacity necessary to meet demand, while local investment prioritizes trams and light rail systems to enhance urban mobility. Additionally, shipping practices shift towards utilizing smaller vessels, aligning with a sustainable and environmentally conscious approach to transport.

Energy
Since material consumption reduces and the entire supply chain is not within the Netherlands, the energy demand also reduces. The number of wind farms in the North Sea is kept to a minimum. Neighborhoods generate their own renewable energy. This also significantly reduces dependency on large-scale power plants. In case the energy produced is not sufficient, it can be imported from other countries.

Nature

Nature
The Nature Network in the Netherlands has seen significant expansion to harmonize with natural processes rather than seeking to dominate them. Infrastructure such as dikes remains unaltered, allowing nature to reclaim land as it sees fit, with seasonal flooding along the Rhine and in regions like Zeeland becoming common. There are new swamps in the Groene Hart, which double as vital water reservoirs.

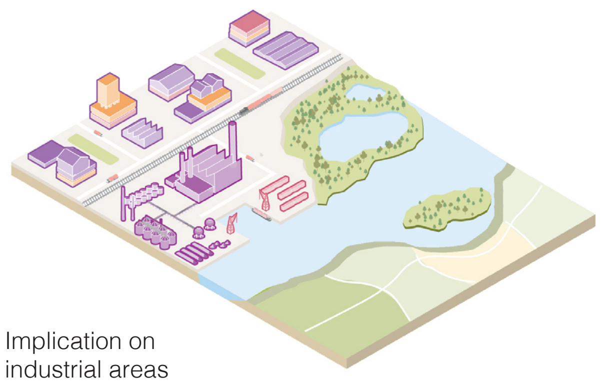
Agriculture is reimagined to prioritize local food production. Urban planning seamlessly integrates green and blue spaces within cities, enhancing biodiversity and recreational opportunities within the cityscape. Forested areas have expanded, contributing to carbon sequestration, and providing vital habitats for wildlife.

The coastline has evolved into a wide, permeable edge with natural landscapes, facilitating a dynamic interaction between land and sea. Riverbanks have been restored to their natural states, re-establishing open connections with the sea, while peatlands transition into pond marshes, enriching the ecosystem's diversity.

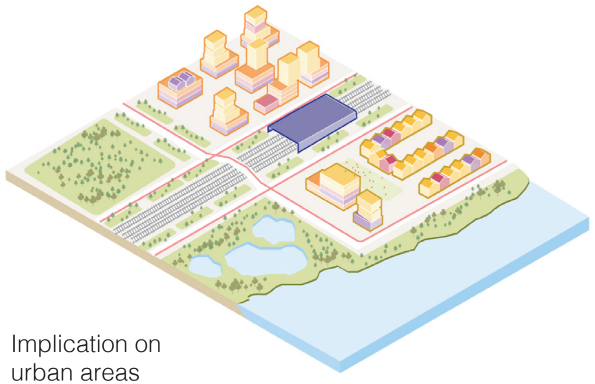
Map of the Netherlands 2050

This map illustrates the implication in the Netherlands if this scenario is realized.

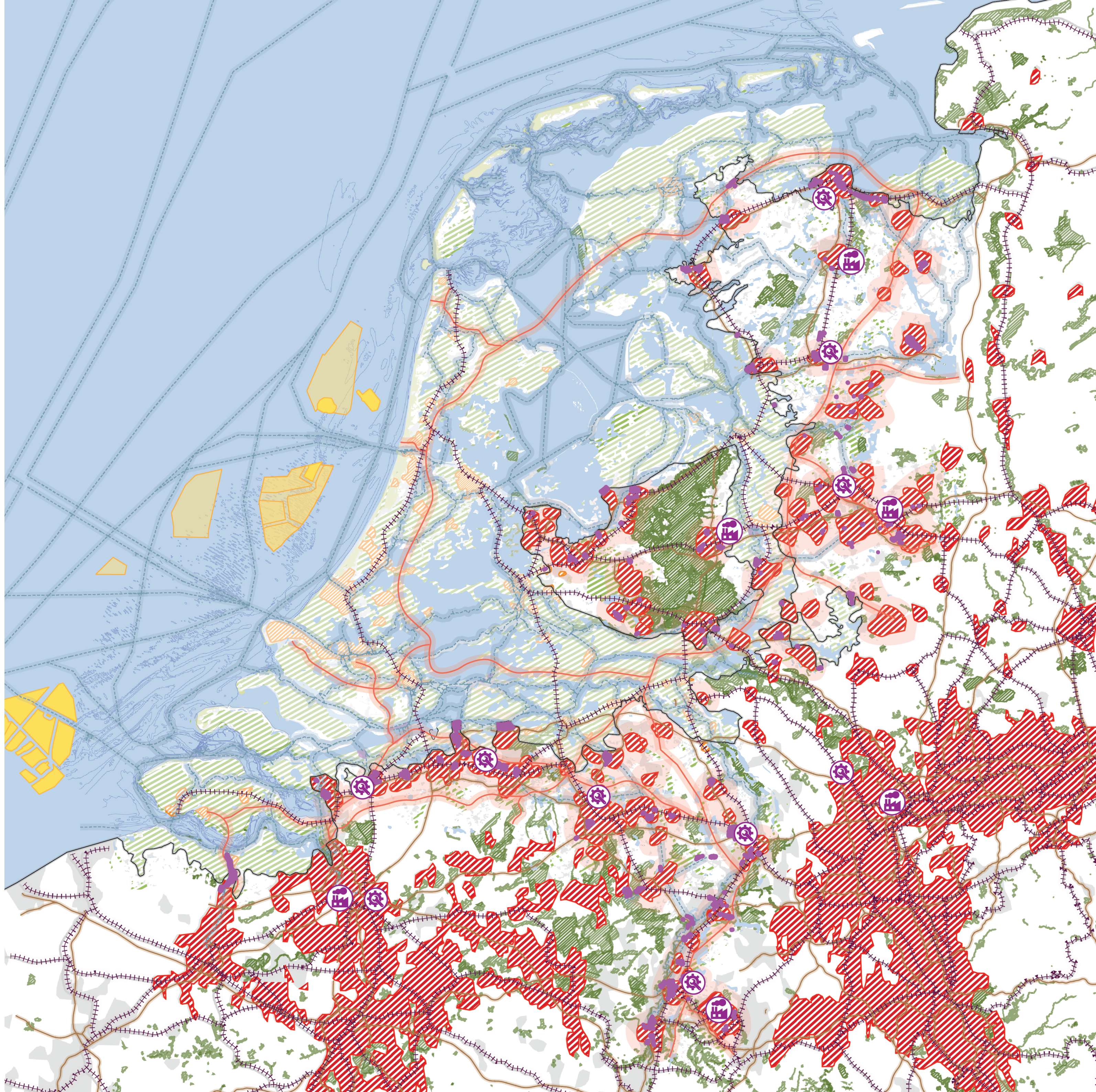
Indusrtrial areas
Urban areas (grow)
Urban areas (do not grow)
Natura 2000
Railway
Highway
Waterway
Hydrogen network
Processing locations
Manufacturing locations
Areas for seasonal agriculture (prone to flooding)

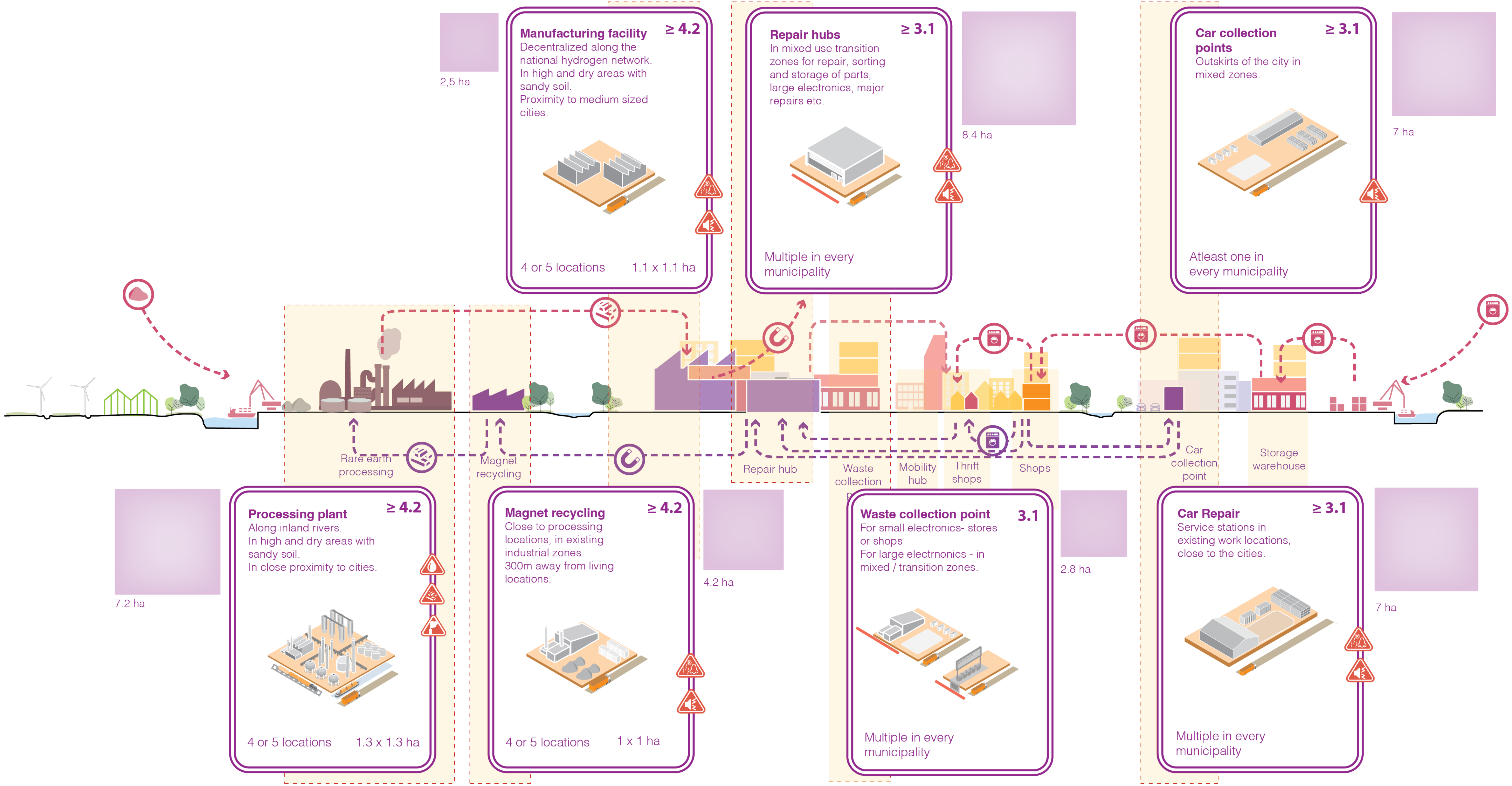


Implication on industrial areas



Implication on urban areas




2,5 ha
Manufacturing facility
≥ 4.2
Decentralized along the national hydrogen network.
In high and dry areas with sandy soil.
Proximity to medium sized cities.
4 or 5 locations
1.1 x 1.1 ha
Repair hubs
≥ 3.1
In mixed use transition zones for repair, sorting and storage of parts, large electronics, major repairs etc.
Multiple in every municipality
8.4 ha
Car collection points
≥ 3.1
Outskirts of the city in mixed zones.
Atleast one in every municipality
7 ha
Rare earth processing
Magnet recycling
Repair hub
Waste collection
Mobility hub
Thrift shops
Shops
Car collection point
Storage warehouse
7.2 ha
Processing plant
≥ 4.2
Along inland rivers.
In high and dry areas with sandy soil.
In close proximity to cities.
4 or 5 locations
1.3 x 1.3 ha
Magnet recycling
≥ 4.2
Close to processing locations, in existing industrial zones.
300m away from living locations.
4 or 5 locations
1 x 1 ha
4.2 ha
Waste collection point
3.1
For small electronics- stores or shops
For large electrnonics - in mixed / transition zones.
Multiple in every municipality
2.8 ha
Car Repair
≥ 3.1
Service stations in existing work locations, close to the cities.
Multiple in every municipality
7 ha

5) Scenario transfer

This phase involved a description of the further application and/or processing of scenarios which have been generated.
In this next section the scenarios are compared based on spatial condition and claims. Then they are evaluated based on 5 main aspects.

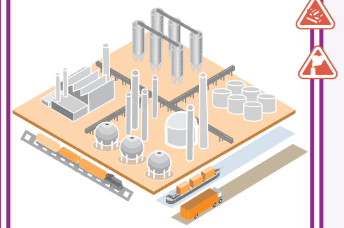
Scenario comparison
(for detailed calculations and suitability analysis view appendix)

Processing

Spatial conditions
& spatial claims
(for detailed calculations
see appendix)

Industrial Leaders

Processing plant 6
Concentrated in high
enviromnmental category zones
in the port
1.5 km away for living locations.

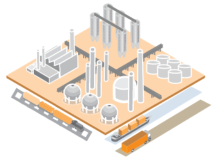


1 large location 5.5 x 5.5 ha

30 ha

Self Sufficient

Processing plant ≥ 4.2
Decentralized along smaller
inland rivers.
300m away from living
locations.
Around medium sized cities.

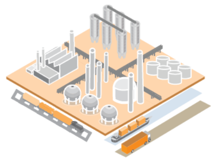


4 or 5 locations 2 x 2 ha

18 ha

Regenerative

Processing plant ≥ 4.2
Along inland rivers.
In high and dry areas with
sandy soil.
In close proximity to cities.



4 or 5 locations 1.3 x 1.3 ha

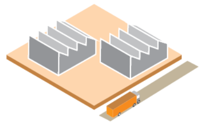
7.2 ha

Manufacturing

Spatial conditions
& spatial claims

Industrial Leaders

Manufacturing facility ≥ 4.2
Mainly in and around Eindhoven
or along the Delta corridor.
200m away from living
locations.
In existing industrial zones

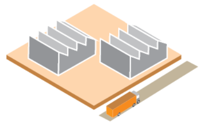


2 or 3 locations 2 x 2 ha

10 ha

Self Sufficient

Manufacturing facility ≥ 4.2
Decentralized along the national
hydrogen network.
In existing work locations.
Proximity to medium sized
cities.

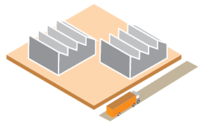


4 or 5 locations 1.1 x 1.1 ha

6.2 ha

Regenerative

Manufacturing facility ≥ 4.2
Decentralized along the
national hydrogen network.
In high and dry areas with
sandy soil.
Proximity to medium sized
cities.



4 or 5 locations 1.1 x 1.1 ha

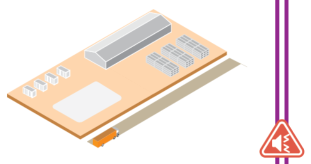
2,5 ha

Scenario 1 Knowledge Economy is
not inculded because it does not
have any processing capacity

Circular Activities

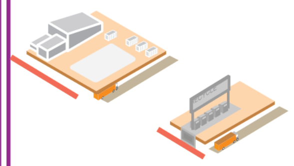
The spatial conditions remain the same across all scenarios, with only the concentration increasing in areas that are projected to grow in the future.

Car collection ≥ 3.1
Outskirts of the city in existing work locations.



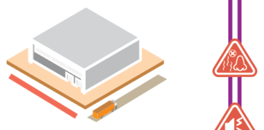
Atleast one in every municipality

Waste collection 3.1
For small electronics- stores or shops
For large electronics - outskirts of the city in existing work locations.



Multiple in every municipality

Repair Hubs 3.1
In bedrijventerrainen for collection, sorting,storing parts, large electronics, major repairs etc.

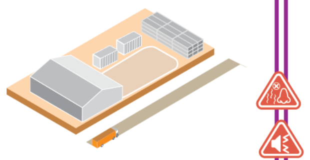
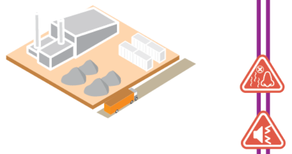


Multiple in every municipality

	Knowledge Economy	Industrial Leaders	Self Sufficient	Regenerative
Car collection	13 ha	13 ha	7 ha	7 ha
Waste collection	4 ha	4 ha	2.8 ha	2.8 ha
Repair Hubs	12 ha	4.8 ha	8.4 ha	8.4 ha

Circular Activities

The spatial conditions remain the same across all scenarios, with only the concentration increasing in areas that are projected to grow in the future.

