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DOI
10.3390/su12219269

Publication date
2020

Document Version
Final published version

Published in
Sustainability

sustainability

MDPI

Article

Patterns of Circular Transition: What Is the Circular Economy Maturity of Belgian Ports?

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Received: 30 September 2020; Accepted: 5 November 2020; Published: 8 November 2020

Abstract: Large seaport hubs in Northwestern Europe are aiming to develop as circular hotspots and are striving to become first movers in the circular economy (CE) transition. In order to facilitate their transition, it is therefore relevant to unravel potential patterns of the circular transition that ports are currently undertaking. In this paper, we explore the CE patterns of five Belgian seaports. Based on recent (strategy) documents from port authorities and on in-depth interviews with local port executives, the circular initiatives of these ports are mapped, based on their spatial characteristics and transition focus. The set of initiatives per port indicates its maturity level in terms of transition towards a circular approach. For most studied seaports, an energy recovery focus based on industrial symbiosis initiatives seems to dominate the first stages in the transition process. Most initiatives are not (yet) financially sustainable, and there is a lack of information on potential new business models that ports can adopt in view of a sustainable transition. The analysis of CE patterns in this paper contributes to how ports lift themselves out of the linear lock-in, as it demonstrates that ports may walk a different path and at a diverging speed in their CE transition, but also that the Belgian ports so far have focused too little on their cargo orchestrating role in that change process. Moreover, it offers a first insight into how integrated and sustainable the ports' CE initiatives currently are.

Keywords: circular economy; ports; strategy; maturity; patterns; transition; process; circular initiative; case studies; Belgium

1. Introduction

The circular economy (CE) poses a challenge to ports around the world. In general, the business models of ports and (semi-)independent port authorities (PAs) are based on volume and financial growth, whereby the PAs at least break even, preferably making profits [1,2]. Landlord ports and their PAs increasingly incorporate activities beyond the maintenance of infrastructure as their core business, and now also include the development of the local economy, business integration, urban development and environmental protection [3–6]. However, the main source of income for PAs is still the leasing of land and port dues on incoming and outgoing cargo. In other words, the business models of PAs are based on the expansion of their port area and increasing throughput volumes. Considering the pollution, decrease in wetlands, congestion and many other external effects of core port activities, the environmental impact of this business model is apparent [4,7–9].

The CE is seen as a new business model whereby economic growth is decoupled from environmental impact. The CE implies cleaner production patterns at the company level and the use of renewable materials as much as possible [10,11]. However, the CE is only in its early stages as an industry or business line, and a lot is still uncertain [12,13]. Nevertheless, if a CE is the main or only sustainable business for the future, beyond what we already do "circular" today, a significant amount of innovation is necessary [11,14]. The CE in practice currently seems to focus primarily on (re)production, but also in terms of product design, logistical processes (cf. collection and treatment of waste), management and production networks, a lot of innovations and potential benefits can be generated [1,15–17].

While in the first instance, a decoupling of economic growth and environmental pressure poses a problem to the landlord PAs' prevailing business model, at the same time port areas have the potential to become essential places in fostering a CE. The European Parliament as well as European port organizations, such as the European Federation of Inland ports (EFIP) and the European Sea Ports Organisation (ESPO) [18–20], have stressed the enormous potential of ports to play a leading role in the context of the CE transition. Indeed, ports are crossings of transport modes and waste flows, but also accommodate industrial sites and/or unlock urban areas and economies. Ports operate within a competitive and clustering (industrial) environment, which may offer opportunities to treat residual flows and products in a circular way. Furthermore, ports close to urban areas may offer the necessary space for recycling activities of all wastes created by the city or help in their energy transition. In addition, ports are essential nodes wherein and whereby (global to local) production networks are possible, in terms of established technologies and processes, and in terms of incremental innovation. Especially the combination of extensive, specialized industrial and logistical maritime areas with urban economies, explains why ports are attractive for circular activities [21,22]. These circular activities are broad and can vary from small companies or start-ups focusing on new management processes, the establishment of new educational programs training the circular skills of tomorrow [23,24], engineering bureaus dealing with product design, new (spatial) policies encouraging circular activities, new infrastructure connecting companies whereby existing material flows become connected, and the creation of circular consortia and think thanks [5] (e.g., [12]), to large-scale projects involving the construction of new circular industrial plants or labs. Hence, for the identification of circular actions or activities within ports, we focus in this paper on hard investments (plants, space allocation and other infrastructure) as well as on soft commitments such as networks and skill development.

