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Circular Economy: Closing The Loops, An Innovative
Business Model, and the Case of How the Port of
Rotterdam is Transitioning into a Circular Port

By

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To my dearest parents Mohan and Geetha

Abstract

Port of Rotterdam (PoR) in terms of its size and strategic location is in a strong position to transition itself into a full Circular Economy (CE) and the future circular hub of Europe by 2050. The port sees CE as the potential solution to meet the climate change regulations along with energy transition, and in the larger context of sustainability. In this paper, we try to understand and explore how the PoR monitors and fosters its CE ambitions. Based on analysis of port documents and unstructured in depth interviews with Port CE experts we could identify indicators used, but based largely on CE objectives and goals existing in the port. Employing a triangulation strategy using the Vlaanderen Circular – OVAM (VC-OVAM (2022) study) longlist indicators, the number of CE projects found the largest match along with future infrastructure developments to support and foster the growth of CE. Few of the objectives reported by the port could not find a match to the VC-OVAM (2022) study indicators while many indicators could not find matching objectives, which could result once the port raises its CE ambitions. Not only does this study exhibit the robustness of the longlist indicators while validating its applicability to any port but also enforces the recommendation that the PoR can use this indicator set effectively to monitor, further its CE goals and use it as a strategic tool set to foster its CE ambitions. Moreover, it also helps us understand the current and future initiatives that are in progress in the PoR. Finally, a benchmark analysis with the PoA allows us to understand the steps, which the PoR can adopt to evolve and improve their strategies while comparing its existing performance with that of PoA.

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List of Abbreviations

C2C: Cradle-to-Cradle

CCUS: Carbon Capture Utilisation & Storage

CE: Circular Economy

CEAP: Circular Economy Action Plan

CTI: Circularity Transition Indicator

DCE: Digital Circular Economy

EC: European Commission

EFIP: European Federation of Inland Ports

EOL: End of Life

ESPO: Sea Ports Organization)

EU: European Union

GD: Green Deal

GDP: Gross Domestic Product

GHG: Green House Gases

KPI: Key Performance Indicators

MCI: Material Circularity Indicator

OECD: Organisation for economic Co-operation and development

PA: Port Authority

PET: Polyethylene Terephthalate

PMB: Port Management Bodies

PoA: Port of Amsterdam

PoR: Port of Rotterdam

RE: Resource Efficiency

TAG: Tar-Retaining Asphalt

UN: United Nations

VC-OVAM: Vlaanderen Circulair – OVAM

WBCSD: World Business Council for Sustainable Development

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1. Introduction

1.1 BACKGROUND

The human footprint on the natural world is believed to be at its peak, a magnitude that we have not encountered and seen before. It has reached such proportions that the economic activities have the power to influence major planetary systems as well as bring about certain irreversible changes in our planet as well in the view of many eminent scientists. This in turn putting enormous strain on our natural resources, which adds to a sort of deadweight loss to the economy in relation to Gross Domestic Product (GDP) when viewed from the economic perspective (Steer, 2014). Resource depletion continues unabated, as majority of the production processes are stuck in a linear lock-in structure of take – make – waste. In addition to the conservation of resources, we need to think much beyond this. Re-utilisation of materials through re-engineering, re-extraction of raw materials through End of Life (EOL) mining etc.; will gather prominence. Recycling alone, and low-grade recycling in particular, is very much related to a linear economy, and it is herein the concept of Circular Economy (CE) gathers prominence. CE offers an attractive and illustrious way to break away from the linear lock-in, a new business model that has the power to decouple the engine of economic growth from environmental impact (Haezendonck & van den Berghe, 2020). From a supply chain perspective, reusing the materials at their EOL cycle, and thereby not generating waste would lead to a truly circular supply chain. This has a wide range of implications, and transforms the way products need to be designed, and bring about a business model renewal as far as companies are concerned (Bocken et al., 2016). The transitional trend towards circular supply chains can be viewed as being driven by direct profit potential for companies and manufacturing businesses. More than the profit generation, it is perhaps the overarching societal awareness towards the need to increase the sustainable practices within the economy that leads to a policy level change to improve or promote sustainability as well as promote the green element associated with purchasing of consumers and companies. CE concepts has its origins deeply embedded within industrial ecology concepts which dates back to the 1980's and mention of the waste hierarchy concepts of 3R's, 4R's etc. evolving to the 10R's as depicted in **Figure 1**, which we seen mentioned in the current literatures (Haezendonck & van den Berghe, 2020). It was Stahel (Haezendonck & van den Berghe, 2020; Stahel, 2016) who initially introduced the concept of CE in his paper “ The product life factor”, where he has viewed it as a spiral system in which an overall reduction of the inputs, waste flows and ecological detriment can be achieved, without limiting economic, social and technological

advances. Further, he propounded that CE affects products as well as processes, and primary as well as secondary materials (Haezendonck & van den Berghe, 2020; Potting et al., 2017). Based on the laws of thermodynamics, that energy can neither be created nor destroyed, Peace and Turner (Bennett, 1991; Haezendonck & van den Berghe, 2020) were successful to add another dimension to the CE concept that was introduced by Stahel. The idea of extracting the energy to such an extent that reducing it to one of non-valuable quality is also incorporated. CE processes maybe viewed in the light of upcycling rather than recycling, wherein valuable resources are extracted from the end of life products to be used as the raw materials in the new value chain as explained in 2002 by McDonough and Braungart (Haezendonck & van den Berghe, 2020; McDonough, 2002a). One could argue that notwithstanding the importance of the classical value chain concept of reducing, reusing and recycling in the context of CE, we could say that it is far from being ambitious in the sense of its relevance in the present day context.

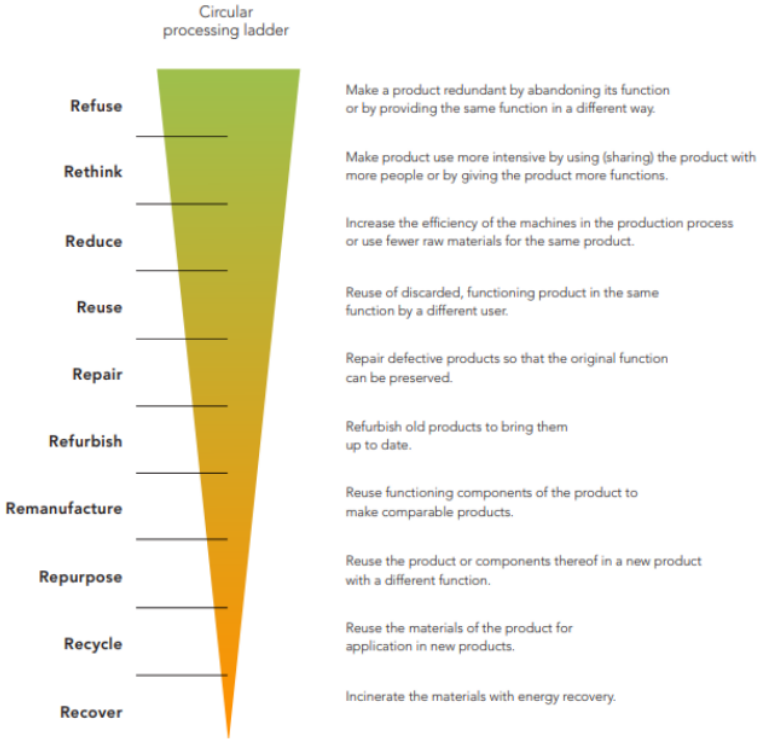


Figure 1. The 10'R Waste Hierarchy Concept (Source: Amsterdam Circular Strategy 2020-2025)

1.2 Ports as Actors in the Climate Change Debate

Climate change, its potential impacts and the need for solutions are the foci of a global collective consciousness, and need of the hour. The Paris agreement has set the tone to achieve and limit the global average temperature to below 2 degree Celsius above the pre-industrial levels while pursuing efforts to limit the temperature increase to 1.5 degree Celsius above pre-industrial levels (UN 2015). To achieve the global temperature goals set by the Paris climate accord calls for immediate and transformative actions. Ports are the hotbed of industrial activities, and therefore automatically qualify as salient partners in the climate change debate (Azarkamand et al., 2020; Ng et al., 2013). Ports mostly operating on the landlord model solely rely on revenue generation by offering to their clientele land leases and concessions. In addition, revenue generation through handling large volumes of primary raw materials is also common and prevalent. Therefore, this growing demand for resources with the corresponding environmental disruptions, and natural resource depletion is one of the critical drivers necessitating this shift (Hoorweg et al., 2013), and ports become conspicuous and contributory actors in the drama. Globally port cities operate within the take – make – dispose linear model that is unsustainable, and over the last few decades ports especially have come under severe pressure and scrutiny due to environmental challenges. The type of activities the ports entertain lead to severe environmental impacts resulting in negative externalities such as air and water pollution that mirror the destructive linear economic models. This has caused them to wake up, take notice and act with CE offering a sustainable solution to the problem (Fusco Girard, 2013; Gravagnuolo et al., 2019). **Figure 2** seen below from the Ellen McArthur Foundation captures the importance and projects CE as the solution to cut down global Green House Gases (GHG), which is projected to be 51 Billion Tonnes by 2050, by following a three-pronged approach of improving energy efficiency, technological innovation and transitioning to CE.

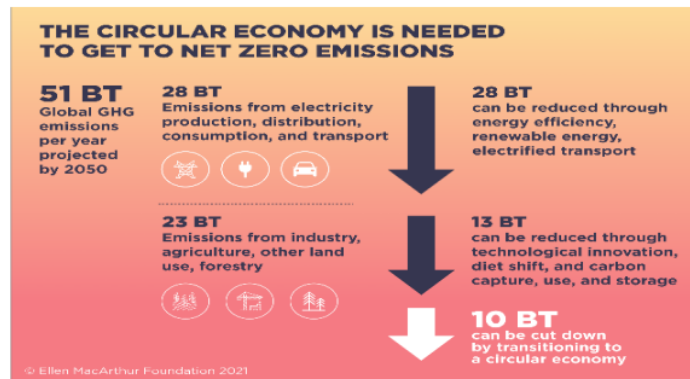


Figure 2. Importance and role of CE in cutting down global GHG emissions
(Source: Ellen McArthur Foundation)

1.3 Ports, Circular Economy and A New Business Model

From time immemorial, ports have been the gateway of international trade and commerce through the high seas. They have directly or indirectly contributed towards the development of a country and the surrounding cities by not only generating employment, but also by providing a field or platform where other commercial activities can take root and flourish. In this regards ports are acknowledged crucial for the economic development of any coastal country. As a result, port-towns and port-cities, as nodes or focal points for trade and commerce, became a prominent feature in the urban hierarchy of many countries (Lee & McNamara, 2022). Ports are also important for the support of economic activities in the hinterland since they act as a crucial connection between sea and land transport. As a provider of jobs, ports not only serve an economic function but also one of social function (Dwarakish & Salim, 2015). Besides being a hotbed of industrial and commercial activities, helping the cities surrounding the port areas develop as well as benefiting the society as a whole, a renewed focus is encountered in these recent times towards viewing ports as havens of sustainable development. In a world that is highly globalised, ports form critical nodes in the global supply chain, and form the irreplaceable pillars propping economic development (T. Notteboom, 2016). They form irreplaceable cross-links through which commerce flows between different trading countries and act as cornerstones of a burgeoning world trade and economy in the context of globalisation. CE in the port context is still at a nascent stage. Much interest in, and focus on the concept of sustainable ports and green ports is evident with numerous in-depth studies and discussions available (Mańkowska et al., 2020), but the CE concept as a new business model that can be widely applied to ports stands neglected. CE in the port context continues to be a

fledgling area of research but is perceived and recognised by many as a prerequisite for the sustainable growth of any seaport (Geissdoerfer et al., 2017) as we move forward into the future. This approach is well evident and entrenched in the European Union (EU) policy (Closing the Loop—An EU Action Plan for the Circular Economy COM/2015/0614 Final; European Environment Agency: København, Denmark, 2015., n.d.; COM(2014) 398 Towards a Circular Economy: A Zero Waste Programme for Europe; European Commission: Brussels, Belgium, 2014., n.d.; COM(2019) 190 Report from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions on the Implementation of the Circular Economy Action Plan; European Commission: Brussels, Belgium, 2019., n.d.), in which seaports that function within a circular economy model may constitute a driving force towards sustainable growth. Along with European Parliament, the European port organizations, European Sea Ports Organization (ESPO) & European Federation of Inland Ports (EFIP) lays huge emphasis on the enormous potential that the ports wield to make an initiative in transitioning towards CE. Ports being nodal points for all kinds of waste and industrial flows, transport modes, and in addition harbouring industrial clusters with urban proximity make them ideal locations to develop, and see progress towards CE transition (Haezendonck et al., 2019). The CE ambitions of ports and Port Management Bodies (PMB) appear to be strongly cemented, especially in the European as well as in the Asian context where majority of the trade is being carried out, but are herculean and circuitous to manoeuvre. These ambitions have caused many PMB to embark on the CE transition with much gusto, and claim the first mover advantage in this realm in spite of the challenges. Even though some PMB claim to be first movers in this journey towards circular transition, the initiatives appears to be fragmented or disjointed, and not sustainable on the long run. Ports and PMB perform the dual task of going about their own business as well as facilitating the activities of the businesses housed within the port domain. This proves to be a conundrum as far as the PMB are concerned as they have the double task of initiating the circular transition within their sphere of business, but also bring about the transition by following a bottom up approach with the other businesses housed within the port area. PMB are after all space allocators for businesses to set base, and it is important that a synergistic approach be embraced to cement a sustainable CE transition. In the present it is seen that many CE initiatives both within the ports and within the port city concept are heavily subsidised thus making them unsustainable on the long run. It is important therefore that CE transition should be seen from the lens of a business model where economic profit can be realised to make it self-sustainable. The transition toward circularity will definitely hold threats to ports, mainly

in terms of a reduction of throughput volumes. However, this transition will also give rise to new business opportunities to the ports and provide new revenue streams. In this context, it is vital to emphasize the increasing relevance of physical colocation of factories, which enables reuse of materials and energy, through increased and synergistic use of infrastructure between companies etc. PMB should also look at evolving and increasing their spatial activities in creating synergies with the surrounding areas to develop a symbiotic relationship in the port-city concept whereby the business model of CE can remain self-sustainable, take deep roots and thrive.