	Knowledge Economy	Industrial Leaders	Self Sufficient	Regenerative
Car Repair ≥ 3.1 Service stations in existing work locations, close to the cities.  Multiple in every municipality	21 ha	5.2 ha	7 ha	7 ha
Magnet recycling ≥ 4.2 Close to processing locations, in existing industrial zones. 300m away from living locations.  4 or 5 locations 1 x 1 ha	Not in the Netherlands (World)	8.2 ha	4.2 ha	4.2 ha

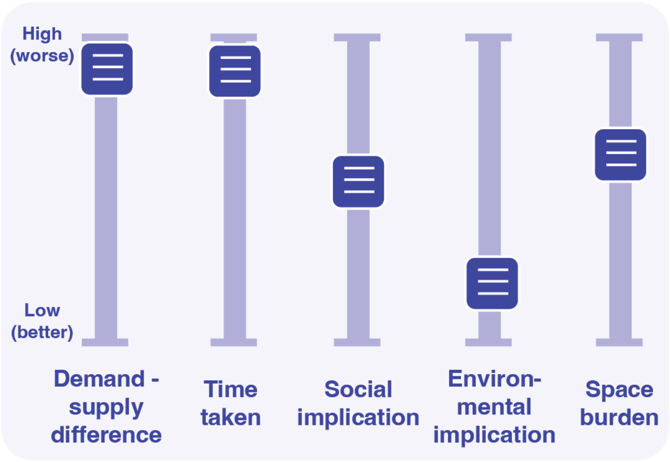
Other Activities

	Knowledge Economy	Industrial Leaders	Self Sufficient	Regenerative
Motor/ Generator Production **Product Assembly Locations**	Not in the Netherlands (World)	Not in the Netherlands (Europe)	Along the Hydrogen network. In existing bedrijventerrainen. Proximity to medium sized cities.	Outside the Netherlands. In the region (Germany or Belgium)
Distribution Locations	Import of final product Smaller container ports along the logistical corridor XXL warehouse Along the logistical corridor, in existing work locations category 2/3 Shops / Stores City centers, XXL stores outside of cities.	Import of final product Smaller container ports along the logistical corridor XXL warehouse Along the logistical corridor, in existing work locations category 2/3 Shops / Stores City centers, XXL stores outside of cities.	Storage warehouse In transition zones at the edge of cities. Shops / Stores City centers, stores in mixed areas.	Import of final product Smaller port areas in high and dry locations. Shops / Stores City centers, stores in mixed areas.

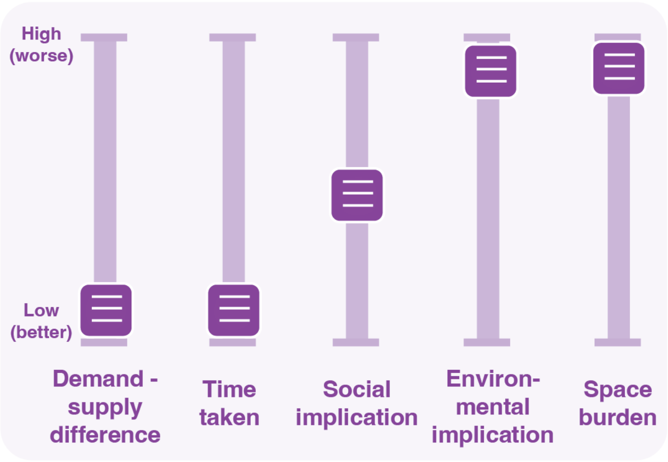
Scenario Conclusions

	Knowledge Economy	Industrial Leaders	Self - Sufficient	Regenerative
Space needed for circular activities (logistic hubs, storage locations etc.)	Space is needed for circular hubs for collection, sorting and storage large logistic hubs for temporary storage of imports/ exports	A lot more space is needed for circular hubs for sollection, sorting and storage large logistic hubs for temporary storage of imports/ exports	Some space is needed for circular hubs for collection, sorting and storage	Dedicated space is not needed for circular hubs.
Space needed for industrial activities (processing and manufacturing)	Since processing and manufacturing does not increase more space is not needed. Space is needed only for the expansion of transportation networks.	A lot more space is needed for processing and manufacturing. Space is also needed only for the expansion of transportation networks.	Space is needed for processing and manufac-turing but less due to less consumption.	Space is needed for processing and manufac-turing but less due to less consumption.
Amount of primary resource consump-tion (exploitation of natural resources, promotes extraction)	As there no reduction in material use, primary resources are still needed.	As there no reduction in material use, primary resources are still needed.	As there reduction in material use, less primary resources are needed.	As there reduction in material use, less primary resources are needed.
Extent to meet deadlines (CRMA, Paris agreement)	Deadlines are difficult to meet due to geopolitical uncertainities	Deadlines might be met.	Deadlines might not be met since a lot of infrastructure that needs to be developed	Deadlines might not be met since societal changes require a longer time span.
Resilient supply chain (people have reliable access to resources)	Supply chain is not resilient due to geopolitical uncertainities	Supply chain is resilient, because processing is done in the Netherlands	Supply chain is resilient, because it is self sufficient.	Supply chain is somewhat resilient, because only 40% processing happens in the Netherlands
Ecological impact in NL (air, water, soil contamination)	High due to mechanical control on natural areas and increased consumption	Very high due to heavy industrial activities and increased consumption	Low due to small scale processing combined with less material consumption	Low due to small scale processing combined with less material consumption
Nuisance in NL (air quality, odour, sound pollution)	Only because of increased transportation capacity	In locations close to industrial areas	Due to closeproximity to industrial locations, nuisancne can be high.	Due to closeproximity to industrial locations, nuisancne can be high.
Risk to human health in NL (extended exposure to emissions)	Only because of increased transportation capacity	Very high risk in locations close to industrial areas	Some risk due to close proximity to industrial locations	Some risk due to close proximity to industrial locations

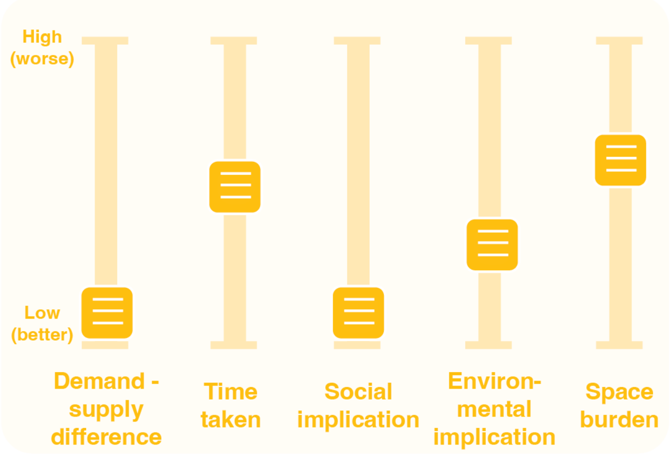
Negative Neutral Positive



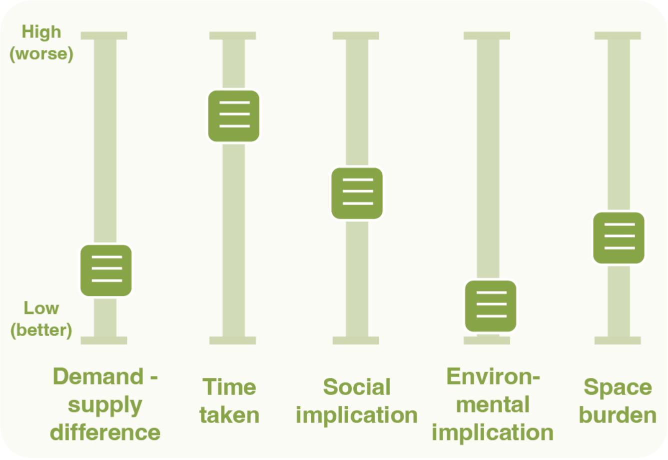
Knowledge Economy



Industrial Leaders



Self Sufficient



Regenerative

Evaluation Results

The figures provide a comparative analysis of various scenarios, focusing on several key aspects. The criteria of supply-demand balance and time taken were selected because they are fundamental to the CRMA. Additionally, social and environmental implications, as well as space burden criteria were chosen because they highlight the primary gaps identified in this research.

The first scenario performs worst in the supply-demand ratio, suggesting that not developing processing capacities could lead to major challenges in the near future like fluctuations in product prices due to geopolitical instabilities. However, even with no processing, the space burden would be comparable to other scenarios because the space necessary for circular activities is a lot more than that for processing.

The second scenario performs best at meeting the supply-demand difference and the transition might happen within the 2030 deadline. However, this scenario fails to perform in terms of environmental sustainability. This concludes that even though we meet the deadlines, this scenario would result in spatial and economic lock-ins within areas unsuitable for development, thereby posing severe environmental challenges in the future.

The third scenario performs best in terms of social sustainability because growth is much more distributed, investment is not directed towards just one part of the country, and social well-being is a priority. While this scenario would be able to meet the supply-demand difference, this transition would take a long time because it requires a large infrastructural change and cooperation between different provinces. So, in this case the time taken to meet the 2030 deadline would be extended.

The fourth scenario reduces the supply-demand difference to some extent while performing best in terms of environmental sustainability. However, the time required could also be longer as it will require a huge mindset shift to realize this scenario.

Envisioning the Netherlands 2050

In this chapter, the future vision of the Netherlands with a resilient supply chain of Neodymium magnets for 2050 is formulated. The process begins by identifying conflicts and synergies within the four potential scenarios, to pinpoint the most advantageous outcomes. Subsequently, we outline key strategies essential for shaping a coherent national vision and explain it further through exemplary projects.

The Paradox

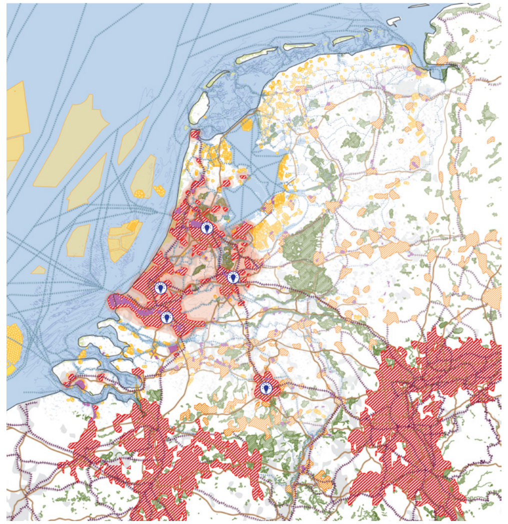
The scenarios described in the last chapter illustrate extreme futures based on specific conditions and values. However, as noted in the evaluation, none of the scenarios completely achieves all the desired outcomes.

The Critical Raw Materials Act (CRMA) provides a strategic direction for developing future processing capacities. Failing to meet its deadlines would result in multifaceted challenges. The European Union might struggle to secure access to renewable technology that could either delay the transition to renewable energy and extend reliance on fossil fuels or force the EU to purchase these technologies from other countries at unreasonable prices, thereby impacting economic stability.

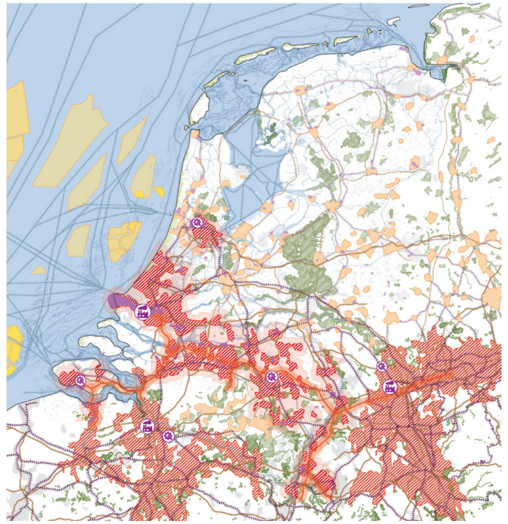
The scenarios highlight a paradox between two choices:

1. Meeting the deadlines by rapidly building capacity to transition from fossil fuels to renewable energy, potentially leading to future crises due to economic and spatial lock-ins in locations unsuitable for building.

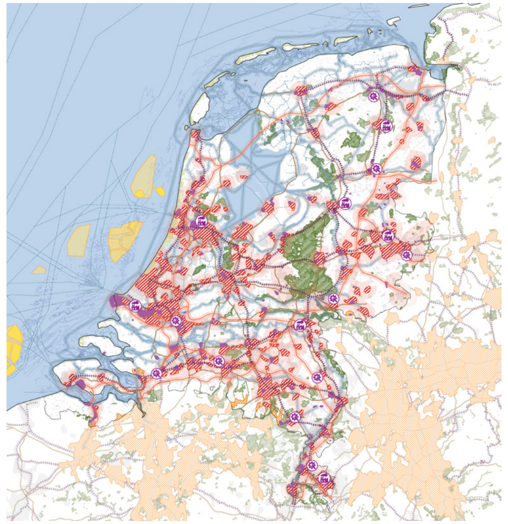
2. Delay meeting the deadlines, risking prolonged dependence on fossil fuels and economic instability, while planning with a long-term vision to build sustainable capacity.



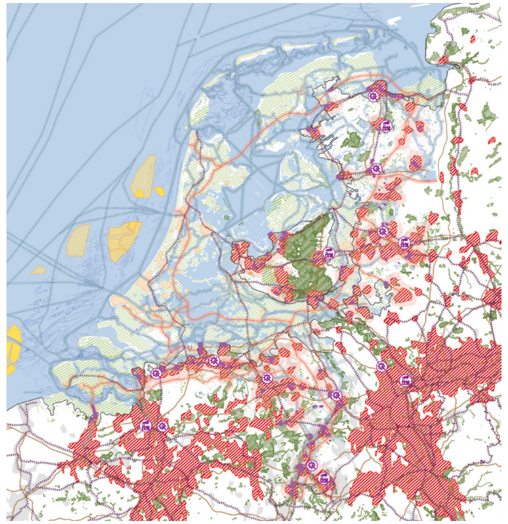
Knowledge Economy
+ Building knowledge hotspots
- Economic risks



Industry Leaders
+ Supply meets demand within set timeframe
- High social and environmental risks



Self Sufficient
+ Decentralization of industrial activities
- Time delay due to large infrastructural changes



Regenerative
+ Soil and water form the basis of development
- Time delay due to mindset shifts

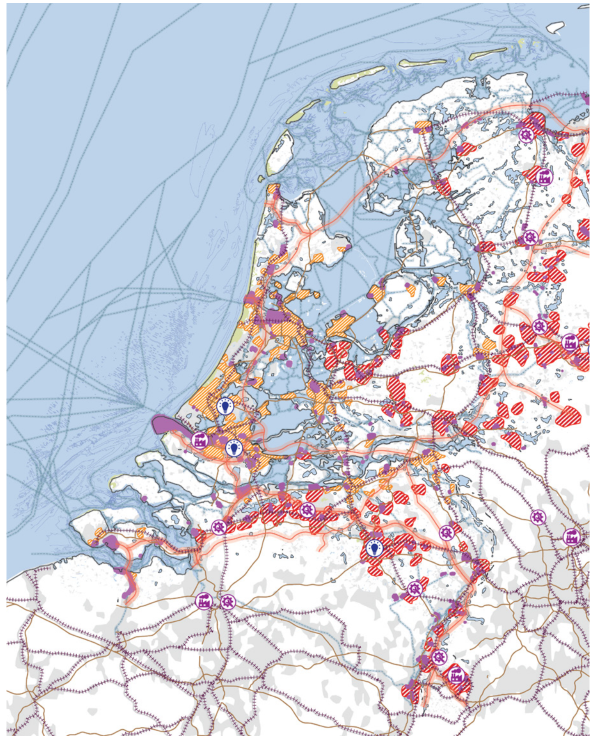
Phasing

This thesis proposes a balanced approach: developing baseline capacity now to gain leverage and time for thoughtful long-term planning. This strategy represents a trade-off between the urgent need to transition and the importance of a long-term sustainable future. The following sections will elaborate on this approach.

Urban areas (grow)
Urban areas (do not grow)
Natura 2000
Railway
Highway
Waterway
Hydrogen network
Processing locations
Manufacturing locations

Until 2030,

- The vision outlined for 2030 includes establishing a facility in Rotterdam capable of processing Rare Earth materials. The existing infrastructure at the Port of Rotterdam facilitates a more rapid and streamlined realization of this facility.
- Simultaneously, sites in other locations will be identified for future facilities, although these new facilities will not need to be operational by 2030.
- Alongside these efforts, circular activities will be established to gather secondary materials from items reaching the end of their lifecycle. Given the current densification around the Randstad, these activities will be more concentrated in this region.
- The development of inland hydrogen infrastructure will commence, supporting the transition of inland industries.
- Knowledge centers will also be established to enhance understanding of processes, materials, and supply chains, for improving efficiency and fostering innovation.



After 2030,

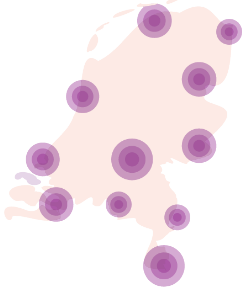
- After 2030, other processing facilities will commence operations, utilizing local end-of-life materials. Industrial activities will become more decentralized as the hydrogen network is completed.
- To support material reduction, various other urban measures will be implemented. Private vehicles will be decommissioned, and active mobility routes will be enhanced. Public transport will expand its capacity, while shared mobility hubs and other shared facilities will be established.
- Future growth will be concentrated in areas suitable for long-term development, with circular activities also focused on these locations.
- Additionally, infrastructural connections with Germany and Belgium will be strengthened to support this regional approach.

