



Thesis submitted in partial fulfillment of the requirements for the
degree of Master of Science in Management

Analysis of Circular Economy Maturity of Dutch Seaports

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- Revising sentences/paragraphs originally written by me to improve them to provide a more academic language.
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For screenshot examples of AI use, please refer to the Appendix C.

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List of Acronyms

CCU: Carbon Capture and Utilisation

CE: Circular Economy

CO2: Carbon dioxide

EU: European Union

ESPO: European Sea Ports Organisation

GHG: Greenhouse gas

GWP: Gateway port

GSP: Groningen Seaports

NSP: North Sea Port

NVCE: Nederlandse Vereniging Circulaire Economie

PA: Port Authority

PERS: Port Environmental Review System

PMB: Port Managing Body

PoA: Port of Amsterdam

PoR: Port of Rotterdam

PDC: Port Development Company

ROI: Return on Investment

SAF: Sustainable Aviation Fuel

SDE++: Subsidie Duurzame Energie (Sustainable Energy Subsidy)

Abstract

The take-make-use-dispose model of the dominant linear economy places increasing pressure on the environment and natural resources, highlighting the need to decouple economic growth from environmental degradation and resource use through a transition to a circular economy (CE). As key nodes in global supply chains and centres of industrial clustering, ports can play a pivotal role in this CE transition. This thesis assesses the CE maturity of four Dutch seaports by mapping circular initiatives identified from recent port authority documents according to a CE maturity model. The findings indicate that these seaports primarily focus on energy recovery initiatives, reflecting a low level of CE maturity. However, a limited number of initiatives related to orchestrating new cargo streams suggest potential for advancing to higher CE maturity levels. In particular, the focus on the import and export of green hydrogen presents a promising opportunity to progress further in the CE transition. The research also finds that the CE maturity of Dutch seaports is broadly comparable to that of Belgian seaports. This thesis offers valuable insights for port authorities and can support the development of strategies to accelerate the CE transition by moving beyond energy recovery to higher levels of CE maturity.

Keywords: circular economy, seaports, CE maturity, CE transition, circular initiatives, case studies, Netherlands, Belgium

1. Introduction

Environmental degradation and growing resource scarcity are placing increasing pressure on the dominant linear economy, underscoring the urgent need to decouple economic growth from environmental impacts and resource consumption (Ellen MacArthur Foundation, 2013; UNEP, 2024). In this context, the circular economy (CE) concept has gained significant attention from scholars and policymakers as a way to put sustainable development into practice (Ghisellini et al., 2016; Kirchherr et al., 2017; Kirchherr et al., 2023; Murray et al., 2017). CE can be broadly defined as a regenerative system aiming to replace the ‘end of life’ concept with “reducing, alternatively reusing, recycling, and recovering materials throughout the supply chain” (Kirchherr et al., 2023, p. 7). Rising resource prices due to recent global events, such as the coronavirus pandemic and the war in Ukraine, have highlighted the vulnerability of dependence on imported raw materials, further increasing the attractiveness of recycled and circular materials (Groningen Seaports, 2022). Despite growing interest in CE, its global adoption remains limited, with only 7.2% of materials entering the economy in 2023 coming from secondary sources (CGR, 2024).

To unlock the CE’s latent potential, policymakers at various levels have added CE to the agenda. At the European level, the European Commission (2019) adopted the European Green Deal to decouple economic growth from resource use and achieve climate neutrality by 2050. One of its cornerstones is the Circular Economy Action Plan, which aims to reduce resource consumption and create sustainable development by addressing product lifecycles (European Commission, 2020). At the national level, the Netherlands strives to be at the forefront of the CE transformation, with the aim of halving primary resource use by 2030 and becoming fully circular by 2050 (Ministerie van Infrastructuur en Waterstaat, 2016). To achieve this goal, the Dutch government has developed the National Circular Economy Programme 2023-2030, which outlines five key sectors and highlights the importance of industries in advancing the CE transition (Ministerie van Infrastructuur en Waterstaat, 2023).

The European Sea Ports Organisation (ESPO) emphasises the pivotal role of European ports in facilitating this transition (ESPO, 2024). Their industrial clustering, nodal position in global logistics and supply chains, and proximity to urban areas create vast potential for industrial symbiosis, recycling, and incremental innovation (de Langen

& Sornn-Friese, 2019; ESPO, 2024; Haezendonck & Van den Berghe, 2020; Van Buren et al., 2016). Dutch ports in particular can contribute significantly to the European CE transition, as they handle the highest volume of goods among all European Union (EU) Member States (Eurostat, 2024a). The four largest Dutch seaports, Port of Amsterdam, Groningen Seaports, North Sea Port, and Port of Rotterdam, recognise the importance of CE and all have incorporated circularity in their strategies (Port of Amsterdam, 2025b; Groningen Seaports, 2024a; North Sea Port, 2023a; Port of Rotterdam, 2025a).

However, despite this strategic shift, the CE transition threatens the traditional business models of ports. CE's focus on resource efficiency and value maintenance challenges ports' traditional focus on growing cargo volumes and accommodating ever-larger ships (Carpenter et al., 2018; de Langen & Sornn-Friese, 2019). As the global economy becomes increasingly circular, fossil fuel-based industries will gradually lose relevance, creating opportunities for ports to gain competitive advantages by attracting CE activities early (de Langen & Sornn-Friese, 2019). Advancing the CE transition requires ports to think strategically by understanding where they are now, determining where they want to go, and how to get there. Yet, most ports lack a structured method to assess their current level of progress towards CE, which complicates effective decision-making and reduces the impact of CE initiatives. To this end, Haezendonck and Van den Berghe (2020) developed a CE maturity model that can help ports evaluate their level of CE maturity, that is, their level of progress in the CE transition, and assist them in planning the next steps to advance in this transition.

This thesis aims to assess the level of CE maturity of Dutch seaports by analysing and mapping the ports' CE initiatives using the maturity model designed by Haezendonck and Van den Berghe (2020) as an analytical framework, which will be explained in detail in Chapter 2. In so doing, the research seeks to acquire insight into the CE maturity of Dutch seaports, how CE maturity levels compare across Dutch seaports, and how the CE maturity of Dutch seaports compares to that of Belgian seaports, as analysed by Haezendonck and Van den Berghe (2020).

This thesis aims to answer the following main research question:

What is the circular economy maturity of Dutch seaports?

The research further addresses the following subquestions:

- *What are the similarities and differences in the CE maturity of Dutch seaports?*
- *How does the CE maturity of Dutch seaports compare to that of Belgian seaports?*

A growing body of case studies examines the CE transition in European ports. These include studies on individual ports, such as Amsterdam, Copenhagen-Malmö, Gävle, and Zeebrugge (Carpenter et al., 2018; Courtens et al., 2023; de Langen et al., 2020; Karimpour et al., 2019). Other case studies compare several European ports (Gravagnuolo et al., 2019; Kovačič Lukman et al., 2022). Finally, country-specific case studies have been performed on ports in individual EU Member States, such as Belgium and Poland (Czermański et al., 2024; Haezendonck & Van den Berghe, 2020). However, studies that assess the level of CE advancement in ports by use of a maturity model are rare, with Haezendonck and Van den Berghe's (2020) work being the only notable example. Considering the continued evolution of the CE transition and the five-year gap since the publication of their research, similar studies to determine current levels of CE maturity in European ports would provide a valuable contribution to the literature. While Dutch seaports have been the subject of CE-related case studies before (de Langen & Sornn-Friese, 2019), a study to assess the CE maturity of Dutch seaports based on a maturity model has, to my knowledge, not yet been conducted. This thesis on the CE maturity in Dutch seaports not only enables comparison with the Belgian seaports in the original 2020 study, albeit with a five-year gap, but also adds a longitudinal dimension through the inclusion of the crossborder port North Sea Port, which features in both studies. Furthermore, the application of Haezendonck and Van den Berghe's (2020) framework to a new dataset may yield new insights about the model and help identify potential adjustments.

This thesis is structured as follows: Chapter 2 presents the literature review, introducing the CE concept, examining its relevance in seaports, outlining the analytical framework, namely Haezendonck and Van den Berghe (2020)'s CE maturity model, and describing the scope of CE initiatives in ports. Chapter 3 presents the methodology, which includes the case selection of Dutch seaports and the methods used for data collection and analysis. Chapters 4 and 5 report the results and discuss the findings, while also addressing the study's limitations. Finally, chapter 6 concludes the thesis and offers suggestions for future research.

2. Literature Review

This chapter outlines the relevant literature in the transition from the predominant linear economic model towards the CE concept. It begins by underlining the need for a systematic change, supported by the limitations of the linear economic model, followed by the introduction of the CE concept and its principles. The chapter then delves into the implications of CE specifically within the context of ports, such as the transition in the role of port authorities. Next, the analytical framework of the study developed by Haezendonck and Van Den Berghe (2020) is introduced and explained in further detail. Finally, the scope of CE initiatives used in the analytical framework is described to offer a sufficient understanding of the analysis in the following chapters.

1.1. The Linear Economy

The linear economy is the dominant global economic model in which products are manufactured from raw materials, used, and discarded, creating a constant demand to extract more raw materials, thus driving pollution and waste generation (EEA, 2024). To serve the demand of a growing global middle class and continued industrialisation, global extraction of raw materials is expected to increase by 60% from 2020 levels by 2060, exacerbating the environmental impact (UNEP, 2024). In 2022, all economic activities and households in the EU generated 2.2 billion tonnes of waste, of which only 40.8% was recycled and 30.2% ended up in landfill (Eurostat, 2024b). Sustainable development requires the decoupling of resource use from environmental impacts and economic growth (UNEP, 2024). Thus, the linear economy's "take-make-use-dispose" design undermines sustainable development, as its reliance on the extraction of raw materials is inextricably linked to negative environmental impacts. Moreover, growing resource scarcity since 2000 has led to a sharp increase in resource prices and resource price volatility, casting doubt on the future economic potential of the linear economic model (Ellen MacArthur Foundation, 2013). Raworth (2018) expresses an urgent need to move from the linear, degenerative economy to a regenerative one that meets humanity's needs without exceeding planetary boundaries. Against this backdrop, the circular economy has emerged as an alternative economic model that promises to close resource loops and decouple economic growth from resource consumption and environmental degradation.

1.2. The Circular Economy

1.2.1. The Circular Economy Concept

The Ellen MacArthur Foundation (2013) defines CE as an industrial system which is regenerative by design; it aims to design out waste by creating products for a cycle of disassembly and reuse, thus replacing the end-of-life concept with restoration. The concept of CE can be distinguished from sustainability. Whereas sustainability is open-ended, aiming to benefit the environment, economy and society at large, CE mainly aims to close loops, with economic actors as its main beneficiaries (Geissdoerfer et al., 2017). In the circular model, waste becomes a secondary raw material which is recirculated to produce new products (Bianchini et al., 2019). However, CE has received criticism for being overly focused on recycling, which uses a large amount of energy and tends to degrade material quality (Bocken et al., 2025; Allwood, 2014; Cullen, 2017). While recycling can extend material use, it still involves the input of raw materials and generation of waste, creating an “economy with feedback loops” rather than a fully circular economy, which closes these loops (Van Buren et al., 2016). Thus, a true CE goes further than recycling, aiming to keep the maximum amount of value in the cycle (Ellen MacArthur Foundation, 2013). In addition, the energy to fuel the CE should come from renewables, while the linear and recycling economy still rely on finite materials, such as oil and gas (Van Buren et al, 2016; Ellen MacArthur Foundation, 2013). Another criticism is that CE currently has a limited effect on resource demand, suggesting higher recycling or circularity rates do not necessarily reduce the extraction of primary resources, as global trends, such as growing consumption, continue (Bianchi & Cordella, 2023). Figure 1 visualises the difference between a linear and circular economy.

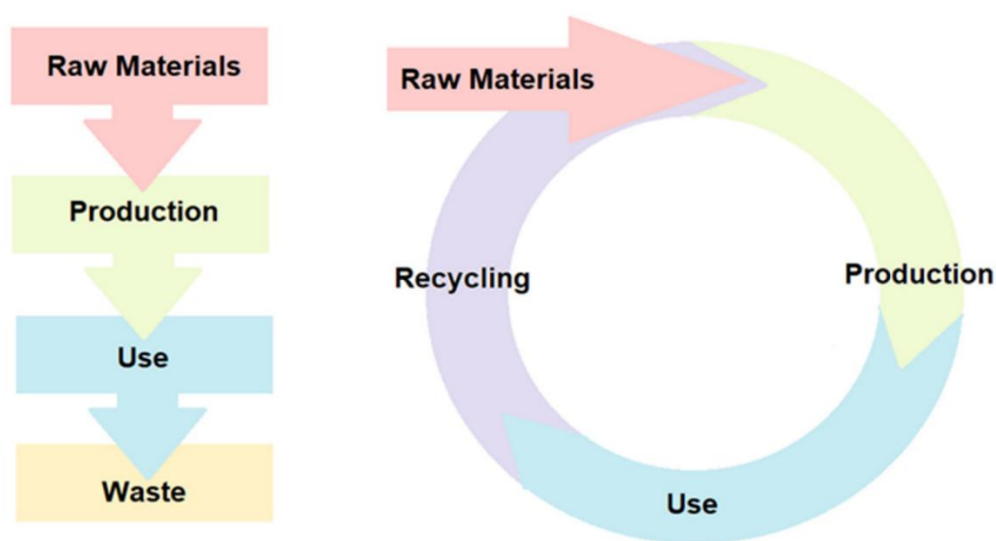


Figure 1. *Linear economy (left), and circular economy (right).* Source: Roberts et al. (2021, p. 3), adapted from Bianchini et al. (2019)

The CE systems diagram shown in Figure 2, also referred to as the Butterfly diagram, demonstrates the CE process in detail. The first steps are identical to the linear model: resources are extracted, converted into products, which are then used. Whereas in the linear model, the majority of products are discarded after use and turned into waste, CE aims to cycle products through the system longer to avoid and reduce negative externalities (Ellen MacArthur Foundation, 2013). Technical materials are reintroduced through maintenance, reuse, remanufacturing, and recycling; biological materials are returned to the biosphere through regeneration processes (Ellen MacArthur Foundation, 2013).