The PMB see CE as an alternative and innovative business model, which allows them to grow without limits by decoupling growth from the scarce resource use thereby helping mitigate the environmental impact. CE provides the key to managing the challenges at the micro, meso and macro levels when bogged down with the issues of climate change, environmental and societal pressures. This allows them to deviate from the traditional business model helping them to inject a fresh breath of life and function sustainably. At present most of the PMB operate a business model, which is based on the volumes handled, and the financial benefit obtained helps them to operate in a manner, which helps them to break even, and make profits (Burger et al., 2019; Haezendonck & van den Berghe, 2020; L. van der Lugt et al., 2013b). The main source of income for the PMB is operating on the traditional landlord model, continues to be from land leases, and cargo volumes handled within the port. This leads us to conjure the opinion that the business model of PMB is largely based on the port area expansion and focusing on increasing the throughput volumes. The associated negative externalities arising in way of pollution, congestion, and flood plain reduction to name a few becomes conspicuous and apparent when the ports pursue the traditional business model (Haezendonck & van den Berghe, 2020). Ports continue to be cross-docks for cargo, waste flows and transportation modes while harbouring industrial clusters. The industrial environment can be home to numerous opportunities to treat residual flows and products in a circular manner. Depending on the port type, if located in close proximity to urban cities, they may offer extensive and apparent recycling and urban mining potential to treat the waste generated, extract and upgrade valuable primary resources, which could then deployed or used as raw materials in manufacturing and production processes. Additionally ports can harbour and help accelerate the energy transition, be proactive actors in curtailing environmental impacts, platforms in innovation / innovative activities thus making them attractive for circular activities to prosper. They can also act as facilitators by providing infrastructure thus facilitating a conglomeration

of players who can utilise the connected material flows to the benefit of each other. CE as a new business model can help ports break the linear lock in, and can attract new investments through network effects thereby helping them to continue operating in a profitable and sustainable manner.

With vast numbers of seaports, being home to a large number of industrial activities, and the European Commission (EC) Green Deal (GD) recognising the role of seaports as important partners in this it is no wonder that an accelerated approach is seen by many PMB towards CE transition (Kovačič Lukman et al., 2022). Scientific research assails the importance of measuring this CE transition in ports through indicators, but there is an obvious void seen when it comes to port specific indicators (Gravagnuolo et al., 2019).

1.4 Relevance Of Circular Economy Indicators and Gap Identification

Indicators to measure the amount of circularity, and circular transition within ports can be more or less considered as non-existent, and not much research is seen to be carried out in this domain. While there exists some research in identifying indicators for port cities these are not relevant when they are applied in the context of ports (Cerreta et al., 2020; Gravagnuolo et al., 2019). Lack of measurable data can be cited as a major concern when it comes to developing indicators for ports. Whatever indicators are prescribed by the PMB lack coherence, and completeness (Gravagnuolo et al., 2019). More frequently, we see companies whose main activity is CE having their own set of indicators, and the ports using a different system. A lack of holistic approach is seen in maintaining a common set of indicators. Perhaps it is difficult to attain this given the large number of companies operating within the port domain, and the difficulty faced to evolving a common indicator set. However, any organisation with a strategic intent needs to be equipped with a set of key performance indicators, which may be employed as managerial levers to measure the progress and monitor the transition of an organisation based on tangible results, and this is clearly missing when it comes to ports (Gravagnuolo et al., 2019). The recent study published by Kovacic Lukman, Brglez & Krajnc (2022) came out with a list of 31 such CE indicators. These indicators were each assigned a weight, which were then combined to arrive at a single CE indicator for the port in concern. The identified indicators are based on those currently being reported by ports. The drawbacks of having just a single indicator is that it will not be able to capture and accommodate the stages in the CE transition of a port. This single indicator also brings forth the handicap of not being able to

accommodate port specific indicators as well as indicators that could be developed in the future, as the port evolves or matures on the path of circularity.

In this regards the recent study to develop a functional set of PORT CE indicators were undertaken on the behest of **Vlaanderen Circulair – OVAM** (VC-OVAM (2022) study) that prescribes a long list of 32 indicators of which 21 indicators can be applied to any port. These 21 indicators are neither time nor dependent on the port typology. The remaining 11 indicators arrived at for evaluation purposes are both time dependent as well as port type dependent while remaining variable.

1.5 Research Question

How can Europe’s largest seaport, the Port of Rotterdam, monitor and foster its CE ambitions?

Sub Research Questions

- 1 What is Circular Economy in relation to ports, its strategic importance, and potential impact as the new business model?**
- 2 Why are indicators important as a tool to monitor the circularity progress, help the PMB make strategic decisions, and ensure the embeddedness of CE within the port in general?**
- 3 How does the Port of Rotterdam currently monitor and record its Circular Economy transition, are there any indicators which the PMB of the PoR employs for this purpose, and do any gaps exist in relation to the prescribed set of indicators for VC-OVAM?**

1.5.1 Research Objective

From the above sections that we have analysed, it is very evident that every PMB needs to be equipped with the right / pertinent set of indicators as an essential tool for monitoring the circular transition as well as a strategic decision making tool. This will help the PMB come up with a business model to safeguard, and further the prospects of the port as a hub of circularity by actively monitoring these indicators while also giving the freedom to develop port specific indicators as well as allowing them the leeway of prescribing new and relevant indicators as

time progresses and the need arises. Therefore, the core objective of the study is to conduct a detailed desktop analysis on the backdrop of the explorative research work carried out on behalf of VC-OVAM (2022) study, which has successfully developed a dynamic set of 32 indicators. We will explore which of the activities related to circularity in the Port of Rotterdam (PoR) can find a fit with the longlist of 32 indicators, of which 21 are fixed, and can be applied to any port. In addition, which of the 11 port specific indicators maybe applied to the Port of Rotterdam. This is done by performing a three-step gap based analysis with the port specific indicators, if they are indeed used or if there exists elements of activities that the PMB undertakes that can find a fit with the VC-OVAM (2022) study indicator set.

In doing this we can analyse and find out whether the PoR is indeed on its way towards transforming itself into a fully circular port, thereby continuing to be a frontrunner in the CE transition and securing its position as the largest port in the Europe.

1.6 Thesis Structure

The thesis is structured in a way to lead us to the answer of the questions we have framed.

Chapter 1 gives an introduction into the concept of Circular Economy, and its relation with ports especially in the context of climate change, and the importance of indicators to measure circularity within a port followed by the main research question and sub research questions.

Chapter 2 is based on the detailed literature review, conceptualises the idea of CE within the port context, and introduces the business strategy that ports need to take as well as reasserting the importance of PORT CE indicators

Chapter 3 details the research methodology, data collection and introduces the benchmark Port of Amsterdam (PoA).

Chapter 4 approaches the empirical analysis, captures the results along with the gap analysis using the VC-OVAM (2022) study port CE indicators set and the results from the gap analysis, and benchmarking with the Port of Amsterdam along with the results.

Chapter 5 discusses the results obtained, the limitations of the research, the scope for further research and captures the conclusion with recommendations to the stakeholders.

2. Review of Literature

2.1 Conceptualising Circular Economy in the Port Context

The CE concept has evolved over the years, and the responsibility of a single, clear definition cannot be traced back to a single author. Yuan et al. (2008, p.5) writes, “There is no commonly accepted definition of CE (Yuan et al., 2006). To this effect, there exists in extant literature multiple definitions of CE, which may be identified with different schools of thought. The earliest mention of CE can be found in the book by Kenneth E. Boulding where he cites a “cyclical” system of production. It was in 1982 that Stahel in his pioneering paper, “The Product Life Factor” described CE as a spiral system with the aim of reducing the used inputs, waste flows and ecological detriment, without limiting economic, social and technological advances. A CE would help transform EOL goods into resources for others, thus closing the loops existing in the traditional linear industrial systems, thereby helping to minimise or reduce waste. A dramatic shift in the economic thought process or economic logic can be brought about because it helps to replace production with sufficiency where we reuse what we can, recycle what cannot be reused, repair what is broken, and remanufacture what cannot be repaired (Stahel, 2016). In addition he goes on to proclaim that, it is not only products that the CE would affect, but also processes, primary and secondary materials (Haezendonck & van den Berghe, 2020). According to the law of thermodynamics, energy and matter can neither be created nor destroyed, and following this line of thought Pearce and Turner (Bennett, 1991) added to Stahel’s description by propounding that a CE system will be the only sustainable production process moving forward. Following this line of thought, we could only say that the resources can only be reduced to a non-valuable quality. Another dimension to the definition of CE was added, when in 2002 McDonough and Braungart (McDonough, 2002b) introduced their Cradle-to-Cradle (C2C) process, in which relevant new processes such as upcycling and upgrading the value of outputs into new inputs find a mention. The definition of CE by Kirchherr et al. as a basis of advancement has been mentioned in studies carried out by Alhawari et al., where he defines CE as “A circular economy describes an economic system that is based on business models which replace the ‘end-of-life’ concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes, thus operating at the micro-level (products, companies, consumers), meso level (eco-industrial parks) and macro-level (city, region, nation and beyond), with the aim to accomplish sustainable development, which implies creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations”. The

Ellen McArthur foundation further defines CE as “A systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. A currently prevailing definition of CE proclaims CE as a new model for industrial organization, which enables us to decouple growing welfare from using more raw materials and one which goes beyond efficiency gains and helps in the realization of a transformative change (regenerative by design). Currently, CE practices are carried out at the meso, micro and macro levels (Alhawari et al., 2021). Below is the well-recognised butterfly diagram, depicted in **Figure 3** that helps us to capture and visualise the CE concept briefly. This is based on the C2C concept propounded by Braungart & McDonough in 2002. CE is the set of organizational planning processes for creating, delivering products, components, and materials at their highest utility for customers and society through effective and efficient utilization of ecosystem, economic, and product cycles by closing loops for all the related resource flows (Alhawari et al., 2021). The CE concepts are well embedded in the industrial and product environments, and has found its place in extensive literatures in the last two decades. However, it is only now that the CE concepts are taking root in the service industry.