Industry & Infrastructure

National strartegy: Decentralisation of industrial activities along inland rivers and hydrogen network. Prefered location of new facilities to be in high and dry areas.
Both national and international infrastructure are strengthened. Prefered mode of transport for long distance travel is through trains or water.

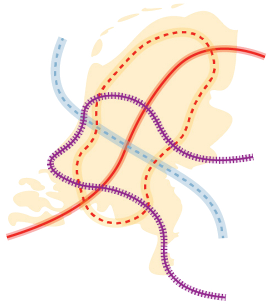
City-scale strartegy: Close proximity of heavy industrial activities to medium sized cities to reduce travel distnces and promote active mobility. New industries also act as a catalyst for densification or a means for solving local problems. Light industrial activities can happen in mixed areas along with commercial and residential locations.

Key strartegies



Building decentralized industrial clusters.

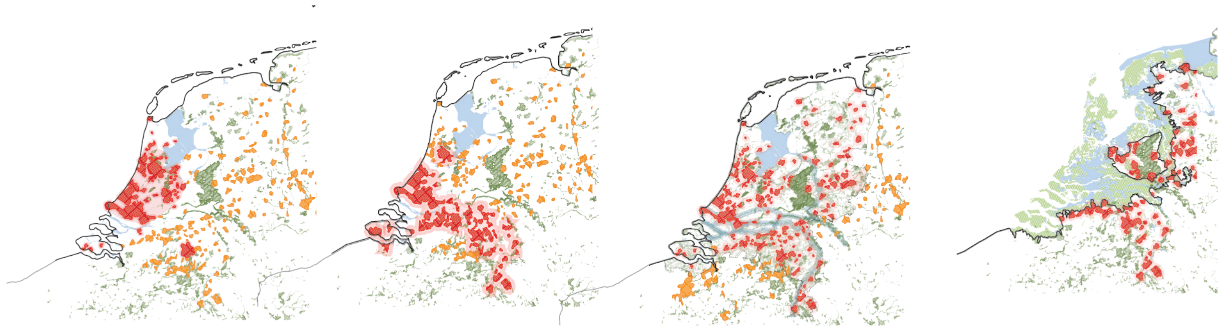
Facilitating research and development hotspots



Adapting existing infrastructure for urgent action

Using the transition for local revitalisation

Urbanization and Nature



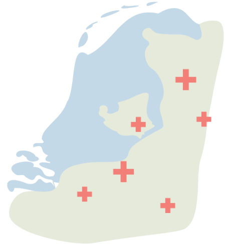
National stratergy: Soil and water conditions form the basis for future urban growth. Growth only happens in locations with are suitable to build(Deltares, 2021).

In areas unsuitable for building, there is no mechanisation involved to protect them. These areas are designated to naturally evolve into wetlands, allowing nature to reclaim them without human interference.

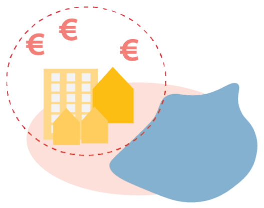
In locations which have less suitablity for building, urban areas are protected and other areas are used for seasonal flood management and agriculture. Significant investments have already been made in less suitable locations so these areas need to be protected. But there will not be any further growth to safeguard against environmental risks.

City-scale stratergy: The city-scale strategy focuses on optimizing existing urban areas rather than expanding city boundaries. The aim is to promote densification within current urban locations, complemented by a diverse mix of uses.

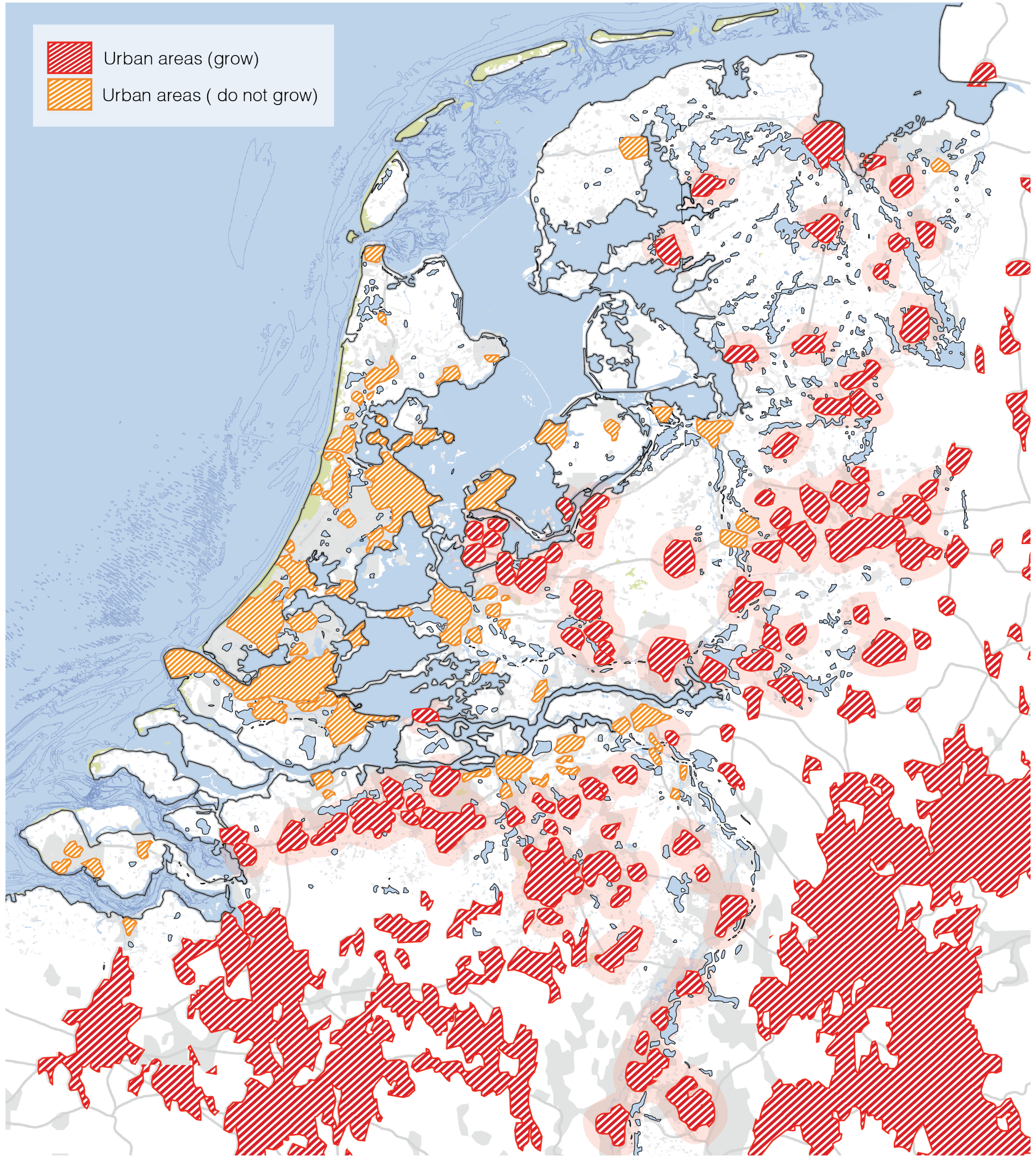
Key stratergies



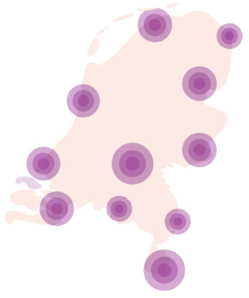
Soil and water conditions form the basis of future growth



Safeguarding locations with invested capital

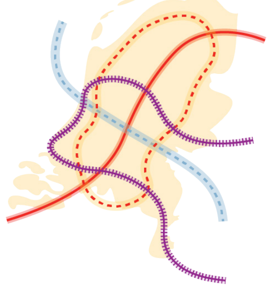


Neodymium Vision 2050



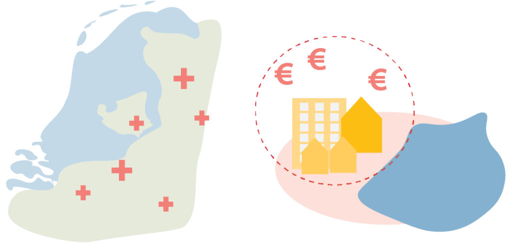
Building decentralized processing clusters

Facilitating research and development hotspots

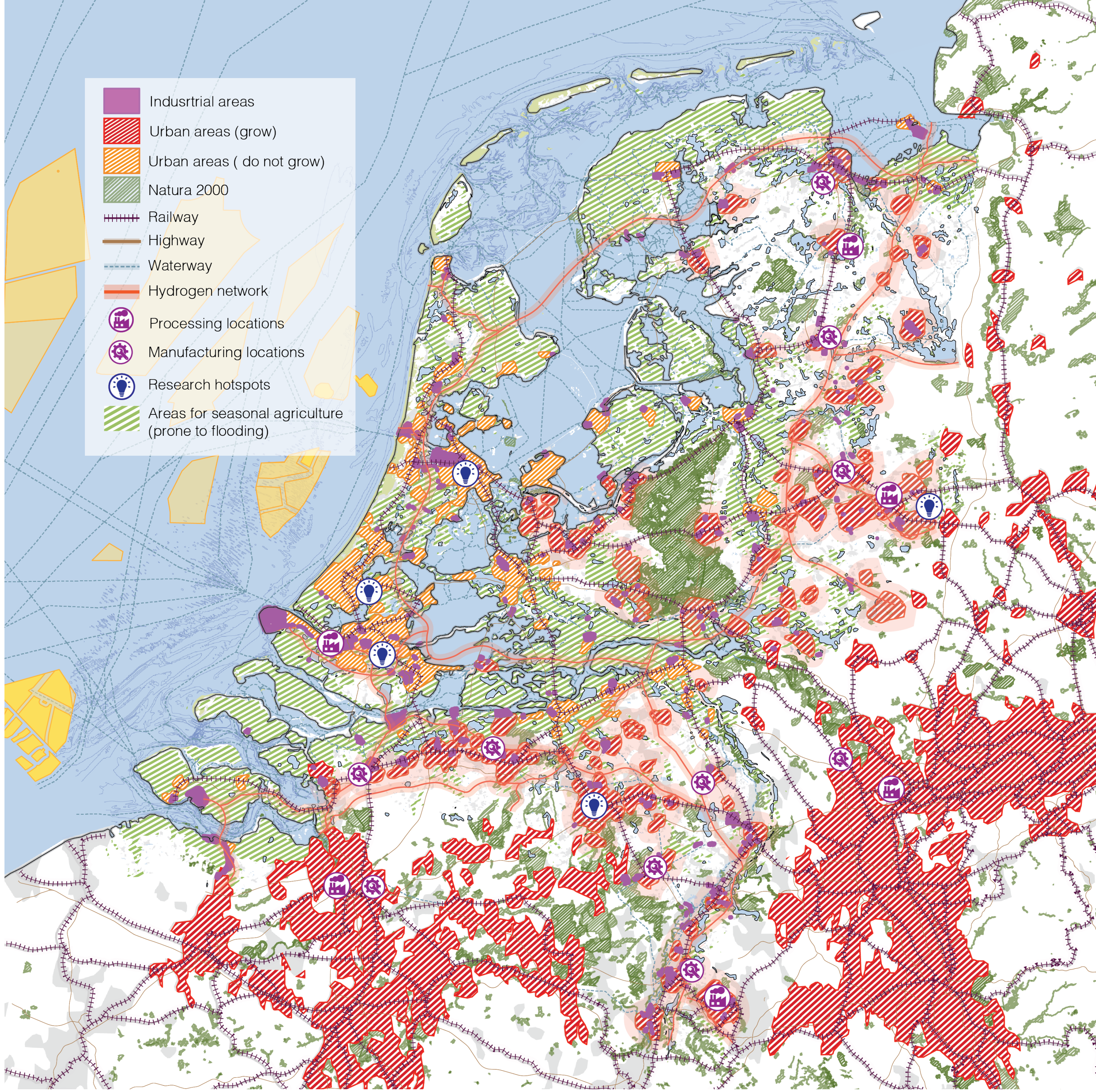


Adapting existing infrastructure for urgent action

Using the transition for local revitalisation



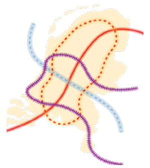
Alleviating areas with water problems.



Strategic projects

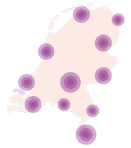
The vision impacts different locations in different ways. Five strategic locations are chosen to illustrate the different implications of the five strategies. Here is a brief description of each location:

1) Rotterdam
The strategy envisions a new processing facility for Rare Earths in Rotterdam. Despite the addition of this facility, there will be no further densification in the area.



Adapting existing infrastructure for urgent action

2) Hengelo
Like Rotterdam, Hengelo is also proposed to have a processing facility. However, unlike Rotterdam, this location is targeted for future densification.



Building decentralized processing clusters

3) Roosendaal
In Roosendaal, the strategy involves incorporating a new manufacturing facility. This zoom-in shows how this facility will be integrated into the existing fabric of the city, potentially addressing current urban challenges.

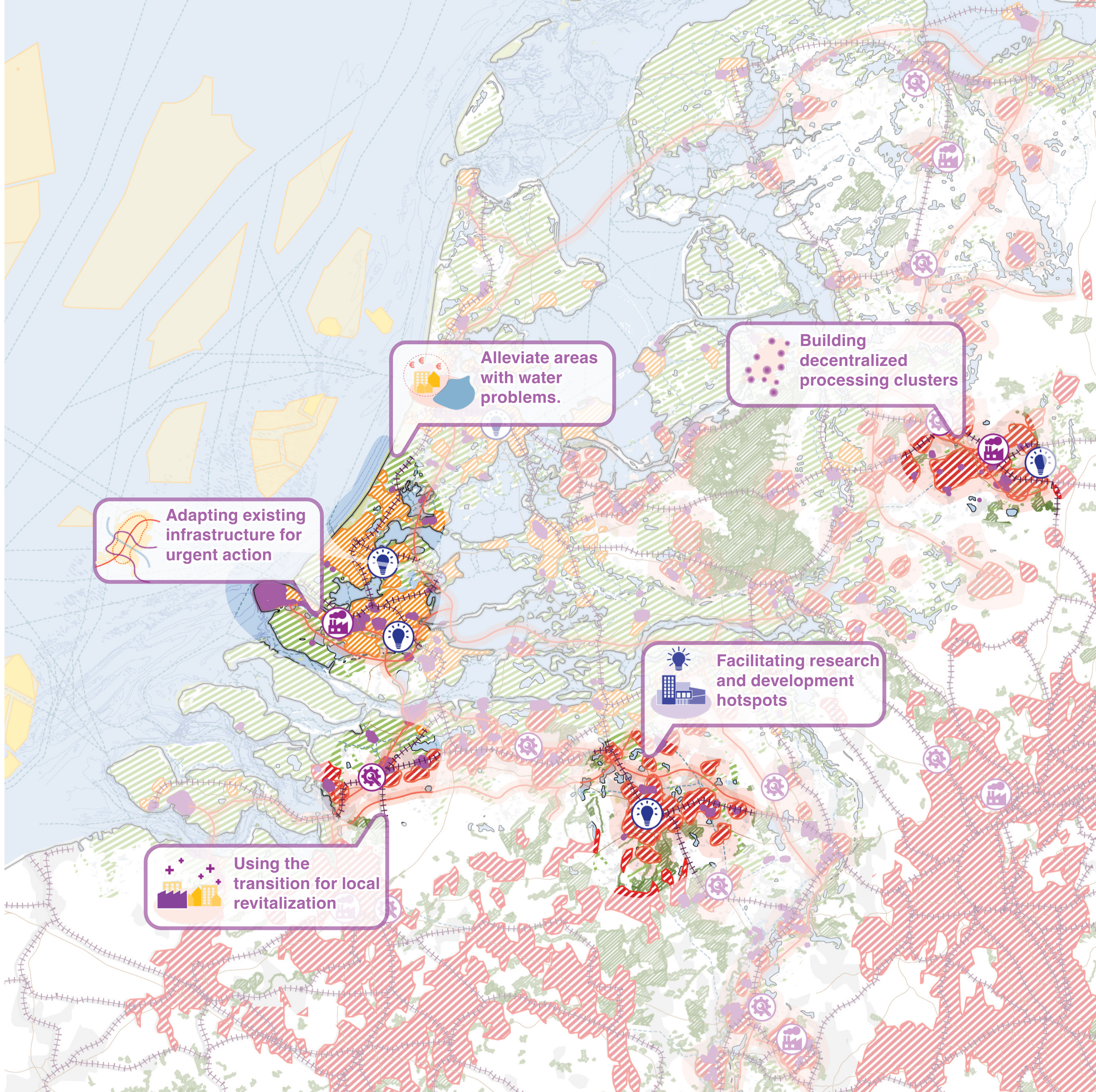
Using the transition for local revitalization

4) Eindhoven
Eindhoven, already known for its knowledge centers and manufacturing industries, is projected to undergo significant transformation into a densely populated urban area. This zoom-in focuses on managing this transition by leveraging its knowledge facilities.