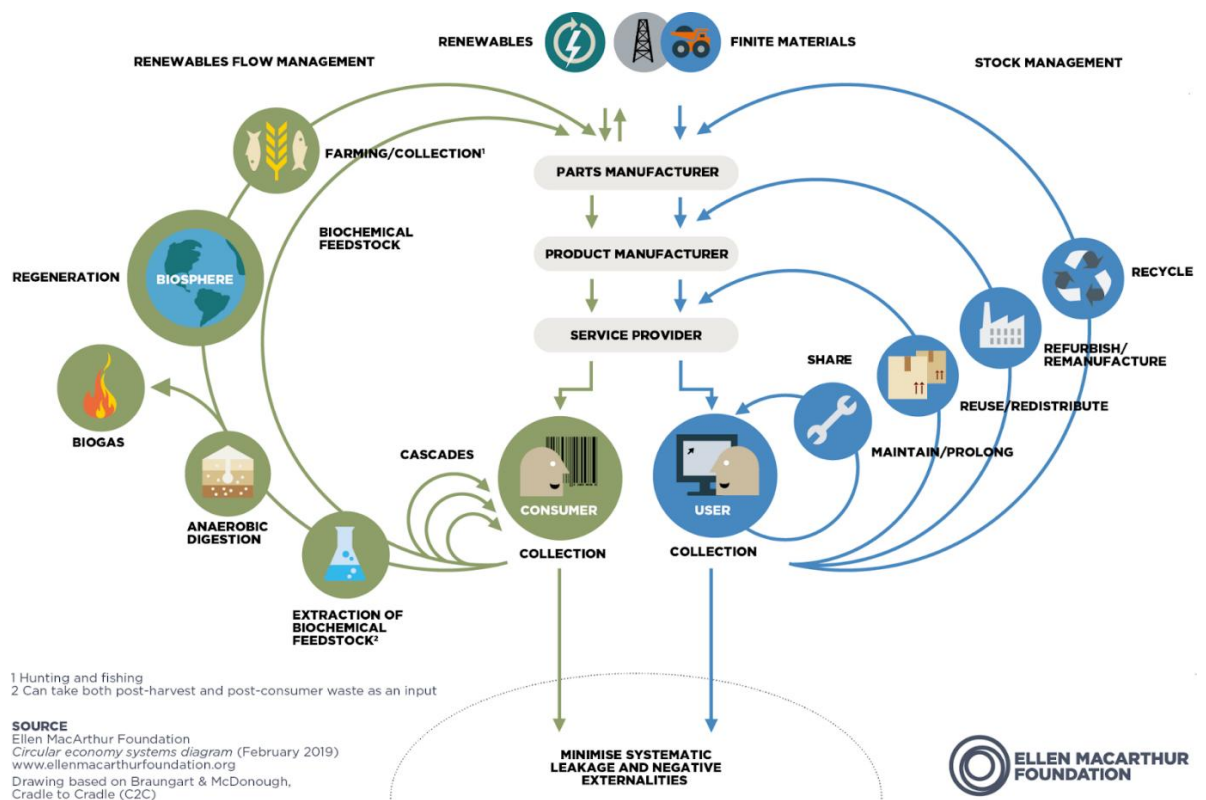


Figure 2. Butterfly Diagram. Source: Ellen MacArthur Foundation (2021)

Over the last decade, the interest towards CE in academic literature has increased, and the concept of CE has evolved, resulting in various definitions. Revisiting a previous analysis by Kirchherr et al. (2017), Kirchherr et al. (2023, p. 7) underlined that a consensus on a CE definition has not yet been reached, and derived the following conceptualisation of CE from 221 definitions in the body of literature:

“CE is a regenerative economic system which necessitates a paradigm shift to replace the ‘end of life’ concept with reducing, alternatively reusing, recycling, and

recovering materials throughout the supply chain, with the aim to promote value maintenance and sustainable development, creating environmental quality, economic development, and social equity, to the benefit of current and future generations. It is enabled by an alliance of stakeholders (industry, consumers, policymakers, academia) and their technological innovations and capabilities.”

The 4R - reduce, reuse, recycle, recover - waste hierarchy mentioned in Kirchherr et al.’s (2023) definition can be expanded with Potting et al.’s (2017) 9R framework, which provides a more comprehensive hierarchy of CE strategies. Potting et al. (2017) distinguish ten CE strategies organised from the highest level of circularity (R0) to the lowest level of circularity (R9), grouped into three categories with decreasing priority: “smarter product manufacture and use” (R0-R2), “product lifespan extension” (R3-R7), and “material recycling and energy recovery” (R8-R9) (Potting et al., 2017, p. 19). Figure 3 illustrates Potting et al.’s (2017) 9R framework. Reike et al. (2018) propose a similar framework with ten CE strategies. Morseletto (2020) argues that, although the two frameworks are nearly identical, the Rethink strategy present in Potting et al. (2017) is more relevant than Reike et al. (2018)’s little-studied ‘Re-mine’ strategy.

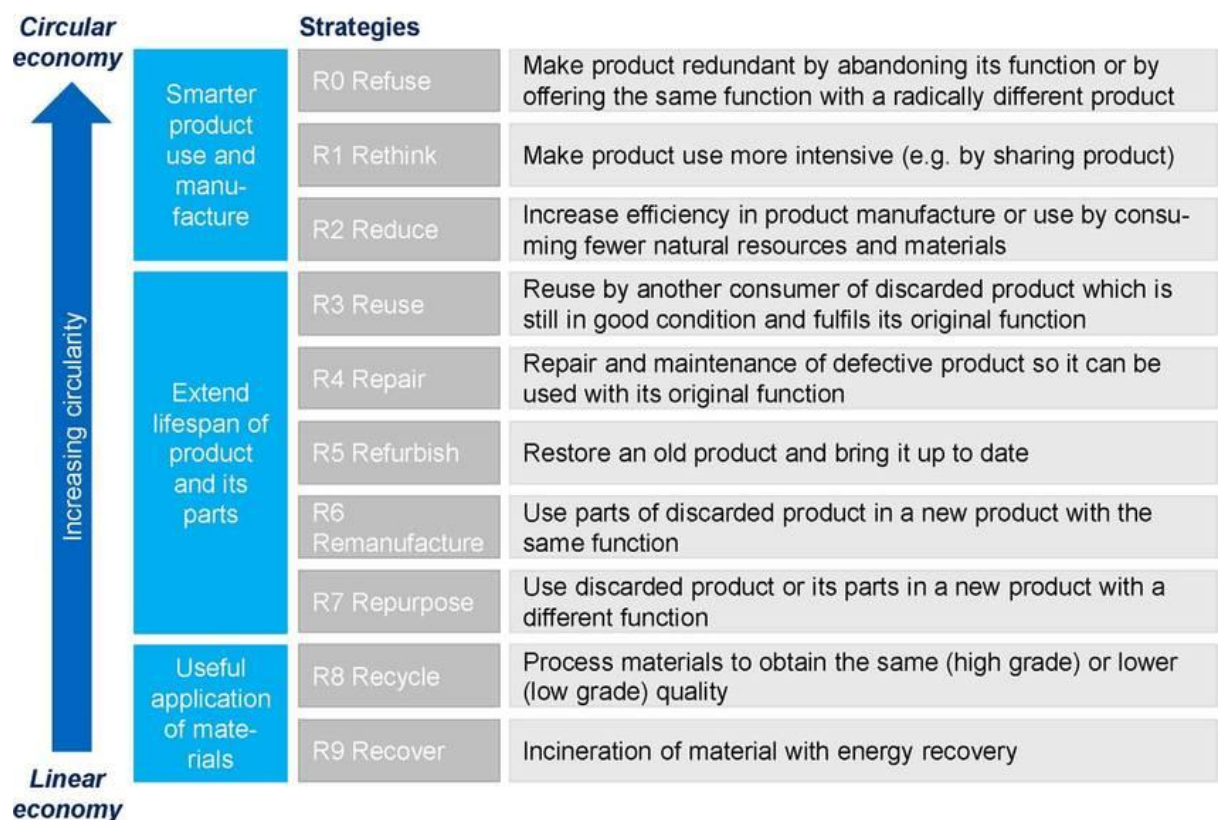


Figure 3. *The 9R framework.* Source: Kirchherr et al. (2017, p. 224), adapted from Potting et al. (2017, p. 5)

CE can also be approached from a systems perspective. Here, Kirchherr et al. (2017) distinguish three levels on which the CE transition takes place: the micro level, which examines how to increase the circularity of products, individual firms, and consumers, the meso level, which focuses on eco-industrial parks, and the macro-level, which looks at the city, region, nation, and beyond.

1.2.2. The CE Transition in Seaports

Through their commercial and industrial activities, ports cause significant strain on the environment, contributing to waste generation, and air, water, soil, and noise pollution (Barberi et al., 2021; Roberts et al., 2023; Trozzi & Vaccaro, 2000). Consequently, ports have to comply with increasingly strict regulatory requirements and have to address sustainability to retain their social licence to operate, which threatens ports' business models and competitive advantage (Carpenter et al., 2018; Moeremans & Dooms, 2021). By embracing CE, ports can “ensure their continued economic viability” while improving sustainability (Carpenter et al., 2018, p. 539). At the same time, logistics, with ports as their key nodes, are seen as an enabler of CE (Van Buren et al., 2016), meaning ports can be potential drivers of the CE transition. Indeed, ports have the potential to play a central role in the CE transition, offering the space, industrial infrastructure, and services required to develop CE activities (Courstens et al., 2023; de Langen & Sornn-Friese, 2019; ESPO, 2020; Haezendonck & Van den Berghe, 2020).

Beyond its environmental benefits, the CE transition creates opportunities for ports to attract new logistics-industrial activities, in which they have potential advantages over other industrial locations, since their excellent connectivity gives access to circular feedstock and markets, and they can be centres for demand of circular products (de Langen & Sornn-Friese, 2019). As ports are clusters, they also benefit from a higher potential for synergies through colocation in developing CE activities (de Langen & Sornn-Friese, 2019). In addition, ports can obtain “early mover advantages” by developing new CE activities ahead of other ports (de Langen & Sornn-Friese, 2019, p. 101). Roberts et al. (2021, p. 21) find that ports have both the will and potential to spearhead the CE transition, with various CE opportunities presenting themselves, such as “end-of-life fishing gear, residual heat capture from vessels, end-of-life vessels, scrubber sludge and wastewater, industrial waste, and scrap metals”.

Given the regulatory and social pressures on ports to improve sustainability, and the opportunities stemming from CE, in recent years, the interest in CE has been increasing amongst Port Authorities (PAs), also referred to as Port Managing Body (PMB) or Port Development Company (PDC) in the literature. PAs consider CE as a possible answer to various issues, such as “increased congestion and environmental impact, the need for added value and job employment, and the need to remain competitive” (Haezendonck & Van den Berghe, 2020, p. 2). According to ESPO’s 2022 Governance Report, “70% of the respondent port managing bodies have a circular economy strategy in place” (ESPO, 2022, p. 28). The main Dutch seaports all mention circularity in their strategies. Port of Amsterdam pursues its strategic goal to develop a future-proof revenue model in which the circular process industry plays a key role (Port of Amsterdam, 2025b). Groningen Seaports’ corporate plan envisions the creation of sustainable energy and resource value chains, among others, by strengthening the value chains of circular industry and the bio-based chemistry cluster (Groningen Seaports, 2024a). The strategic plan of North Sea Port, a cross-border port area stretching from Vlissingen in the Netherlands to Ghent in Belgium, includes a specific programme called “investing in the circular economy” (North Sea Port, 2023a). The Port of Rotterdam highlights climate neutrality and circularity as one of the four strategic focal points of its corporate strategy, aiming to “transform the port and industrial complex into one that produces clean energy (carriers) and uses sustainable and circular raw materials” (Port of Rotterdam, 2025a).

Despite ports’ CE ambitions, they face barriers to advancing the CE transition. One of the primary functions of ports is to act as a transport hub, where success is traditionally measured by the volume of cargo throughput. Here, CE poses a threat, because its reduced reliance on raw materials reduces maritime transport volumes in the form of raw material bulk (de Langen & Sornn-Friese, 2019). As key nodes in logistics and supply chains, ports are subject to the same barriers impeding the CE transition in the logistics industry. These are (1) institutional barriers, rooted in the linear economic tradition, (2) economic barriers, such as vested interests in traditional supply chains, (3) social and people-related barriers, such as lack of awareness among consumers, producers, and logistics companies, (4) professional barriers, i.e. lack of knowledge development and dissemination regarding CE (Van Buren et al., 2016). In addition, ports face challenges related to coordination and information sharing, product traceability, and

internal resistance to change (Mańkowska et al., 2020). In port cities, the main barriers for ports are competing land use and high costs, which can be successfully managed through collaboration between ports, cities, and other stakeholders, enabling industrial development while mitigating its negative impacts (Roberts et al., 2021). Crucially, the CE transition in ports is limited by the amount of influence PAs can exert on companies in or beyond the port area to adopt circularity in design, production, and logistics (Haezendonck & Van den Berghe, 2020). If PAs want to tackle these challenges, they need to position themselves not as a passive bystander but as an active stakeholder in the port's CE transition.