In this paper, we focus on the CE initiatives of ports from the viewpoint of the port cluster managers, most often PAs. Besides smart digitalization and Internet of Things (IoT), the CE is high on the strategic agenda of PAs. PAs regard the CE as a (potential) solution to many of their problems, for example, the increased congestion and environmental impact, the need for added value and job employment, and the need to remain competitive. Yet, PAs are struggling to develop an integrated CE strategy and find their role in this transition. Hence, the relevant research questions addressed in this paper are: "How are ports facing the CE transition in relation to an integrated approach, and what can port cluster managers learn from CE port patterns?"

To answer these questions, this paper uses a cross-case analysis with primary and secondary data on the portfolio of CE activities in five Belgian ports, a sample consisting of an interesting variety of port clusters, ranging from large hubs, medium-sized diversified ports, a niche port and an inland port. The paper is organized as follows. In the next section, we give a brief overview of the origin of the concept and theoretical foundations of CE. We will show how "circularity" originates from within (applied) industrial ecology, and therefore the majority of existing studies relate to material flows and stocks but lack a connection to (port) business models and socioeconomic processes [7,16,17,20]. In the third section, we develop a framework presenting a potential CE development path based on the nature and (spatial) impact of circular projects within ports. We then present our method, data collection and empirical results in the fourth section. We end this paper with a discussion section, and finally some concluding remarks and future research suggestions.

2. Circular Economy Concept

Circular economy has its origins within industrial ecology and goes back to the 1980s with the waste hierarchy concepts, better known as the 3Rs, 4Rs, etc. [14,16,17,25]. The circular economy concept was initially introduced by Stahel [26] in his paper 'The product life factor', where he described it as a spiral system with the aim of reducing the used inputs, waste flows and ecological detriment, without limiting economic, social and technological advances [27]. He also claimed that the circular economy impacts products as well as processes, and primary as well as secondary materials. Peace and Turner [28] added to Stahel [26] that a circular economic system is the only sustainable future for production, based on the laws of thermodynamics, saying that energy and material can neither be created nor destroyed. Instead, they can be reduced to a non-valuable quality. In 2002, McDonough and Braungart [29] presented their cradle-to-cradle process, which was seen as a first step towards new processes including upcycling or upgrading the value of outputs into new inputs. In the aftermath, researchers focused on decoupling growth and welfare [30,31], and on internalizing external costs [26,32]. We could argue that most classic frameworks of reducing, reusing and recycling are far from being ambitious. A currently prevailing definition of CE [33–36] proclaims CE is a new model for industrial organization, which enables us to decouple growing welfare from using more raw materials and which goes beyond efficiency gains and realizes a transformation change (regenerative by design). In fact, waste from industries becomes valuable input for other processes, and products can be reused or upcycled.

As the CE concept is trending, especially in industry-wide management practice and policy, the concept tends to diffuse [18,22]. Several literature reviews on this topic have been conducted, and a more recent systematic and comprehensive one by Kirchherr et al. [18] concludes that the CE definition of van Buren et al. [33] is complete and yet understandable, and therefore recommended the use of this one out of hundreds as a basic concept to build upon.

While in the past two decades CE was very much directed at industrial and product environments, more attention in recent years has been given to CE in services (examples can be found in [15,16,23,37]). Van Buren et al. [33] developed their concept for the Dutch logistics industry, a typical sector offering services, which they saw as "a genuine enabler (so for other industries as well) to implement a successful and sustainable circular strategy". Ports are salient nodes in logistic networks, and therefore, the present paper builds upon their definition of CE: "A circular economy aims for the creation of economic value (the economic value of materials or products increases), the creation of social value (minimization of social value destruction throughout the entire system, such as the prevention of unhealthy working conditions in the extraction of raw materials and reuse) as well as value creation in terms of the environment (resilience of natural resources)" [33].