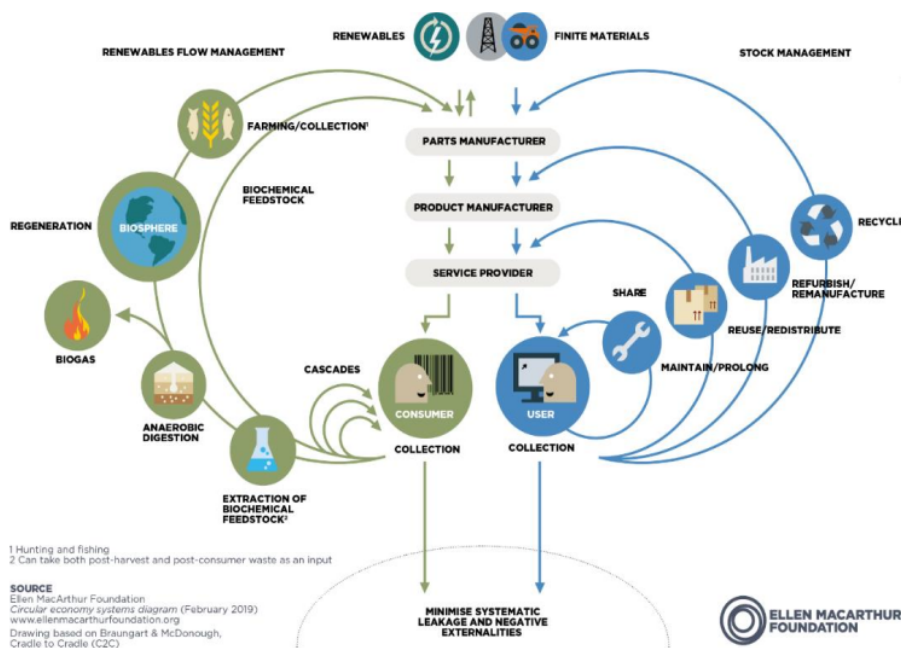


Figure 3. Butterfly diagram depicting the cradle-to-cradle concept (Source: Ellen McArthur Foundation)

Ports can be defined as the logistical nodes in the international trade network and is the product of the derived demand for goods in the transportation network, gateways offering connection of the country housing the port region to the rest of the world through international shipping transport (Bird, 1983; Cerceau et al., 2014). Ports constitute and play an irreplaceable role in the management and co-ordination of material and information flows, conspicuously located at an invisible boundary between land and water transport entrenched in the global supply chain network (Carbone & Martino, 2003; Cerceau et al., 2014). They can be likened to an aggregating medium where the transit, storage, collection and distribution as well as industrial processing for the main material and energy flows converge (Cerceau et al., 2014; van Klink, 1994). The concept of sustainability and green ports have already become embedded in the PMB strategy with numerous studies carried out in this respect (*COM(2014) 398 Towards a Circular Economy: A Zero Waste Programme for Europe; European Commission: Brussels, Belgium, 2014.*, n.d.; Davarzani et al., 2016; P. de Langen & Sornn-Friese, 2019; Dooms, 2019; Lam & Notteboom, 2014; Mańkowska et al., 2020; Oniszczyk-Jastrzabek et al., 2020). But, the concept of CE in the port arena is a relatively new concept. Therefore, it is not surprising that not much research has been done in this field, and work is still in its embryonic stage. In as much as a seaport is concerned CE is believed to be a prerequisite for any port to continue to do its business sustainably (Geissdoerfer et al., 2017; Mańkowska et al., 2020). As sustainable development with respect to ports has become a key focus of research, the CE has started receiving increasing attention as an additional means of adding value, whilst reducing environmental impact and increasing social equity (Roberts et al., 2021). The EU has recognised this while formulating its policies as far as port development goes, and clearly recognises the CE model as a strategy towards driving sustainable growth (*Closing the Loop—An EU Action Plan for the Circular Economy COM/2015/0614 Final; European Environment Agency: København, Denmark, 2015.*, n.d.; *COM(2014) 398 Towards a Circular Economy: A Zero Waste Programme for Europe; European Commission: Brussels, Belgium, 2014.*, n.d.; *COM(2019) 190 Report from the Commission to the European Parliament, The Council, The European Economic and Social Committee and the Committee of the Regions on the Implementation of the Circular Economy Action Plan; European Commission: Brussels, Belgium, 2019.*, n.d.; Mańkowska et al., 2020).

Also according to the EU, ports act as facilitators bringing together various actors in the industrial arena especially the production and recycling industry. This makes ports don many roles; they act as crossing points or junctions for all kinds of waste and industrial flows, act as

logistical hubs for the import and export of waste materials, and accommodate industries that are active in the treatment, collection, and shipment of waste. Ports have been also successful as actors providing a platform to promote innovation and technology. In recent times, they also provide the location, and act as hubs where alternate energy production can be kindled and expanded. Despite the increased interest in the role of ports in the CE as enumerated above, and the huge impact circularity may have on the PMB business, the topic has received only limited attention in academic research. For instance, an early and a recent review of circular supply chain research did not mention ports or maritime transport nor has maritime transport been identified as a relevant research topic in the context of circularity (P. de Langen & Sornn-Friese, 2019; Govindan et al., 2015; Guide & van Wassenhove, 2009). As such, ports “are ideal places to further develop the circular economy” (Kyllo’nen, 2017). Therefore, it is obvious the interest the concept of CE is evoking amongst the major PMB globally, so that they can benefit from the first mover advantage that this business model has to offer.

2.2 Impacts and Barriers towards Circular Economy Implementation in Ports

The transition towards a full-fledged circular port can be seen to have both positive as well as negative impacts as far as the PMB are concerned. Although the path of transition being explicit, the scope and pace of the CE transition in ports is highly uncertain (P. de Langen & Sornn-Friese, 2019). The PMB therefore need to be both aware and cognisant of such impacts which is both interesting but at the same time concerning too. Predominantly, a port acting as a node for cargo flows and as actors in the derived demand concept as mentioned earlier will be impacted by a dramatic change in the volumes of cargo handled by them. The other impact will be in relation to the possible opportunities that the PMB will encounter in way of attracting innovative and new business opportunities to accommodate the circular transition because of the reduced or altered cargo flows. In this regards, contemporary and state of the art logistics, and related industrial activities can take root within the port area. Ports handle huge volumes of non-renewable primary resources, which are the feedstock or raw material that support production processes. The reduction in such cargo flows or maritime transport volumes will materialise as a threat as far as ports are concerned. The obvious reason for this reduced demand may be attributed to the fall in demand for primary (bulk) materials that represent the majority of volume handled in most ports. Additionally it could be said that the transition towards CE in relation to certain supply chains could be deemed synchronous with a shift away from global and toward regional supply chains. Trending with the assumption that information from the past could provide the context for the future could prove wrong and the PMB must be wary of

this. It will be noteworthy to understand that near sourcing, which will be the outcome, could result in major changes to the transit flows encountered as well as affect the revenue streams of the ports. As ports mature in their life cycle, they may end up facing the possibility of being outdated in their approach when not being able to cope up with the changes that are happening in the industry. This causes the existing building and transportation infrastructure to become obsolete, and cause them to be driven to a position where they will no longer be relevant, and unable to cater to the prevalent industries that exist. Therefore adopting solutions such as industry relevant redevelopment, activities which are in vogue and futuristic will help them retain the licence to operate while strengthening the revenue streams and thereby help the ports retain their strategic edge. However, this also presents room for opportunities as well: related businesses will try to collocate within the port area where each party then stands to benefit from the other in terms of materials as well as energy, boosted by common utility infrastructure availability between the companies. The Ecluse project within the Port of Antwerp is such an example where waste heat from waste handling companies like SLECO and INDAVER in partnership with Fluvius successfully meets the requirements of multiple chemical manufacturing companies located within the port area. Many ports thereby stand to benefit through their evolution into industrial and logistical clusters, besides holding promise to develop into “eco-industrial parks” (Guide & van Wassenhove, 2009). The change towards circularity has always been associated with sustainable energy, and this holds vast promise and a positive impact towards the ports migrating towards CE. A positive impact may be adjudged through the port using its fallow lands and shallow coastal boundaries, to harbour wind turbines for generating clean energy as well as providing for its storage. Moving ahead as the port distances itself from traditional fossil fuel based industrial complexes in its quest to become a true CE, new age alternate fuel complexes like that of green Hydrogen, and green Methanol is already becoming a reality in the PoR. Through these newer activities, PMB are set to gain impetus and thus benefit from the first mover advantage if they toy the path of CE. PMB largely remain unaware of the opportunities that the shift to a CE provides besides the largely evident ones like economic growth and employment opportunities (Gravagnuolo et al., 2019; Karimpour et al., 2020). Indeed it is here where the concept of CE can provide the much required solution, a way to bridge the gap which will help the ports rise up to the challenges, and make sure that their competitiveness in a resource – constrained world is sustained, additionally giving birth to innovation and simultaneously help address environmental concerns.

The potential that the concept of CE yields is well recognised in literature, as a powerful and futuristic business tool holding considerable potential. Despite this, implementation is noticed to be rather limited (Roberts et al., 2021; Sehnem et al., 2019). The benefits of a port's economic activities are becoming increasingly wide spread, whilst the negative externalities created by ports remain concentrated in the local area (Roberts et al., 2021). Despite the potential, that CE as a business model holds, which is quite considerable, the concept is still at a fledgling stage facing a multitude of barriers in way of its successful implementation (Kirchherr et al., 2018; Roberts et al., 2021). Cultural attitudes veering towards paucity of consumer interest and awareness, and a glut of relevant knowledge and collaboration between businesses and stakeholders (Hart et al., 2019; Roberts et al., 2021). Other dominant barriers that exist include the lacuna of policy willingness to adapt and provide the essential consistent framework for guidance, technological limitations, and a lack of financial viability existing for the CE business models (Kok et al., 2013; Merk, 2013; Pheifer, 2017; Roberts et al., 2021). The transformation to a circular economy is an arduous process that will require legislative perseverance and fortitude, as well as some level of predictability and consistency from European institutions so that industry and, in this case, ports can make long-term investments (Kyllo'nen, 2017; Roberts et al., 2021; van den Berghe et al., 2019). The transition from a linear economy to a circular economy requires systemic changes of the whole economy. Accordingly, it is a significant difficulty to foster full awareness of the circular economy for businesses, citizens, and government authorities, as well as to reach common consensus among them. Space and land-use conflicts between expanding industries and expanding residential areas in cities could prove to be an area of conflict and concern depending on the typology of the ports (Roberts et al., 2021; van den Berghe et al., 2019). Investing in technology towards recycling, extraction of virgin materials and their re-use could prove to be more expensive and act as major deterrent towards the growth of a CE when raw or virgin materials are available at low costs (Hart et al., 2019; Mont Oksana et al., 2017; Roberts et al., 2021). A challenge is to reach enough critical mass in the circular economy business model for certain wastes to obtain economic profitability. There is a clear lack of economic incentives and market mechanisms to engage relevant stakeholders in this model. Investment in CE infrastructure is rather expensive, and this poses a roadblock for many innovative and novel CE ideas. CE being an upcoming and unique economic concept greatly suffers from the lack of acceptance and acknowledgement (Kirchherr et al., 2018; Roberts et al., 2021) forcing it into an area of risk and failure to achieve widespread adoption (Roberts et al., 2021). Most of the CE investments are long term and unpredictable, making it a major concern to attract investments (Gravagnuolo

et al). This is also true in the case of CE where the ports consider it as the new go to business model, and embrace the transformation challenge (Haezendonck, 2020). (Gravagnuolo et al., 2019; Roberts et al., 2021) discusses the importance of cooperation in port cities if CE is to be implemented, and Mankowska et al. recognised the importance of communication between PMB and external stakeholders. Haezendonck and Van den Berghe state that although port authorities must play a key role in CE implementation within ports, networking, exchange of ideas, and funding provision is crucial. Girard illustrated the importance of collaboration with stakeholders from outside the port area, eventually enabling CE over larger areas, growing from industrial symbiosis within the port, to urban symbiosis within the port city, and eventually city-territorial symbiosis, including the wider area and hinterland. Port cities, especially when the port is privatized, may suffer from a lack of unified leadership, due to the competing interests of port and city authorities makes implementing CE potentially more challenging. Challenges in way of transportation and infrastructural issues, non-availability of suitable and reliable supply chain partners, product traceability, uncertainty of return and high up-front costs (Mańkowska et al., 2020; Roberts et al., 2021) also exists. De Langen & Sornn-Friese (2019) discuss how CE affects supply chains because of their becoming more local and how this in turn affects ports. Key cultural barriers, such as resistance to change, coordination, and information sharing have been identified (Mańkowska et al., 2020; Roberts et al., 2021), as well as the challenges presented by varying types of ports all having unique opportunities and challenges. This makes creating a universal framework for port cities more challenging. Moreover, the CE transition may be viewed as a threat by many PMB, who are acclimatized to operating their ports in a traditionally linear way and are averse to the idea of embracing change when it comes CE, which automatically comes with an associated amount of uncertainty (Balz & Qu, 2021; Karimpour et al., 2020; Libera Amenta & Paolo De Martino, 2018). PMB are finally dependent on the companies, which are located within the port area to help transition towards a CE in spite of the support, encouragement that they can offer and even when it dons the role of a matchmaker (Cerreta et al., 2020; P. de Langen & Sornn-Friese, 2019). As landlord and matchmaker they have the commercial assets to only stimulate the industries within the port area. The development of the circular economy heavily depends on the final market uptake and initiatives of individual companies. “PA’s are struggling to develop an integrated CE strategy and find their role in this transition” (Haezendonck & van den Berghe, 2020).

2.3 The New Strategic Role of Port

2.3.1 Port as an Ecosystem

A vast majority of the ports are autonomous and continue to be government owned with a goal of maintaining financial sustainability and creating a larger societal value. The concept of a port as a business ecosystem is in assessing the role and business model of the port development company (de Langen et al., 2020). This auger well with various studies that also analyse circular economic activities with a business ecosystem perspective (de Langen et al., 2020; Martins, 2016). (Jacobides et al., 2018) defines ecosystems as ‘a set of actors with varying degrees of multi-lateral, non-generic complementarities that are not fully hierarchically controlled’. A business ecosystem stands apart due to the existence of these non-generic complementarities, which leaves room for some amount of customisation and thereby their uniqueness (de Langen et al., 2020). Ports by the virtue of being home to a large number of businesses can be viewed from an ecosystem perspective i.e. where a group of interacting firms depends on each other’s activities with focus bestowed on complementarity of products, services and shared infrastructures (Bichou & Gray, 2005; de Langen et al., 2020; Dhanaraj & Parkhe, 2006).