Traditionally, PAs have been regarded as relatively passive actors in the CE transition, primarily fulfilling their role as landlords, focusing on providing port infrastructure (de Langen et al., 2020; ESPO, 2022). This can be attributed to ports' commercial and economic viability being dependent on their ability to retain ships and remain accessible to them (Carpenter et al., 2018). However, there are several reasons causing PAs to adopt a more proactive approach in the CE transition. Firstly, most ports are publicly owned (ESPO, 2022), which means their mission is focused on creating value for society by reducing negative externalities and creating positive ones, rather than maximising profits (de Langen & van der Lugt, 2017; de Langen et al., 2020). Secondly, the competitive landscape of the maritime sector has caused ports to "expand beyond their traditional roles" to overcome the shortcomings of their customers (Notteboom et al., 2022, p. 359). While ports are confronted with challenges due to the CE-driven shift, this transition also presents certain strategic opportunities such as expanding and diversifying their portfolio of business activities by actively supporting and facilitating circular activities, which then evolves the port's role from passive landlords to proactive enablers of the CE transition (Carpenter et al., 2018; de Langen et al., 2020).

Kirchherr et al. (2017) draw attention to the importance of engaging business models and consumers in the CE transition. Since then, there has been a significant scholarly interest in circular business models; however, there is more to be discovered in the implementation of circular policies and strategies to achieve effective CE adoption (Kirchherr, 2022; Kirchherr et al., 2023). As their core revenue streams (port dues and land fees) are becoming more intertwined with sustainable goals, PAs also take on greater responsibility in leading the long-term success of circular initiatives, causing a shift in their business models (de Langen et al., 2020). Consequently, PAs are increasingly taking

a more active role in developing services and tools to strengthen the productivity and competitiveness of the port (de Langen et al., 2020). This shift in the port's role and the engaged activities to be implemented in the port business eco-system lead to a change in the overall port business model. Although the CE transition is still in its infancy (Carpenter et al., 2018), it is predicted to shift ports' focus to circular and local businesses while engaging more stakeholders and creating more diversified roles for the PAs, such as matchmaker, creating synergies between companies, or facilitator (de Langen et al., 2020). Indeed, ESPO (2022) has observed a transition in the role of ports in the CE from that of a landlord toward a facilitator. PAs may also go beyond the facilitator role by making investments where private investment is not an option (Notteboom et al., 2020).

While ports are increasingly adding CE to their agenda, as of today, they rarely measure the CE transition. For instance, Port of Rotterdam's strategy only mentions targets for greenhouse gas (GHG) emissions reductions and replacing 20% of fossil fuels produced and used in the port by 2030 (Port of Rotterdam, 2025). Most ports only report on the progress towards a CE by simply listing CE initiatives, for example, in their annual reports (Groningen Seaports, 2025; North Sea Port, 2023a; Port of Amsterdam, 2025b; Port of Rotterdam, 2025b). Faut et al. (2023, p. 5) argue that such an unstructured measurement system enables neither "objective monitoring over time" nor "comparing of ports' CE objectives and goals". However, due to CE's growing interest, there is an increasing demand for measurement and monitoring of the CE transition, both from potential investors seeking to assess the impact of investments, as well as from the port's stakeholders expecting transparency (Faut et al., 2023). One way to measure the CE transition is using CE indicators, such as those developed by Faut et al. (2023). Another way is a maturity model, such as designed by Haezendonck & Van den Berghe (2020), allowing ports to assess the current level in the CE transition and develop strategies for future CE growth.

1.2.3. Analytical Framework: A Maturity Model for Mapping the CE Transition

To measure ports' level of advancement in the CE transition, a maturity model can be employed. A maturity model is a tool that helps organisations assess their current level of advancement, such as in the CE transition, and provides structure by laying out an evolution path from which they can create plans for further development (Uhrenholt et al., 2022). Maturity is a gradual process consisting of multiple sequential levels, each

with its own specific requirements (Hein-Pensel et al., 2023). A maturity model, then, consists of a sequence of maturity levels for a class of objects with an expected, desired, or typical evolution path from the bottom stage, an initial state, to the highest stage, representing total maturity (Becker et al., 2009). Development through the maturity levels occurs through a process of continuous improvement, based on incremental changes (Sehnem et al., 2019). Maturity models have six distinct goals: (1) determine a starting point, (2) learn from the experience and knowledge of others, (3) provide a common language and shared vision, (4) describe the meaning of improvement and maturity for an organisation, (5) provide a framework for prioritising actions, and (6) lay out a roadmap and return on investment (ROI) for increased maturity (Caralli et al., 2012). Thus, maturity models can be a means for PAs to determine their port's position in the CE transition and design plans to gradually and continuously advance their level of maturity. At the same time, they provide a common language for understanding and communicating about the CE transition in ports, not only for internal use, but to transparently communicate to stakeholders.

Maturity models for the CE transition in ports are scarce, with the most notable example being Haezendonck and Van den Berghe's (2020) model, which maps CE initiatives according to maturity levels based on the type of circular activity and the geographic scale on which they take place. The model classifies CE initiatives in clear, distinct categories and can be conducted based on publicly available data, such as annual reports, in contrast to CE indicators for which data might be difficult to obtain, as evidenced by Kovačič Lukman et al. (2022).

The CE maturity model by Haezendonck and Van den Berghe (2020) uses two axes, each with three categories, as illustrated in Figure 4. On the x-axis, the three types of CE activities, which Haezendonck and Van den Berghe (2020) refer to as the three strategic pillars of a CE transition strategy for ports, are mapped from the lowest level (1) to the highest level of CE maturity (3):

- (1) energy recovery,
- (2) recycling,
- (3) orchestrating new cargo streams.



Figure 4. *Development path for CE in ports.* Source: Haezendonck and Van den Berghe (2020, p. 8)

The authors note that actions with higher circularity according to the 9R framework can be assumed to demonstrate a higher level of maturity in the transition from a linear to a circular economy. Therefore, the first stages of a port's CE transition in the model are energy recovery and recycling, the lowest Rs, R9 and R8, in the R9 framework. Focusing solely on energy recovery and recycling leads to an “economy with feedback loops”, in which the reuse of materials is not the priority but a “separate optimisation step”, rather than a truly circular economy (Van Buren et al., 2016). To develop a CE, ports should therefore aim to orchestrate new cargo streams, the highest level of maturity, by creating “valuable new inputs” (Peace & Turner, 1989, as cited in Haezendonck & Van den Berghe, 2020, p. 4), which can be achieved by considering “the flows following the initial choices of firms” (Haezendonck & Van den Berghe, 2020, p. 4). Thus, to orchestrate new cargo streams, ports need to look at the integral value chain and embrace circularity by design. An example is Avantium's flagship factory in the Delfzijl chemical cluster in Groningen Seaports, which produces bio-based building blocks for circular plastics. While it currently uses first-generation renewable feedstocks, its goal to increase the use of second- or third-generation feedstocks would move it closer towards a fully circular chemistry (Avantium, n.d.).

The y-axis represents the level of governance complexity at which a CE initiative takes place. The three levels are, from lowest to highest:

1. intra-port symbiosis,
2. port-city symbiosis,
3. territorial symbiosis.

These levels are based on Fusco Girard's (2013) levels of symbiosis in the port city system, respectively industrial symbiosis, urban symbiosis, and city-territorial symbiosis. Industrial symbiosis is a "business-focused collaborative approach oriented towards resource efficiency", in which companies work together to reuse each other's waste streams (Cecchin et al., 2020, p. 1). It is important to note that while industrial symbiosis usually takes place within clusters and between companies in close proximity, it can also occur over longer distances, e.g. the reuse of CO₂ transported via pipeline. Intra-port symbiosis, then, can be understood as industrial symbiosis within the port area. Urban/port-city symbiosis refers to the relationship between a port and the adjacent urban environment, and (city-)territorial symbiosis occurs in the hinterland of ports, "bringing larger parts of the supply chain into a CE transition" (Haezendonck & Van den Berghe, 2020, p. 5). A higher level of symbiosis brings with it more complexity due to an increasing number of stakeholders involved (Verbeke et al., 2013). Fusco Girard (2013) connects the geographical dimension to the type of CE activity, with industrial symbiosis often being linked to energy recovery in particular, urban symbiosis generating opportunities for recycling activities, and territorial symbiosis being most related to orchestrating new cargo streams in the hinterland.

As mentioned earlier, maturity models lay out an expected, desired, or typical development path from an initial state to maturity (Becker et al., 2009). Haezendonck and Van den Berghe (2020) argue that ports are predicted to move from left to right on the x-axis, starting with energy recovery, then developing new initiatives in recycling, and finally orchestrating new cargo streams. As the CE transition progresses and becomes increasingly complex, ports will also move higher on the y-axis, with initiatives initially focusing on industrial symbiosis within the port area, then collaborating with the adjacent or surrounding urban areas, and finally incorporating the hinterland. This leads to the expected path of development of the CE transition for ports, illustrated by the progression in Figure 4.

While the model predicts a general development path, it must be noted that the CE transition differs depending on port type and characteristics, and CE transition strategies differ accordingly (Faut et al., 2023; Haezendonck & Van den Berghe, 2020). Faut et al. (2023) outline a framework for port types shown in Figure 5. Haezendonck & Van den Berghe (2020) claim that urban ports, which can be classified as metropolitan ports or diversified hubs depending on the importance of industrial activities in the port area, have an advantage in progressing faster to the right of the maturity model, due to their proximity to large urban areas, which creates potential for recycling. The port type can be linked to the type of CE initiative, with industrial ports being more likely to have access to secondary resources for CE activities, for example, for energy recovery, due to their high potential for industrial symbiosis (Courstens et al., 2023; Faut et al., 2023). Meanwhile, while metropolitan ports usually start CE initiatives with recycling initiatives, gateway ports (GWPs) should focus on orchestrating new cargo streams (Courstens et al., 2023). In their research on CE indicators, Faut et al. (2023) argue that metropolitan ports will likely score higher on indicators related to innovation and R&D, mainly in the form of the number of start-ups in the port area due to their proximity to educational institutions. This innovation advantage may suggest that metropolitan ports could have a potential advantage in the development of new value streams. In this regard, Haezendonck & Van den Berghe (2020) highlight that the CE transition depends not only on disruption but also on incremental innovations.

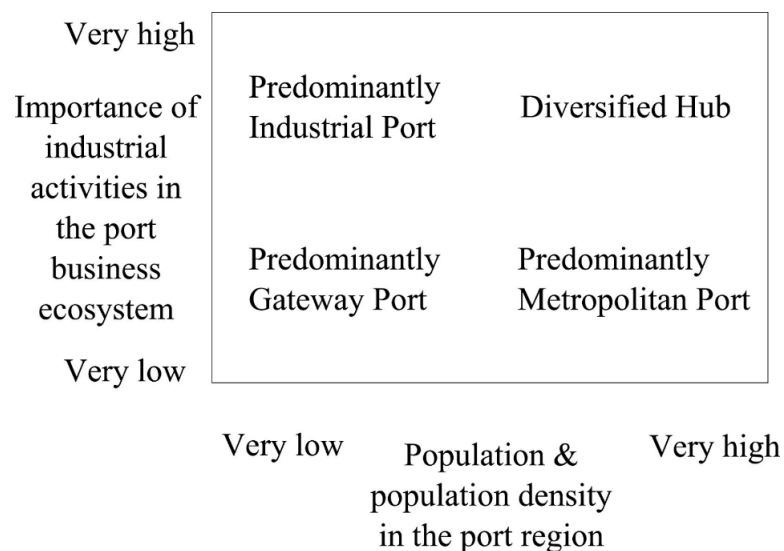


Figure 5. *Port types.* Source: Faut et al. (2023, p. 11)

Having discussed the benefits of using a CE maturity model for ports, I will briefly reflect on its potential limitations. Mettler (2011) argues that many maturity models exhibit a “knowing-doing gap”, in that they are effective tools for identifying areas of improvement, but often fail to clearly describe how to implement the necessary actions to achieve that improvement. The current maturity model may partially suffer from this issue, mainly due to the fact that ports are composed of numerous stakeholders, many of whom have a role to play in the CE transition. As the PA has limited influence over the actors in the port area, identifying the current CE level and describing the expected or desired path forward may not be sufficient to guide ports’ actions to accelerate the complex CE transition. However, since the CE transition in ports is still in its early stages (Roberts et al., 2021), Haezendonck and Van den Berghe’s (2020) model can be a useful starting point for ports’ development. Considering the CE transition is only beginning for many ports, the plans and strategies required to progress toward higher levels of CE maturity need not be overly complex. The main purpose of the model, then, beyond determining the current state of the CE transition in ports, is to gather and share knowledge on the CE transition in ports and serve as a foundation from which ports can design strategies to accelerate their CE transition.

1.2.4. Scope of CE initiatives in Ports

The maturity model described by Haezendonck and Van den Berghe (2020) assesses a port’s maturity level in the transition towards CE based on the classification of the port’s CE initiatives. In order to map CE initiatives, it is necessary to define their scope and characteristics. CE initiatives can be classified as activities, projects and platforms (Courtens et al., 2023). Whereas an activity is an initiative that is economically sustainable and does not depend on subsidies, e.g. recycling plants and waste-to-biofuel plants, a project is not (yet) economically sustainable or has a limited time frame, scale and/or business model (Faut et al., 2023). Projects are often initiatives that are still in the pilot or test phase and receive financial support (Courtens et al., 2023). A platform is a forum for collaboration and knowledge sharing between stakeholders to build projects or activities together or boost existing ones (OVAM, 2019; Courtens et al., 2023). Examples are the Smart Delta Resources platform connecting companies in the North Sea Port area and the platform Groningen Drenthe Circulair, co-founded by Groningen Seaports.