3. A CE Transition Framework for Port Clusters

3.1. Three Pillars of a Strategic CE Port Vision

According to van Buren et al. [33], a distinction can be made between options or levels of circularity when applying CE. Although different levels are used, commonly one refers to the R hierarchy here, such as the 9Rs model. These are (1) Refuse (preventing the use), (2) Reduce (using less materials), (3) Reuse (second-hand), (4) Repair, (5) Refurbish, (6) Remanufacture (new products by assembling old parts), (7) Repurpose, (8) Recycle (reuse of materials) and (9) Recover energy (incineration of residual flows) [27,33]. In line with this, van Buren et al. [33] suggest that "recovering energy" is the final option for extracting value from resources as it ends the resource cycle. Recycling, as the eighth R, is the one before the last option to extract value. Recycling is a process that often degrades the materials and makes secondary resources of a lower quality [33]. In the R model, the degree of increasing circularity is considered inversely related to the number of the R strategy, so where recovering energy (R9) is "less circular" than recycling materials (R8), which is then again "less circular" than for example repair (R4) etc. [27]. As sectors and industries attempt to gradually move from linear to circular economic models, it can be assumed that "increased circularity" indicates a higher maturity level in this change process.

Applying this to the port industry, R9 and R8 in the circular R model are in line with the concepts of reusing materials and energy of de Langen and Sornn-Friese [38]. These authors argue that a circular supply chain does not end with waste nor just with reusing it. Hence, these activities are preceding a more advanced CE transition of ports. In fact, the activity of reusing energy and materials could be considered as the first stages of a port's CE transition. Van Buren et al. [33] add to this that a circular economy should be much more than recycling and energy recovery, because in focusing too much on these two aspects, it would result in a so-called "economy with feedback loops", rather than a serious circular economy. In a recycling-based economy or an "economy with feedback loops", the reuse of materials or resources is regarded as a separate (or secondary) optimization step [33]. As such, it is seen as a potentially interesting new business line, next to or maybe less important than "business as usual", and nice to communicate to stakeholders sensitive to environmental issues. Within port clusters, (industrial) energy consumption is for example primarily based on the large-scale use of oil and gas, which may be partly offset when these industries connect to waste-to-energy plants where steam is turned into electric energy, for example in the *Ecluse* project in the Antwerp seaport (The Ecluse project is a port heating network in the Waasland part of the Antwerp seaport, where steam is sluiced from the Indaver and SLECO waste-to-energy plants to industrial (mainly oil) companies in the port. More details on the Ecluse project can be found via http://www.ecluse.be). Although the *Ecluse* project is considered as a showcase circular project by the port of Antwerp, the initial choices of the industries partnering in this project are not circular. The primary choices made in the phase of design and production should be integrated as well. In sum, if a port takes the circular challenge seriously, it should therefore not only consider recycling and energy recovery, but also consider the flows following the initial choices of firms. This would therefore indicate a more advanced level of maturity in a port's CE change process.

The problem with this advanced CE transition is that any port is only partly able to influence those (industrial) companies within or beyond their port area, and for which the port operates as a nodal point in their logistics chain. Ports actually depend on the circular transition in those industries using port services, and their transition thus requires simultaneous changes in many port subsystems, or (trans)port demanding clusters. So, the challenge for ports is also in how much they can actually put pressure on their clients and leverage subsystems to become circular in their design and production, or collaborate with shippers to facilitate their transition and control the changing flows of goods, because it ultimately affects the circular strategy of ports as well.

Many industries using port facilities operate beyond the port boundaries, so a circular port is also one that impacts products and processes beyond the port cluster demarcations [38]. A port should therefore be looking at "valuable new inputs", as already suggested by Peace and Turner in 1989 [28], in terms of new cargo flows for example. A simple look into the strategy reports of most European ports, disclosing information on their circular initiatives, intuitively indicates that most ports do not yet address this third essential pillar of circularity, besides energy recovery (pillar one) and recycling (pillar two). In fact, we may even question whether ports at all recognize this advanced yet crucial stage in their CE transition. Here, the Ellen MacArthur Foundation (2017) [36] was right in stating that some circularity models may not be ambitious enough, and this may also be the case for ports.