2.3.2 Existing Port Business Strategy

Port governance has captured the audience of academicians with a considerable number of studies carried out and literature available in this regards. However, there is a lacuna in the number of research works carried out in comparison on the topic of port strategy. However, this is seen to be changing and the last decade has seen a lot of attention bestowed on the PMB business models, and the strategies that they are employing. PMB are to be considered the organizational managers in charge of ensuring a competitive, sustainable, safe and holistic development of the ports (Chlomoudis & Pallis, 2004; P. W. de Langen, 2004; T. E. Notteboom & Winkelmanns, 2001; L. M. van der Lugt et al., 2017). Most of the ports governed by the PMB though autonomous are largely government owned carry out the function of port development (P. W. de Langen & Heij, 2014). The orientation of these PMB is generally seen to be more towards creating societal value, and while they operate commercially, profit maximization is not on their agenda (P. W. de Langen & van der Lugt, 2017). Over time, seaports have largely developed into a playing field for private investors and companies with the PMB evolving to

don a landlord role. Here the commercial operations are largely undertaken and controlled by the private companies within the ambit of the port while the PMB largely act as matchmakers, while also acting as the interface between the public and the private companies. The PMB act to meet the requirements and the strategic intent of the private companies and forms a sort of liaison agent with the public institutions while also accomplishing the important act of following their own strategy (L. van der Lugt et al., 2013b; L. M. van der Lugt et al., 2017). The PMB continue to face changing external forces and are forced to acclimatize for e.g.; in the case of the recent energy transition within ports, in addition to the changing environmental concerns, scarcity of natural resources and changes encountered in the cargo flows. Over the last few decades, the changes in the ports functioning has resulted in the PMB being viewed through a very different analytical lens with elements of management science being used to formulate port strategies. This being the case, over the last two to three decades PMB have reformed from task-oriented organizations to more autonomous and commercially acting organizations (Brooks & Cullinane, 2006; Debrue et al., 2013; Ng & Pallis, 2010; L. van der Lugt et al., 2013a). In spite of the large number of studies on strategies undertaken by PMB, the significance of port strategic management for PMB is still lacking. New PMB functions include those of a cluster manager on top of the traditional landlord functions where the PMB is acting more like an infrastructure manager (P. W. de Langen, 2004; L. van der Lugt et al., 2013a; Verhoeven, 2010). The burgeoning scope of port activities spilling over from the port area to regional and even global level is clearly noticed. Goss in his serial article “Strategies for Port Authorities” comes up with four strategies, the typology of each strategy deals with the focus on how the PMB should deal with the involvement of the private sector mainly about how the cargo is handled. The strategies are:

1. Being a rather minimalistic PMB by giving the freedom to the private sector to handle and control all cargo handling functions.
2. Maintaining and imposing certain amount of control over the private sector.
3. Play an active role in stimulating some amount of competition through strategic issuance of concessions.
4. Run the port as a fully public port.

This is not the case today, and ports largely have developed into industrial clusters with a huge array of interconnected businesses, technologies, consumers and cargo mixes. While not restricting their attention on geographically bounded systems such as ports, three potential strategies are distinctly identified for an ecosystem developer such as a port: a landlord strategy, a keystone strategy and a dominator strategy (Iansiti & Levien, 2004). PMB who are in possession of key assets, in this case, the land and infrastructure, benefit from the all-round development of the ecosystem, and towards this, the keystone strategy is best suited when considering the long-term development of the ecosystem. Instead of being passive, like in the case of landlord strategy, the keystone strategy employs a more active approach in ensuring the profitability and sustainability of the port ecosystem. keystones while providing a proper level of diversity, and creating a platform within the port ecosystem are oriented towards creating value and capturing value for the third party businesses within the port ecosystem (P. W. de Langen et al., 2020). With CE touted as the new business model for ports the circularity transition will bear an impact on the business strategy of the ports as a developer of ports clusters which will be explored below.

2.3.3 Evolving strategies for Port Management Bodies

Today there is considerable interest evoked in the port context when it comes to CE as the new business model. CE is considered as a solution to many of the problems faced by large port hubs while allowing them to progress on the path of sustainability, at the same time remaining profitable, mitigating the environmental challenges while curtailing the negative social image of the ports. This is also true in the case of CE where the ports consider it as the new go to business model, and embrace the transformation challenge (Haezendonck, 2020). So that clarity and direction is offered to strategic planners on the way forward, it is important to pose the question: What are the business strategies of the PMB in order to transition the port ecosystem to a CE model. The move to a CE model is an example of a disruptive change, which will require a new way of thinking and doing business. The business strategies needed to bolster and sustain the CE within the seaports calls for long-term planning and solutions with strong stakeholder and partner inclusion. The keystone strategy advocated by Iansiti and Levien is in line with the strategies developed by many PMB (P. W. de Langen et al., 2020; L. V. D. Lugt et al., 2015) can be considered a vital first step. With most PMB operating on the landlord model earning revenues from offering concessions by expanding their land use if available, and by increasing the throughput volumes that are handled. The CE model is considered a

disruptive change which if strategically implemented will take the port on the path of sustainable development. The PMB following a facilitating strategy of providing a platform where companies already having a circular business model can set base and help progress the concept of circularity. Circularity materialises by attracting companies that can benefit out of the synergy thus helping to embed CE within the port. By physically collocating companies and by developing and providing the right infrastructure through an implicit arrangement with the companies can be considered to help speed up CE. Circular companies can make use of the common infrastructure to drive their growth thereby improving circularity. Industrial symbiosis has been mentioned as an effective strategy to be employed by the PMB, which acts as an ecosystem manger. The port is home to a large number of businesses and while catering to the internal port related activities, considered the ports primary activity, it is also vital to take into consideration the activities of stakeholders housed within the port ecosystem when changing the business model to CE. CE should be viewed with optimism by the PMB where opportunities will evolve towards handling new and varied cargo flows while deviating from the traditional flows of raw material and cargo. Instead of seeing this as an impending threat on the ports revenues, this should be viewed as an opportunity to enhance and create new revenue streams to ensure the ports sustainability and profitability. In addition, to be expected with the cargo flow changes, is an implied localized or regionalized supply chain of goods and a likely inversion in material trade (P. de Langen & Sornn-Friese, 2019). In order to capture these new opportunities it is essential to collaborate and facilitate this collaboration within the port ecosystem. The major implication for the PMB as ecosystem mangers would be to incorporate and work out strategic changes in order to capture value thereby maintaining financial or business sustainability because of the business model change to CE.

2.3.4 Port Ecosystem CE Performance Measurement

Adoption of performance measurement and monitoring systems is not rampantly undertaken by PMB, and even now, the use of standard reporting indices or indicators can be mentioned as being very limited. Only very few progressive PMB are seen to be undertaking these reporting measures, and that too in recent years. Most of the PMB publish their annual financial reports, throughput figures and modal split figures regularly. Key Performance Indicators (KPI) sets to monitor the ports specific activities is seen to be largely missing, and if present are not standardized and appear to be fragmented. With PMB largely evolving towards ecosystem mangers, it becomes important to have a separate indicator set to monitor the progress of CE

within the port domain so that they may be employed as managerial levers (van der Lugt et al., 2013).

2.4 Circular Economy Indicators for Ports

2.4.1 Indicators and an Indicator based framework

There are a lot of research on indicators and the need for indicators in different fields does exist, but the word “indicators” can carry or encompass different meanings, and there is often no clear understanding of what it means (Kristensen & Mosgaard, 2020b; Papageorgiou et al., 2021). Indicators maybe defined as variables or functions of variables that prove an indication or information in support of decision-making (Papageorgiou et al., 2021). Indicators help the decision maker by providing a clear summary that is a focused and a condensed version of complex information in a way that is both simple and meaningful. Thereby, they serve as powerful and effective tools both for measuring progress and performance while at the same time translating complicated information (Papageorgiou et al., 2021; Saidani et al., 2019; Singh et al., 2009; Tapia et al., 2021). An indicator, as a rule of thumb is mostly likened to a reference value, a target, a goal or a benchmark (Papageorgiou et al., 2021; Waas et al., 2014) which helps the indicator assume a meaning thereby distinguishing it from raw or unfiltered data (Moldan et al., 2012; Papageorgiou et al., 2021). As defined by Organisation for economic Co-operation and development (OECD) the term “indicator” is a “quantitative or qualitative factor or variable that provides a simple and reliable means to measure achievement, to reflect changes connected to an intervention, or to help assess the performance of a development actor”. The above definition captures the principal features of indicators, in connection with their ability to be a measure of achievement and performance and to represent changes, and highlights that they can be based both on quantitative as well as qualitative data (Papageorgiou et al., 2021). An indicator accomplishes the task of providing a specific information about an entity that is being measured (Gudmundsson, 2003; Papageorgiou et al., 2021). Indicators are often based upon an indicator-based framework, which is constituted by an integrated system of indicators that helps to “convey a broader purpose and significance to the individual indicator and provides a comprehensive picture of some problem or entity” (Wisse, 2016). An indicator is ‘a sign or signal that relays a complex message (Jackson et al., 2000). The distinguishing feature of an indicator is its ability to encapsulate with focus and condense the complexity of a dynamic environment to a manageable amount of relevant information.

Therefore, in order to effectively monitor and evaluate the progress of a particular business strategy it is of vital importance for the managers to be equipped with a dynamic set of indicators.

2.4.2 CE Indicators in General and for Ports

CE is a growing topic, especially in the European Union, that promotes the responsible and cyclical use of resources possibly contributing to sustainable development. CE is an umbrella concept incorporating different meanings. In order to assist the progress towards CE, the capability to measure and monitor circularity through monitoring frameworks, evaluation tools and indicators is essential (Cayzer et al., 2017; Kristensen & Mosgaard, 2020a; Saidani et al., 2019). However, indicators for measuring CE are still at its infancy (Ghisellini et al., 2016; Giurco et al., 2014; Mesa et al., 2018) showed that only a few studies (10 out of 155) include a focus on indicators for assessing CE strategies. Numerous studies and academic literature on Indicators at the product level, like the Material Circularity Indicator (MCI) developed by The Ellen McArthur Foundation do exist. Another circularity measurement indicator that exists for industries is the Circularity Transition Indicator (CTI) of the World Business Council for Sustainable Development, which is used by more than 30 companies.

The transition to a CE being complex and one of multi dimensionality requires a holistic indicator based monitoring system as a measure of progress towards circularity from a systemic perspective. Indicator based frameworks can capture multiple CE aspects, thus being able to provide a more comprehensive picture of progress towards a CE in contrast to a single indicators or indices which are able to focus only on one specific CE aspect. Therefore, the mapping of CE indicator based frameworks become all-important as efforts to accelerate the transition towards a CE intensify.

Ports operate and go about their business in a rather complex environment involving multiple stakeholders both within and outside the port ecosystem. It is therefore important that the port, when transitioning with CE as its business model, be equipped with a set of indicators to monitor and evaluate the progress towards circularity and that too holistically. Studies indicate that CE as a business model is gaining traction, and numerous CE activities are detected in a number of ports especially in Europe, with definitions appearing in their CE vision and strategy along with the participation in CE projects (Kovačič Lukman et al., 2022). Studies have been carried out by (Gravagnuolo et al., 2019) developing a framework for evaluating circular cities, focusing on a built environment and using port cities as a testbed. Another attempt at evaluation

emerged within the Horizon 2020—Defining the concept of “Port of the Future” (*Port of the Future KPI Set Deliverable 3.1*, 2020). (Haezendonck & van den Berghe, 2020) Mentions of the lack of indicators existing in the seaports while throwing light into the CE initiatives undertaken by them. (Mańkowska et al., 2020) goes on to assert the absence of indicators to measure the progress of circularity in the port sector, but no model or indicator set is proposed. Ports view CE as important to their progress and sustenance while regenerating their surroundings (Kovačič Lukman et al., 2022). It is quite evident then that there exists a clear requirement to measure the progress and success of such port initiatives tangibly (Williams, 2019). In the absence of a clear set of monitoring indicators, individual CE projects can be considered as interesting indicators to observe the pathway of a port’s development in its CE transition (Haezendonck & van den Berghe, 2020). Encapsulating, for any port adopting CE as the business model, and for it to be successful, profitable and sustainable on the long term, it is of vital importance to have a set of indicators to monitor the performance of its circular activities (Haezendonck, 2020). The circular transitions are not always associated with disruptive changes, but can be also be linked to progressive and innovative sustainability innovations (Haezendonck & van den Berghe, 2020). Taking into account just the disruptive innovation may slow down the incremental processes as such disruptions will help mitigate the issues later as time progresses (Anderson & Peters, 2016; Haezendonck & van den Berghe, 2020). The ideal transition through innovation then jeopardises the linear lock-in optimisations. A simultaneous progress using both the pathways will be the ideal solution (Haezendonck & van den Berghe, 2020; MacArthur et al., 2015).