Facilitating research and development hotspots

5) Leiden
For Leiden, the vision involves no additional densification. A significant agricultural part of Leiden would be flooded if this vision is realized. This zoom-in highlights the implication this would have in Leiden.

Alleviate areas with water problems.



Adapting existing infrastructure for urgent action - Rotterdam

In Rotterdam, the strategy envisions a new processing facility for Rare Earth materials. There is an existing facility for processing aluminium - Aluchenie which was decommissioned in 2021. While there are plans for the transformation of this facility, it can be transformed into a facility for processing Rare Earth materials.

The port of Rotterdam, while being an obvious location for building the processing facility, also has its shortcomings. The port faces many shortages in labor. The possible reasons could be unavailability of people and the unattractiveness of the port. While the first problem is beyond the scope of this research the second can be addressed through this strategy. Currently, the port is not an attractive working location due to the pollution and distance from living locations.

There are a lot of oil and petroleum companies in the port which will be decommissioned shortly. Also, as the vision proposed decentralization of industries, the competition for space in the port would also be less and land will be available for other uses.

This available land can be turned into green fields or places for energy production. The Shell facility at Pernis can be turned into an oil industry museum for cultural activities and informing people about their oil past.

In the future, the intensity of activities in the port will reduce, leading to less pollution and noise, thus providing a better quality of life for the residents of Rotterdam.

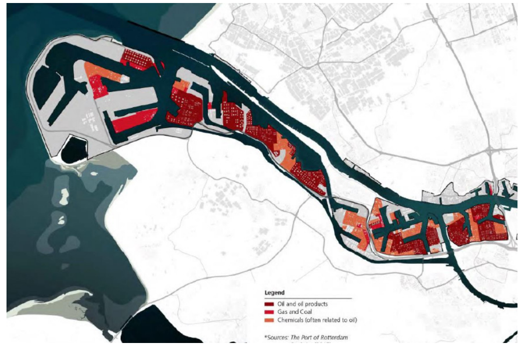
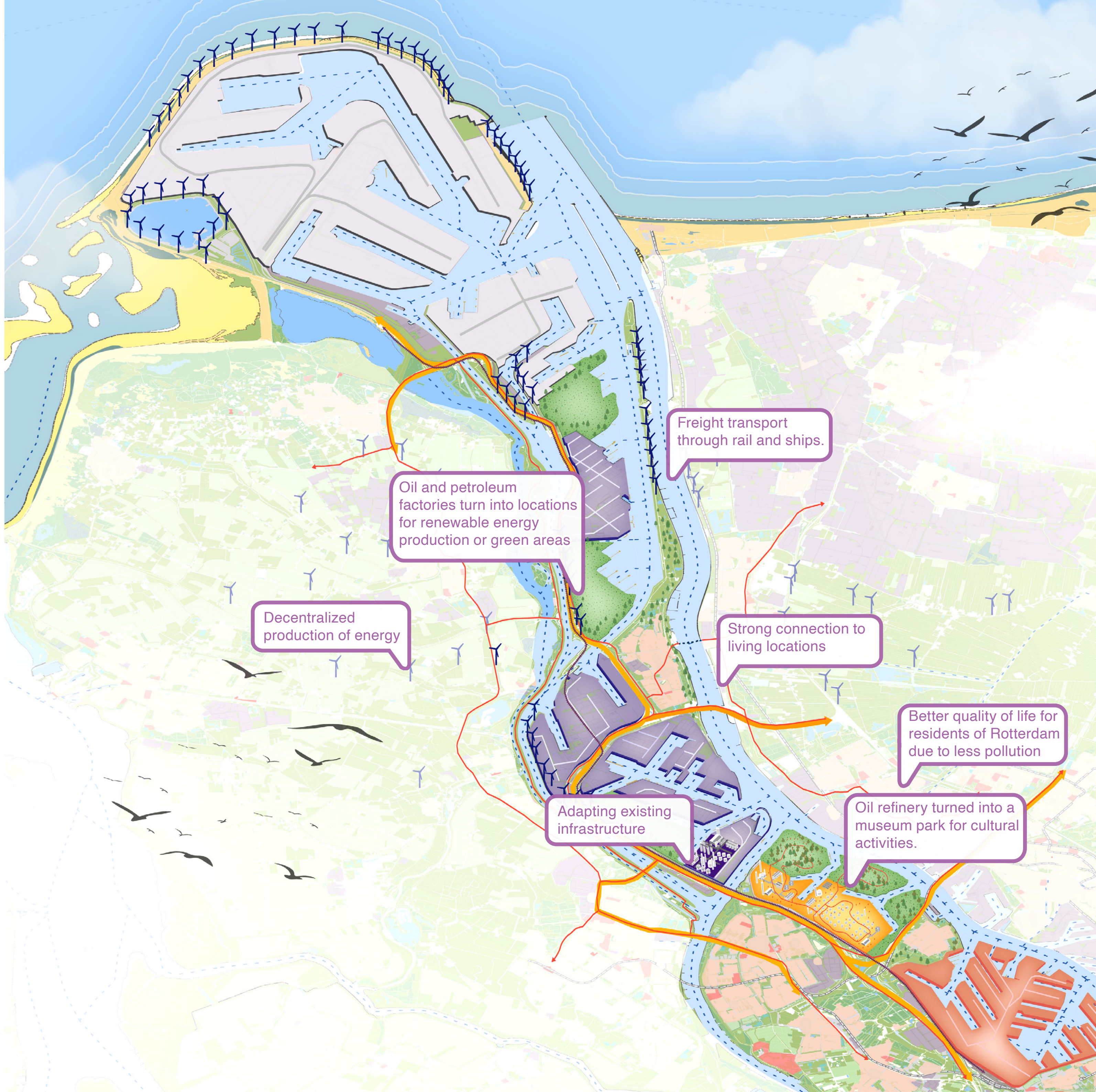
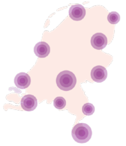


Fig : Oil and petrol products, Port of Rotterdam
Source: Kruipers, challenges for the port of rotterdam

Fig 8.1 : Vision for the Port of Rotterdam 2050

Industries
Energy production areas/ green areas
Oil museum
Mixed use development
Bike network
Road network





Building decentralized processing clusters - Hengelo

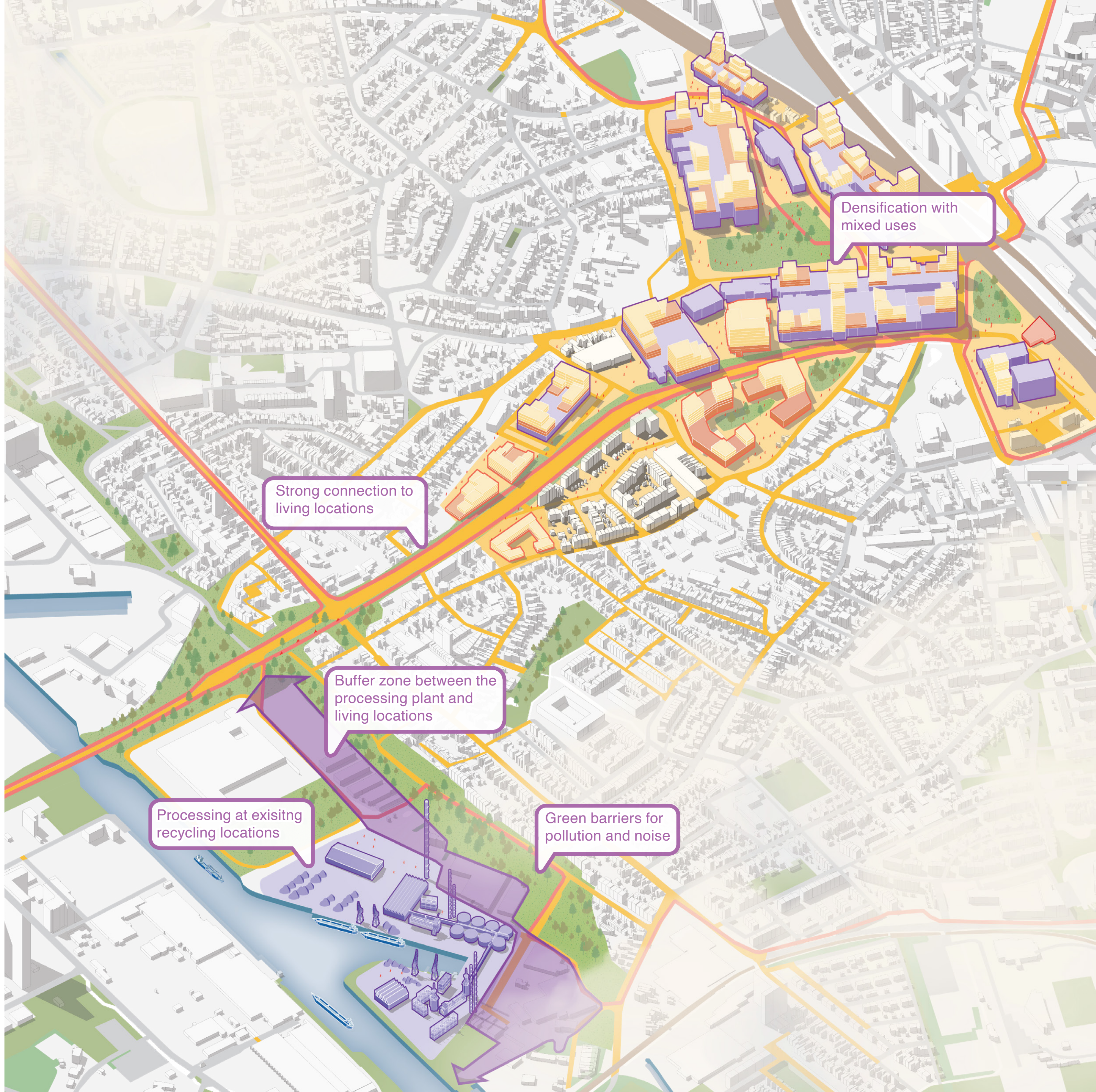
In Hengelo, there is a proposal to establish a new processing facility. This facility is strategically planned to be situated at the city's periphery, an area already hosting various circular activities such as plastic recycling, metal collection points, building material storage, and a metal recycling location. Coincidently, there is a company called Varo, with a liquid terminal adjacent to the metal recycling site. This terminal is slated for decommissioning and can be repurposed into a Rare Earth processing facility.

Locating the processing facility close to the city has several potential benefits. It can stimulate local growth as workers would prefer living near their workplaces. This proximity reduces travel distances, making the facility more accessible and fostering public awareness about the origins of the products they use, potentially leading to reduced material consumption. However, such facilities can also cause disturbances, including noise and air pollution.

To address these issues, the chosen location falls within a designated environmental zone, and various measures are planned to mitigate impacts. These measures include maintaining a certain distance from residential areas and creating a green barrier to buffer the facility. Additionally, there are plans for urban densification in Hengelo. The suitable location for which could be the older industrial zone near the station. This area can be transformed into a mixed-use space, incorporating industrial, residential, commercial, and circular functions.

Fig 8.2 : Vision for Hengelo 2050

Industrial
Residential
Storage/ warehouses
Commercial
Bike network
Road network



Using the transition for local revitalization - Roosendaal

The proposed vision involves establishing a manufacturing facility in Roosendaal, situated in a mixed-use area. Roosendaal is currently identified by the Dutch Ministry of the Interior and Kingdom Relations (BZK) as one of the twenty vulnerable urban areas concerning quality of life and safety. This municipality experiences significant disparities in the quality of life among its residents, leading to social segregation.

The site for the proposed design is planned for residential development. However, a more efficient and impactful use of this space would be to construct a high-density, mixed-use development that integrates residential and industrial functions.

The proposed design aims to address urban challenges by fostering social cohesion and improving the quality of life for all residents. Key elements of the design include:

Residential Diversity:
A variety of housing units catering to different sizes and needs.
Reserved housing for various income groups to ensure inclusivity.

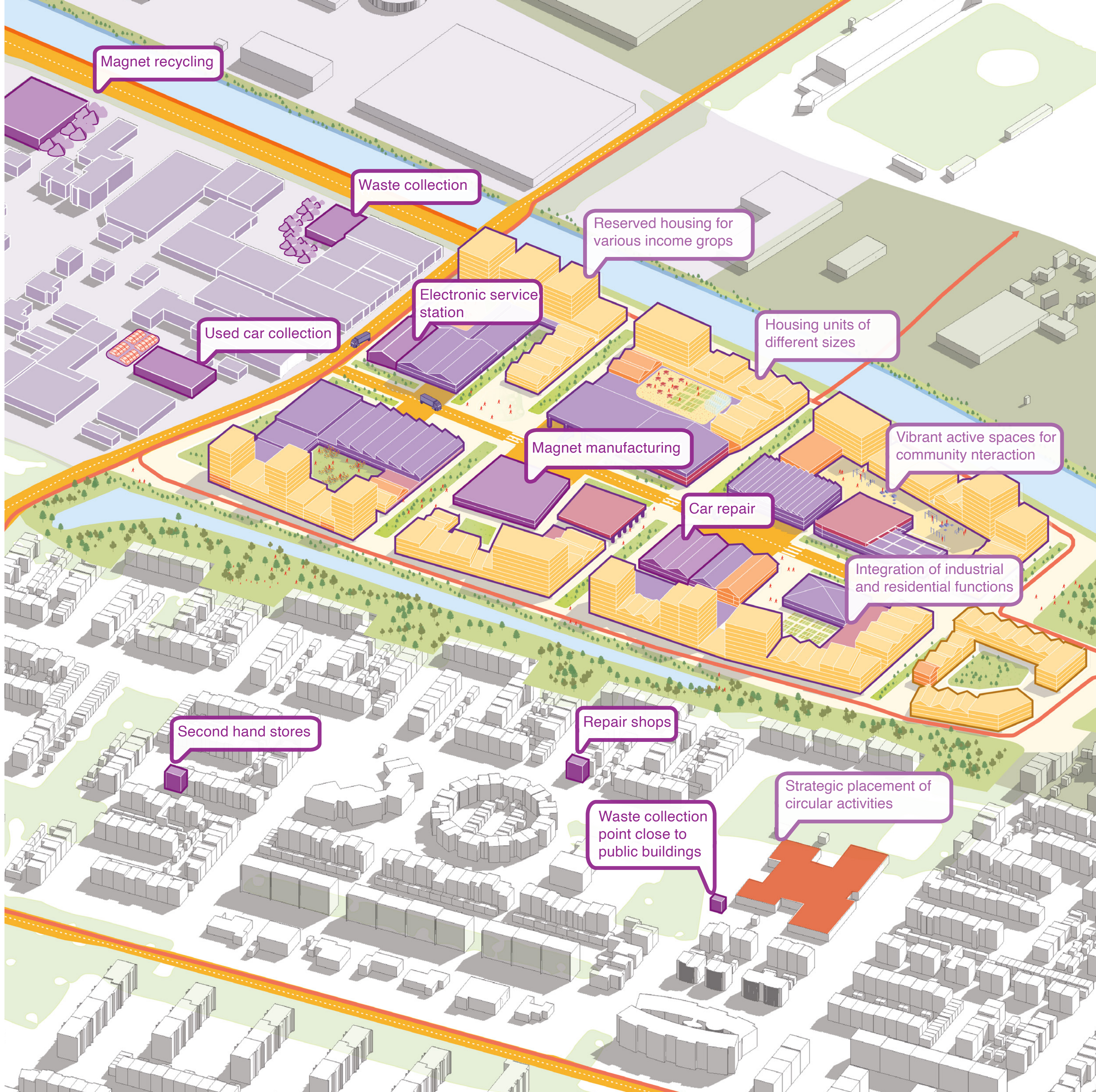
Mixed-Use Development:
Integration of residential and industrial functions within the same area.
Spaces for both, living and working to promote convenience and reduce commuting times.

Active and Common Spaces:
Creation of vibrant, active areas for community interaction.
Common facilities and recreational spaces for people of all ages and income levels to enjoy together.
Strategic placement of circular activities integrated within the fabric, fostering ease of access.

By combining residential, industrial, and communal functions, the design seeks to bridge social divides, enhance quality of life, and create an inclusive and vibrant community.

Fig 8.3 : Vision for Roosendaal 2050

Industrial
Residential
Storage/ warehouses
Public buildings
Bike network
Road network



Facilitating research and development hotspots - Eindhoven

Eindhoven plays a significant role in this vision due to its unique research campuses focusing on high-tech industries and its existing manufacturing companies. It is also home to ASML, the most significant company impacted by Neodymium magnets in the Netherlands. Consequently, these factors position Eindhoven to become a major research hub and a densely populated city.