3.2. Territorial Level of CE in Ports and Space as an Accelerator

Given the challenge of reaching out beyond port borders to realize the huge circular ambition, ports should also collaborate with actors outside the port area itself. Fusco Girard [39] researched how port areas can circularize from a territorial perspective. He suggested that three levels of symbiosis, or mutually beneficial relationships, can interestingly take place between three different spatial levels, as depicted in Figure 1, which he named: industrial symbiosis (IS), urban symbiosis (US) and city-territorial symbiosis (CTS) [39].

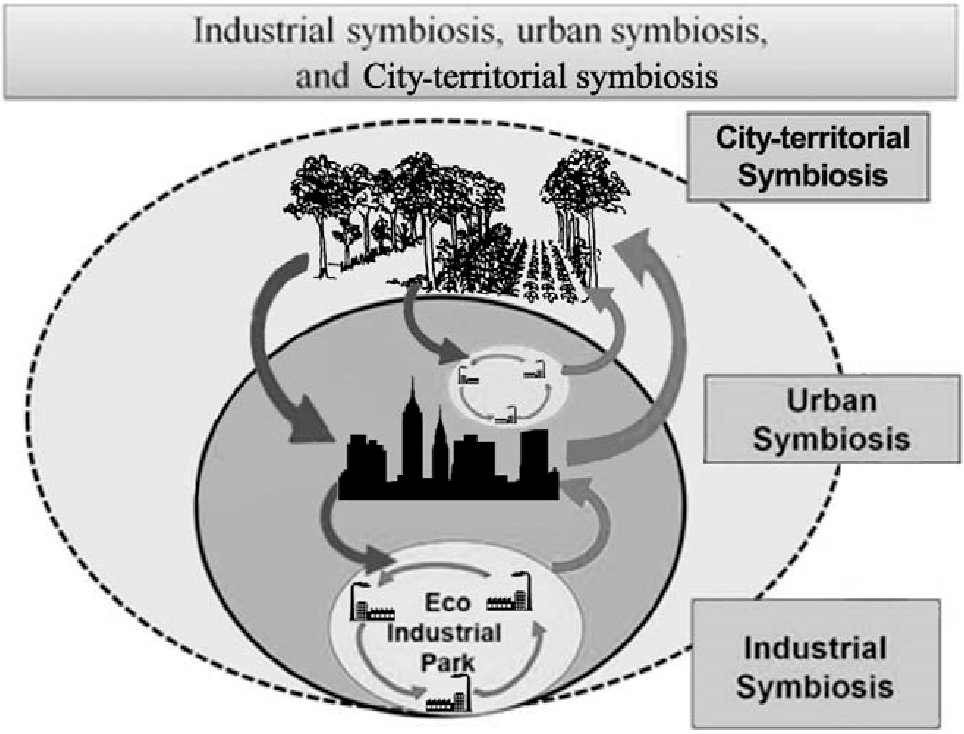

Figure 1. Port area/urban circularization [39].

The earlier argued three pillars for the CE transition of ports are in line with the proposed relations of Fusco Girard [39]. He [39] actually links the geographical level to the strategic CE pillars of ports, where industrial symbiosis mainly reflects the energy recovery potential, urban symbiosis creates a huge opportunity for recycling activities, and territorial symbiosis points at relationships with the hinterland to organize new cargo streams. Moreover, this implicitly suggests which actors in that geographical dimension can become interesting partners, may have innovative ideas and/or may possess CE know-how. In turn, the (landlord) port may be the best partner and location to provide space to develop CE knowledge, relations, products and processes. These symbiosis levels add another dimension to the dual CE transition of ports as argued by de Langen and Sornn-Friese [38], beyond "renewable energy" and "renewed materials for products", which we earlier suggested to complete a third CE transition pillar or strategic focus.