Therefore, individual CE projects are interesting as indicators to monitor the progress of the port on its path to CE. Such indicators are important as finally the investments of the port, which is considerable, needs to pay off and the PMB need to ensure breaking even if not turning profitable. Additionally monitoring the CE transition will help to throw light on the steps that need to be further taken to increase the CE ambition level of the PMB.

2.4.3 VC-OVAM Long list of circularity indicators for ports

The Roadmap towards a Resource Efficient Europe (2011) and the commitment of The Action Plan towards The Circular Economy (2015) recently has set the tone towards improving the Resource Efficiency (RE) and the Circular Economy transition by the EC. This policy push has stimulated and triggered some very ambitious national programmes for RE and CE as well as institutional advances but is not yet bound by targets or mandatory reporting (Domenech & Bahn-Walkowiak, 2019).

Here, ports are considered essential and important nodes for embedding and progressing CE as per the EU parliament, and local governments (Kyllo"nen, 2017). Taking into consideration the policy level requirements for ports to embrace CE as the new business model, the need to strategize, monitor and sustain the growth trajectory of CE within the port arena becomes quintessential. Here the longlist of 32 indicators developed for VC-OVAM (2022) study, based on its policy domain, and specific to the port context in the Flemish region in Belgium gains prominence. This is particularly important given the importance of ports in the European context, and due to the unavailability of port specific indicator set to measure the circularity within the port (Haezendonck & van den Berghe, 2020; Kovačič Lukman et al., 2022; Mańkowska et al., 2020).

Developing our own set of indicators is well outside the scope of this research and therefore we rely on the 32-longlist indicators and their effective applicability to the case of PoR to find a match with those set out by the PMB.

Depicted below in **Table 1** and **Table 2** are the longlist of 32 indicators, which are developed for VC-OVAM (2022) study. 21 indicators are independent of the type of port or the timeframe of the indicator and 10 indicators are dependent on the type of port and time-frame dependent. Further, these indicators are grouped under different themes, Economic / Spatial, Social / Organization / Innovation, Waste & Material Flows, and Infrastructure.

Table 1. Independent accepted Indicators (fixed)

Economic / Spatial	1	Number of CE activities within the port area
	2	Number of CE projects within the port area
	3	Number of port companies whose core business directly relates to CE activities
	4	Share of port companies which engage in CE activities
	5	Hectares of CE activities in port area
	6	Share of revenue from CE activities of PDC in port area
	7	Investment in CE activities by PMB in port area
	8	Added value for PMB from CE activities in port area
Social / Organization / Innovation	9	Share of direct employment from CE activities and projects in port area
	10	Number of FTEs in CE activities and projects in port area
	11	Circular procurement policy
	12	Number of CE certifications held by the PMB and companies in the port area
	13	Presence of a circular port incubator
	14	% of port companies participating in regional, national or EU programs for R&D&I in circularity set up by PMB
	15	Waste management ISO standards
	16	The presence of a CE strategy or roadmap within port companies and within the port authority
Waste & Material Flows	17	Tonnes of ship waste
	18	Share of Import of secondary resources
	19	Share of Export of secondary resources
	20	Import of waste to be recycled
	21	Export of waste to be recycled

(Source: VC-OVAM (2022) study)

Table 2. Port Specific and Timeframe dependent indicators (variable)

Waste and Material Flows	22	Waste production within the port area	Timeframe
	23	Tonnes of waste in port area	Port specific
	24	Tonnes of waste in port area follow-up indicator: Share of waste recycled, share of waste reused	Timeframe
	25	Tonnes of ship waste follow-up indicator: Share of waste recycled, share of waste reused	Timeframe
	26	Secondary material consumption in the port area	Portspecific (industrial ports) Timeframe
Infrastructure	27	Share of infrastructure (partially) built from secondary materials	Timeframe
	28	Share of superstructure (partially) built from secondary materials	Timeframe
	29	Share of infrastructure designed for circular use	Timeframe
	30	Share of superstructure designed for circular use	Timeframe
Social	31	Share of jobs by education level in the CE (low,medium,high skilled) in the port area	Timeframe
	32	% of workforce trained in CE	Timeframe

(Source: VC-OVAM (2022) study)

3. Research Methodology

3.1 Choice of Methodology

In this section, we discuss one in-depth case study of Europe's largest port, the Port of Rotterdam. This applied research entails the choice of a single, strong case study strategy (de Langen et al., 2020; Eisenhardt, 1989; Gerring, 2004) to study the applicability of port CE indicators developed by VC-OVAM (2022) study. Following (Ridder, 2017), we see the case study as a research strategy that employs a variety of data sources to examine a particular phenomenon in its natural context and in this process relate theories and concepts with practice. Following (Piekkari et al., 2009), we furthermore understand case studies as the thorough study of a single unit for the purpose of understanding a larger class of similar units.

Therefore, we undertake a single case study and perform a desktop research because of the exploratory nature of this research dealing with the use of CE specific indicator set developed for VC-OVAM (2022) study, apply it to the case of Port of Rotterdam to validate and check its suitability of use. The limited availability of resources, the low incidence of the selected study and the fact that we are examining a nascent research area makes this single case study approach valuable, providing future possibilities for both quantitative and qualitative analysis.

3.2 Case of Port of Rotterdam and Benchmarking with Port of Amsterdam

The PoR is the largest seaport in Europe and the world's largest seaport outside of East Asia. The port continues to serve as the major hub of oil trade while also supporting a large array of unsustainable material flows. It is home to a large industrial cluster, which is a major consumer of raw materials. In addition, the presence of a large logistics sector, and a surrounding region that is home to a large population generating a variety of waste flows. This is both beneficial and advantageous as recycling of these residual flows bides well with the PoR's ambition to transition to a new system of raw materials while offering Rotterdam new socioeconomic opportunities during its transition to a waste-to-value port. The PoR in terms of its size and strategic location is well positioned to develop into a circular hub (Circular Port: Rotterdam as a Circular Hub, n.d.). However, indications or indicators to monitor such transition seem to be lacking. The PMB are therefore at a discernable disadvantage due to the lack of having a robust set of indicators as a strategic tool to monitor the circular transition of the port, and within the port.

The case of Port of Amsterdam (PoA), considered a front runner or first mover in CE in the port context is particularly interesting with a large number of 21 CE activities embedded within the port, and with specific ambitions to foster a fully CE by 2050. This is similar to the PoR's ambitions, but the road maps for the both the ports are different with on the one hand PoR focusing on energy transition as the end goal with CE as one of the objectives, while the PoA engages innovative startups to reuse and recycle industrial materials more efficiently (de Langen et al., 2020). Therefore, the PoA can be considered the perfect benchmark for the PoR case, being a Dutch port and by serving as a model or threshold for PoR.

3.3 Data Collection

There exists only limited availability of data and this seriously curtails empirically validated conclusions on the effectiveness of an indicator set to monitor the PoR's circularity transition.

The data collection for the empirical analysis were done from various sources mentioned below:

- Unstructured interviews conducted with the circularity experts of the PoR and the PoA, on the availability of indicator sets, their usefulness in the port domain, and the existence of specific indicators if any, which these PMB are using to monitor and accelerate the progress of circularity within their specific ports.
- Gray literature, which allowed us to identify indicators hidden in the guise of goals and objectives that are being monitored by the PMB.
- The annual reports of the PoR from 2015 – 2021 which is available on the ports website.
- Independent studies and the jointly published report carried out by the PoR and Circle Economy in 2019.
- Port Vision 2030 report for PoR.
- Strategic documents and reports of the PoR that is available in the public domain.

3.3.1 Breaking down the PoR Initiatives: Are they truly circular?

In this section, we take a look at the activities and the projects that the PoR is undertaking and have undertaken in the past to evaluate that they are truly circular in nature. Towards this, we rely on the data available on the PoR website, secondary data sources such as news articles and data from studies conducted, as well as data obtained through interviews from the PoR circularity domain expert. The PoR intends to achieve this transformation through the four pillars as mentioned below:

Pillar 1: The industry takes efficiency measures. Residual warmth is used to heat homes, commercial buildings and greenhouses. CO₂ is captured and stored under the North Sea and infrastructure sufficiency is created to aid the transformation and transport the captured carbon as feedstock and green hydrogen (in the future) to relevant industries.

Pillar 2: A change in the energy system or a transformation towards non-polluting electrification of industries, and use of fuels such as hydrogen and green hydrogen using the vast non-conventional energy sources such as the sun and the wind is envisioned moving forward.

Pillar 3: Involves replacement and reducing the reliance on fossil fuels by transitioning towards biomass, increasing the recycling activities, increasing the reliance on green hydrogen and using the carbon captured as feedstock for synthetic fuels.

Pillar 4: Transportation and logistics are important activities as far as the port is concerned, and with the ambition of reducing the CO2 emissions and becoming climate friendly, the port along with its partners aims at decarbonisation of this sector (Data Source: PoR website).

There is a clear mention of promoting circular activities and projects on the website, but further analysis of the initiatives under the four pillars throw a different light. It is seen that Pillar 3 activities, and projects envisioned under this hold the most promise with the presence of truly circular activities and projects.

3.3.2 Data from website, annual reports, grey literature and interview

From the website, companies whose activities and projects that are truly circular include:

Recycling:

- Waste-to-Jet Rotterdam is an important step towards a more sustainable chemical industry and circular economy. The facility will be the first of its kind in Europe to provide a sustainable solution for non-recyclable wastes, converting waste plastics and other mixed wastes into new raw materials.
- The Floating Farm is a sustainable floating cow farm in the port of Rotterdam. The Farm is circular within the city by adding residual flows from the local industry to the cows and thus upgrading it to traditional dairy products. We then sell these products locally. We are also circular within the farm itself by closing the waste, water and energy cycles as much as possible. In this way, we produce high-quality food in a sustainable and future-proof way.
- REKO: The largest licensed integrated processing location in the Netherlands for mineral waste products. Three main activities take place on the 33-hectare site: a crushing plant for the production of granulate, two thermal cleaning systems for cleaning tar-retaining asphalt (TAG) and a CHP plant for generating electricity from residual heat. The crushing plant and the thermal cleaning plant are among the largest of their type.
- European Metal Recycling: Recycling of scrap metal originating from many sources such as discarded consumer products, industry, construction and demolition.
- Reym B.V.: Reym BV is a Total Care service provider in the field of industrial cleaning, waste management and transport. Total Care stands for a skilled staff, a cost-efficient and safe implementation, a single point of contact and a lasting customer relationship.

- Indorama: We at IVL see the recycling of polyethylene terephthalate (PET) at the very core of our contribution to the global effort to create a Circular Economy, a system where the use of virgin resources are minimized and materials are recycled repeatedly.
- TES: Aims at recycling and raw material extraction from the batteries used for electric vehicles.

Re-use:

- Boskalis Environmental: Boskalis Environmental is a global leader in the large-scale treatment of mineral waste streams like soil, sediment, incinerator bottom ash (IBA) and mineral waste materials, from sewers, drains, pumping stations and street sweeping waste. We design and manage the entire integral process, from excavation, transport, treatment, quality control, re-use and disposal of the various material streams.
- Octopi: The preeminent digital platform for matching supply and demand in the area of equipment and machinery for the petrochemical sector. An emporium for ARA-related spare equipment and overstock. An online market for end users, contractors and traders alike.
- Suez RR IWS Remediation B.V.: In a world where resources are becoming increasingly scarce, industries are developing new strategies for further growth. More than ever, soil remediation and groundwater treatment have become a key factor in industrial performance, so resources can be safeguarded via effective water management. SUEZ Remediation presents industrial clients with solutions for the processing of contaminated and polluted soil and groundwater, while simultaneously offering a remediation strategy that takes due account of all aspects of the project.

Repair:

- Quay wall with sensor: Many quay walls in Rotterdam's port area are nearing the end of their technical service life. Sensors installed on these quay walls can supply data regarding the structure's current condition. This input can be put to good use by both the owner of the quay and its users. This enables more efficient maintenance on existing quay walls, resulting in cost savings and less downtime and disruptions.

Repurpose:

- Groene Poort: Using excess soil taken from the surrounding area, the groyne fields along the southern bank of het Scheur are made shallower. And clean rubble from

demolished quays and structures in the area is used to construct 'parallel dams' between the groynes that extend into the waterway. These parallel dams will be run the same way as the banks, which will lead to development of sandbars between the groynes: small zones between land and water that emerge during low tide and are gradually submerged during high tide. All sorts of aquatic plants, migratory fish and birds feel at home in these transition zones, where the water's waves break on the parallel dams.