The properties of a CE initiative are the involved organisation, platform or type of collaboration, the process in the port, and the products or resources impacted by the initiative (OVAM, 2020). Additional relevant information about CE initiatives is their location, the stakeholder driving the initiatives and other partners, the start date, and the collaborative actions taken to give a clear image of the evolution of stakeholders throughout the initiative (Haezendonck & Van den Berghe, 2020). CE initiatives demand collaboration between various stakeholders, bringing together “coalitions of the willing” of different port users and the PA (Courtens et al., 2023, p. 6). Since CE initiatives can differ vastly in scale and level of commitment, ranging from small-scale training activities to large-scale infrastructure projects, the maturity model considers both hard investments, such as infrastructure, and soft commitments, such as networks and skill training, as CE initiatives (Haezendonck & Van den Berghe, 2020).

Courtens et al. (2023) find that current CE initiatives do not necessarily require considerable levels of surface area, indicating that large port areas do not have an advantage in the CE transition over smaller ones. They also distinguish two approaches to initiative development, with the key stakeholders being either internal or external to the port; in the former case, they further distinguish between a top-down or “orchestrated” approach, emanating from the PA, and a bottom-up or “organic” approach, emanating from port users (Courtens et al., 2023). They claim that, in the case of GWPs, a critical success factor for CE initiatives is the top-down support of the PA or a key external stakeholder (Courtens et al., 2023).

The next chapter of this thesis will describe the methodology employed to analyse the CE maturity of Dutch seaports using the model of Haezendonck and Van den Berghe (2020).

3. Methodology

This section presents the methodological approach and methods used in the study, including the research design, the case selection, data collection and analysis. The research aims to examine the CE maturity of the selected Dutch seaports by mapping their current CE initiatives according to the maturity model developed by Haezendonck & Van den Berghe (2020), which forms the analytical framework of the study. Two different data collection methods were used to ensure the robustness of research, namely document and content analysis, as well as expert interviews. These methods will be explained in detail in the following sections.

Although CE has gained traction in recent years, there is still a significant gap in the research on the CE maturity in seaports. Furthermore, ports' unique characteristics, such as geographic location, size, and strategies, make it especially difficult to compare the CE maturity of ports in a structured way. Therefore, due to the exploratory nature of the research questions, this qualitative research adopts a multiple case study strategy. The multiple case study design can provide insights into the CE maturity within each seaport and across all ports, which can help identify similarities and differences between them to explore any possible common or unique barriers, any patterns or differences in implementation of CE initiatives by observing each case in detail within itself while also providing a cross-case analysis (Baxter & Jack, 2008; Gustafsson, 2017; Haezendonck & Van den Berghe, 2020).

3.1. Case Selection

The case selection consists of two parts: first, the selection of a common element between the group of ports, in this case, the country, and second, the selection of the specific ports within that group.

This thesis focuses on the CE maturity of Dutch ports. A single country was selected for two reasons: first, choosing a single country allows an overall assessment of CE maturity in seaports within that country. Second, by selecting ports from one country, the ports share the same national regulatory environment. This ensures that national regulatory differences do not influence the differences in CE maturity between the ports, allowing the focus to rest on the impact of port-related characteristics, such as port size, surface area, and port type, on CE maturity. The Netherlands was selected as the country of choice because its ports handle the highest volume of goods in the EU, representing

16.1% of the EU total in 2023 (Eurostat, 2024a). Their economic importance means that Dutch seaports have a significant role to play in the CE transition in Europe and can serve as potential examples for other European ports. Furthermore, the Netherlands was chosen because it seeks to be fully circular by 2050 and, with its “National Circular Economy Programme 2023-2030”, has developed a clear national CE strategy. De Langen and Sornn-Friese (2019) noted that the Dutch program to become circular by 2050 has been embraced by companies and associations and has led to various circular initiatives in specific sectors. This may point to the development of CE initiatives in Dutch ports.

The specific Dutch seaports were selected based on their economic significance, specifically their cargo throughput. A second factor that was taken into account was data availability. To be considered for selection, a port must have a website where data on CE initiatives can be retrieved. Four ports were selected for this study. Table 1 shows an overview of throughput in Dutch ports in 2024, with the selected ports marked in bold.

Gross weight of goods handled in 2024 (thousand tonnes)	
Rotterdam	397,322
Amsterdam	78,756
Zeeland Seaports (North Sea Port)	37,293
Vlaardingen	10,382
Delfzijl (Groningen Seaports)	7,982
Moerdijk	5,695
Harlingen	396
Netherlands - other ports	292

Table 1. *Gross weight of goods handled in Dutch ports.* Source: Eurostat (2023)

The first three ports, Port of Rotterdam, Port of Amsterdam, and North Sea Port were selected based on their throughput. All three have a website via which data can be collected. It has to be noted that North Sea Port is referred to in Table 1 as Zeeland Seaports, which includes Vlissingen and Terneuzen. In 2018, Zeeland Seaports merged with Ghent to form the cross-border port North Sea Port. For the purpose of this thesis, North Sea Port will be considered as a whole. Its cross-border nature introduces

regulatory complexity, which may impact the implementation of CE initiatives. While this sets it apart from the other Dutch ports, it may also highlight differences or similarities between it and the other ports. Furthermore, its inclusion in Haezendonck and Van den Berghe's (2020) study on the CE maturity of Belgian seaports adds a longitudinal aspect, allowing for the evaluation of the progress in its CE maturity over the last 5 years.

The fourth port selected is Groningen Seaports, which includes Delfzijl and Eemshaven. While Table 1 shows that Vlaardingen has a higher throughput than Delfzijl, in contrast to Groningen Seaports, it does not have its own website, which would complicate data collection. Moreover, Eemshaven is not included in the list, meaning that the total throughput of Groningen Seaports could be closer to or higher than that of Vlaardingen. In its 2024 annual report, Groningen Seaports reported a total throughput of 13.6 million tonnes (2025), which, according to the maritime news outlet Schuttevaer (2025), was separated between approximately 5.1 million tonnes in Delfzijl and approximately 8.4 million tonnes in Eemshaven. While this cannot be compared directly with the data from Eurostat in Table 1 due to potentially different methods used, since Eemshaven has a higher throughput than Delfzijl, Groningen Seaports as a whole can be assumed to have a higher throughput than Vlaardingen.

In sum, the four selected ports are the Port of Amsterdam, Groningen Seaports, North Sea Port, and the Port of Rotterdam. All four ports include circularity in their strategy, which could indicate data availability (Port of Amsterdam, 2025b; Groningen Seaports, 2024a; North Sea Port, 2023a; Port of Rotterdam, 2025a). Port of Amsterdam is a large, diversified port with a small surface area, which is active in the energy industry and is an important logistics hub for agribulk. Groningen Seaports is a medium-sized industrial port consisting of Eemshaven, which is active in the offshore wind farm industry, and Delfzijl, which hosts a large chemical cluster. North Sea Port is a large cross-border port, which includes the ports of Vlissingen, Terneuzen and Ghent. Its focus is on energy and heavy industry, such as chemicals and steel. The Port of Rotterdam is the largest port in Europe and a major cargo and energy hub.

3.2. Data Collection and Analysis

The study is mainly based on desk research, with data collected from documents and content published by the PAs and other relevant sources to help map the CE initiatives

of each port according to the maturity model. The findings of this analysis are supported and enriched further with expert interviews.

3.2.1. Document and Content Analysis

As explained in the literature review, the maturity model determines the level of maturity by mapping the CE initiatives of each port according to their CE transition strategy categories (energy recovery, recycling, orchestrating new cargo streams), and the geographical scale at which they occur (intra-port, city-port, territorial) (Haezendonck & Van den Berghe, 2020). Within the scope of this research, a CE activity, project, or platform is considered a CE initiative (Courtens et al., 2023). It should also be noted that, as CE is a dynamic field, what is counted within these strategy categories may change over time. Therefore, to be consistent with the original study by Haezendonck and Van den Berghe (2020), renewable energy initiatives such as wind farms are considered as a CE initiative, even though it may be argued that they are not inherently circular, as they could be used as an excuse to further prolong the use of raw materials.

To identify and categorise the CE initiatives of each selected port, document and content analysis are considered the most fitting methods. The scope of the analysis is limited to the publicly available data from the last five years, exclusively focusing on reported currently ongoing CE initiatives. Here, ongoing refers to the initiatives that are operational or in the planning phase. This is to limit the scope so that it is manageable in the context of a master’s thesis. After having identified publicly available secondary data, the main data sources were annual reports published between 2020 and 2025 (both inclusive) and news articles from the official websites of PAs. The available annual reports are shown in Table 2. This data was complemented by additional sources, namely strategy documents, EcoPorts PERS (Port Environmental Review System) application documents where available, and relevant platform and cluster websites, e.g. Smart Delta Resources for North Sea Port, and Chemport Europe for Groningen Seaports, from 2020 up to the present. These additional sources were used to fill in the gaps in reporting and to confirm the active status of analysed initiatives.

Annual Reports	Port of Amsterdam	Groningen Seaports	North Sea Ports	Port of Rotterdam

2020	✓	✓	-	✓
2021	✓	✓	-	✓
2022	✓	-	✓	✓
2023	✓	✓	✓	✓
2024	✓	✓	-	✓

Table 2. *Availability of annual reports between 2020-2024 by the port authorities.*

There were certain limitations during the analysis. None of the four ports had a dedicated sustainability report available. The annual reports of 2020, 2021, and 2024 for North Sea Port, and 2022 for Groningen Seaports were missing. The experts at these ports were informed and requested to share the documents. While they did not provide the annual reports, the expert at North Sea Port shared a document which included some of their CE projects. These CE projects were checked to confirm they are still ongoing, then added to the analysis for this port accordingly. To support data triangulation of findings, each expert at the selected ports was sent the completed mapping of their port's CE initiatives for feedback. However, none of the ports shared any feedback. During the interviews, the experts at the ports were also asked to share two to three flagship CE initiatives from their ports in an effort to address gaps in the data and highlight their focus on CE transition. It should be noted that some initiatives may not be included within the data due to PAs' potential lack of awareness of all ongoing CE initiatives in their port.

3.2.2. Expert Interviews

Semi-structured expert interviews were employed as a supportive method to confirm some findings from the CE mapping analysis, as well as to gain a deeper understanding of the complexities of the CE transition in seaports. One expert per port was selected among professionals working in CE within the selected ports. In addition, to offer a broader perspective on the CE transition in European, Dutch and Belgian seaports, an interview with an expert from ESPO was conducted. The experts were contacted via email and/or phone first to explain details of the research and the interviews. Upon confirmation, every expert was sent the following documents prior to the interview

to give them time to prepare for the interview: the CE maturity model by Haezendonck & Van den Berghe (2020), the interview questions, and the informed consent form.

The interviews embraced an inductive approach, consisting of open-ended questions to give experts space to share their insights freely, without being narrowly guided, to better understand the complex nature of CE transition within seaports. The interview questions consisted of two sets of questions, one set of questions for the circularity experts at the selected ports and another set of questions for the expert at ESPO. These questions can be found in the Appendix. Due to its unique position as a cross-border port, North Sea Port's expert was asked an additional question to delve into the dynamics between Belgium and the Netherlands.

Before starting the recording, participants were given explanations about the study and informed about the anonymity of the interviews to make them feel more comfortable and to reduce social desirability bias. Before starting the recording, a short amount of time was allocated to build rapport with the experts and to provide an opportunity to ask any questions they may have had beforehand. All interviews were conducted via online meetings, and lasted between 35 minutes to 1 hour 10 minutes. In order to protect the anonymity of the participating experts, their names and positions were removed from the thesis and the transcripts. The recordings and transcripts of the interviews and the informed consent forms are available upon request.

After the interviews, the transcripts were shared with the experts to enhance the accuracy and reliability of the data and to give them an opportunity to revise and/or retract statements if necessary. The interviews were analysed through manual inductive analysis. Document and content analysis findings have been used to triangulate the data. It is important to note that the views expressed by the experts are their own and do not necessarily represent the views of the ports.

In the next chapter, the findings from the document and content analysis, and expert interviews will be presented.

4. Results

This chapter begins by presenting the results of the document and content analysis of CE initiatives for each of the four ports, incorporating relevant insights from the expert interviews. It then provides a general overview of the findings across all ports, highlighting similarities and differences. Subsequently, the ports' CE initiatives are mapped onto the transition framework designed by Haezendonck & Van den Berghe (2020), as introduced in Figure 4. Finally, the chapter concludes by outlining general themes that emerged during the expert interviews.

4.1. Document and Content Analysis

4.1.1. *Port of Amsterdam*

The Port of Amsterdam counts 49 CE initiatives, of which over 40% are initiated by the PA. Over three quarters of initiatives are related to energy recovery (37), while the remaining initiatives are approximately evenly divided between recycling (5) and organising new cargo streams (7). A flagship energy initiative is the Greenmills complex, which turns waste streams into biofuels through industrial symbiosis (Expert at PoA, personal communication, July 7, 2025). The number of recycling initiatives is remarkably low. This was further emphasised by the expert at Port of Amsterdam (personal communication, July 7, 2025), who estimated that, disregarding new cargo streams, 70% of CE initiatives are related to recycling and only 30% are related to energy recovery. The low number of recycling initiatives recorded may be related to the fact that many recycling companies have been operating for a long time in the port with little change to their activities, causing those CE activities to be potentially excluded from data published in the last five years. Of the initiatives classified as orchestrating new cargo streams, over half are related to facilitating the future import and export of green hydrogen.