In line with the work of Fusco Girard [39], more recently, Salomone et al. [30] have argued that in order to effectively achieve a sustainable development, it is necessary to relate the CE concept to the concept of industrial symbiosis (IS), especially to understand the crucial social and organizational aspects of the circular transition. IS is namely a business-focused approach to promote sustainability by recovering residues from one entity for use in another [3]. In recent years, IS has become a sub-field of the CE, rising to become the primary concept in relation to sustainable development [19], and referring to the first strategic CE pillar, as explained in the previous section.

Urban symbiosis reflects the relationship a port, and city-ports in particular, may develop with its surrounding or adjacent urban environment. Recycling activities in city or inland ports, being faced with huge waste issues, were already developed decades ago as the first port CE projects.

City-territorial symbiosis may take place in the wider hinterland of ports, so this symbiosis level reflects the starting point of a new "port-logistics provider/forwarder–customer/shipper" relationship, bringing larger parts of the supply chain into a circular transition. It may also result in more local or regional freight flows and supply chains, different cargo types to handle, and opportunities for new (reversed) logistics.

Finally, CE should today be applied in an even broader sense. It should not only deal with the design of products, but also with processes and infrastructure. Because CE has been rapidly brought to the forefront by many public and private organizations [6,19], it is only gradually being linked from operational to also more organizational aspects [20,21]. Actually, it also influences the different planning initiatives, e.g., spatial planning and product design [16,17]. The CE era is still in its early stages, and multiple issues and trade-offs related to spatial, temporal and scale impacts have not yet been extensively explored [30]. For example, CE strategies can aim for degrowth and thus a reduced demand for (and flow of) new goods. Ports are still mainly aiming at maximizing cargo volumes, so it may feel contradictory to invest in CE strategies at the same time. On what scale such degrowth will happen, and if maybe on other levels more (regional and local) growth will consequently be triggered, is yet to be explored [12,34]. Crucial hereby will be to understand if and how existing global production networks will be reconfigured, or in other words, what (re)consumption and/or (re)productive elements of proximity, tangible or intangible [1,21], will be more or less important. Especially for ports, being core locations within the current local to global production networks, this could be a true game changer.

A recent Belgian study commissioned by OVAM (OVAM stands for Openbare Afvalstoffenmaatschappij (translated as "Public Waste Organization"). OVAM is a Flemish government agency making sure that Flanders (Belgium) treats its waste, materials and soil in an environment-friendly way) [40], "Circular City Ports", revealed indeed how proximity and spatial aspects, within and beyond the port cluster area, are intertwined with the symbiosis opportunities of ports. The development of ports towards a more circular economy depends on qualitative coalitions between the PA, businesses, the city, knowledge institutes, federations and policy makers. This study also revealed how the PA can gradually use its own space or land as an accelerator of the symbiosis levels. Indeed, ports may host eco-industrial parks or other important colocation spaces, ideal for accommodating CE initiatives. Moreover, PAs have the potential, through their sites, to unlock urban areas and to organize test-phase sites and recycle hubs for urban mining. Proximity is key to qualitative coalitions here.

3.3. An Integrated Framework for Circular Maturity of Ports

3.3.1. Scope of Circular Economy-Related Port Projects

In previous sections, we have elaborated on the CE strategic goal for ports, based on three pillars "energy recovery", "recycling" and "orchestrating valuable new cargo streams". We continued with how symbiosis levels are linked to those strategic pillars, and how spatial aspects can contribute to these levels of a port's CE transition. In this section, the scope and key characteristics of CE initiatives in ports contributing to one or more of the three CE pillars for ports are described.

Building upon the results of OVAM's "Circular City Ports" [40], presented in a Workbook, a non-exhaustive set of several European city-port CE practices was explored. All practices were structured according to three categories of aspects of the initiative, which contributed most to the CE transition in that project: "orgware", referring to the organization, platform or collaboration type, "framework", referring to the process in the port, and "materials", which are the tangible products or resources that are impacted through the initiative, see Figure 2.