Companies with a mix of processing types:

- AVR: AVR specialises in processing various types of general waste: wastewater, paper residue, household and industrial waste, waste wood and hazardous general waste. Our ongoing aim is for maximum recycling of energy and materials from this general waste via effective, efficient and safe operational management. We ensure that metals are recycled and minerals are used in road construction and construction. We supply sustainable steam, heat and electricity to our environment, thus preventing the use of coal and gas. In doing so, AVR delivers an important contribution to national and European climate and energy objectives.
- A&M Recycling: A&M Recycling does everything possible to create useful raw materials from waste. Its innovative, socially responsible and customer-oriented business policy ensures that this mission is a success in practice.

Location where start-ups and grow-ups further develop their circular ideas and technologies:

- Blue City: Blue City is a breeding ground for innovative companies that link together their residual flows. Within our ecosystem of social entrepreneurs and radical disruptors, waste forms a valuable building block – with one enterprise's output serving as the other's input. This allows us to jointly create a model city for the circular economy. A development that is becoming more urgent every day.
- M4H: M4H is a location that gives ample room for experimentation, creation and growth. At M4H, new technologies based on new and sustainable approaches to energy and materials are conceived, developed and applied.
- RDM: RDM Rotterdam is the hotspot for innovation in the port: this is where the manufacturing industry of the future is gradually taking shape.
- Plant One: Plant One Rotterdam B.V. focuses on the realisation and operation of a site where businesses and research institutes can test their innovative ideas relating to

sustainable technology on a commercial scale, as well as work on the manufacture of products through this technology and the associated activities.

The PoR publishes annual reports as stipulated by regulations. However, neither sustainability reports nor any strategic reports concerning the CE transition are published and as evident from extant literature analysed. Annual reports from the year 2015 were scanned to pinpoint circular activities, projects and monitoring activities within the port.

The PoR, in their annual report of 2015 has briefly mentioned on the ports ambition to embrace CE as a plausible route to ensure that the port follows on the path of sustainable growth. The start-up accelerator PortXL was launched in the same year, to attract innovative companies into the port ecosystem.

Moving forward in the annual report of 2016 mentions fostering circular processes as well as a push to attract industries specialising in CE activities.

In the annual report of 2017 the mention of CE as a route to sustainable port development finds mention alongside increasing the efficiency and utilisation of existing fossil energy and chemical technology, to stimulate sustainable energy, bio-based industry and the circular economy and to realise CO₂ capture and sequestration.

Quite surprisingly, in the annual report of 2018 the mention of CE is dropped but mention of energy transition in the port and industrial complex in a sustainable manner finds mention. Attracting companies to the port to benefit from the synergistic effect also finds a mention.

Having skipped the mention of CE in the 2018 annual report, in the 2019 annual report a three pillar strategy to take the port on the path of sustainable development is mooted to bring the industrial cluster in line with the climate objectives. Here, the third pillar is all about development of new raw materials, renewable fuels, chemicals, hydrogen and CE. Noteworthy is the collaboration with Shell in the waste to chemical W2C plant that is an important milestone towards the CE transition for the PoR.

The 2020 annual report while skipping the CE catchword, brings the concept out through the third pillar of the ports strategy where the proposal to make synthetic kerosene as a replacement for jet fuel is highlighted. This is evidence enough that the port has its focus aligned in developing CE.

In the 2021 annual report, the CE is mentioned under the Pillar 3 strategy of the port where the port is looking at attracting players specialising in CE activities, and who can contribute to the circular economy development.

While the absence of separate sustainability reports is felt, it is evident that the PA corporate strategy has sustainable development well entrenched in its ambitions.

However, the Port Authority is actively advancing four circular pathways in collaboration with a range of partners to make the port and port-based supply chains more circular. The pathways are Innovation Ecosystem, Sorting and Recycling, Industrial Symbiosis and Carbon Capture Utilisation & Storage (CCUS). Monitoring of waste flows are seen to be carried out by the PA, which was revealed during our discussion with the PoR circularity expert and from the joint report on Circular Economy in the PoR published by PoR Authority and Circle Economy a global consultancy firm specialising in CE implementation and monitoring.

This is interesting to us as moving forward monitoring will become a necessity as per the EU Circular Economy Action Plan (CEAP). Therefore, in order to check the applicability and fit of the set of indicators developed for the Flemish ports by VC-OVAM (2022) study, we perform a three-stage gap analysis in the PoR context.

The consultancy report which was jointly published by the PoR and the Circle Economy, an independent consultancy specialising in Circular Economy Projects is noteworthy. This report published in 2019, helps to bring out the ambitions of the PoR into a full-fledged circular port by transitioning to a Waste-To-Value Port through the re-designing and re-developing of the industrial and logistical activities within the Rotterdam cluster. This will help the port add value not only to the port area, but also to the broader economy. Barring this the ports also aims to be the focal point of energy and raw material transitions due to its extensive network of hinterland connections offering excellent opportunities for CE aggregation. This along with waste mapping and valorisation will be an added opportunity to the port both short term as well as long term.

According to the Circle Economy report, as a means to further these ambitions four pathways are followed by the PoR to realise its circular ambitions:

The circular pathways are as follows: 1. Innovation ecosystem, stimulating the creation of start-ups, the advancement into scaling up and becoming established and the connection to the existing cluster. 2. Sorting and recycling, in particular, aimed at developing and implementing

applicable technologies that turn waste into new products. 3. Industrial symbiosis, developing infrastructure and partnerships to exchange products and residual streams, like waste heat, steam, CO2 and solid waste flows. 4. Carbon Capture, Utilisation & Storage (CCUS), using carbon emissions as a new and valuable feedstock for the chemical and other sectors

The following indications related to CE exist within the port as per the study:

Table 3. Port of Rotterdam Circular Economy Objectives and Matching Indicators

Objective	Indicator
The production of different wastes by 74 of the largest industrial companies in the port and how these wastes are currently being processed. These companies are involved in several sectors and industries, including refining, chemicals, energy, waste and food. It highlights that although the majority of the industrial waste in the port is either recycled or used as internal or external fuel, a substantial part of the waste is still incinerated or landfilled.	Time frame dependent and port specific indicator exists; Records of waste flows of different categories are monitored and recorded but is not regular and up to date.
The Port Authority is actively advancing four circular pathways in collaboration with a range of partners to make the port and port-based supply chains more circular.	Investment in CE activities by PMB in port area
To capitalize on these residual flows, the Port Authority is investing in, among others, industrial symbiosis and synthetic chemicals projects, as well as supporting infrastructure.	Investment in CE activities by PMB in port area
Additional opportunities that are aligned with the port’s industrial profile and ambitions include high-value recycling of metals and chemicals, as well as the development of remanufacturing capacity to process the wide array of manufactured goods that flow through the port after reaching their end-of-life.	Missing Indicator: Waste Valorization Future plans available for each kind of waste flows from plastics, metal, minerals, biomass, industrial waste etc.
Clear ambitions shown to work on supporting policies, and set new milestones for the future.	Missing Indicator : Policy

(Source: PoR and Circle Economy report, 2019)

It is also clear from the interviews with the Circular Economy expert at the PoR, that there does not exist an indicator set to monitor the CE activities and projects within the port. This is simply due to the enormity and the complexity that CE monitoring holds with over 2000 companies operating within the port area, and due to the unavailability of proper and complete data sets. Even if data were to be available, the correctness of the data, and the challenges faced to acquire the data, which in some cases is proprietary or confidential, proves to be a challenge. Individual projects were mentioned to be monitored but objective evidence was fund lacking. The four-pillar strategy with the aim to achieve the target of becoming a CO2 neutral port with the third pillar revolving around CE was discussed as the road map. It is noteworthy that the PoR in 2017 joined the World Business Council for Sustainable Development (WBCSD) a group of 200 top companies in the world with the aim to monitor and report on the sustainable activities as per the standards set, and in order to see the transition to a full-fledged CE.

3.4 Data processing through triangulation and its limitations

Data was collected from the sources mentioned above i.e. the detailed interviews conducted with the port circular economy expert of the PoR and the extensive scanning of grey literature including the PoR website, the annual reports, independent reports, vision documents, roadmap documents, business reports and strategic documents available in the public domain. Additional information on CE initiatives and indicators were obtained from the interview carried out with the port circularity expert. This data was then triangulated using the longlist indicator set developed for VC-OVAM (2022) study to validate its applicability in the case of PoR.

The major limitation encountered was with the paucity of time, as large amounts of data had to be scanned to understand the indicators that were being employed to monitor CE activities and their progress. The difficulty to obtain the interviews from the port circularity experts and strategic experts to elicit their views and opinions on the subject coupled with the inaccessibility to certain strategic documents where the road map for the port to achieve CE is charted was challenging and proved arduous.

4. Empirical Analysis and Results

4.1 CE indicators used by the Port of Rotterdam

An extensive literature search into the availability of specific indicators used to monitor the circular activities within the PoR by its PMB does not yield any result with the PMB conclusively not using a set of monitoring indicators or KPI (Key Performance Indicators) to track the circularity progression. However, the PoR webpage clearly mentions about “Circular Port” and the map of the Port detailing the circular companies, which are already in operation, and the kind of circular activities that they are performing. The 5 R’s of “Recover”, “Recycle”, “Repair”, “Repurpose” and “Re-use” find a mention along with companies that deal with a mix of processing types. PoR follows the strategy of promoting its Innovation hubs where start-ups and grow-ups further develop their circular ideas and technologies (Circular Port: Rotterdam as a Circular Hub, n.d.). Further, the webpage contains information on the projects that are in progress and on the anvil based on the four pillars of:

- Efficiency and Infrastructure
- A New Energy System
- New Materials and Fuel System
- Making Logistic chains more sustainable

All the projects that the port undertakes under the auspices of these four pillars maybe considered circular by the PMB. Therefore, monitoring the progress of such projects within the PoR may be considered an effective measure of circularity by the PMB. An indicator set to measure and monitor the progress is missing.

4.2 CE indicators used by the Port of Amsterdam

An extensive literature review was carried out into the availability of specific indicators to monitor and measure the circular activities in the PoA by its PMB, but no specific results came out of the exercise except for the hectares of land set aside for circular initiatives (Source: PoA website). The PoA is considered one of the frontrunners concerning circularity, and has added a lot of companies into its portfolio. The PMB in its website quite vociferously declares its vision and commitment in making the PoA into a circular and sustainable hotspot. Close to 30 CE activities are already present within the port arena.

4.3 Port of Rotterdam’s Circular Economy Objectives, Ambitions and Reporting

On the auspices of climate change and the agreements that various governments have undertaken, the PoR becomes an important stakeholder in the EU Green Deal. CE has been recognised as one of the important pillars to achieve the 2030 and 2050 goals on CO2 emissions and for PoR to transition to a carbon neutral and a climate neutral port. This calls for effective reporting of the CE objectives of the port, and if these objectives were to be truly realised the need to have indicators becomes cardinal. The indicators prescribed should be ideally a one-to-one reflection of the objectives set forth. Therefore, we try to understand the port's CE objectives, obtained through a thorough screening of different data sources that have been mentioned in the earlier sections, and match them with one or more indicators of VC-OVAM (2022) study.

This further leads us to undertake a Gap Analysis. This is to identify the missing indicators on the one hand while on the other hand helping us identify indicators without any objective related to them. While the former should be added, the latter needs deletion from the longlist.

Different port typologies (industrial port, metropolitan inland port, coastal port) will call for different strategies to effect circularity due to the different maturity levels they are at with respect to the CE transition (Haezendonck & van den Berghe, 2020).

4.3.1 Port of Rotterdam and its CE Goals

The PoR is very vocal when it comes its progress towards carbon neutrality by 2050 with a 49 percent reduction targeted by 2030 compared to the 1990 levels (Source: PoR Website). Way back, in its 2015 Annual report the PoR states that in order to achieve sustainable growth the PA works to make the system and processes more efficient especially in the fossil energy and chemical technology, to stimulate sustainable energy, bio-based industry and the circular economy and to realise CO2 capture and storage. The annual report of 2016 saw a renewed focus laid on the mitigation of the climate change on the backdrop of the Paris climate and achieving CO2 neutrality by 2050. This translated to the much-needed push for the port to be a frontrunner in the large-scale development of current and emerging technologies aimed at reducing the fossil fuel consumption on the one hand while fostering the drive towards circular processes and the use of renewable energy on the other. This trend seems to permeate into 2017, and is reflected clearly within their annual report. The 2018 annual report goes on to lay emphasis on the previous strategy developed, and mentions the continued energy transition program while also continuing as the engine of economic innovation. In 2019, a three-pillar strategy is mentioned to achieve the climate neutrality of which the third pillar associates with

development of a new raw materials system: renewable fuels, chemicals, hydrogen and a circular economy. The 2020 annual report sets the agenda towards achieving energy transition in line with the National Climate Agreement: 'In three steps towards a sustainable Rotterdam-Moerdijk industry cluster'. It sets out concrete plans to bring the Rotterdam port and industrial complex in line with local, national and international climate targets. The report also sees an alignment with the UNSDG. The latest report, annual report of 2021 while also aligning to the UNSDG also sees an additional pillar being added to the already existing three pillar strategy, which lays focus on green transportation to and from the port to help achieve reduction in CO2 emissions.