However, the current locations of these research campuses are suboptimal. Initially planned around the highway at the city's edges, they have lost connectivity to the urban core. Their considerable distance from train stations worsens this issue, as many employees commute from outside Eindhoven, making the campuses predominantly car-oriented with numerous parking structures. Additionally, these campuses lack active public spaces.

The city's future design aims to strengthen the connection between the research-business campuses and the urban surroundings. Future densification efforts in Eindhoven will focus on areas around these campuses, integrating public functions to foster activity and innovation. This approach aims to create better connected, vibrant, and pedestrian-friendly urban research hotspots and living locations.

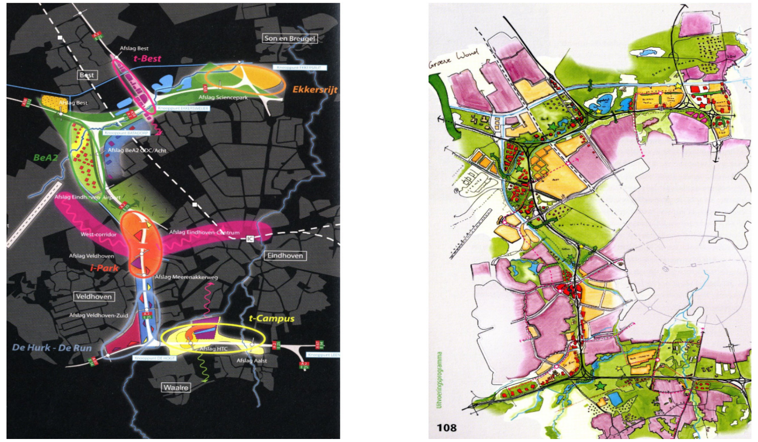


Fig 8.5: A2 Implementation Program
Source: DIO

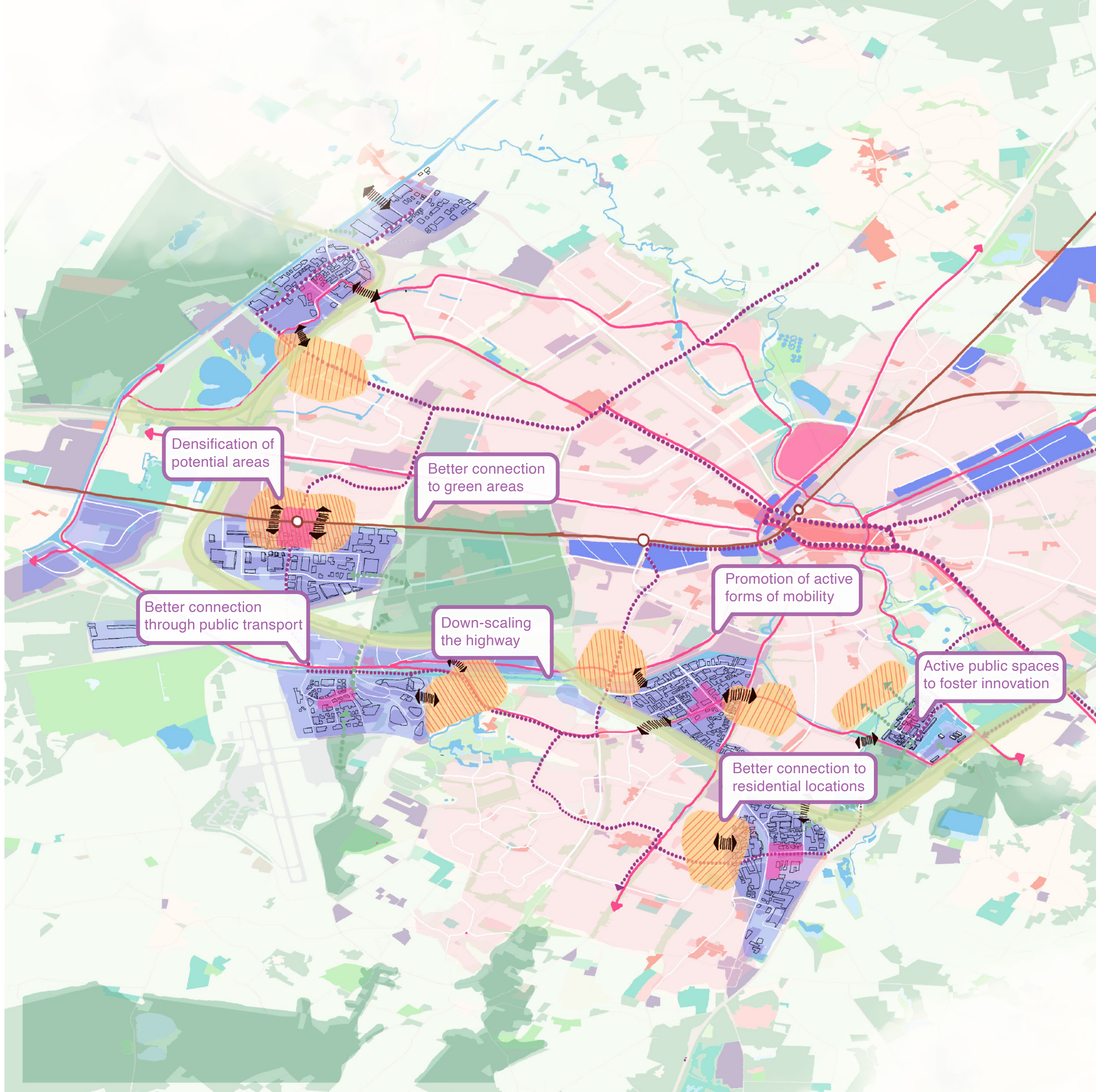


Fig 8.4 : Vision for Eindhoven 2050

Research campuses
Active spaces
Densification
Bike network
Ov network

Alleviate areas with water problems - Leiden

The vision rejects raising dikes higher or mechanically controlling the landscape and instead focuses on preserving only urban centers of significant value in the western part of the Netherlands. This approach will inevitably result in rising water levels in these regions, leading to the flooding of certain areas.

This approach will bring profound impacts, transforming these regions into rich natural habitats. The influx of water will foster the development of diverse ecosystems, creating attractive landscapes rich in biodiversity. These new natural areas will not only enhance the aesthetic appeal of the region but also contribute to environmental sustainability and ecological health.

Moreover, by not promoting further densification in these areas, the vision relieves the longstanding pressures of housing and urban activities. This shift will also reduce the pressure on infrastructure and resources. The resulting open spaces and natural environments will offer opportunities for recreation, conservation, and tourism, significantly enriching the quality of life for residents and visitors.

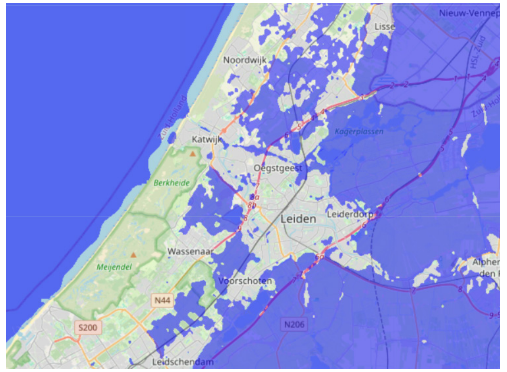


Fig 8.7: Flood risk map
Source: floodmap.net

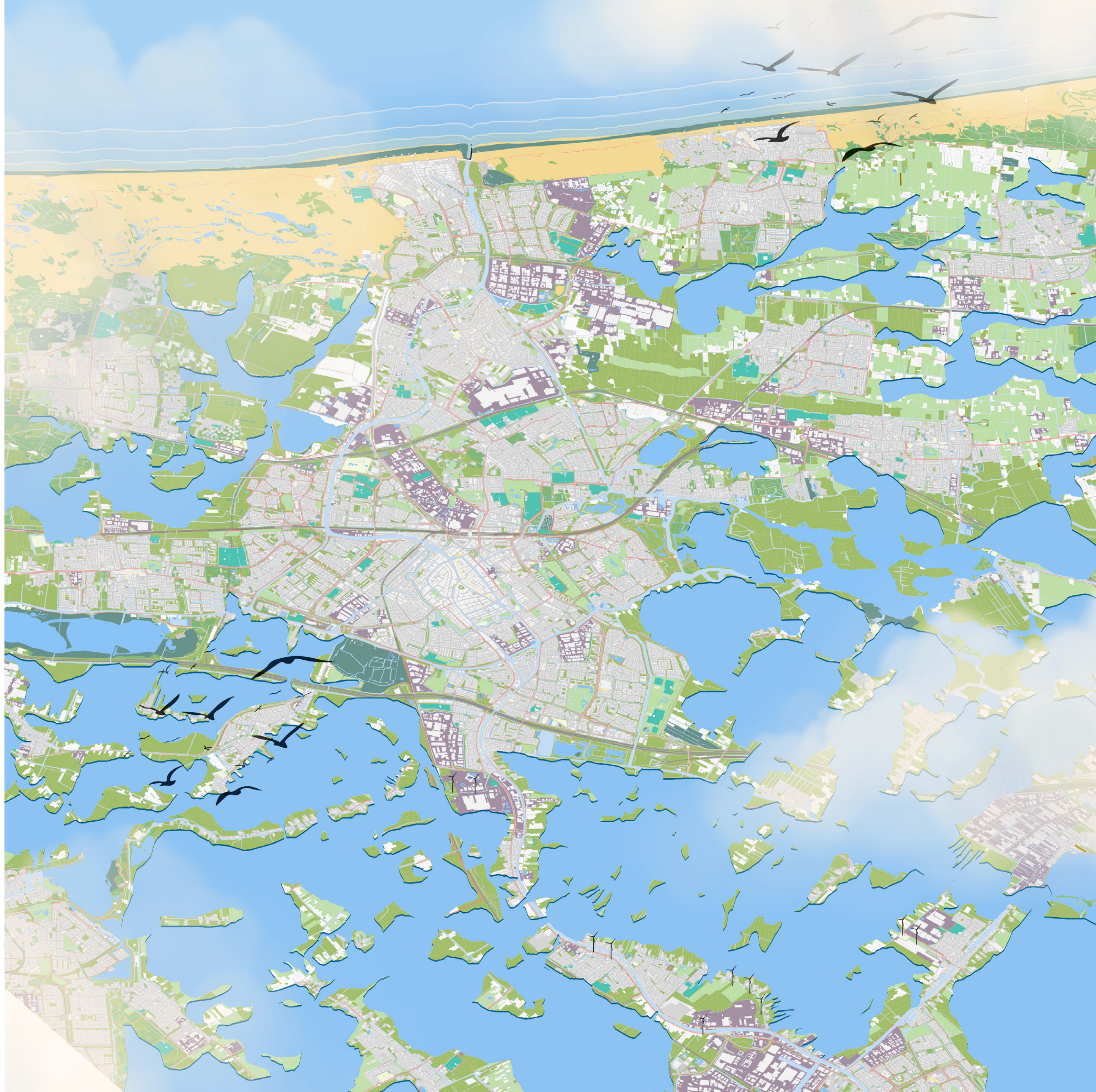


Fig 8.6 : Vision for Leiden 2050

Conclusions

In this chapter, the results, conclusions, reflections, and limitations of this research are presented

Overview

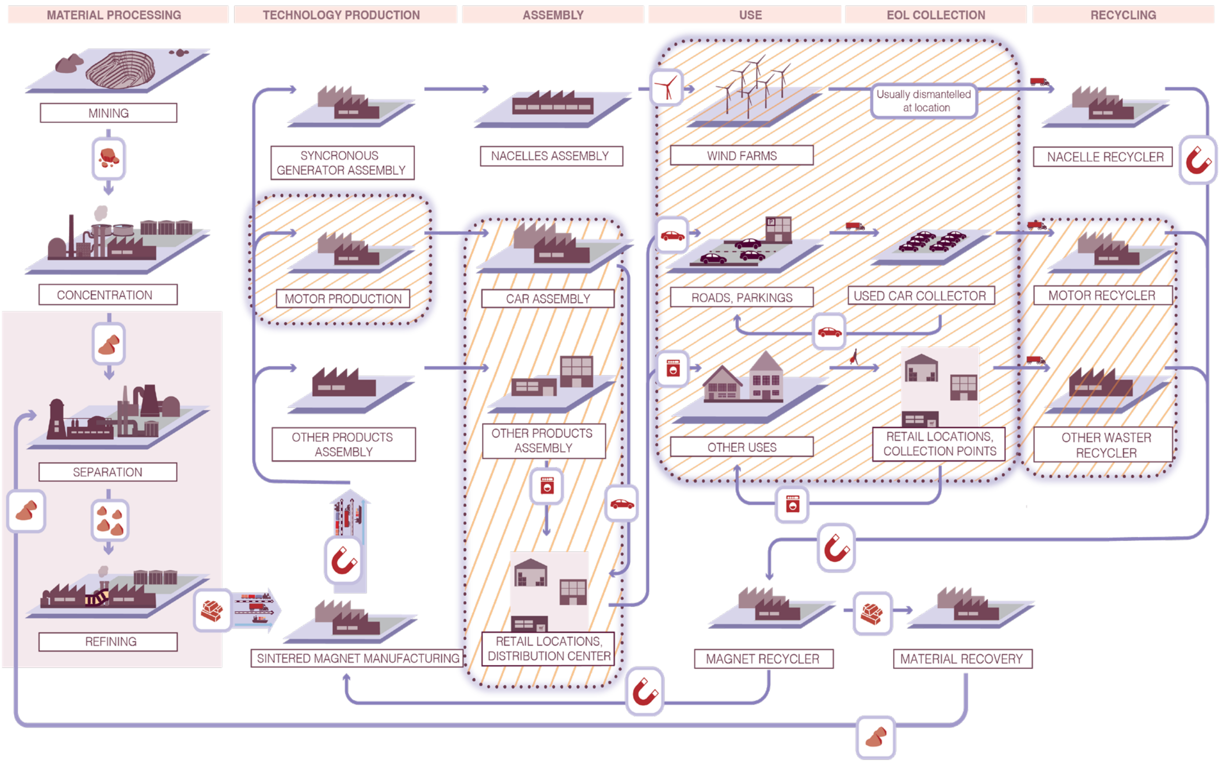
This thesis explores the spatial implications of the Critical Raw Materials Act in the Netherlands by developing a strategy to build a circular supply chain for Neodymium magnets. The act presents certain ambitions by 2030 but lacks the roadmap to build capacity, and does not state its spatial implications and environmental impacts. This thesis combines different economic growth models with circularity concepts to 1) Build extreme future scenarios based on different processing capacities, 2) Identify key synergies and conflicts in the scenarios, and 3) Formulate a vision that is detailed through 4) Five exemplary projects. These results are aimed at addressing the research question proposed in this thesis: What could be the spatial impacts of the Critical Raw Materials Act based on different economic growth paradigms?

This research aimed to explore the spatial implications of the CRMA by devising a spatial strategy to establish a resilient, circular supply chain in the Netherlands for Neodymium magnets. However, the scope of this research extends beyond the immediate logistical challenge and delves into critiquing the current approach to economic growth by exploring the extent of processing capacities in alternative growth paradigms. This is achieved through 4 sub-research questions whose results are listed in the following section.

Results

In this section the sub research questions are answered.

SRQ1 What could the future supply chain of NdFeB magnets look like and what could be its socio-ecological impacts?
An understanding of the potential circular supply chain of Neodymium (NdFeB) magnets was developed through an extensive literature review, which mapped the processes involved in processing, manufacturing, and recycling these magnets. This research also identified various facilities worldwide, analyzing their spatial demands to find the area required and the volume of magnets processed. The diagram illustrates the prospective future supply chain.



SRQ 2 How could the spatial requirements for a circular supply chain differ depending on different economic paradigms?

To explore different potential futures of the supply chain, scenario building was employed as a research method, developing four distinct scenarios to examine variations in spatial requirements. A central variable in these scenarios was the processing capacity, which, as previously noted, is crucial in the circular supply chain and is a significant focus of the Critical Raw Materials Act. The scenarios also diverged based on factors such as differences in material consumption, societal values, and economic agendas.

The analysis included an examination of various facilities worldwide, assessing how their spatial demand corresponds to the areas needed for the processes. The results of this analysis were consolidated into a table that outlines the spatial claims for each process under different scenarios, providing a structured comparison to understand the different spatial claims.

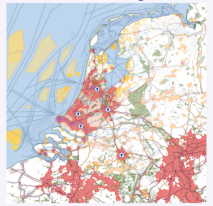
SRQ3 What could be the suitable spatial conditions for setting up a circular supply chain for NdFeB magnets in the Netherlands?

The spatial conditions for the creation of a circular supply chain for NdFeB magnets also varied significantly based on the scenarios. The table highlights the different spatial conditions and locations based on different scenarios.