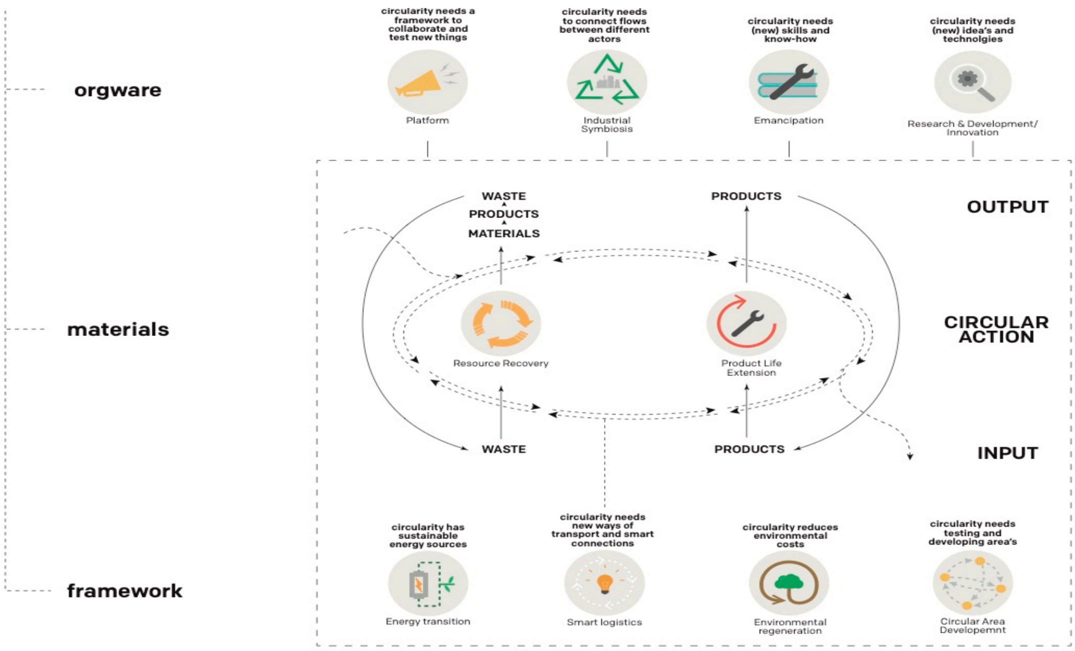

Figure 2. Types of initiatives and circular economy (CE) building blocks [40].

Other valuable variables for each initiative are the location where the initiative takes place or is developed, which stakeholder took the initiative and who are the other partners involved (cf. role of actors in line with de Langen, Sornn-Friese and Hallworth [41]), when was the initiative started and what collaborative steps have been taken since the start, to more comprehensively understand the evolution of the involved actors. Together, these characteristics enable us to map port CE initiatives according to their strategic goal (for PAs, especially when they are initiating the CE project), location and territorial collaboration.

3.3.2. An Analytical Framework to Map a Port's Strategic Transition to CE

The above information explains what the CE transition for ports should entail, but does not tell us how ports or PAs should or can implement this. To adopt a new strategy, organizations often rely on a maturity model that includes all steps to consider towards the implementation of an innovation process [9,42], in this case CE transition in ports. A maturity model for strategic change is based on the levels of maturity or developed capabilities as set out by Crosby [43]. The evolutionary process consists of succeeding levels of maturity, and provides the prerequisites for improvements that lead to the next stage [42]. Sehnem et al. [42] added that these levels guide growth based on continuous improvement and incremental changes, rather than radical transformations. Hence, maturity levels lead the organization to identify and evaluate its current state in the pursuit of excellence [42,44]. In line with the R hierarchy model for CE transition, as discussed in Section 3.1, the succeeding levels of CE maturity for ports, in relation to the ambitious three strategic pillars of a CE transition process, are (1) energy recovery, (2) recycling materials and (3) orchestrating new cargo streams. With maturity levels in the context of this paper, we do not aim to measure the progress of CE transition in terms of results or business success, but to outline what potential patterns or CE project dynamics characterize ports, which may help them in view of the next step in their change process.