4.3.2 Gap Analysis using the set of indicators developed for VC-OVAM

4.3.2.1 Gap Analysis 1: Matching the long list indicators with currently reported indicators by the PoR

During this exercise, a one on one comparison study was carried out between the VC-OVAM (2022) study longlist indicators and those reported by the PoR. This was accomplished by identifying the source of each of the longlist indicators as depicted in **Table 4** and scrutinising whether the PoR was reporting it either on their website or on their annual/sustainability reports. If a comparison does exist then this would mean that the PMB could adopt the longlist indicator set for their monitoring purpose. It is found through this exercise, the PoR, as per the table are reporting six of the longlist indicators. Analysis using **Table 5** leads us to conclude that the PoR does report on indicators and these can be matched with the longlist indicators published by VC-OVAM (2022) study. When looking at the theme for the indicators, three indicators are from the Economic/Spatial, two for the Social/Organisation/Innovation and one from the Waste & Material Flows.

Table 4. Sources Used for Gap Analysis 1

Port	Documents Analysed
Port of Rotterdam	Annual Report 2015
	Annual Report 2016
	Annual Report 2017
	Annual Report 2018
	Annual Report 2019
	Annual Report 2020
	Annual Report 2021
	PoR website

Table 5. Table showing match between a longlist indicator and an objective set by the Port of Rotterdam

THEME	LONGLIST INDICATOR	REPORTED BY PoR
Economic Spatial	Number of CE activities within the port area	The port website has a dedicated page towards CE, and companies having CE as their primary activity is captured via an interactive map.
	Number of CE activities within the port area	Reported through the news portal of PoR Annual/Sustainability Reports Independent Reports
	Number of port companies whose core business directly relates to CE activities	PoR CE Interactive webpage
Social/Organisation/Innovation	Presence of a circular port incubator	Incubators present like PortXL, BlueCity,M4H,RDM, Plant One and reported upon in PoR website, Annual/Sustainability Reports & Independent Reports
	The presence of a CE strategy or roadmap within port companies and within the port authority	PoR & Circle Economy Independent Study Annual Reports Website
Waste & Material Flows	Tonnes of ship waste	Waste disposal facility available at the port mentioned in the PoR website; Scrubber waste collection and disposal facility

		available; Plastic waste disposal facility available
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(Source: Compiled by author)

4.3.2.2 Gap Analysis 2: Matching longlist indicators with CE objectives expressed by PMB

Here we delved into the goals and the objectives set by the PoR and the steps in place in order to achieve these goals with particular relevance to CE. As mentioned in the earlier chapters the PoR sees progressing energy transition as the end goal thereby achieving CO2 neutrality and with a clear road map set out towards achieving this. A four pillar approach where the move towards new raw materials and fuel system holds sway over the development and embeddedness of CE within the port domain.

To meet the objectives the PoR promotes industrial symbiosis often collaborating with companies in a synergistic manner. Developing common infrastructure such as pipelines for carrying waste heat, green hydrogen and Carbon Capture Utilisation & Storage (CCUS) are few of the dominant projects that are in the pipeline.

Here, the list of objectives were compared against the longlist indicators to arrive at matches with the predominant indicators being “Number of CE activities” and “Number of CE Projects”. This analysis is captured in the **Table 7** given below.

Table 6. Sources used for Gap Analysis 2

Port	Documents Analysed
Port of Rotterdam	Annual Report 2015
	Annual Report 2016
	Annual Report 2017
	Annual Report 2018
	Annual Report 2019
	Annual Report 2020
	Annual Report 2021
	PoR website
	Independent study carried out by Circle Economy

Table 7. Matching objectives set by the PoR that does not have an indicator from the longlist, and for which a separate indicator may have to be developed.

CE GOALS	INDICATOR FROM LONGLIST
<p>Realize the goal of CO2 neutrality in 2050 thus contributing to the mitigation of climate change through energy transition and a fully CE.</p> <p>Achieved by improving infrastructural efficiency like common pipelines for transport of waste steam, CO2 etc, switching over to new steam, CO2 etc, switching over to new and cleaner fuel sources like electricity & hydrogen, promoting circular use of raw materials & new fuel system such as green methanol, bio diesel etc</p>	<p>Number of CE Activities</p> <p>Number of Projects</p>

(Source: Compiled by author)

The second gap analysis identifies which longlist indicators have a matching CE objective, which the PoR has agreed upon with external organizations. In other words, the objectives, which the PoR has committed to via a contractual agreement with external organizations. Ideally, we would have liked to scrutinize the individual agreements, but due to the data access concerns we look at indications where the PoR has reached agreements, signed contracts, joint ventures (JV) with external as well as other government organizations which is publicly available. The analysis of which is depicted in **Table 8**.

Table 8. Matching objectives of the PoR on individual projects with external organisations and government organisations.

CE GOALS	LINK OF CE GOALS & LONGLIST INDICATORS	INDICATOR FROM LONGLIST
<ul style="list-style-type: none"> • Improve/Undertake Efficiency Measures • Build Infrastructure for synergistic use and spur industrial symbiosis 	<p>Meets the Pillar 1 strategy of PoR to improve the efficiency & infrastructure</p>	<ul style="list-style-type: none"> • Number of CE Project • Share of Infrastructure designed for circular use

		<ul style="list-style-type: none"> Share of superstructure designed for circular use
CE OBJECTIVES IN PROGRESS TO ACHIEVE THE LONGTERM GOAL		
Sustainable heat for home heating in Hague and for greenhouse horticulture region by Gasunie (A Government of Netherlands Concern)	Reducing the consumption of natural gas by reusing the heat from industries located within PoR, and supplying it to homes and horticultural units.	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
HyTransport Pipeline infrastructure for hydrogen transmission with Gasunie (A Government of Netherlands Concern)	Future hydrogen transmission pipeline infrastructure.	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
Pipeline infrastructure for hydrogen transmission with Rotterdam Rijn Pijpleiding Maatschappij (RRP)	Future hydrogen transmission pipeline infrastructure.	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
CCUS Project Porthos being jointly developed with Gasunie and EBN	Carbon capture use and storage pipeline infrastructure	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
CE GOALS	LINK OF CE GOALS & LONGLIST INDICATORS	INDICATOR FROM LONGLIST
<ul style="list-style-type: none"> Migration to cleaner & greener fuels 	Meets the Pillar 2 strategy of PoR towards transitioning to a cleaner and greener energy system	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure

		<ul style="list-style-type: none"> designed for circular use Share of superstructure designed for circular use
CE OBJECTIVES IN PROGRESS TO ACHIEVE THE LONGTERM GOAL		
Production of green hydrogen at Maasvlekte with Uniper	Future green hydrogen production capacity being jointly developed in partnership.	<ul style="list-style-type: none"> Number of CE Project Share of superstructure designed for circular use
Production facility for Green Hydrogen with BP & Nouryon	Future green hydrogen production capacity being jointly developed in partnership.	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
Green Hydrogen Storage facility with Koole Terminals, Chiyoda Corporation & Mitsubishi Corporation	Future green hydrogen storage facility being jointly developed	<ul style="list-style-type: none"> Number of CE Project Share of Infrastructure designed for circular use
CE GOALS	LINK OF CE GOALS & LONGLIST INDICATORS	INDICATOR FROM LONGLIST
New Materials and fuel systems	Meets the Pillar 3 strategy towards transitioning towards new materials and fuel systems.	<ul style="list-style-type: none"> Number of CE Project
CE OBJECTIVES IN PROGRESS TO ACHIEVE THE LONGTERM GOAL		
Non recyclable waste conversion to advanced bio fuels with Gidara (Bio Methanol)	Future advanced bio methanol fuel plant being jointly developed	<ul style="list-style-type: none"> Number of CE Project

		<ul style="list-style-type: none"> • Share of Infrastructure designed for circular use
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(Source: Compiled by author)

4.3.2.3 Gap Analysis 3: Matching newly expressed CE objectives and long list of indicators and currently measured indicators as per PMB

In this phase, gap analysis 3, we look at the newly expressed port objectives and aim to match them with the longlist indicators. The objectives were identified from vision documents and those published on the PoR website. The challenge in this exercise was in identifying the objectives. These were often disguised in the form of plans, projects or general ambitions. In 2017, PoR joined the World Business Council for Sustainable Development alongside 200 progressive companies with the aim to bring in a culture of setting targets, monitoring and reporting on the targets. The port objectives were extracted from the published annual reports, the website, report of Circle Economy, and the Port Vision 2030 document. Four of the CE goals identified could not be matched to longlist indicators. There exists a clear ambition towards CE transition, many objectives simply relate to individual and separate CE projects that are planned to take place, but not as a higher, future proof CE objective. This analysis is depicted in **Table 10**.

Table 9. Sources used for Gap Analysis 3

Port	Documents Analysed
Port of Rotterdam	Annual Report 2015
	Annual Report 2016
	Annual Report 2017
	Annual Report 2018
	Annual Report 2019
	Annual Report 2020
	Annual Report 2021
	PoR website
	Independent study carried out by Circle Economy
	Port Vision 2030

Table 10. Indicators which are currently not used to measure any CE objectives (the indicator from the longlist is too specific to be linked with broader objectives, the longlist indicator is not as relevant as initially thought, or the ports CE ambitions are not high enough yet)

CE GOALS	INDICATOR FROM LONGLIST
By 2025 circularity can be measured at the company level, activity level and port level by instituting the right framework, data collection tools, material flows	<ul style="list-style-type: none"> • The presence of a CE strategy or roadmap within port companies and within the port authority
By 2030 companies will be connected through an infrastructure that forms the basis for a circular system for electricity, hydrogen, residual gases, steam, high and low temperature heat, CO2 and other residual flows. The extensive infrastructure of the port and industrial complex means that energy and residual flows can be fully utilised.	<ul style="list-style-type: none"> • Number of CE Project • Share of Infrastructure designed for circular use • Share of superstructure designed for circular use • The presence of a CE strategy or roadmap within port companies and within the port authority
PoR raising land levels for green companies	<ul style="list-style-type: none"> • Hectares of CE activities in port area
By 2050 the port and industrial complex of Rotterdam is circular and it has developed into a waste-to-value hub. Residual products are the new raw materials. Industrial activities are connected to a circular system without wasting energy and raw materials.	<ul style="list-style-type: none"> • The presence of a CE strategy or roadmap within port companies and within the port authority
By 2050 the desired carbon emissions reduction will also be achieved through the application of new circular technology	<ul style="list-style-type: none"> • The presence of a CE strategy or roadmap within port companies and within the port authority
We need to make optimal use of the legal latitude we have and, in the meantime, work on creating more legal latitude for circular initiatives	<ul style="list-style-type: none"> • Missing Indicator: Information sharing and also policy related
The ambition for the labour market (see 'employment') requires investments in relatively labour-intensive sectors such as the production, assembly and maintenance of renewable energy sources (mainly offshore wind), distribution, innovative	<ul style="list-style-type: none"> • Number of CE activity • Number of CE project

manufacturing, the circular economy and port-related business services.	
Sound collaboration between national government, the Port of Rotterdam Authority, the business community, the City of Rotterdam and the Provincial Authority of South Holland, for example in the areas of permits, accessibility/transport network, spatial planning and environmental space, has allowed the circular economy to develop further.	<ul style="list-style-type: none"> • Missing Indicator: policy
Valorising waste flows	<ul style="list-style-type: none"> • Missing indicator
Looking ahead to 2050, the desired carbon emissions reduction will also be achieved through the application of new circular technology	<ul style="list-style-type: none"> • The presence of a CE strategy or roadmap within port companies and within the port authority • Number of CE activity • Number of CE project
In line with the energy transition, we are also seeing a raw materials transition	<ul style="list-style-type: none"> • Missing indicator
The carbon ambitions and growing demand for raw materials favour the emergence of a circular economy focusing on different ways of using products and raw materials	<ul style="list-style-type: none"> • The presence of a CE strategy or roadmap within port companies and within the port authority • Number of CE activity • Number of CE project

(Source: Compiled by author)

4.3.2.4 Results from Gap Analysis

The following findings from the gap analysis could be drawn:

Almost all the objectives of the PMB of the PoR could find a match with the longlist indicators of VC-OVAM (2022) study. Not a single objective with a matching indicator and reported by the PoR were observed. Four of the objectives were found to be lacking indicators. Indicators that did not have a matching objective were also not observed through our analysis.

Table 11. Legend of the list resulting from the gap analysis.

Dark Green	Indicators that have a matching objective and are already being reported.
Light Green	Indicators that have a matching objective but are not yet being reported.
Yellow	Objectives that do not have an indicator.
Orange	Indicators that do not have a matching objective.