	Knowledge Economy	Industrial Leaders	Self Sufficient	Regenerative
Processing Spatial claim	Not in the Netherlands (World)	Concentrated in high enviromnmental category zones in the port 1.5 km away for living locations. **30 ha**	Decentralized along smaller inland rivers. 300m away from living locations. Around medium sized cities. **18 ha**	Along inland rivers. In high and dry areas with sandy soil. In close proximity to cities. **7.2 ha**
Manufacturing Spatial claim	Not in the Netherlands (World)	Mainly in and around Eindhoven or along the Delta corridor. 200m away from living locations. In existing industrial zones **10 ha**	Decentralized along the national hydrogen network. In existing work locations. Proximity to medium sized cities. **6.2 ha**	Decentralized along the national hydrogen network. In high and dry areas with sandy soil. Proximity to medium sized cities. **2.5 ha**
Car collection Spatial claim	Outskirts of the city in existing work locations. **13 ha**	Outskirts of the city in existing work locations. **13 ha**	Outskirts of the city in existing work locations. **7 ha**	Outskirts of the city in existing work locations. **7 ha**
Waste collection Spatial claim	For small electronics- stores or shops For large electronics - outskirts of the city in existing work locations. **4 ha**	For small electronics- stores or shops For large electronics - outskirts of the city in existing work locations. **4 ha**	For small electronics- stores or shops For large electrnonics - in mixed / transition zones. **2.8 ha**	For small electronics- stores or shops For large electrnonics - in mixed / transition zones. **2.8 ha**
Repair Hubs Spatial claim	In bedrijventerrainen for collection, sorting,storing parts, large electronics, major repairs etc. **12 ha**	In bedrijventerrainen for collection, sorting,storing parts, large electronics, major repairs etc. **4.8 ha**	In mixed use transition zones for repair, sorting and storage of parts, large electronics, major repairs etc. **8.4 ha**	In mixed use transition zones for repair, sorting and storage of parts, large electronics, major repairs etc. **8.4 ha**
Car Repair Spatial claim	Service stations in existing work locations, close to the cities. **21 ha**	Service stations in existing work locations, close to the cities. **5.2 ha**	Service stations in existing work locations, close to the cities. **7 ha**	Service stations in existing work locations, close to the cities. **7 ha**
Magnet recycling Spatial claim	Not in the Netherlands (World)	Close to processing locations, in existing industrial zones. 300m away from living locations. **8.2 ha**	Close to processing locations, in existing industrial zones. 300m away from living locations. **4.2 ha**	Close to processing locations, in existing industrial zones. 300m away from living locations. **4.2 ha**
Motor/ Generator Production	Not in the Netherlands (World)	Not in the Netherlands (Europe)	Along the Hydrogen network. In existing bedrijventerrainen. Proximity to medium sized cities.	Outside the Netherlands. In the region (Germany or Belgium)
Distribution Locations	Import of final product Smaller container ports along the logistical corridor XXL warehouse Along the logistical corridor, in existing work locations category 2/3 Shops / Stores City centers, XXL stores outside of cities.	Import of final product Smaller container ports along the logistical corridor XXL warehouse Along the logistical corridor, in existing work locations category 2/3 Shops / Stores City centers, XXL stores outside of cities.	Storage warehouse In transition zones at the edge of cities. Shops / Stores City centers, stores in mixed areas. Mobility hubs For car sharing and rent at central stations/ major nodes etc.	Import of final product Smaller port areas in high and dry locations. Shops / Stores City centers, stores in mixed areas. Thrift & repair stores For sorting, storing and repairing electronics

SRQ 4 How could the establishment of a circular supply chain for neodymium impact territory, ecological sustainability, and societal well-being in the Netherlands?

Through the scenarios, the different ways in which the territory can transform in the Netherlands due to the future NdFeB magnet supply chain are depicted. The evaluation conducted to find the impact of these scenarios presented interesting results, which are summarized in the table below.

	Knowledge Economy	Industrial Leaders	Self Sufficient	Regenerative
				
Supply meets demand	– –	++	++	+
Time taken	– –	++	–	–
Social implication	–	–	++	– –
Environmental implication	–	– –	–	++
Space claim	50 ha	75 ha	55 ha	40 ha

++ Positive 0 Neutral – – Negative

Conclusion

A key finding was the importance of processing in closing the loop for metal chains. The lack of processing capacity for certain end-of-life (EOL) materials often necessitates their export. However, once these materials are exported, there is no assurance they will be recycled properly. This uncertainty can result in improper disposal, leading to material loss and significant environmental damage. Therefore, establishing adequate processing facilities is essential for recycling these materials, enabling them to be re-magnetized and reintroduced into the supply chain.

The diachronic analysis and literature review also identified that the shift in material dependencies (due to technological advancements, crisis or shortages, availability of cheap labor and resources, and economies of scale) has led to a shift in the patterns of production that has changed from decentralized local chains to global centralized production systems that serve international markets. Moreover, this transition has affected human consumption behaviors. As people become more detached from production activities and landscapes, their consumption also increases. This relationship between urban centers and their surrounding hinterlands, coupled with the mechanization of landscapes, has fostered a world where commodity production and consumption are prioritized, which poses significant challenges from an ecological perspective.

These findings led to the formation of scenarios with varying patterns of production (centralized or decentralized) and consumption (increased or decreased).

In the first scenario, which involved increased consumption without any processing capacity, the performance was notably poor. This illustrates that taking no action in response to the Critical Raw Materials Act might have serious risks for the Netherlands, especially in terms of securing access to resources, and could lead to instability due to increased prices of commodities and an impact on the economy due to lack of diversification.

Despite the absence of processing capacity, the spatial requirements of this scenario are comparable to others. This highlights that even if the

Netherlands opts not to engage in processing activities, there will still be significant implications on space as the space needed for circular activities remains considerable.

The evaluation highlighted that the Industry Leaders scenario, which follows the Green Growth model also promoted by the European Union, while formulating these acts does not seem socio-ecologically resilient. The current way of establishing facilities without proper environmental investigation might result in economic and spatial lock-ins in unsuitable locations, leading to a crisis in the future. Thereby concluding that the ambitions laid out by the deadlines like the Critical Raw Materials Act might be unsustainable in the longer run.

The third scenario with also comparably high processing capacity performs much better in terms of sustainability, proving the importance of reduction of material consumption as stated in the theories earlier.

The Regenerative scenario, with low processing and low consumption, performs best in terms of ecological sustainability and requires the least amount of space, however in doing so the Netherlands is still dependent on others for access to resources.

Another key finding from the scenarios would be that under the given conditions as in the scenarios, a regional supply chain (Eurodelta) seems better in terms of social and ecological sustainability.

The scenarios performing well in different aspects presented a paradox with two possible options:
1. Meeting the deadlines by rapidly building capacity to transition from fossil fuels to renewable energy, potentially leading to future crises due to economic and spatial lock-ins in locations unsuitable for building.
2. Delay meeting the deadlines, risking prolonged dependence on fossil fuels and economic instability, while planning with a long-term vision to build sustainable capacity.

The vision mediated this paradox through a balanced approach of developing baseline capacity now to gain leverage and time for thoughtful long-term planning. This strategy aimed to have a trade-off between the urgent need to transition and a long-term sustainable future. The strategies involved in this process highlight that while building capacity is often viewed as environmentally taxing (which discourages nations from doing so), this transition can actually be used to revitalize existing locations by addressing their current issues.

Reflection

This thesis explores the spatial and environmental implications of the Critical Raw Materials Act in the Netherlands focusing on building socio-ecological resilience to global supply chain disruptions. In doing so, the study addresses the broader role that urban planning can play in achieving resilience to global supply chain disruptions, which is often overlooked.

Reflection on the problem, scope, and process

This topic represented a deliberate shift towards a problem that is typically assumed to be beyond the scope of urbanism presenting a unique set of learning opportunities. Initially, the topic was closely aligned with those typically addressed within the scope of an industrial ecology thesis. The first challenge hence was relating the problem with urbanism and defining it spatially which presented also an opportunity to advocate for the agency of urban design in these transitions. In doing so, the studio methods and graduation intensives were instrumental in streamlining my thoughts and refining the project's scope.

Participation in the elective course 'Planetary Urbanization' deepened my understanding of the issues at hand. Theories like 'Capitaloecne by Jason Moore' broadened my understanding of the problem highlighting that the development of extractive industries on the planetary scale has led to an acceleration of resource use within the emerging economies. This has reached a point where over-exhaustion and imbalance in the earth's system combined with the socio-ecological upscaling of human society has led to the very evident climate crisis. This led me to discover a crucial issue while concerns about resource depletion are valid, the more immediate and pressing issue remains the environmental impact of resource extraction and production processes that come with our increasing capitalistic pursuits. This developed into the main challenge that I address with my project of balancing capacity building with the need to reduce our reliance on resources.

To find further direction in the project, literature related to alternate growth paradigms like post-growth and degrowth, specifically by Dr. Fredrico Savini built the theoretical basis of futures which presented an alternative to an ever-growing consumption society. The theories related to circularity presented a way to move away from the exhaustion of land and resources. These theories formed the major concepts of the thesis and related it to urbanism.

The initial phase of the problematization addressed planetary boundaries, thereby necessitating an exploration of the implications within the Netherlands. Given the focus on quantifying the spatial requirements for a circular supply chain, the scope was narrowed to a specific material, to align with the time constraints of the master's program.

A straightforward reactive approach to this project could involve simply designing a processing facility and its connection to the existing fabric within the present societal framework like the processing facility in Hoboken, Belgium. However, this would not have been the solution to the root cause of the problem as described in the previous paragraphs. With the approach used in the project, I could formulate a holistic research project by critically reflecting on the economic system, and societal behavior and presenting an alternative future.

After developing the scenarios, I initially gravitated toward the ecologically favorable option, as it excelled in environmental sustainability. However, discussions with my mentors highlighted potential shortcomings. They pointed out that solely prioritizing ecological benefits might lead to missing crucial deadlines.

The CRMA deadline is important. If we fail to secure the necessary materials for renewable technologies our ability to manufacture and deploy wind turbines, solar panels, industrial motors, and batteries at scale will be severely hindered. This delay would prolong our reliance on fossil fuels, aggravating greenhouse gas emissions and accelerating climate change. This would eventually lead to a rise in global temperatures causing frequent and severe natural disasters, such as droughts, and floods, while also causing irreversible damage to ecosystems, endangering biodiversity, and threatening human security. Therefore, ensuring a steady supply of critical raw materials is crucial for achieving a sustainable and resilient future.

The problem is that the current way in which these facilities are being set up would create lock-ins in unsuitable places that could lead to a crisis in the future and the places which are suitable to build do not currently have the infrastructure to facilitate capacity building.

In response, this problem is tackled in the final vision by building a certain baseline capacity in unsuitable locations to gain time and leverage for setting up the infrastructure and facilities in suitable locations. This approach allowed me to balance the urgent agendas of the deadlines and achieve socio-ecological resilience in the long term.

Transferability

Scales - This thesis explored the implications of the Critical Raw Materials Act specifically on the Netherlands, due to the limited timeframe of this thesis. But the implications of this act would be on the whole of Europe and the method used in this thesis could be applied for it. The main difference here would be that the main threat in the Netherlands is because of water problems which would be different for each location. With systemic analysis of different environmental threats and potential at different territories , suitable locations for particular facilities can be found. Other factors for choosing the locations could be the availability of resources and labor, soil capacity and quality, or other strengths like knowledge or experience about a particular process. In this way, this method could be applied to the whole of Europe and would be an ecologically better way of building capacity than the current model.

Material – In this research, I focused on Neodymium. The methodology applied here can potentially be adapted for other metals, given the general similarities in their supply chains. However, it is important to note that while the overarching structure of these supply chains may be alike, I currently lack detailed information about the specific characteristics of other material chains. Therefore, without a deeper understanding, it would be irrational to assume that the same approach would be universally applicable to all supply chains.

Reflection on Scenario Building

In formulating alternative futures, the method of scenario building played a crucial role. The scenarios were built through an extensive literature review of growth paradigms theories. While literature formed a crucial aspect, imagination also played a huge part in identifying each scenario with a specific processing capacity and relating it to the underlying value that it brings. For example, if the Netherlands plans to do 40% of the processing for the whole of European consumption it is related to green growth because this huge amount of capacity building would require such a paradigm, and the decision to do so by the government highlights that they are racing to become the best players in Europe.

The underpinning value is driven by only economic growth.

Alternative methods, such as using an XY-axis to differentiate scenarios, were considered. However, such approaches seemed too restrictive for this project, as the differences between scenarios extended beyond just two variables. This complexity required a more nuanced method of scenario development, which the chosen approach successfully provided as it gave me a way to build different imaginaries and understand their consequences.

Time horizon

Initially, the determination of the appropriate time scale for the scenarios posed a dilemma. The current act extends only until 2030, and it was logical to take this as the timeframe. However, the decisions made within this timeframe are likely to have long-term impacts on space, society, and the environment. To know these consequences of the act, I extended the time horizon to 2050 for my scenarios, enabling a more comprehensive illustration of how the prevailing growth model could lead to irreversible effects. This approach allowed me to outline strategic interventions that should be implemented by 2030 to ensure that development remains within ecological limits while also building resilience against future uncertainties. This emphasizes the necessity of long-term planning beyond immediate policy timelines to manage the interplay between human activities and environmental implications in the long run.

Critical Raw Materials Act

The European Critical Raw Materials Act comes as a deadline for building certain capacity. While it is understood that the act is mainly directive, it should be accompanied by a roadmap or plan that considers a longer time horizon. With that, the act should also include the probable negative implications it might have on the environment or land so that while implementing certain ambitions that can also be kept in mind to prevent further crises from happening.

Comparison to scenarios by PBL

TThe method of building scenarios is similar, but also has a lot of differences from the report by PBL titled *'Four scenarios for reaching 2050'*.

For me the methods involved in scenario building were a literature review of growth paradigms like green growth, degrowth post-growth; designing, and the calculations of certain processes of the supply chain. PBL based their scenarios on stakeholder participation, exploring literature, designing, and performing model calculations. The literature that forms the basis of the scenarios for PBL is mainly based on the different reports on sustainability and technological developments by the European Union, EEA, etc., and the tasks based on the NOVI.

The difference is that my scenarios differ based on processing capacities and the underlying value attached to them, with the goal of building capacity and a circular supply chain. On the other hand, the PBL scenarios are based on different values and the goal is to achieve sustainable development.

Another comparison can be that PBL integrates different themes like room for climate adaptation, strong and healthy cities, and regions to different degrees in each scenario. But in my case, different values like economic growth, social equity, or environmental well-being are maximized.

While the method has some similarities, the final outcome is extremely different due to the fact that in my scenarios everything is a consequence of a specific material chain (structural) and the PBL the scenarios are a combination of different themes (integrated).

Reflection on Circularity

Throughout this thesis, the concepts of circularity, circular economy, and sustainability have been big questions in my mind. With the review of different frameworks for circularity, it became very clear to me that they do not necessarily work for urban and regional planning. The R ladder works for smaller scales but it is difficult to translate it in terms of urbanism.

For urban planning, ***regeneration*** would mean using the potential of the ecosystem as a basis for urban planning. *Reducing* could mean minimizing usage, such as reducing the number of cars, which aligns with concepts like the 15-minute city or improving public transport. *Recycling* in this context would involve creating infrastructure to support recycling processes. *Reusing* would mean repurposing existing infrastructure for future needs. However, these principles have been integral to urban planning for many decades.

In this project, circularity was used as an approach to foster a transition. The primary objective was not to achieve circularity, but to achieve sustainability. Alternatively, a project could focus on transforming a supply chain to be circular, aiming for a circular economy rather than sustainability. My approach in this project has consistently been towards achieving circular sustainability rather than creating a circular economy, which might have led to different outcomes.

Relevance

[scientific]
The existing body of research on critical materials predominantly focuses on the vulnerabilities inherent in their supply chains. In contrast, this study applies a socio-ecological resilience framework to explore the spatial development of robust supply chains, while adhering to the ecological limits of the system. This project adds to the existing literature on critical materials by incorporating a spatial dimension that encompasses both the quantification of necessary space and defining the required spatial conditions.

Additionally, this thesis addresses a notable gap in the literature by examining the relationship between the Circular Economy and spatial-territorial dynamics. It specifically quantifies the spatial requirements and conditions essential for the implementation of circular economy practices, thereby providing a new perspective on the integration of circularity and critical materials in the context of urban planning.

[Social]
This thesis explores significant crises across multiple scales, On the planetary scale it highlights that outsourcing processing activities have led to an unequal exchange between production and consumption economies causing the appropriation of land labor and resources in these areas. The proposed repatriation of these capacities to Europe aims to ensure adherence to strict ethical standards and regulations, potentially repairing these imbalances.
At the regional level, the thesis confronts the dilemma faced by the Netherlands in localizing processing capacities. While establishing these facilities domestically could mitigate supply chain vulnerabilities and prevent resource scarcity amid geopolitical uncertainties, it also poses potential environmental risks. This reflects a tension between short-term solutions and long-term sustainability goals, as the current act fails to adequately consider being within ecological thresholds over extended periods.

Furthermore, the thesis addresses behavioral patterns, critiquing the prevalent consumer culture that equates material accumulation with enhanced living standards. It highlights the environmental costs associated with this lifestyle and suggests that a shift in consumption patterns could significantly lessen ecological pressures. This not only deepens our understanding of the spatial and territorial dimensions of the Circular Economy but also contributes to the discourse on alternative growth paradigms.