Over one fifth of the CE initiatives in the Amsterdam port area are publicly subsidised, with energy initiatives being the primary beneficiaries. The highest subsidy of a maximum value of €400M was awarded by the Dutch government to Gidara Energy's planned Advanced Methanol Amsterdam facility under the scheme "Subsidie Duurzame Energie" (SDE++), or sustainable energy subsidy. This energy recovery initiative will turn unrecyclable waste into biofuels. For all but a few of the initiatives, the overall budget is unknown.

4.1.2. Groningen Seaports

Groningen Seaports yielded 60 CE initiatives, the highest among the studied ports. Nearly 20% of these initiatives are led by the PA. When looking at the distribution of the types of initiatives, the number approximately halves from one category to the next. 36 initiatives, or 60% of all initiatives, are classified under energy recovery, 16 under recycling, and 8 under organising new cargo streams. Among the energy recovery initiatives, nearly half take place on the territorial level. Notably, recycling initiatives make up half of the initiatives led by the PA, including the €40M investment in the development of Circulands industrial park, purpose-built for the reuse of waste flows, such as e-waste, plastics, and wind turbine blades (Groningen Seaports, 2024b). The majority of new cargo streams stem from the chemical cluster in Delfzijl. A flagship initiative in this category is Avantium's factory producing plant-based polymers for circular plastics (Avantium, n.d.; Expert at GSP, personal communication, July 15, 2025).

Over one fourth of CE initiatives in Groningen Seaports are supported by public subsidies. The highest public subsidy, up to €870M for the construction of an offshore wind farm, is the largest in the four ports (European Commission, 2021). Here also, the information on budgets is limited. Despite limited information, over half of the new cargo streams initiatives have significant budgets, totalling over €400M.

4.1.3. North Sea Port

North Sea Port has 38 CE initiatives, the lowest number among the four ports. This may be partly related to the fact that only the 2022 and 2023 annual reports were available, potentially leading to missing data. However, the impact of the missing annual reports is thought to be limited, as a list of CE projects provided by the PA, news from the PA's website and the Smart Delta Resources platform were used to fill in the gaps in the data. The PA plays a leading role in nearly 20% of the initiatives. 23 initiatives, representing approximately 60% of the total, fall in the energy recovery category. The remaining initiatives are almost equally divided between recycling (7) and new cargo streams (8). The new cargo streams are mostly related to promoting the green hydrogen trade. There is a significant emphasis on industrial symbiosis through the development of designated areas centred around large industrial sites, such as Valuepark Terneuzen, a joint venture with DOW Terneuzen, and North-C Circular, a joint venture with ArcelorMittal in Ghent. North-C Circular, which was identified as a flagship initiative,

aims to decarbonise ArcelorMittal's operations, for instance, through Carbon Capture and Utilisation (CCU) and waste-to-energy projects (Expert at NSP, personal communication, July 8, 2025; North Sea Port, 2023b). One such example is the Torero project, which transforms waste wood into bioethanol (Torero, n.d.). Valuepark aims to promote circularity in the plastics value chain through the production of circular raw materials based on advanced recycling and CO₂ reuse (North Sea Port, n.d.c). Currently, activities at Valuepark seem to be mostly linked to industrial symbiosis within the chemical cluster, most closely associated with energy recovery. However, it has the potential to develop new value streams in circular plastics in the future, supporting DOW's goal to become fully circular by 2050.

Over 25% of initiatives received public funding. The majority of subsidies, both in number and value, were awarded to energy recovery initiatives. The largest known subsidy is a €35M combined investment by the EU, the Belgian, and the Flemish government for ArcelorMittal's Steelanol project, which converts industrial waste gases to bio-ethanol (Smart Delta Resources, 2025). Budget information was available for only a small number of initiatives.

4.1.4. Port of Rotterdam

In the Port of Rotterdam, 56 CE initiatives were identified. The PA initiated over 25% of these initiatives. Over 70% of the initiatives are related to energy recovery (40), with the rest of the initiatives nearly evenly distributed among recycling (7) and orchestrating new cargo streams (9). Just shy of half the energy initiatives take place at the territorial level, which is reflective of the scale and global supply chains of energy companies in the Rotterdam port area. An example is Neste's €1.9B expansion of its biofuel and sustainable aviation fuel plant in Maasvlakte, which is the largest in Europe (Neste, 2022; Neste, 2025). A flagship initiative is REKO, a large-scale tar and construction material recycler operating at the territorial level (Expert at PoR, personal communication, July 14, 2025). Notably, all initiatives in the "orchestrating new cargo streams" category are related to developing the green hydrogen market with the Netherlands and the Port of Rotterdam as their focal points.

Approximately one fifth of initiatives benefit from public subsidies. Energy initiatives make up the bulk of these, with the largest being a €99M EU subsidy for Elygator, a planned green hydrogen plant with a total investment of over €1B (Air

Liquide, 2025; European Commission, 2023). Again, only a few initiatives clearly communicate their budget.

4.1.5. General Overview

Table 3 displays the main information on the CE initiatives in each of the four ports as well as their throughput, port area, available space, and port type. The latter was determined based on Faut et al. (2023)'s framework, illustrated previously in Figure 5.

	Port of Amsterdam	Groningen Seaports	North Sea Port	Port of Rotterdam
Throughput in 2024 (tonnes)	62,200,000 (a)	13,600,000 (c)	66,300,000 (e)	435,800,000 (h)
Port Area (ha)	1,200 (b)	2,802 (d)	9,100 (f)	12,600 (i)
Available space (ha)	unknown, but limited	482 (d)	500 (g)	unknown, but limited
Port type	Diversified hub	Industrial	Diversified hub	Diversified hub
CE strategic focus	Energy hub	Energy hub	Energy hub	Energy hub
# of initiatives	49	60	38	56
# of initiatives initiated by PA	20	11	7	15
# of supported initiatives by public subsidies	10	17	10	12
Total budget of public subsidies	511,857,610	922,100,000	79,967,253.61	172,593,725.39

Table 3. *Overview of characteristics and circular initiatives of Dutch seaports.* Sources: (a) (Port of Amsterdam, 2025a, p. 4), (b) (Port of Amsterdam, n.d.), (c) (Groningen Seaports, 2025), (d) (Groningen Seaports, 2024c), (e) (North Sea Port, 2025), (f) (North

Sea Port, n.d.a), (g) (North Sea Port, n.d.b), (h) (Port of Rotterdam, 2025b, p. 6), (i) (Port of Rotterdam, n.d.)

In total, 199 initiatives were counted. It should be noted that this is lower than the sum of initiatives in each of the ports, because some initiatives involved multiple ports and were therefore counted as a separate initiative for each port. Of the 199 CE initiatives, 68% are energy initiatives (144), 17% recycling (34), and 15% orchestrating new cargo streams (29). All four ports have a clear energy focus. While around half the energy initiatives (67) are limited to the port area, a sizable number (54) have a territorial dimension. The majority of recycling initiatives (21) take place within the port. Finally, nearly all new cargo streams (26) occur at the territorial level.

The relatively low recycling initiative numbers could be caused by the possible exclusion of older active initiatives from the PAs' reporting. This may have had an outsized effect on recycling, since many ongoing recycling operations have been present in the ports for many years. However, since there are more recycling initiatives than new cargo streams in Groningen Seaports and only slightly fewer recycling initiatives than new cargo streams in the other ports, it can be assumed that recycling initiatives are more prevalent than orchestrating new cargo streams in all ports. Considering energy initiatives represent the majority of initiatives in every port, it can be further assumed that, even when including older ongoing initiatives, energy initiatives will remain the most common.

Table 3 shows that the absolute number of CE initiatives across the four ports is relatively similar, with North Sea Port as an outlier, despite their differences in throughput, surface area, available space, and port type. The level of involvement of the PA varies considerably across the four ports. The Port of Amsterdam takes the lead, being the only PA to initiate over 40% of the CE initiatives. The Port of Rotterdam leads around 25% of initiatives, and Groningen Seaports and North Sea Port each initiate close to 20% of initiatives. The four ports largely follow a similar distribution of CE initiatives, with the majority being energy-related and the remaining initiatives approximately evenly divided over recycling and orchestrating new cargo streams. Groningen Seaports stands out as the only port with more recycling initiatives than new cargo streams, and follows a more gradual decline in the number of CE initiatives across the three strategic CE pillars. All four ports have a similar number of new cargo streams, and the majority of

these initiatives are related to facilitating and facilitating the import and export of green hydrogen.

Around one fourth of total CE initiatives are supported by public subsidies, and most of these subsidies are for energy projects. Regarding the total budget of subsidies, a wide range of budgets can be observed across the ports. North Sea Port has the lowest budget, and Groningen Seaports has by far the highest budget, which can be largely attributed to a single subsidy for an offshore wind farm. Information on budgets is scarce for all ports, but, in general, energy initiatives have the highest budgets.

4.1.6. Mapping of CE Initiatives

In Figure 6, the CE initiatives are mapped according to Haezendonck and Van den Berghe's (2020) CE transition framework in nine distinct categories based on the type of CE initiative (energy recovery, recycling or orchestrating new cargo streams) and the geographical level at which the initiatives take place. For all ports, the majority of initiatives is located on the left-hand side of the framework, with the highest single category either the lower left corner (energy recovery, intra-port symbiosis) or upper left corner (energy recovery, territorial symbiosis). The numbers in the colored circles and squares represent the number of initiatives in the port for a specific category. The circles represent the initiatives for which the budget is known, while the squares represent initiatives for which the budget is unknown. The five circle sizes indicate the following ranges of total known budget of initiatives: €0 to €10M, €10M to €50M, €50M to €200M, €200M to €500M, and finally exceeding €500M.

Figure 6 illustrates that, limited budget information notwithstanding, the largest budgets can be found in the energy recovery category. Groningen Seaports stands out as the only port with a considerable known budget in orchestrating new cargo streams.

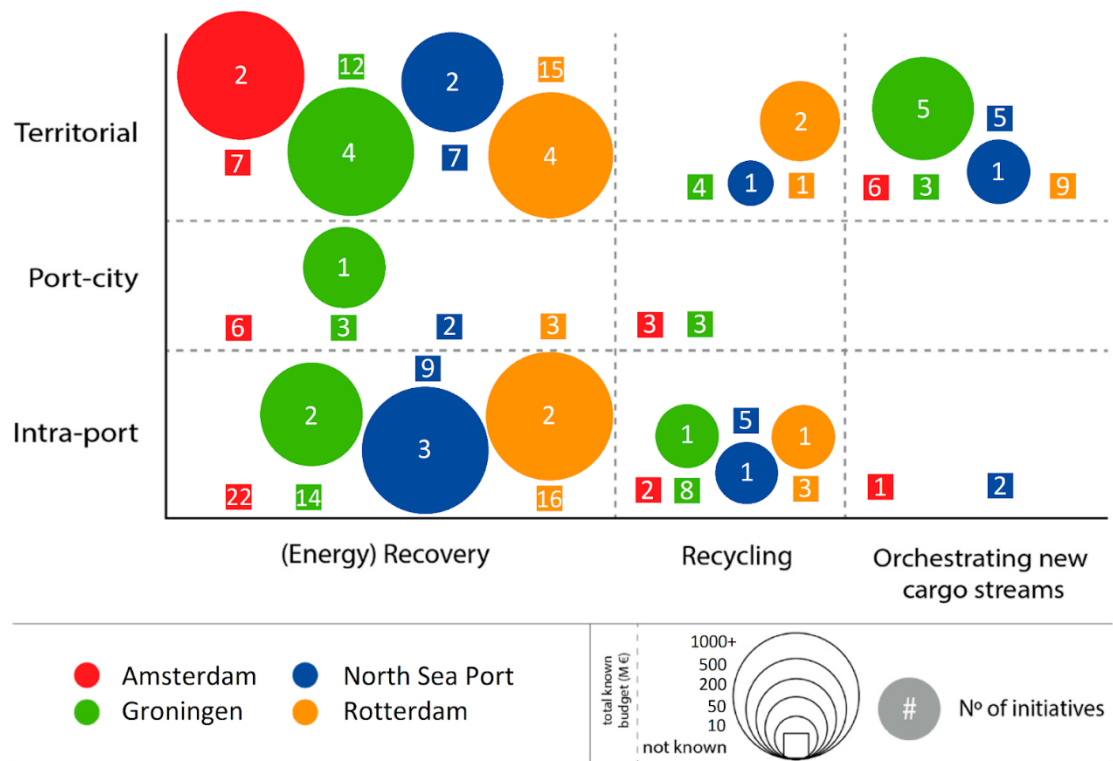


Figure 6. Mapped CE initiatives for four Dutch seaports. Source: adapted from Haezendonck and Van den Berghe (2020)

4.2. Expert Interviews

4.2.1. Port Area

Some experts noted that smaller ports can make faster progress in the CE transition. The expert at Groningen Seaports (personal communication, July 15, 2025) remarked that “we are smaller and we can progress faster”. The expert at Port of Rotterdam (personal communication, July 14, 2025) agreed that smaller ports can move faster and argued their large port area leads to higher complexity due to more stakeholders, governmental levels, companies and activities being involved.

4.2.2. Available Space

The experts perceive available space as an advantage in developing new CE initiatives. Groningen Seaports’ expert (personal communication, July 15, 2025) argued that their available greenfield space gives them an advantage over, for example, Rotterdam, where one company needs to leave to make room for another. The expert at

Port of Amsterdam (personal communication, July 7, 2025) identified space as a difficulty.