It is important to stress that a circular transition is not only characterized by disruptive changes, but is also complemented by incremental sustainability innovations. Even more so, scientists warn that counting too much on disruptive innovation may slow down the incremental processes, because the disruption is supposed to solve all issues later anyway [45]. The paradigm shift through innovation then risks leaving the linear lock-in optimizations [46]. On the contrary, both ways for a sustainable transition should be embraced in parallel. Therefore, individual CE projects can be considered as interesting indicators to observe the pathway of a port's development in its CE transition.

Mapping the individual port CE initiatives or projects in such a way that shows how ports innovate towards a CE paradigm shift can be interestingly done by combining the scale or symbiosis level with the strategic focus (or stages of circularity) of the particular initiative.

This leads us to our analytical framework. In the framework, we combine two axes as described before. On the Y-axis, we map the scale on which the circular activity unfolds. This axis is based on the work of Girard [39], which we translated into, from small to large: intra-port, port-city and territorial levels. The higher the level, the more complex it becomes to organize these, as more and more actors are involved [47]. On the X-axis, we map the type of circular activity, based on the three pillars of a circular transition strategy for ports. Linked to the maturity stages of this circular transition, ports are assumed (from left to right on the X-axis) to first start with energy recovery, then initiate additional, new projects in recycling, and then orchestrate new cargo streams. These two axes lead to our analytical framework in Figure 3, which enables us to plot our empirical results.

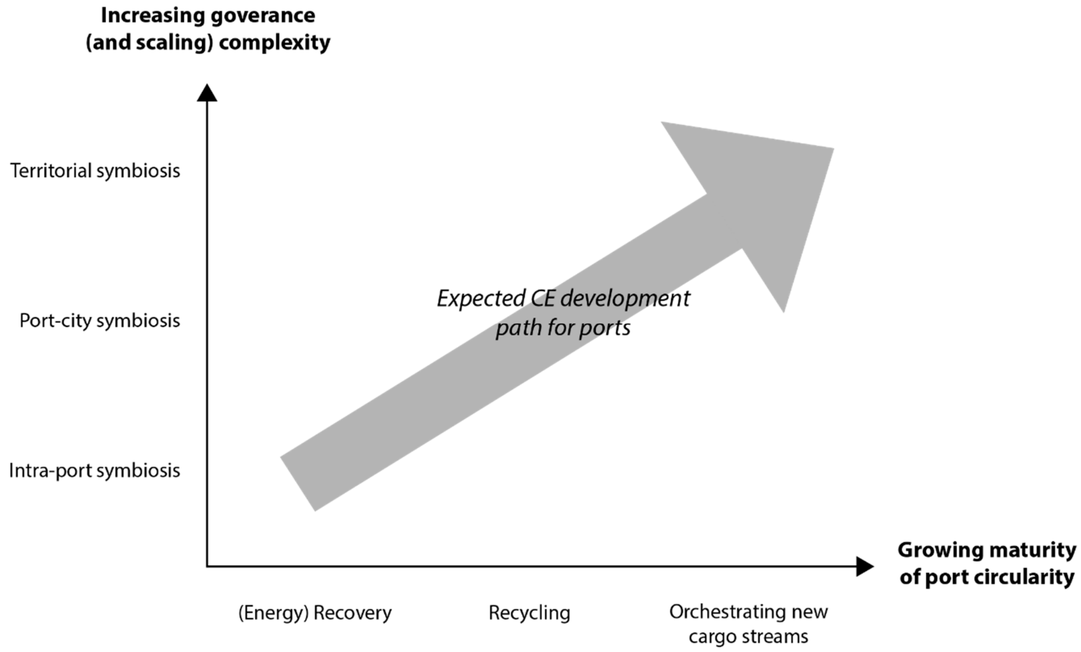

Figure 3. Development path for CE in ports (source: compiled by authors).