Ethical considerations

In conducting this research, every effort was made to adhere to ethical standards. However, it is acknowledged that personal biases, such as my inclination toward reducing material consumption, may have influenced the methodology and results. While all data used was collected and analyzed ethically, it is important to recognize the potential for human error in the process.

Limitations

In the attempt to quantify the spatial demands of the circular supply chain for different scenarios, several assumptions were necessary, potentially leading to skewed results.

The results of the spatial claims of the circular supply chain might also be skewed due to double-counting of the space needed. For example, a car can go to a repair location after EOL directly or it can go to a collection point and then go to the repair hub. In this research, it might be the case that sometimes these steps are accounted for twice.

A lot of the calculations are based on a single source leading to low credibility due to less amount of available data.

The calculations are based on a direct relation between the space required and the amount of product produced, which might not be correct based on economies of scale.

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Appendix

Calculation of space required for processing plant

[calculating metal demand for the Netherlands]

According to Yao et al(2021) "*the expected total demand for neodymium will be 30,000 tons in 2025, 50,000 tons in 2035, and more than 100,000 tons in 2050, reflecting a serious supply challenge over the next three decades,*" for the whole world.

According to the **Metal demand for renewable energy report** by Metabolic (2018) "*the Dutch demand for neodymium - only related to the energy transition - would amount to 4% of the global annual production*"

Therefore, the Dutch demand for Neodymium in 2030 is,

4% of 40000 tonnes = 1600 tonnes

And demand for the year 2050 is,

4% of 100000 tonnes = 4000 tonnes

[metal demand for the Europe]

The demand for Nd in Europe would be 5449t in 2030 and 6896t in 2050

#remark: The projected demand for neodymium by 2050 indicates that the Netherlands will require approximately 4,000 tons and the European Union would need about 6,896 tons. These figures appear incongruous, as the demand for the European Union, encompassing multiple member states, is expected to be significantly higher than that of a single country such as the Netherlands. However, due to lack of other sources these values are taken in this study.

[space required for amount of material]

For the processing plant in Malaysia by Lynas Rare earth, 1square kilometre of space is needed to produce 22,000 tonnes per annum.

For Scenario 1: Knowledge Economy

In this scenario processing is 0% so no space is needed for processing.

For Scenario 2: Green Growth

In this scenario processing is 40% of the whole of Europe. Therefore, the space required for production in 2030 is,

1000000 * 5449 / 22000 = 247681,8 square meters

And space required in 2050 is,

1000000 * 6896 / 22000 = 313454,5 square meters

For Scenario 3: Self Sufficient

In this scenario processing is 100% of the Netherlands' demand. Therefore, space required is in 2030,

1000000 * 1600 / 22000 = 72727,27 square meters

And space required in 2050 is,

1000000 * 4000 / 22000 = 181818,2 square meters

For Scenario 4: Regenerative Scenario

In this scenario processing is 100% of the Netherlands' demand. Therefore, space required is in 2030,

(1000000 * 1600 / 22000) * 40 / 100 = 29090,91 square meters

And space required in 2050 is,

(1000000 * 4000 / 22000) * 40 / 100 = 72727.27 square meters

Calculation of space required for manufacturing

[calculating Nd metal demand for manufacturing]

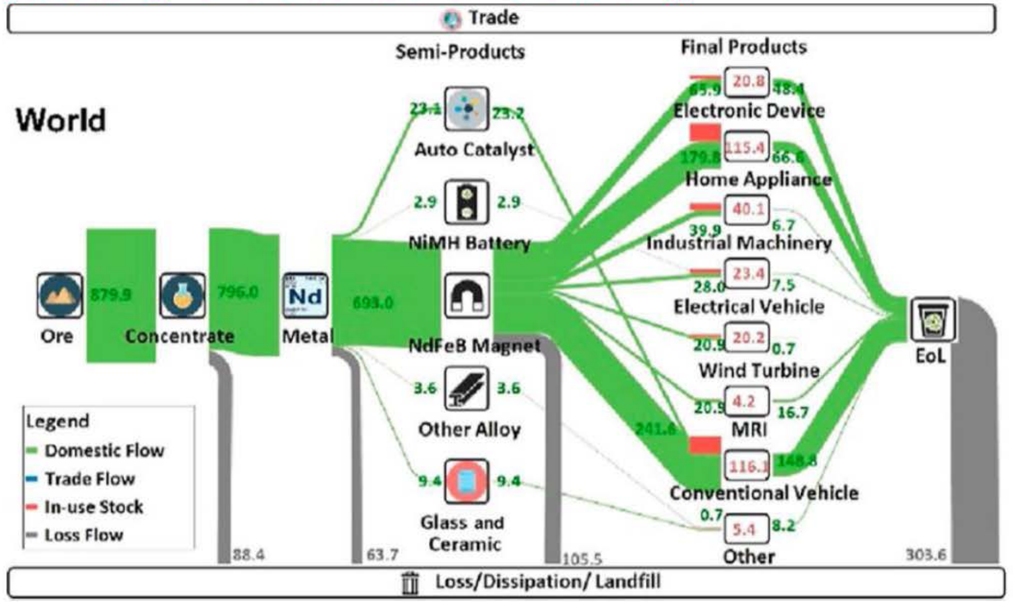


Fig A1.1 (source: *Liu et al., 2022*)

According to Figure A1.1, out of the 796 kt of Nd metal produced globally, 693 kt is used to produce NdFeB magnets. Hence, 87% of the Nd metal produced is used for NdFeB magnet production.

[space needed for manufacturing]
For the manufacturing plant in Estonia, 35869 square meters of space is needed for 2000 tons of magnet per year.

For Scenario 1: Knowledge Economy

In this scenario processing is 0% so no space is needed for manufacturing.

For Scenario 2: Industry Leasders

[metal demand for the Europe]

The demand for Nd in Europe would be 5449t in 2030 and 6896t in 2050

[calculating Nd metal demand for manufacturing]

87% of this would now be used for NdFeB magnets (Yao et al., 2021). Hence the amount of metal used in manufacturing in 2050 is,

87 /100 * 6896 = 5999,52 tons

[space needed for manufacturing]

Therefore, the space needed for manufacturing 5999,52 tons is,

5999,52 * 35869 / 2000 = **107598,4 Square meters**

For Scenario 3: Self-sufficient Scenario

[metal demand for the Netherlands]

The demand for Nd for this scenario is 4000t in 2050

[calculating Nd metal demand for manufacturing]

87% of this would now be used for NdFeB magnets (Yao et al., 2021). Hence the amount of metal used in manufacturing in 2050 is,

87 /100 * 4000 = 3480 tons

[space needed for manufacturing]

Therefore, the space needed for manufacturing 3480tons is,

3480 * 35869 / 2000 = **62412,06 Square meters**

For Scenario 4: Regenerative scenario

Since the amount of manufacturing is 40% of the Netherlands, space needed is 40% of the space needed for self-sufficient scenario. Therefore, space needed for manufacturing is,

62412.06 * 40 / 100 = **24964,82 Square meters**

Calculation of space required for Circular activities

For these activities, some assumptions are made:

1. For the first two scenarios, 1 and 2 (increased material consumption), it is assumed that the increase is linear from 2030 to 2050.
2. For the scenarios 3 and 4 (decreased consumption), it is assumed that inflow and outflow remain constant. However, the rate of increase in the number of cars entering the market will be halved compared to scenarios 1 and 2, since more electric vehicle would still be placed on the market.

Calculation of space required for EOL recycling

[calculating % increase for electronics]

According to Crock (2016),

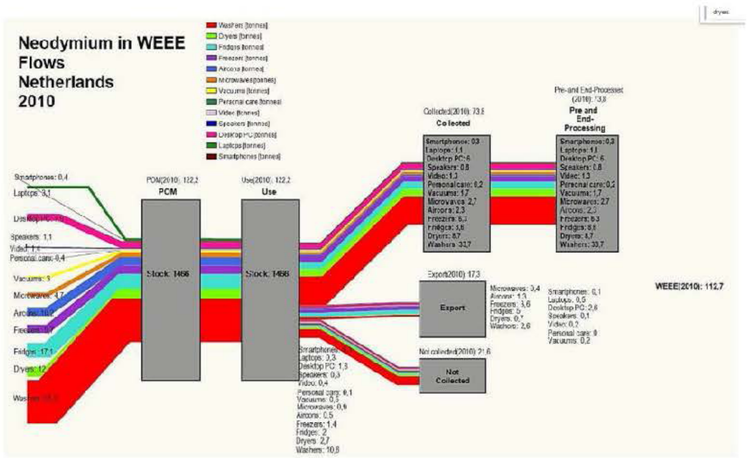


Fig B1.1 (Source: Crock, 2016)

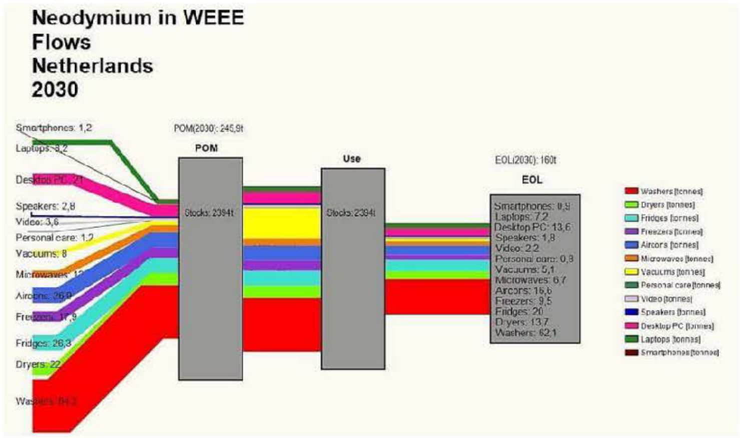


Fig B1.2 (Source: Crock, 2016)

According to figure B1.1 and B1.2 the increase in the amount of Nd that reaches EOL is,

$$(160 - 112{,}7) * 100 / 112{,}7 = 41.9\% \sim 42\%$$

[calculating % increase for vehicles]

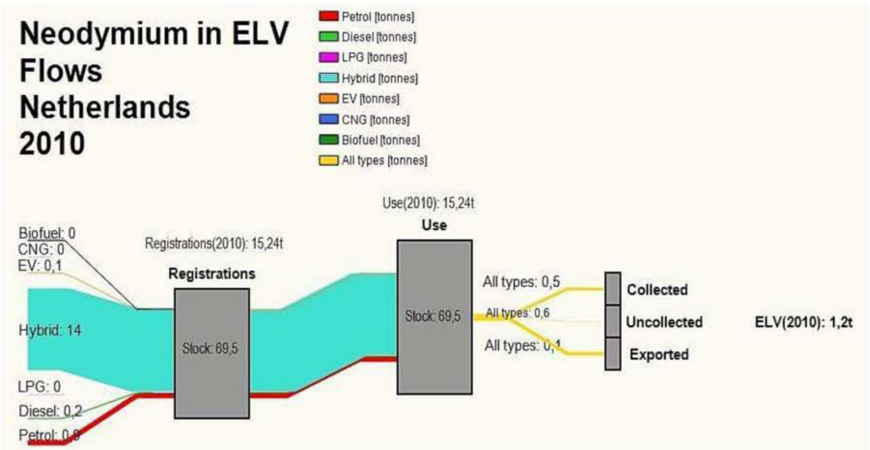


Fig B2.1 (Source: Crock, 2016)

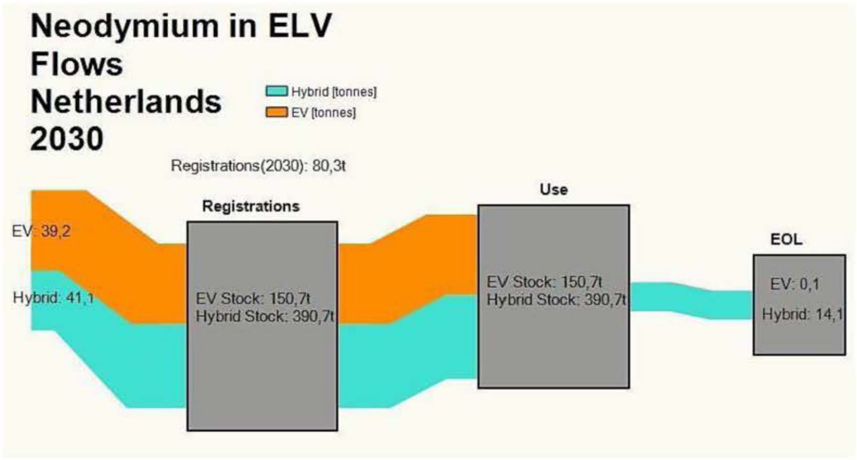


Fig B2.2 (Source: Crock, 2016)

According to figure B2.1 and B2.2 the increase in the amount of Nd that reaches EOL is,

(14,2 – 1,2) *100 / 1,2 = 1083.333 ~ 1083%

[calculating % increase for wind turbines]

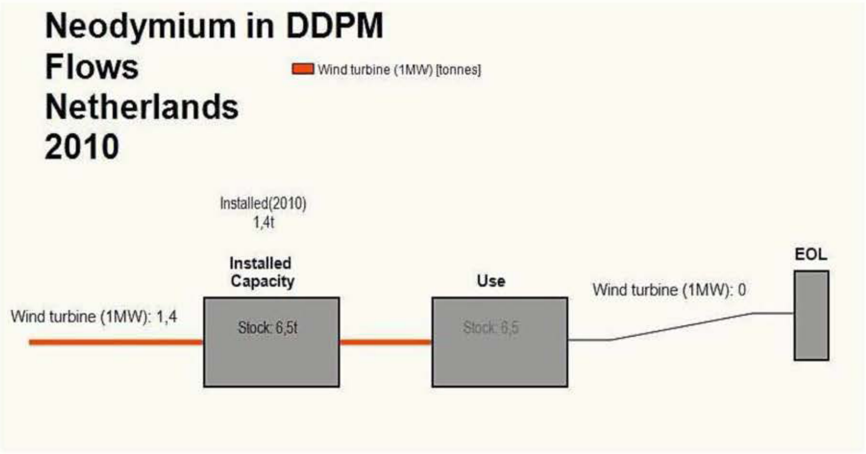


Fig B3.2 (Source: Crock, 2016)

2030		POM		Stock		EOL	
unit	*kg*	*units*	*t*	*units*	*t*	*units*	*t*
Item	Nd composition	total	Nd total	total	Nd total	total	Nd total
DDPM Wind turbine	196	410	**80,4**	3.872	**758,9**	7	**1,4**

Table 33: Neodymium distribution in new DDPM wind turbine installations, stock and EOL DDPM wind turbines

Fig B3.2 (Source: Crock, 2016)

[Calculating EOL ẽows for increased consumption scenarios(1 and 2).]

For electronics the increase is 42% from 2010 to 2030. An increase of 42% between 2030 to 2050 would mean that the total Nd at EOL in 2050 is,

160 + 160*42 /100 = **227.2 tons**

For cars the increase is 1083% from 2010 to 2030. An increase of 1083% between 2030 to 2050 would mean that the total Nd at EOL in 2050 is,

14.2 + 14.2* 1083 /100 = 168 **tons**

For wind turbines if 410 units are in use about 7 reach EOL every year (Figure B3.2)

In 2020 2606 wind turbines generated 15.3 billion kwh of electricity (CBS, 2022)

So average power generation per wind turbine is 5.875 Gwh per turbine per year

In 20590 the Netherlands plans to generate 70 Gw (https://english.rvo.nl/news/netherlands-exceeds-2023-offshore-wind-target)

70 Gw for a year would mean,

70 *8760 = 613,200 GWh per year

Finally, Wind turbine needed to generate this would be 104,444 wind turbines.

According to Ẽgure if 410 wind turbines are in the market 7 reach EOL in a year. So for 104,444 units turbines that reach EOL would be, 1044,444*7/410= 17832 wind turbines

According to figure B3.2, for 7 wind turbines contain 1.4 tons Nd. So EOL Nd for wind turbines in 2050 is,

17832 * 1.4 / 7 = 3566.4 tons

So total Nd at EOL is 227.2 + 168 + 3566.4 = 3961.6tons

[Calculating EOL flows for decreased consumption scenarios(3 and 4).]

For electronics there is no increase in the total Nd that reaches EOL. So in 2050 Nd that reaches EOL is 160t.

For vehicles, it is assumed that the increase is half of increased consumption scenario. So instead of a 1083% increase there is a 541.5% increase which would mean the amount of Nd at EOL is,

14.2 + 14.2 * 541/100 = **91tons**

For wind turbine also , it is assumed that the increase is half of increased consumption scenario. So instead of 104,444 wind turbines we have about 52,222 wind turbines.