4.2.3. Role of PAs in the CE Transition

All experts identified the role of the PA in CE transition similarly, with some nuances. The common roles included landlord, facilitator and matchmaker. In addition, the PA can become an investor to facilitate companies. The experts shared varying opinions about the investor role. While the Port of Rotterdam refrains from investments to provide a level playing field and maintain a neutral position (Expert at PoR, personal communication, July 16, 2025), the Port of Amsterdam indicated its role as a “co-creator”, offering investment if no one is found to invest in infrastructure for synergies in the port (Expert at PoA, personal communication, July 7, 2025). Groningen Seaports sees investing as a way to speed up CE initiatives, such as by developing a Kickstart hydrogen pipeline (Expert at GSP, personal communication, July 15, 2025). Finally, North Sea Port mentioned its “connector” role between the industries and the authorities to discuss “policy issues bothering industries on circularity or other topics” and on “small-scale issues that are not going smoothly” (Expert at NSP, personal communication, July 8, 2025).

4.2.4. CE Maturity in Dutch Seaports and Comparison of CE Maturity of Seaports between the Netherlands and Belgium

The experts were unable to provide clear insights on the CE maturity of their seaport. Despite their limited information on the CE transition in other Dutch and Belgian seaports, they largely estimated that Belgian and Dutch seaports have similar levels of CE maturity (Expert at ESPO, personal communication, July 8, 2025; Expert at NSP, personal communication, July 8, 2025; Expert at PoR, personal communication, July 14, 2025).

4.2.5. Barriers to the CE Transition

A recurring theme in the interviews was the challenge posed by limited nitrogen space, environmental space, and power grid congestion to the development of CE initiatives. The concept of nitrogen space is linked to the Dutch nitrogen crisis, which started in 2019 when the Council of State ruled that the Netherlands was in breach of European regulations and, as a result, implemented strict nitrogen emission limits (RIVM,

n.d.). Ports that are within the emission limits are said to have available nitrogen space. Environmental space refers to limits for noise and odour pollution (Rijksoverheid, n.d.). The experts at North Sea Port, Port of Amsterdam, and Port of Rotterdam drew attention to the need for environmental space for circular activities in ports, including waste streams (Expert at NSP, personal communication, July 8, 2025; Expert at PoA, personal communication, July 7, 2025; Expert at PoR, personal communication, July 14, 2025). The expert at Groningen Seaports (personal communication, July 15, 2025) noted that the port uses its available environmental space, nitrogen space, and power to obtain a “head start in the circular ambition”.

4.2.6. Inter-Port Cooperation

The requirement for cooperation between the ports in advancing the CE transition is highlighted by most of the experts (Expert at PoR, personal communication, July 14, 2025; Expert at PoA, personal communication, July 7, 2025; Expert at GSP, personal communication, July 15, 2025). Whereas they acknowledge the ports’ mutual competition, the experts stated that ultimately, “the Netherlands as a whole” should be positioned in the CE transition to be able to accommodate value flows (Expert at GSP, personal communication, July 15, 2025; Expert at PoR, personal communication, July 14, 2025). Furthermore, the Port of Amsterdam underlined the importance of working together across countries to “make breakthroughs” in CE, such as through collective lobbying to encourage CE transition (Expert at PoA, personal communication, July 7, 2025).

4.2.7. Measurements for CE Transition in Ports

While most experts acknowledge the importance of measuring CE, the interviews show that none of the Dutch seaports actively use indicators to measure the CE transition at this stage. North Sea Port is part of a project to apply the 12 CE indicators developed by Faut et al. (2023), and Groningen Seaports is developing its own CE indicators (Expert at GSP, personal communication, July 15, 2025; Expert at NSP, personal communication, July 8, 2025). Port of Rotterdam and Port of Amsterdam do not yet have KPIs, respectively expressing difficulties quantifying CE and determining what qualifies as circular (Expert at PoR, personal communication, July 14, 2025).

In the next chapter, the data obtained from content and document analysis will be critically analysed, complemented by insights from the expert interviews.

5. Discussion

In this chapter, the findings in Table 3 will be analysed, focusing on the relationships between the ports' characteristics (throughput, surface area, available space, port type) and the data gathered on their CE initiatives. Then, the mapping of the CE initiatives shown in Figure 6 will be used to address the research questions and discuss the implications for Dutch seaports and PAs. The chapter concludes with the limitations of the study.

5.1. Port Throughput

Table 3 shows that among the examined Dutch seaports, port size in terms of throughput does not correlate with the number of CE initiatives. However, Figure 6 indicates that port size does appear to relate to the scale of initiatives. In their analysis of five Belgian ports, Haezendonck and Van den Berghe (2020) found that both the absolute number and the relative size of CE initiatives are higher in larger diversified ports, which they attributed to the fact that such ports have more means and firms to support initiatives. This observation only partially applies to the studied Dutch ports. Groningen Seaports, the smallest port by throughput, has the highest number of CE initiatives and has significantly more initiatives than North Sea Port, the second largest. This suggests that the number of initiatives does not relate directly to port size. Given that all four ports are medium to large in size, this could indicate that beyond a certain point, port size becomes less important for the development of more initiatives. Where exactly this threshold lies remains unclear.

However, when considering the scale of initiatives, projects in the Port of Rotterdam generally involve larger budgets, where data is available. A notable exception is Groningen Seaports, which has high budgets in energy recovery due to its key role in offshore wind farm projects. Yet, these are typically developed by international consortia that use the port as a temporary construction hub, without a permanent presence or financial ties to the port. Not counting these initiatives, the budgets of initiatives in Groningen Seaports are smaller than those in the other ports. The Port of Rotterdam, in particular, hosts multiple large-scale energy initiatives, such as Neste's €1.9B biofuel plant expansion and ELYgator, Air Liquide's planned €1B green hydrogen factory (Air Liquide, 2025; Neste, 2022; Neste, 2025). Thus, there appears to be a relation between port size and the scale of CE initiatives. Budget information remains limited, however,

and it remains to be seen whether the relationship between port size and scale of CE initiatives will persist with more complete data.

It must be noted that throughput is a measure to express port size in the linear economy, where growth is equated with increasing volumes of goods. However, as the global economy becomes more circular, throughput is expected to decline as industries become less reliant on the input of raw materials (de Langen & Sornn-Friese, 2019). Consequently, throughput will become less indicative of port size, highlighting the need for alternative metrics for assessing economic performance to assist PAs in making strategic decisions to advance the CE transition.

5.2. Port Area

Table 3 further indicates that there is no apparent relation between a port's surface area and its number of CE initiatives. In this context, Courtens et al. (2023) claim that CE initiatives currently do not require a significant surface area. This is reflected in the data, as Groningen Seaports, the second smallest port by surface area, hosts the most initiatives, even more than the Port of Rotterdam, which is over four times larger. In fact, a large surface area can be a barrier to the CE transition. The expert at Port of Rotterdam emphasised that their large port area brings with it higher complexity through the large number of stakeholders, governmental levels, companies, and activities involved (Expert at PoR, personal communication, July 14, 2025). Conversely, they observed that smaller ports may be able to progress faster in the CE transition. This was echoed by the expert at Groningen Seaports who noted that "we are smaller and we can progress faster" (Expert at GSP, personal communication, July 15, 2025). These insights highlight the importance of bringing stakeholders on board with the CE transition, which is easier to accomplish in ports with fewer actors.

5.3. Available Space

In the same vein, the amount of available space does not seem to correlate directly with the number of CE initiatives. Groningen Seaports has ample available space and counts the highest number of CE initiatives. Conversely, North Sea Port has even more available space, but hosts the fewest CE initiatives among the four ports. While the examined do not indicate a relationship between available space and the number of CE initiatives, the expert at Groningen Seaports emphasised that its available greenfield space provides a clear competitive advantage in attracting new CE initiatives, unlike ports such

as Rotterdam which rely on the departure of existing companies to accommodate new ones (Expert at GSP, personal communication, July 15, 2025).

Crucially, limited available space can also serve as a lever for the CE transition. The Port of Amsterdam is the smallest of the four ports, with scarce remaining space, which their expert underscored as a significant challenge (Expert at PoA, personal communication, July 7, 2025). Therefore, the PA must use its available space strategically in its aim to accelerate the CE transition (de Langen et al., 2020). It accomplishes this by (1) reserving limited space for CE initiatives, such as the area ‘Circulaire schil’ (Port of Amsterdam, 2025b), (2) gradually replacing polluting activities with circular ones, such as by banning coal throughput by 2030 and allocating some of the freed-up space to CE initiatives, and (3) by negotiating with existing companies in its port area, such as extending the concession of Bunge, an agrifood company, on the condition that its soy is sourced 100% deforestation-free. In so doing, the PA challenges the linear lock-in through influencing companies in its area to become more circular, thus contributing to shifting the port area and its hinterland towards the CE. In contrast, PAs with available space may feel less pressure to transform existing linear activities to circular ones, as they can more easily allocate space for new circular initiatives. If PAs want to achieve ecosystem change towards CE, it is imperative that they not only seek to attract new CE activities but also address existing operations in the port area. Focusing exclusively on the former, risks the perpetuation of the linear economy with circular activities remaining secondary. Instead of a true CE, this may lead to an “economy with feedback loops” based on the continued input of raw materials and generation of waste (Van Buren et al., 2016).

5.4. Port type

The four ports are all similar in type, with only Groningen Seaports an industrial port and the other three diversified hubs with a strong industrial base. The literature suggests that industrial-type ports tend to have more energy recovery initiatives owing to easier access to secondary resources and potential for industrial symbiosis (Courstens et al., 2023; Faut et al., 2023; Fusco Girard, 2013; Haezendonck & Van den Berghe, 2020). This is also evident in the studied Dutch ports. In light of the importance of industrial activities in diversified hubs, this observation can be extended to diversified hubs. The current European context calls for the scaling up of green energy production to reduce energy dependence, as emphasised by the European Commission’s REPowerEU plan,

and the greening of transport to achieve climate neutrality, as outlined in its European Green Deal. In this context, industrial and diversified ports, which often serve as key hubs for energy and fuel production, will likely continue to fulfil this role in the foreseeable future. Consequently, the dominance of energy recovery initiatives in such ports can be expected to persist unless substantial efforts are made to advance recycling and the orchestration of new cargo streams.

5.5. Role of Port Authority

Regarding the role of the PA in the CE transition, Table 3 reveals that PAs, on average, initiate around one-fourth of the initiatives. This is in line with the roles described by port experts, who characterise their PA not only as a landlord, but also as a facilitator and a matchmaker in the CE transformation, indicating a clear shift from the traditional landlord role (de Langen et al., 2020; ESPO, 2022). The evolution of the role of PAs can help them take an active role in speeding up the circular transition; however, the level of involvement by the PA is dependent on each port. The Port of Amsterdam is the only PA to initiate over 40% of initiatives, positioning itself as a key driver of the CE transition. While their expert (personal communication, July 7, 2025) described the PA mainly as a landlord, matchmaker, and facilitator, it sometimes takes on the role of “co-creator” by investing directly in infrastructure, if there is a clear need and no other investors can be found (Expert at PoA, personal communication, July 7, 2025). Thus, the role of the PA is evolving beyond facilitating through investment, as already identified by Notteboom et al. (2020). Here, Groningen Seaports goes one step further, positioning itself as a proactive investor, for instance by investing in a Kickstart hydrogen pipeline to accelerate the development of a green hydrogen network (Expert at GSP, personal communication, July 15, 2025). Groningen Seaports PA’s proactive stance may be an important contributor to its large number of CE initiatives. While the Port of Rotterdam has invested in circular initiatives in the past, it now takes a more cautious approach, maintaining neutrality to preserve the level playing field (Expert at PoR, personal communication, July 14, 2025). This approach may hamper the CE transition, as the PA has an important role to play in providing the funding needed to advance the transition (Haezendonck & Van den Berghe, 2020). Another important role of the PA was identified by North Sea Port, which they described as a “connector”: through their Smart Delta Resources platform, they bring together companies in the port and local authorities, allowing matchmaking but also alleviating potential regulatory barriers to CE.

The PAs have a hand in orchestrating a significant number of new cargo streams. This underscores their crucial role in the CE transition, as without their support, many of the initiatives contributing most to CE would not materialise. This is especially true for those initiatives that require extensive collaboration, both at the national level, such as the development of a green hydrogen exchange (HyXchange), and at the international level, such as establishing collaborations with ports around the world for green hydrogen import and export. As ports' CE maturity progresses, the share of CE initiatives initiated by the PA is expected to diminish, as the CE transition will become increasingly embraced and carried by companies in the port area and by partners beyond the port.

5.6. Budgets and Subsidies

When examining the budgets of the CE initiatives and the public subsidies supporting them, the available information is limited. Approximately a quarter of the initiatives rely on public financing, indicating that they are not yet economically sustainable. Energy projects receive the most subsidies, both in number and value, and generally have higher budgets than initiatives related to recycling and new cargo streams. As already expressed by Haezendonck & Van den Berghe (2020), this can be attributed to the scale and number of actors involved in these projects. While the Port of Rotterdam is home to many high-budget energy projects, the budget of public subsidies it receives is relatively modest. This may be explained by the presence of financially powerful companies capable of financing large-scale initiatives, reducing their reliance on public subsidies. Their private funding also indicates that these initiatives are generally more economically sustainable. Figure 6 shows that Groningen Seaports has the largest budgets in the orchestrating new cargo streams category. This can be primarily attributed to Circotec's €285M circular factory that processes end-of-life tires into multiple new applications, such as circular naphtha, a circular feedstock for the chemical sector. However, the budgets of initiatives in other seaports in this category are largely unknown. The scarcity of financial information complicates the assessment of the economic sustainability of many of the initiatives and thus their ability to progress from projects, limited in scale and dependent on financial support, to self-sufficient activities.

5.7. CE Maturity of Dutch Seaports

As illustrated in Figure 6, for all four ports, the majority of initiatives are situated on the left-hand side of the CE maturity framework, with a clear focus on energy recovery.