(Source: VC-OVAM (2022) study)

Further, it would be interesting to know which of the indicators are being reported more frequently by the port PMB. A cursory run through would reveal that the number of CE activities and the number of CE projects are the ones that got reported most frequently. This is because circular objectives already present in the port as activities, and planned projects do not warrant a specific indicator. This simply is added to the number of circular projects and number of circular activities. The other commonly reported indicators included the share of infrastructure designed for circular use which was reported 10 times, the share of superstructure designed for circular use was reported 4 times, and the presence of CE strategy or road map within port companies and within the PMB, 6 times. The share of superstructure designed for circular use was reported 3 times. The other indicators that found mention include number of port companies whose core business directly relates to CE activities, hectares of CE activities in the port area, presence of a circular port incubator, and tonnes of ship waste which were reported one time each. This is encapsulated in **Table 12** and **Table 13**.

Table 12. Green List: “Ready for use” Fixed Indicators corresponding to PoR CE Objective.

Theme	NR	Indicator	Number of times reported
Economic / Spatial	1.	Number of CE activities within the port area	6
	2	Number of CE projects within the port area	16
	3	Number of port companies whose core business directly relates to CE activities	1

	5	Hectares of CE activities in port area	1
Social/ Organisation/ Innovation	13	Presence of a circular port incubator	1
	16	The presence of a CE strategy or roadmap within port companies and within the port authority	6
Waste and Material Flows	17	Tonnes of ship waste	1

(Source: Results compiled by author)

Table 13. Green list: “Ready for use” Variable indicators corresponding to PoR CE objective.

Theme	NR	Indicator	Dependent On	Number of times reported
Infrastructure	29	Share of infrastructure designed for circular use	Timeframe	10
	30	Share of superstructure designed for circular use	Timeframe	4

(Source: Results compiled by author)

Regarding objectives for which a corresponding indicator was not found in our longlist, most of these are related to objectives of the Port of Rotterdam. While some of these objectives are clear we were not able to link these to a corresponding indicator while others show the need for more collaboration-related indicators such as “policy” related. Monitoring of waste flows and raw material transition are also found to be objectives that are currently not covered by any indicator from the longlist. An overview of the objectives, which so far do not have a corresponding indicator, is shown in **Table 14** below.

Table 14.Yellow list: “Objective still needs indicator”

Port Vision/Consultancy Documents	Objective	Missing indicator Suggestion
Port Vision 2030	We need to make optimal use of the legal latitude we have and, in the meantime, work on creating more legal latitude for circular initiatives	Missing Indicator: Information sharing (and also policy related?)
Port Vision 2030	Sound collaboration between national government, the Port of Rotterdam Authority, the business community, the City of Rotterdam and the Provincial Authority of South Holland, for example in the areas of permits, accessibility/transport network, spatial planning and environmental space, has allowed the circular economy to develop further.	Missing Indicator: policy
Joint consultancy report of PoR and Circle Economy 2019	Valorising waste flows	Missing indicator
Joint consultancy report of PoR and Circle Economy 2019	In line with the energy transition, we are also seeing a raw materials transition	Missing indicator

(Source: Results compiled by author)

The final category of longlist indicators are that which are not used to measure PoR CE objectives presently. Possible reasons for this could be that the indicator from the longlist is

too specific to be linked with the broader objectives or because the longlist indicator is not as relevant as initially thought or, the CE ambitions are not high enough (yet) for the port. This group of indicators is presented below in **Table 15** and **Table 16**.

Table 15: Orange List: Fixed Indicators without objective, “Potentially relevant with higher CE ambition”

Theme	NR	Indicator
Economic / Spatial	4	Share of port companies which engage in CE activities
	6	Share of revenue from CE activities of PDC in port area
	7	Investment in CE activities by PMB in port area
	8	Added value for PMB from CE activities in port area
Social/organisation /innovation	9	Share of direct employment from CE activities and projects in port area
	10	Number of FTEs in CE activities and projects in port area
	11	Circular procurement policy
	12	Number of CE certifications held by the PMB and companies in the port area
	14	% of port companies participating in regional, national or EU programs for R&D&I in circularity set up by PMB
	15	Waste management ISO standards
Waste & Material Flows	18	Import of waste to be recycled
	19	Export of waste to be recycled
	20	Import of waste to be recycled
	21	Export of waste to be recycled

(Source: Results compiled by author)

Table 16. Orange list: Variable indicators without objective, “Potentially relevant when higher CE ambition”

Theme	NR	Indicator	Dependent on?
Waste and Material Flows	22	Waste production within the port area	Timeframe
	23	Tonnes of waste in port area	Port specific
	24	Tonnes of waste in port area follow-up indicator: Share of waste recycled, share of waste reused	Timeframe
	25	Tonnes of ship waste follow-up indicator: Share of waste recycled, share of waste reused	Timeframe
	26	Secondary material consumption in the port area	Port Specific (Industrial ports) Timeframe
Infrastructure	27	Share of infrastructure (partially) built from secondary materials	Timeframe
	28	Share of superstructure (partially) built from secondary materials	Timeframe
Social/Organisation	31	Share of jobs by education level in the CE (low,medium,high skilled) in the port area	Timeframe
	32	% of workforce trained in CE	Timeframe

(Source: Results compiled by author)

4.4 Benchmarking with Port of Amsterdam

In this section we discuss the case of PoA a frontrunner and first mover as far as CE is concerned (de Langen et al., 2020). We look closely at the CE activities that the PoA is pursuing towards evolving into a full CE by 2050 in comparison to the PoR which pursues similar ambitions as well i.e. becoming a full CE by 2050 (Port Vision 2030). We analyse the case to

see what the PoR can imbibe from the PoA's approach to accelerate its journey towards a full CE by 2050 as well.

PoA can be considered the ideal port to carry out the benchmarking for the PoR due to the following reasons. Both the ports are similarly oriented as far as governance is concerned, owned by their respective municipalities, with the aim of generating a sustainable return on investment while aiming to create value for society. Both the ports operate on the landlord business model with revenue generated through land leases and handling volumes. Besides this, both the ports are large Dutch ports and Central Mixed Ports based on the port typology (Source: VC-OVAM (2022) study).

The approach to benchmarking is to make a distinction between three types of variables to be benchmarked:

1. Circular activities in the port area
2. Projects aimed at advancing circularity
3. Reporting on CE (activities and projects) by the PMB.

CE Activities

The companies whose main activity is related to CE is listed on the company's website page "Portle" with 30 companies listed. Majority of the companies listed have their main activity as recycling, bio-based and process based.

The Bio LNG project, which has started operations, has culminated into a full-fledged circular activity with the plant being operational since October 2021. This is a fully circular plant is the result of a collaboration between Renewi, Nordsol and Shell.

CE Projects

Currently there is none in the pipeline with project Athos scrapped after the exit of Tata Steel.

Reporting on CE (activities and projects) by the PMB.

- The PoA reports on the number of companies involved in CE activities through its webpage Portle
- The number of hectares of leased out and set aside for circular activities is being reported by the port on its website.



18.9 ha

Gross site leasing

Site leasing in the port of Amsterdam	2021	2020
In hectares		
Gross site leasing	18.9	19.9
Reclaimed sites	16.8	8.5
Net site leasing	2.2	11.4
Land issued for biobased and circular activities	3.0	0.8

Figure 4. Hectares of land leased at the port of Amsterdam for circular activities. (Source: PoA Website)

- Circular economy finds a clear mention in the Vision 2030 strategy document of the PoA.
- Prodock, the start-up incubator focuses on circular innovative companies, locating twenty circular start-ups and scale-ups in the port.
- PoA does not report on the CE focused employment figures.

It is very clear that as PoA is more proactive in reporting its activities and the way the PMB goes about in reporting the milestones through a clear roadmap, and through the strategic documents. PoA plans to develop five strong clusters of which one is the Circular and Renewable Industry, with a reporting on Circular throughput volumes (PoA Strategy document 2021-2025). In its strategy document the PoA envisions that there is going to be an increase in the share of circular jobs, setting an ambitious target of 20% in circular segments including alternate fuels, building materials, logistics and agro businesses, by setting aside 25 hectares of land to proliferate circular process industry (Goal 5). The PoA is vociferous in proclaiming investing in 18 hectares set aside for a plug and play location for circular activities thus promoting CE. The incubator centre such as Prodock offers space and testing facility for innovators in CE. Strengthening international circular trade chains also finds a mention in the strategy document.

4.4.1 Results from Benchmarking

In carrying out the benchmarking exercise with the PoA, we took a deep dive into the CE goals that it has set out, and how the PMB intends to achieve this. While both the PMB has set out similar targets of achieving a full CE by 2050, the approach seems to be different. PoA is seen

to have a separate objective for developing CE while the PoR has CE as one of the goals set out to finally achieve the larger end goal of climate change mitigation and CO2 neutrality. The PoA is seen to tread a different path here to achieve the same end goal by focussing on developing its recycling, bio-based and process based activities and projects. PoA is seen to be more proactive in reporting their CE activities with higher ambitions such as the hectares of land leased out for circular activities as well as setting aside land to promote circular activities. Reporting on circular throughput volumes, and proclaiming its ambitions in achieving a 20% increase in circular jobs and strengthening the international circular trade chains. PoA is also proactive in pursuing the path of innovation and provision for a testing facility in CE through its incubator Prodock.

However, both PoA and the PoR do not use a set of CE monitoring indicators as is evident from the various sources that have been analysed.

PoR can imbibe and embrace the proactive reporting measures, activities and develop monitoring systems and adopt improvements that can help speed up its CE transition.

5. Discussion and Conclusion

The main discussion point of this dissertation was to explore how Europe's largest port, the Port of Rotterdam can monitor and foster its CE ambitions. This was done by answering the sub research questions. Understanding the complex relationship of CE within the port domain, its strategic importance as far as the PMB is concerned and its potential as the new business model were understood from the literature review carried out. The need for tangible indicators to measure and monitor the progress of CE while equipping the PMB with a tool to undertake key strategic decisions thereby ensuring the embeddedness of CE within the port in general were also ascertained from the literature review. Throwing light on these two cardinal waypoints helped us understand the need to cement CE within the port arena while being equipped with a strong set of indicators. This led us then to explore how the PMB of the Port of Rotterdam currently monitors and records its CE transition having understood that the genesis of CE within the Port of Rotterdam had commenced. This was understood from the detailed study of the ports annual reports, strategy documents such as Port Vision 2030, independent studies such as the ones carried out by the port of Rotterdam and Circle Economy in 2019. Strategic documents of the ports seldom are published and are usually confidential. As the absence of a set of indicators were noticed in relation to CE monitoring in ports, we turned to the recent study conducted to identify a Port CE indicator set. This indicator set

developed for VC-OVAM (2022) study was applied to find a match with the reported activities of the port in a three step gap analysis. There were found to be matches existing but at the same time, there were also indicators that could not be matched to the activities as well as some missing indicators that did not find a match with activities that the port was reporting on. A further benchmark assessment with the PoA was done to understand the differences and similarities in the PMB approach to further and foster CE within both their port domains.

This desktop research is based on a single case study approach and is limited by methodological diligence, researcher subjectivity, and external validity. The absence of systematic procedures due to the relative absence of methodological guidelines is viewed as a major drawback. Reliability and replicability is another main concern of this research methodology, as more number of cases would have lend stronger validity to the approach. Coupled with this is the issue of researcher subjectivity, as the data collated may be the subject of researcher bias.

This applied research carried to the case of the Port of Rotterdam the largest port in Europe, perhaps is a first case to see the applicability and validity of the set of indicators developed for VC-OVAM (2022) study outside of Belgium. This valuable first step in the direction will help us to finally have the first reliable CE port indicator set and at the same time help us in standardisation. It also allows us to further the progress in this realm, and help us to develop port specific CE indicators for objectives present. Identification of CE objectives for which an indicator from our long list cannot be assigned can also be developed. This standardisation offers impetus to the ports to openly publish their indicator data while allowing them to work on CE objectives which they find missing. In addition, this provides the ports ease of benchmarking with other similar ports, thereby helping to speed up their circular transition. This CE Port indicator set further strengthens the already reported indicators such as environmental, sustainability indicators, and financial indicators thus adding value to the port reporting system.

Realising the role of ports as industrial clusters and the PMB playing an elevated role of a port cluster manager, to accelerate the progress of the CE within the port ambit, it becomes a necessity to evolve towards a technologically driven player. Digitalisation is and will become a key contributor to the progress of CE. PMB by developing a digital platform will help connect various businesses while bringing about the much required ease and transparency in reporting, improving efficiency and assuring scalability. Therefore, the combined power of digitalisation and CE can be unleashed to harness a truly sustainable CE transition within the port. Therefore,

it will be pertinent to research on developing a separate indicator and include it in our longlist of indicators foreseeing a future as one of digital circular economy (DCE).

In conclusion, it is seen that with a match obtained by the PoR's current CE objectives and the possibility of matching the future port CE ambitions with the longlist of indicators suggested by VC-OVAM (2022) study, effective monitoring and reporting of the ports CE progress can be ascertained. By applying the set of dynamic indicators, the PMB can ensure that key strategic decisions at important prescribed timelines are met. Not to mention that by using this effective indicator set, fostering CE within the PoR while also cementing the position of the PoR as the largest port in Europe can be fulfilled.

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