According to figure if 410 wind turbines are in the market 7 reach EOL in a year. So for 52,222 units turbines that reach EOL would be,

52,222 *7/410= 8916 wind turbines

According to figure B3.2, for 7 wind turbines contain 1.4 tons Nd. So EOL Nd for wind turbines in 2050 is,

8916 * 1.4 / 7 = 1783tons

So total Nd at EOL is 160 + 91 + 1783 = 2034 tons

[space needed for recycling]

According to the recycling plant by iconic technology plant in UK, 782 square meters is needed for 30 t of EOL Nd.

For Scenario 1: Knowledge Economy

In this scenario since there is no processing capacity, Nd recycling also happens outside the Netherlands. So, no space is needed for recycling

For Scenario 2: Industry Leaders

In this scenario the main priority is recycling, so assuming that 80% of the items are recycled at EOL, the weight to be recycled is,

3961.6tons * 80/100 = 3,169.28 tons

the space needed for recycling is:

782 * 3,169.28 / 30 = **82612.5 square meters**

For Scenario 3: Self Sufficient

In this scenario assuming that at EOL 50% of the items would be recycled, the weight to be recycled is,

2034 * 80/100 = 1627.2 tons

the space needed for recycling is:

782 * 1627.2 / 30 = 42415.68 **square meters**

For Scenario 4: Regenerative Scenario

In this scenario assuming that at EOL 50% of the items would be recycled, the weight to be recycled is,

2034 * 80/100 = 1627.2 tons

the space needed for recycling is:

782 * 1627.2 / 30 = 42415.68 **square meters**

Calculation of space required for EOL repair (electronics)

Note: For recycling only Nd recycling was considered and not the whole product. For repair the space claims calculated is for the whole product. Wind turbines are not considered for repair due to their complex supply chains.

[space needed for repair (electronics)]

According to the Electronic repair facility in Rotterdam, for 9,252items in 1,017.84 m2 is needed.

unit		POM		STOCKS		EOL	
	Growth rate	EEE units (10.000)	t	EEE units (10.000)	t	WEEE units (10.000)	t
item		**total**	**Nd**	**total**	**Nd**	**Total EOL**	**Nd**
washers	2,5%	125	94,2	1.235	931,2	82	62,1
dryers	2,5%	56	22,0	672	263,0	35	13,7
fridges	2,5%	139	26,3	1.528	288,1	88	20,0
freezers	2,5%	42	17,9	757	322,8	22	9,5
aircons	4,5%	62	26,9	404	175,7	38	16,6
microwaves	4,5%	131	12,5	1.293	123,8	70	6,7
vaccuums	4,5%	409	8,0	2.635	51,6	260	5,1
personal care	4,5%	1.545	1,2	9.490	7,1	1.011	0,8
video	4,5%	727	3,6	6.306	31,0	448	2,2
speakers	4,5%	653	2,8	4.868	21,2	413	1,8
desktop pc	4,5%	285	21,0	2.014	148,3	185	13,6
laptop	4,5%	403	8,2	1.199	24,5	350	7,2
smartphone	4,5%	973	1,2	4.720	5,7	701	0,8
TOTAL			**245,9**		**2.394,0**		**160,0**

Table 31: Neodymium stocks and flows in the electronics sector in 2030 based on the assumptions outlined in Annex A14a

Fig B4.1 (Source: Crock, 2016)

[Calculating electronics that reach EOL for increased consumption scenarios (1 and 2)]

For electronics the increase in 42 %.

ITEMS	EOL UNITS (now)	EOL UNITS 2050
Large electronics		
washers	820000	1164400
dryers	350000	497000
fridges	880000	1249600
freezers	220000	312400
aircons	380000	539600
microwaves	700000	994000
vaccuums	2600000	3692000
small electronics		
personal care	10110000	14356200
video	4480000	6361600
speakers	4130000	5864600
desktop pc	1850000	2627000
laptop	3500000	4970000
smartphone	7010000	9954200
TOTOAL UNITS		**52582600**

Fig B4.2 (42% increase for 2050 based on Fig B4.1)

[Calculating electronics that reach EOL for decreased consumption scenarios (3 and 4)]

For these scenarios the items that reach EOL remain same.

ITEMS	EOL UNITS (now)
Large electronics	
washers	820000
dryers	350000
fridges	880000
freezers	220000
aircons	380000
microwaves	700000
vaccuums	2600000
small electronics	
personal care	10110000
video	4480000
speakers	4130000
desktop pc	1850000
laptop	3500000
smartphone	7010000
TOTOAL UNITS	**37030000**

Fig B4.3 (total items for 2050 based on Fig B4.1)

For Scenario 1: Knowledge Economy

In this scenario 50% of the items are repaired. So, items to be repaired is,

52582600 * 50 /100 = 26291300

So, total space needed is,

1018 * 26291300 / 9252 = 2892838.673 square meters

Assuming that the flow is equal throughout the year, and stays for 15 days,

So space needed for repair is,

2892838.673 /(12*2) = **120534.9 square meters**

For Scenario 2: Industry Leaders

In this scenario only 20% of the items are repaired. So, items to be repaired is,

52582600 * 20 /100 = 10516520

So, total space needed is,

1018 * 10516520 / 9252 = 1157135.469 square meters

Assuming that the flow is equal throughout the year, and stays for 15 days,

So space needed for repair is,

1157135.469 /(12*2) = **48213.98 square meters**

For Scenario 3: Self Sufficient

In this scenario assuming that at EOL 50% of the items would be repaired, the items to be repaired is,

37030000 * 50/100 = 18515000 items

So, total space needed is,

1018 *18515000 / 9252 = 2037210.333 square meters

So, space needed for repair is,

2037210.333 /(12*2) = **84883.76 square meters**

For Scenario 4: Regenerative Scenario

In this scenario assuming that at EOL 50% of the items would be repaired, the items to be repaired is, 37030000 * 50/100 = 18515000 items

So, total space needed is,

1018 *18515000 / 9252 = 2037210.333 square meters

So, space needed for repair is,

2037210.333 /(12*2) = **84883.76 square meters**

Calculation of space required for collection point (Electronics)

To calculate the size of a collection point for these items, we need to know the total volume they would occupy.

[Calculating VOLUME of materials that reach EOL for increased consumption scenarios (1 and 2)]

ITEMS	EOL UNITS (now)	EOL UNITS 2050	volume per unit m3	TOTAL VOL PRODUCTS
Large electronics				
washers	820000	1164400	0.306	356306.4
dryers	350000	497000	0.306	152082
fridges	880000	1249600	0.945	1180872
freezers	220000	312400	0.7875	246015
aircons	380000	539600	0.105	56658
microwaves	700000	994000	0.06	59640
vaccuums	2600000	3692000	0.04	147680
small electronics				
personal care	10110000	14356200	0.00375	53835.75
video	4480000	6361600	0.003	19084.8
speakers	4130000	5864600	0.015	87969
desktop pc	1850000	2627000	0.036	94572
laptop	3500000	4970000	0.0026	12922
smartphone	7010000	9954200	0.00006	597.252
TOTAL VOL				**2468234.202**

Fig B5.1 (total volume for 2050 based on Fig B4.1)

[Calculating electronics that reach EOL for decreased consumption scenarios (3 and 4)]

For these scenarios the items that reach EOL remain same.

ITEMS	EOL UNITS (now)	volume per unit m3	TOTAL VOL PRODUCTS
Large electronics			
washers	820000	0.306	250920
dryers	350000	0.306	107100
fridges	880000	0.945	831600
freezers	220000	0.7875	173250
aircons	380000	0.105	39900
microwaves	700000	0.06	42000
vaccuums	2600000	0.04	104000
small electronics			
personal care	10110000	0.00375	37912.5
video	4480000	0.003	13440
speakers	4130000	0.015	61950
desktop pc	1850000	0.036	66600
laptop	3500000	0.0026	9100
smartphone	7010000	0.00006	420.6
TOTAL VOL			**1738193.1**

Fig B5.2 (total volume for 2050 based on Fig B4.1)

For Scenario 1: Knowledge Economy

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days. Also, we assume the stacking height of the facility to be 2.5 m.

Therefore, the footprint of the collection hubs should be:

2468234.2 / (12*2*2.5) = 41137.2 **square meters**

For Scenario 2: Industry Leaders

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days. Also, we assume the stacking height of the facility to be 2.5 m.

Therefore, the footprint of the collection hubs should be:

2468234.2 / (12*2*2.5) = 41137.2 **square meters**

For Scenario 3: Self Sufficient

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days. Also, we assume the stacking height of the facility to be 2.5 m.

Therefore, the footprint of the collection hubs should be:

1738193/ (12*2*2.5) = **28970 square meters**

For Scenario 4: Regenerative

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days. Also, we assume the stacking height of the facility to be 2.5 m.

Therefore, the footprint of the collection hubs should be:

1738193/ (12*2*2.5) = **28970 square meters**

Calculation of space required for EOL collection (cars)

[Calculating cars that reach EOL for increased consumption scenarios (1 and 2)]

For cars the EOL increase is 1083%

PRODUCT	UNITS (now)	UNITS (2050)	AREA REQUIRED PER CAR (m2)	AREA REQUIRED TOTAL(m2)
PHEV	15925	188392.75	16.5	3108480.375
EV	115	1360.45	16.5	22447.425
AREA REQUIRED TOTAL(m2)				**3130927.8**

Fig B5.2 (total volume for 2050 based on Fig B4.1)

[Calculating cars that reach EOL for decreased consumption scenarios (3 and 4)]

For cars the EOL increase is 541%

PRODUCT	UNITS (now)	UNITS (2050)	AREA REQUIRED PER CAR (m2)	AREA REQUIRED TOTAL(m2)
PHEV	15925	102079.25	16.5	1684307.625
EV	115	737.15	16.5	12162.975
AREA REQUIRED TOTAL(m2)				**1696470.6**

For Scenario 1: Knowledge Economy

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days.

3130927.8 / 12*2 = 130455.3 square meters

For Scenario 2: Industry Leaders

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days.

3130927.8 / 12*2 = 130455.3 square meters

For Scenario 3: Self Sufficient

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days.

1696470.6 / (12*2) = 70686.3 square meters

For Scenario 4: Regenerative

Assuming that equal amount of waste is generated every month, and stays at the point for 15 days.

1696470.6 / (12*2) = 70686.3 square meters

Calculation of space required for EOL repair (cars)

[Calculating cars that reach EOL for increased consumption scenarios (1 and 2)]

For cars the EOL increase is 1083%

PRODUCT	UNITS (now)	UNITS (2050)	AREA REQUIRED PER CAR (m2)	AREA REQUIRED TOTAL(m2)
PHEV	15925	188392.75	16.5	3108480.375
EV	115	1360.45	16.5	22447.425
AREA REQUIRED TOTAL(m2)				**3130927.8**

Fig B6.1 (total area for 2050 based on Fig B4.1)

[Calculating cars that reach EOL for increased consumption scenarios (1 and 2)]

For cars the EOL increase is 541%

PRODUCT	UNITS (now)	UNITS (2050)	AREA REQUIRED PER CAR (m2)	AREA REQUIRED TOTAL(m2)
PHEV	15925	102079.25	16.5	1684307.625
EV	115	737.15	16.5	12162.975
AREA REQUIRED TOTAL(m2)				**1696470.6**

Fig B6.2 (total area for 2050 based on Fig B4.1)

For Scenario 1: Knowledge Economy

Assuming 80% of the cars can be repaired, area required is 3130927.8 * 80 /100 = 2504742.24meter square

Assuming that equal number of cars come for repair every month, and stays at the point for 15 days. Space needed only for cars is,

2504742.24/ (12*2) = 104364.26 meter square

Assuming that equal amount of space is needed for circulation, repair bays storage of parts etc,

104364.26 +104364.26 = 208728.5 meter square

For Scenario 2: Industry Leaders

Assuming 20% of the cars can be repaired, area required is 3130927.8 * 20 /100 = 626185.6 meter square

Assuming that equal number of cars come for repair every month, and stays at the point for 15 days. Space needed only for cars is,

626185.6 / 12*2 = 26091 meter square

Assuming that equal amount of space is needed for circulation, repair bays storage of parts etc,

26091 + 26091 = 52182.1meter square

For Scenario 3: Self Sufficient

Assuming 50% of the cars can be repaired, area required is 1696470.6 * 50 /100 =848235.3 meter square

Assuming that equal number of cars come for repair every month, and stays at the point for 15 days. Space needed only for cars is,

848235.3 / (12*2) = 35343.1 meter square

Assuming that equal amount of space is needed for circulation, repair bays storage of parts etc,

35343.1 + 35343.1 = 70686.2 meter square

For Scenario 4: Regenerative

Assuming 50% of the cars can be repaired, area required is 1696470.6 * 50 /100 =848235.3 meter square

Assuming that equal number of cars come for repair every month, and stays at the point for 15 days. Space needed only for cars is,

848235.3 / (12*2) = 35343.1 meter square

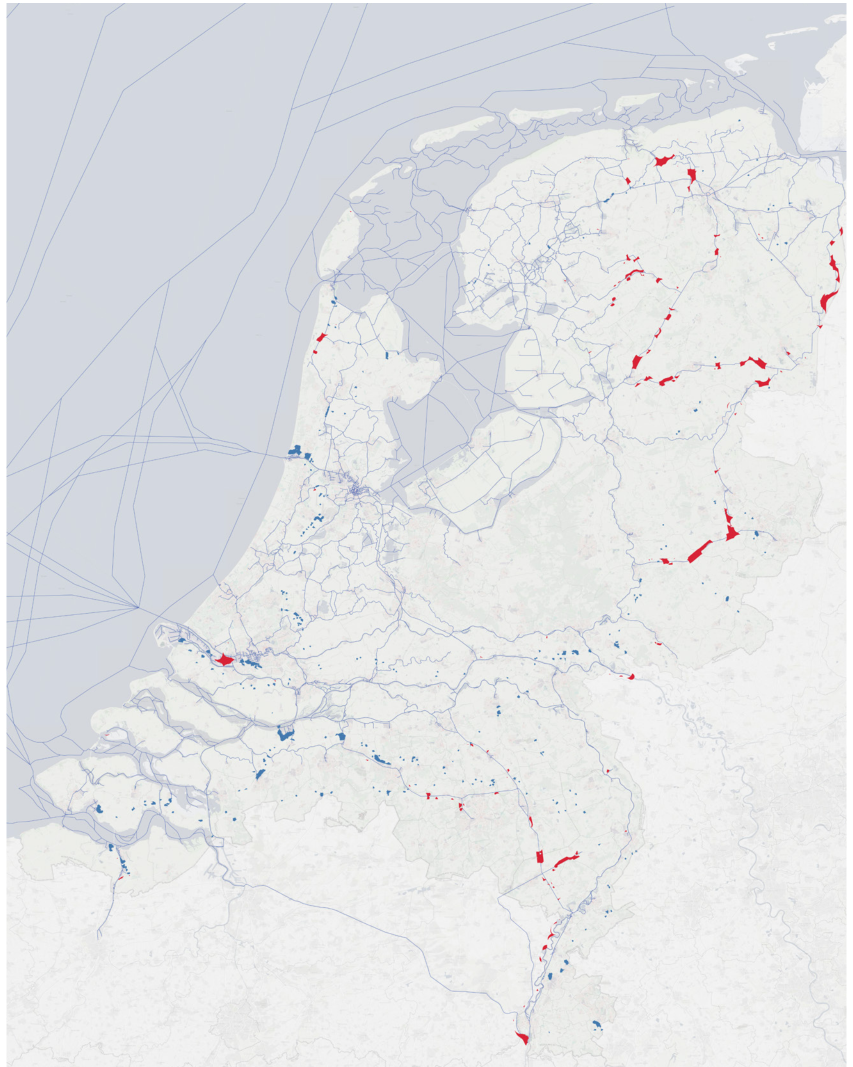
Assuming that equal amount of space is needed for circulation, repair bays storage of parts etc,

35343.1 + 35343.1 = 70686.2 meter square

Existing locations with their spatial claim and amount of materials produced

Facility	Area needed	Materials produced per year	Location	Latitude, Longitude
Metal Processing	1 sqkm	22,000 tonnes	Lynas - Mount Weld, Laverton WA 6440, Australia	-28.86122266, 122.54866358
Magnet Manufacturing	36,000 sqm	2,000 tonnes	NPM Silmet OU, Kesk 2, Sillamäe, 40231 Ida-Viru maakond, Estonia	59.35636728, 28.15302740
Electronic repair	1,000 sqm	9000 items per year (approx)	Electronic Repair Rotterdam Anthonetta Kuijlstraat 15, 3066 GS Rotterdam	51.93330793, 4.538592385
Magnet recycling	800 sqm	30 tonnes per year	Ionic Technologies 6 Heron Wharf, Belfast BT3 9AE, United Kingdom	54.63267628, -5.867112328

Suitability analysis
(processing and manufacturing)



Processing
(distance from living locations 500m, distance from natural areas 500m, within 1000m of the waterway)

Manufacturing
((distance from living locations 300m, distance from natural areas 500m, within 500m of the Hydrogen network)

Extractivism To Circularism

An exploration of the the spatial implications of the
Critical Raw Materials Act in the Netherlands

Master Thesis

Preksha Rautela