This provides an answer to the research question **“What is the CE maturity of Dutch seaports?”**: at present, the CE maturity of the examined Dutch seaports remains low. This is echoed by insights from the expert interviews; for example, the expert at the Port of Amsterdam (personal communication, July 7, 2025) estimated that the CE transition is just scratching the surface. At the same time, the number of recycling initiatives in the Dutch seaports is limited, even when taking into account that recycling initiatives may have been underreported, indicating that they have not yet progressed to the intermediate stages of CE maturity. However, some positive developments can be noted. Within the energy category, many initiatives have expanded beyond the port area, extending the CE transformation into the hinterland. This is particularly evident in the Port of Rotterdam and Groningen Seaports, where nearly half of the energy initiatives occur at the territorial level. Furthermore, all four Dutch seaports are orchestrating several new cargo streams, mostly at the territorial level, the highest level of CE maturity. While the number of these initiatives remains limited, especially compared to energy initiatives, they demonstrate that the Dutch seaports are capable of progressing towards higher CE maturity. Considering the strategic focus on CE across the four ports, this gradual evolution can be expected to continue if ports can overcome the barriers to CE.

Following the assessment of the overall CE maturity of the Dutch seaports, a more detailed comparison of the ports’ individual levels of CE maturity can address the research question **“What are the similarities and differences in the CE maturity of Dutch seaports?”**. The four ports currently have a comparatively low level of CE maturity. In most ports, CE initiatives are divided over the three strategic pillars in a similar pattern, with the majority being energy recovery and the remainder approximately evenly split between recycling and new cargo streams. Groningen Seaports is the exception, with the number of recycling initiatives double that of new cargo streams, and approximately half that of energy initiatives. Taken together with the fact that it has more CE initiatives than the other ports, this could indicate that Groningen Seaports is slightly further advanced in the CE transition. North Sea Port has the fewest initiatives and can be assumed to be the least CE mature of the four ports. When looking at the initiatives in the highest CE strategic pillar, orchestrating new cargo streams, we see that all ports have a similar number of new cargo streams. This indicates that, while their maturity remains low, they all show similar potential to progress to higher levels of CE.

The observation that more new cargo streams than recycling initiatives were identified in all but one of the ports may suggest that not all ports follow the expected CE maturity progression outlined by Haezendonck and Van den Berghe (2020), that is, starting with energy recovery, then recycling, and finally orchestrating new cargo streams. Despite potential gaps in the data on recycling initiatives, the development of more new cargo streams than recycling initiatives over the past five years may indicate that the number of new cargo streams initiatives will gradually surpass the number of recycling initiatives. If this shift continues, ports may be able to immediately progress to advanced levels of CE maturity once the relative share of energy initiatives starts to decline. Whether this trend will continue remains uncertain.

5.8. Comparison of CE Maturity of Dutch Seaports and Belgian Seaports

After determining the CE maturity of Dutch seaports, a comparison can be made with the CE maturity of Belgian seaports, as evaluated by Haezendonck and Van den Berghe (2020), to provide an answer to the research question: **“How does the CE maturity of Dutch seaports compare to that of Belgian seaports?”**. The CE maturity of Dutch seaports appears broadly comparable to the CE maturity of the Belgian seaports studied by Haezendonck and Van den Berghe (2020). Overall, both groups of ports have low levels of CE maturity, with their initiatives concentrated on the left-hand side of the maturity framework. However, it is important to note that the maturity level of Dutch seaports is based on data from 2020 onward, while the maturity of Belgian ports is based on data collected up to 2020. Thus, the current CE maturity of Dutch seaports is effectively being compared against the CE maturity of Belgian seaports five years ago. The inclusion of North Sea Port in both studies offers insight into the evolution of CE maturity over the past five years. Whereas Haezendonck and Van den Berghe (2020) identified 19 CE initiatives in North Sea Port, this research found 38 initiatives. Despite this increase, the port’s CE maturity has not progressed beyond the initial stages of CE maturity. While this does not rule out progress in CE maturity in other Belgian ports, the gradual nature of the CE transition and the limited progress in North Sea Port illustrate that advancing the CE maturity level in ports is an incremental process (Haezendonck & Van den Berghe, 2020). Finally, although they lack information on other ports, most experts believe that Dutch and Belgian seaports have similar levels of CE maturity (Expert at ESPO, personal communication, July 8, 2025; Expert at NSP, personal communication, July 8, 2025; Expert at PoR, personal communication, July 14, 2025).

5.9. Barriers to the CE Transition

Key barriers to the CE transition in the Dutch seaports are the availability of “nitrogen space”, environmental space, and electrical grid capacity. The ports’ ability to address these challenges may accelerate or hinder their progress in the CE transition. Dutch nitrogen emission limits restrict nitrogen-intensive activities, potentially impeding the development of CE initiatives in ports. More generally, environmental space to host polluting activities, such as heavy recycling processes which generate noise pollution, can be an important factor in the capacity to attract CE initiatives. In addition, growing electricity grid congestion in the Netherlands poses a challenge for CE initiatives, which often require large amounts of (green) energy.

Significant differences were observed in how the ports navigate these barriers. The expert at Groningen Seaports (personal communication, July 15, 2025) emphasised that the port uses its available environmental space, nitrogen space and power as a competitive advantage to attract CE activities. Similarly, the expert at Port of Rotterdam (personal communication, July 14, 2025) indicated that the port’s environmental profile enables it to accommodate polluting CE activities, providing an advantage over other areas in the Netherlands. In contrast, the expert at the Port of Amsterdam (personal communication, July 7, 2025) identified environmental space as a challenge in its CE transition. The differences between the ports likely influence their ability to develop CE initiatives, as they can create favourable or unfavourable conditions for companies to establish new activities or expand existing ones. Thus, they may partially explain the high number of initiatives and the prevalence of new recycling initiatives in Groningen Seaports, and by extension, their slightly higher CE maturity compared to the other Dutch seaports.

5.10. Inter-Port Cooperation

A notable finding is that the majority of new cargo streams in the Dutch ports are related to facilitating the import and export of green hydrogen. This reflects a strategic focus among Dutch ports on developing a green hydrogen market. However, establishing a competitive market requires a common approach, as demonstrated by the ports’ joint development of the green hydrogen exchange HyXchange. At the same time, it is clear that the Dutch ports are collaborating not just out of a shared ambition to accelerate the CE transition, but also to obtain a competitive advantage, with the aim of becoming the

focal point of the burgeoning global green hydrogen market. Thus, by attracting activities related to the import and export of green hydrogen earlier than other ports, the Dutch ports can obtain “early mover advantages” in the CE transition (de Langen & Sornn-Friese, 2019). While the four ports work together to improve the collective competitiveness of the Dutch market, they are also competing internally to secure a larger share of this growing market.

This simultaneous collaboration and competition sheds light on the broader issue of cooperation on CE between the Dutch ports. Van Buren et al. (2016) argue that a lack of knowledge development and exchange hinders the CE transition, but structural cooperation between actors is not a given. Indeed, close cooperation between PAs, key facilitators of the CE transition in ports, can help accelerate the CE transition. Yet, while the PAs’ experts agree that more inter-port cooperation on CE is needed, so far little initiative has been taken (Expert at GSP, personal communication, July 15, 2025; Expert at PoA, personal communication, July 7, 2025; Expert at PoR, personal communication, July 14, 2025). This can be attributed to internal competition between ports to attract CE activities (de Langen & Sornn-Friese, 2019; Expert at GSP, personal communication, July 15, 2025; Expert at PoR, personal communication, July 14, 2025). However, similar to the collaboration on the green hydrogen market, structural cooperation and knowledge sharing among Dutch ports can increase the collective competitiveness of the Netherlands for attracting CE activities, benefiting the CE transition in all Dutch ports. Indeed, some experts argued that the Netherlands should position itself as a whole to attract CE initiatives rather than compete internally (Expert at GSP, personal communication, July 15, 2025; Expert at PoR, personal communication, July 14, 2025). In sum, PAs should not be afraid to cooperate closely on CE in fear of losing their competitive advantage, as it can improve their shared competitive position.

While local platforms bringing together PAs and businesses in the port area exist, more attention should be given to the development of platforms for national-level collaboration between PAs and other relevant stakeholders. A good practice is the Nederlandse Vereniging Circulaire Economie, the Dutch Circular Economy Association, which represents over 1700 companies in the Netherlands, including the Port of Rotterdam and Groningen Seaports, the latter through its participation in the regional platform Circulair Groningen Drenthe. Beyond this broad cross-sector cooperation

platform, the creation of a more targeted platform for structural collaboration between Dutch PAs and port-related industries is recommended.

5.11. Measuring the CE Transition in Dutch Seaports

The interviews show that the Dutch seaports do not yet possess a structured means of measuring the CE transition, making it difficult to understand their own level of advancement as well as complicating comparisons with other ports. While several ports have taken steps to develop CE indicators, their application remains limited. North Sea Port is collaborating on a project to apply 12 CE indicators for ports developed by Faut et al. (2023) (Expert at NSP; personal communication, July 8, 2025). Groningen Seaports is developing its own CE indicators, highlighting its ambition to be a frontrunner in the CE transition. The overall limited adoption by PAs of CE indicators may be attributed to limited available data, for instance, Port of Rotterdam possesses data on waste but not on inputs (Expert at PoR, personal communication, July 14, 2025). Another possible reason is PAs' potential reluctance to be benchmarked, out of concern for being held accountable for a lack of progress (Expert at ESPO, personal communication, July 8, 2025). Finally, the interviews revealed a lack of a clear understanding of how to define CE and CE initiatives, underscoring the need for standardisation of the CE concept and CE indicators within seaports (Expert at PoA, personal communication, July 7, 2025; Expert at PoR, personal communication, July 14, 2025). This would allow PAs to effectively assess their progress and communicate transparently with different stakeholders (Faut et al., 2023).

5.12. Limitations

An important limitation is linked to the explorative nature of this research. The analysis of the relationships between port characteristics and CE initiatives, in particular between port size, surface area, available space, port type, and the number and scale of CE initiatives, should not be interpreted as generalisations for all ports, but rather as an observation about the Dutch seaports studied. Many possible factors could influence these relationships. Similarly, the assessed CE maturity of the studied Dutch seaports should not be equated with the maturity of all Dutch ports.

Addressing the research question comparing the maturity of Dutch seaports to that of Belgian seaports is challenging because of the five-year gap since the publication of the original study by Haezendonck and Van den Berghe (2020) on the Belgian seaports. Since then, the CE maturity of Belgian seaports may have progressed. This is illustrated by the fact that North Sea Port appears in both the current and original study and doubled in the number of initiatives, although its CE maturity remained similar. Moreover, the comparison with Belgian seaports is exclusively based on the findings of the study of Haezendonck and Van den Berghe (2020) and the insights from expert interviews rather than a comprehensive research on the Belgian ports. In addition, the interviewed experts showed limited familiarity with the maturity model and lacked awareness of the CE transition in other ports, which complicated the cross-country comparison. Therefore, the validity of the maturity comparison between Dutch seaports and Belgian seaports is limited.

While the expert interviews aimed to gain insights into the self-evaluations of CE maturity within each port, they generated limited results regarding the mapping of initiatives. This may be attributed to a lack of preparation or insufficient time for the experts to familiarise themselves with the provided literature. Notably, even experts who had prepared expressed difficulties in understanding the model and in determining which activities qualify as CE initiatives. Although the question regarding the mapping of initiatives onto the model was not answered, the interviews highlighted a need to standardise the understanding of CE and CE indicators within seaports to enable assessing progress and communicating with stakeholders (Faut et al., 2023).

Another limitation relates to the identification of CE initiatives. Due to the limited scope of the master's thesis, the document and content analysis focused on data from the last five years. Consequently, ongoing CE activities that started before 2020 may have been underreported. This may partly explain the low number of recycling initiatives found, as many recycling companies have been operating for a long time in port areas with little change to their activities, potentially causing them to be excluded from the analysed material.

The PA's CE strategic focus also matters for the number and type of CE initiatives it reports on. The Dutch ports are industrial hubs, home to large-scale energy initiatives. The high budgets involved in these energy initiatives may make them more attractive for

PAs to report on, leading them to be potentially overreported compared to other initiatives. Conversely, many recycling activities have existed in ports for a long time and tend to have lower budgets, potentially causing them to be underreported.

Furthermore, some initiatives may be excluded from the data due to the PA's limited awareness of CE activities within the port. This may be due to companies keeping some developments secret or simply because the PA is not aware of their existence. Another potential limitation of the content and document analysis is the fact that the examined resources are not made for the express purpose of reporting on circular initiatives. In light of the advent of mandatory sustainability reporting, the focus of many PAs seems to rest on decarbonisation, which may lead to sustainability projects taking precedence over CE initiatives in reporting.

Finally, the focus on ongoing projects ignores the value and knowledge obtained from completed limited-time projects such as pilots. A notable example is the pilot Raising Agricultural Land in Groningen Seaports, which tested the reuse of sludge for agricultural land. The project ended and was deemed a success. While this project is no longer ongoing and thus not included in the reporting, its main benefit stems from the knowledge that was acquired and its potential to be replicated in the future. Thus, the focus on active initiatives ignores the value and knowledge obtained from completed limited-time projects.

6. Conclusion

This thesis determined the level of CE maturity of Dutch seaports by positioning their circular initiatives on the CE maturity framework developed by Haezendonck and Van den Berghe (2020). The initiatives were mapped based on their strategic CE focus (energy recovery, recycling, or orchestrating new cargo streams) and their geographical scale (intra-port, port-city, or territorial symbiosis). The research shows that the examined Dutch seaports have a strong energy focus and are thus concentrated on the left-hand side of the framework, indicating a low level of CE maturity. The energy focus is not wholly unexpected, given all four ports are either industrial ports or diversified hubs with a significant presence of industrial activities, which creates potential for energy recovery through industrial symbiosis (Courstens et al., 2023; Faut et al., 2023; Fusco Girard, 2013; Haezendonck & Van den Berghe, 2020). Despite their clear energy focus, the study found that all four Dutch seaports also have a limited number of initiatives in the highest level of CE maturity, namely orchestrating new cargo streams at the territorial level, which underscores their potential to advance towards higher levels of CE maturity. The majority of new cargo streams result from the import and export of green hydrogen, which offers a pathway to accelerate the CE transition in Dutch seaports. The inclusion of circularity in the ports' strategies suggests that this gradual development towards higher CE maturity can be expected to continue, provided the ports can address the challenges to CE.

The low CE maturity of Dutch seaports is similar to the overall CE maturity of Belgian seaports, as studied by Haezendonck and Van den Berghe (2020). While the Belgian seaports may have progressed over the last five years, North Sea Port's inclusion in both the current and the original study provides some insight. The fact that the initiatives in North Sea Port have doubled in number but remain concentrated on the left-hand side of the model suggests that its CE maturity has not progressed significantly in the last five years.

This research can be of interest to the PAs as their strategic focus on circularity means that they likely possess both the willingness and resources to advance the CE transition (Port of Amsterdam, 2024a; Groningen Seaports, 2024a; North Sea Port, 2023a; Port of Rotterdam, 2025). This thesis provides them with an understanding of their current CE maturity and can inform their next actions in the CE change process (Haezendonck & Van den Berghe, 2020). The CE maturity assessment can also help PAs communicate

about CE progress, in response to growing demands for measurement and monitoring, both from potential investors who want to evaluate the impact of their investments and from stakeholders who expect transparency (Faut et al., 2023). Moreover, the analysis of CE initiatives presents an opportunity for PAs to learn from best practices, which is important as knowledge development and dissemination are barriers to the CE transformation (Van Buren et al., 2016). One recommendation is the need for more inter-port cooperation on CE, which could be achieved by means of a platform bringing together Dutch PAs and port-related industries. The Dutch seaports should look beyond mutual competition to attract CE activities and collaborate structurally on CE to strengthen the overall competitiveness of the Netherlands in the CE transition by gaining collective “early mover advantages” (de Langen & Sornn-Friese, 2019).

The analysis of CE initiatives in this thesis is limited by its reliance on recent data largely provided by the PAs. The use of recent data may have resulted in the underrepresentation of older CE initiatives, in particular recycling activities. Moreover, data obtained from PAs may be incomplete or biased due to the PAs’ strategic CE focus, lack of awareness of all CE initiatives in the port, and priority on reporting on initiatives related to sustainability rather than CE. A fundamental limitation of this research is its exploratory nature, which seeks to gather insights in the CE transition in Dutch seaports and therefore does not permit the generalisation of observations.

Since the observed relationships between port characteristics, such as port size, surface area, available space, and port type, and the number and scale of CE initiatives are not generalisable, future research should examine these relationships using larger datasets. In addition, data on the budgets of CE initiatives is limited and further research is required to confirm the observed relation between port size and the scale of CE initiatives. Another research direction involves the stages of the CE transition in ports. Whereas Haezendonck and Van den Berghe (2020) argue that ports are expected to start with energy recovery initiatives, then gradually move towards more recycling, and finally orchestrate new cargo streams, this may not be true for all ports. Further research is required to evaluate whether ports starting in the lower maturity stages can skip the intermediate stages and advance directly to the highest maturity levels focused on orchestrating new cargo streams. In addition, the development of alternative metrics of port size, beyond traditional throughput, could offer a deeper understanding of economic performance as the predominantly linear economy transitions towards CE. Finally, the

literature would benefit from more country-specific studies on the CE maturity of ports to enable cross-country comparisons.

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Appendix A

Interview Questions for Circularity Experts at the Selected Ports

*The circular expert at North Sea Port has been asked one additional question due to the unique, cross-border location of the port. It is added at the end of this question list.

Q1: What role does the port managing body (PMB) play in the CE transition?

- Follow-up: Who usually drives circular economy (CE) initiatives: the port authority, private companies, municipalities, or others?
- Follow-up: Which companies or clusters are the most active in CE within the port?

Q2: Could you name two or three flagship CE initiatives in your port? Why are these important to your port, and how do they reflect your CE strategy?

Q3: How do you perceive your port's CE maturity, based on the provided maturity model?

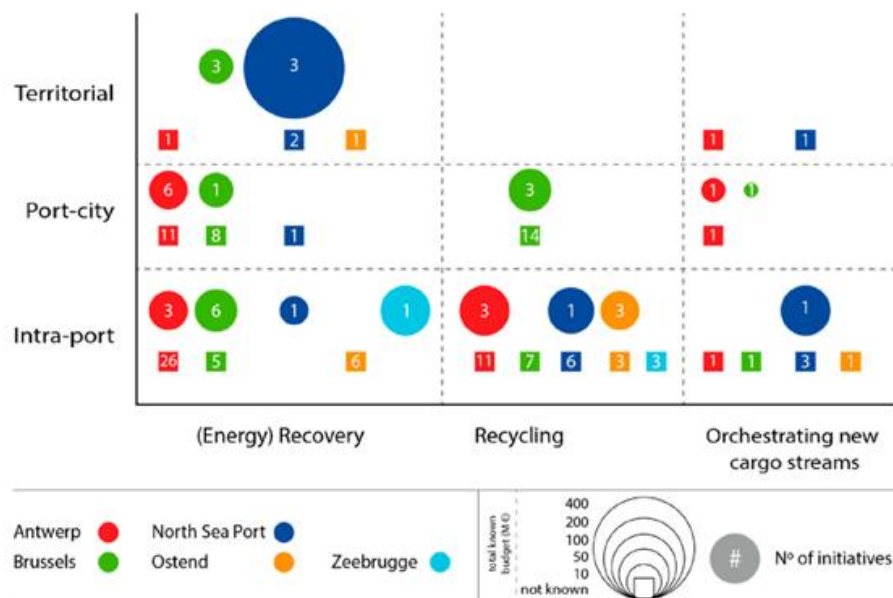


Figure 4. Mapped circular initiatives for five Belgian (sea)ports (source: compiled by authors).

Figure 4 (Haezendonck & Van den Berghe, 2020, p.11)[1]

- Follow-up: Does your port use CE indicators or a maturity model to measure CE transition, and how are these integrated into the broader port strategy?

Q4: How would you compare your CE maturity to other Dutch seaports?

Q5: How would you compare the CE maturity of Dutch seaports to Belgian seaports?

- Follow-up: Do you see differences in approaches or challenges between the Netherlands and Belgium?

Q6: What are the unique strengths of your port in the CE transition and how do you capitalize on them? What weaknesses or challenges do you identify and how have you or do you plan to overcome them?

Closing question:

Are there any additional insights that can be useful for understanding the CE transition or CE maturity in your port or Dutch seaports in general that you would like to add?

**The circular expert at North Sea Port has been asked an additional question during the interview due to the cross-border location of this port. Please see the additional question below:*

Q7: As a cross-border port, how do the Belgian-Dutch dynamics affect the CE strategy in North Sea Port?

- Follow-up: Is the CE strategy aligned or fragmented across Ghent, Terneuzen, and Vlissingen ports?

[1] Source: Haezendonck, E., & Van den Berghe, K. (2020). Patterns of Circular Transition: What Is the Circular Economy Maturity of Belgian Ports? *Sustainability*, 12(21), 9269. <https://doi.org/10.3390/su12219269>

Appendix B

Interview Questions for the Expert at ESPO

Q1: How would you characterise the overall and individual CE maturity of Dutch seaports (Amsterdam, Rotterdam, North Sea Port, Groningen), based on the provided model?

- Follow-up: Are there similarities or differences between them?
- Follow-up: Considering your experience with benchmarking progress in CE across EU seaports, how do you view this maturity model?

Q2: How does the CE maturity of Dutch seaports compare to Belgian seaports?

- Follow-up: Are there differences in strategy or approaches between the countries? How do they compare to current EU trends in circularity?

Q3: How do you see the role of ESPO in advancing the CE transition in European seaports? How does ESPO concretely support the CE transition?

Q4: In your view, what role should PMBs play in advancing CE within ports?

- Follow-up: Which stakeholders should drive CE initiatives?

Q5: Do you see any gaps in CE maturity across the European seaports?

- Follow-up: Considering your experiences and knowledge, what do you think are the most important aspects to be studied further on CE transition and maturity in the EU?

Closing question:

Are there any additional insights that can be useful for understanding the CE transition or CE maturity in your port or Dutch seaports in general that you would like to add?

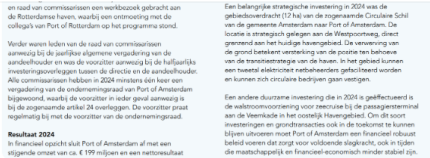
Appendix C

Statement Around the Use of AI: Screenshot Examples of Use of AI

ChatGPT:

ChatGPT 

 Share 



Could you please translate this to English?

Certainly! Here's the English translation of the Dutch text in the image:

Meetings and Themes

Meetings

In 2024, the Supervisory Board met seven times in regular meetings, six of which were attended by the Executive Board. Additionally, a strategic themed meeting was held in early June, and two digital meetings took place in July and November, both attended by the Executive Board. In June, the Executive Board and Supervisory Board conducted a working visit to the Port of Rotterdam, which included a meeting with colleagues from the Port of Amsterdam.

Ask anything

  Tools  

ChatGPT can make mistakes. Check important info.

Is it correct in-text citing if I use "Expert at PoA, personal communication, month day, year" format for expert interviews with anonymity for APA 7th Ed. referencing?

Yes, your citation format is **correct** for APA 7th edition when citing **anonymous expert interviews as personal communications**.

✔ Correct Format in APA 7th Edition:

(Expert at PoA, personal communication, July 7, 2025)

This meets APA 7 requirements because:

- **Personal communications** (e.g., emails, interviews, phone/online meetings) are **not retrievable by readers**, so they are cited **in-text only**, not in the reference list.
- You may **anonymize** the interviewee by using a descriptor such as **"Expert at PoA"** (Port of Amsterdam).
- You must include the words **"personal communication"** and the **exact date** of the interview.

Figure 1. Linear economy (left), and circular economy (right). Source: Roberts et al. (2021, p. 3), adapted from Bianchini et al. (2019)

how do you cite in the text under a table in APA 7th ed, is this correct, and how the style should be?



You're very close! Here's how to format a **figure caption** with a source under it in **APA 7th edition**, including when the figure is **adapted** from other works:

✓ Correct APA 7 Style for Figure Caption:

Figure X

Title of the figure in sentence case and italics. (If adapted), write: Adapted from...

Figure 1

Linear economy (left) and circular economy (right). Adapted from Roberts et al. (2021, p. 3), based on Bianchini et al. (2019).

Grammarly – Chrome Extension:

ironmental space, nitrogen space and power as a competitive
ities and thus create a “head start in the circular ambition”.
Rotterdam (personal communication, July 14, 2025) indicated
profile enables it to accommodate polluting CE activities,
other areas in the Netherlands. In contrast, the expert at the
communication, July 7, 2025) identified environmental space
sition. The differences between the ports likely influence their
s, as they can create favorable or unfavorable conditions for
activities or expand existing one
initiatives and the prevalence of
ision, their slightly higher CE mat

Use the right word

unfavourable

Dismiss

See more in Grammarly

on CE

at the majority of new green spaces in the Dutch water en

Consensus.app:

circular economy as a competitive advantage in seaports for port authorities

Pro · 1 search · 13 sources

Circular economy (CE) practices are increasingly recognized as a source of **competitive advantage for seaport authorities**. By adopting CE principles, ports can improve operational efficiency, attract new business, enhance sustainability, and strengthen relationships with local communities and stakeholders.

Key Competitive Advantages for Port Authorities

Advantage	Description	Citations
Enhanced Operational Efficiency	CE practices (e.g., waste reuse, resource sharing) streamline logistics and reduce costs.	1 7 8 4
Attraction of New Business & Investment	Ports with CE infrastructure attract companies seeking sustainable supply chains.	1 7 3 5
Improved Stakeholder Relations	CE initiatives foster collaboration with local communities, industry, and government.	2 7 4 13
Regulatory and Social License to Operate	CE adoption helps ports meet environmental regulations and maintain public support.	2 4 6 7
Innovation and New Revenue Streams	CE enables new business models (e.g., industrial symbiosis, circular economy) Results	7 5 6 8

amsterdam port CE maturity

1 query

Results

Results

- 1** The Role of Port Development Companies in Transitioning the Port Business Ecosystem; The Case of Port of Amsterdam's Circular Activities
2020 · 47 citations · P. D. de Langen et al. · Sustainability · PDF
- 2** When a Fire Starts to Burn. The Relation Between an (Inter)nationally Oriented Incinerator Capacity and the Port Cities' Local Circular Ambitions
2020 · 16 citations · Karel Van den Berghe et al. · Sustainability · PDF
- 3** Patterns of Circular Transition: What Is the Circular Economy Maturity of Belgian Ports?
2020 · 28 citations · E. Haezendonck et al. · Sustainability · PDF
- 4** Sustainable circular cities? Analysing urban circular economy policies in Amsterdam, Glasgow, and Copenhagen
2023 · 36 citations · Martin Calisto Friant et al. · Local Environment · PDF
- 5** Spatial planning of the circular economy in uncertain times
2024 · 3 citations · Karel Van den Berghe et al. · Maritime Transport Research
- 6** The implementation of the Circular Economy: Barriers and enablers in the coffee value chain
2020 · 79 citations · Maarten van Keulen et al. · Journal of Cleaner Production · PDF