4. Empirical Analysis of CE Patterns in Five Belgian Ports

4.1. Multiple Case-Study Method and Data Collection

Because our research is problem-driven and we are, in particular, searching for circular activities within ports related to their strategy and geographical scale of symbiosis, we turn towards a multiple case-study method. The research is explorative in nature, and little research currently exists on the CE transition of ports. A cross-case analysis is suitable in this context and enables the discovery of a variety of transition processes based on ports' CE initiatives and in quite different port contexts. The choice of the cases will be discussed in the next section. A cross-case analysis enabled us to focus on an individual port's results, but also on results in reference to each other. As for the data, we first collected all available secondary information on the different CE activities of the ports, with port sustainability and annual reports, information retrieved from the PA websites and all specific websites existing for some CE initiatives. In the first instance, we limited ourselves to the most recent 5-year period because CE has only recently been added to the strategy of port authorities. However, some circular initiatives existed before 2015; thus, in the second instance we also looked at the important circular projects initiated before that date and still active (e.g., recycling of ships). Our first dataset was cross-checked with the sustainability manager and/or CE project responsible of each port under study, and finetuned together with the authors. For each initiative, we collected data on the strategic focus, the territoriality and relationship with actors, the role of the port authority, and the investment amount and level of subsidies (if available). In using these data for our mapping, we especially focus on the level of circularity (energy, recycling, new cargo streams), the scaling and the involved budget. For the latter, if available, we differ the amount of public and private budgets. Lastly, we look at the involvement of the port authority within the several activities. In what follows, we first describe our results per port and finally bring our results together.

4.2. The Case Selection of Five Belgian Ports

The selection of the five Belgian ports, namely, the ports of Antwerp, Zeebrugge, Ostend, Brussels and North Sea Port, is based on the size, function and diversification of these port clusters, including two large hubs, a medium-sized diversified port, a niche port and an inland port. These five selected ports are all important ports active in the same region of Flanders in Belgium, yet diverse in their size, operations or traffic scope. The case selection includes an inland port (Brussels) and a cross-border merged port cluster (North Sea Port), two coastal ports of different size and focus (Zeebrugge and Ostend), and a large seaport hub (Antwerp) considering closer cooperation with the port of Zeebrugge. This variety of cases enables us to obtain rich insights into their patterns of CE initiatives, linking to their unique position and clustering dynamics, yet all operating in the same area and under similar regulations and policies.

The port of Antwerp counts no less than 65 circular initiatives, of which almost half are initiated by the PA and publicly subsidized. There is a clear imbalance in the number of activities related to energy recovery (47), recycling (14) and new cargo streams (4). The energy focus may be embedded in the long-term development of the Antwerp port hub, with a large industrial cluster of petrochemical and chemical companies. Given these businesses' environmental impact, many of them have been triggered a long time ago to invest in ways to reduce and recover waste and energy. For the majority of these initiatives the budget is unknown, yet for those where it is known, the public subsidies are quite high. Recycling activities seem to mainly occur in relation to port companies within the port hub, but not in relation to the adjacent city for example. Organizing new cargo streams seems to be the newest activity developed and remains very explorative at this stage.

The Dutch/Flemish North Sea Port exists since the merger in 2018 between the Dutch port of Zeeland Seaport, being a merger itself between the ports of Flushing and Terneuzen, and the Belgian port of Ghent. We found 18 relevant circular activities. These are almost equally distributed over the different circular activities, with six related to energy, seven to recycling and five to orchestrating new cargo streams. Looking at the involved budget, there are more clear differences. Most of the focus is on energy. The most important activities here are the approved hydrogen factory in Flushing (around 100 M €) and the factory in Steelanol (around 160 M €). The latter project strives to transform the CO_2 of the steel plant of ArcelorMittal into bio-ethanol. Currently, the project is within the demonstration phase, the last one before the potential upscaling. Another point is that these relative large projects go beyond the port area and relate to the whole territory. Next, the recycling activities are mostly related to existing companies, some for more than a century. Here, no relevant important investments have been made. Lastly, and most recently, activities focus on creating an industrial symbiosis within the port. Here, the most relevant is the ongoing Steel2Chemicals project. This project strives to convert the CO_2 of the steel plant of ArcelorMittal into naphtha, which can be used as an input commodity by the chemical plant of DOW Terneuzen. Here, the port authority is an important partner because ArcelorMittal is located within Ghent, while DOW is located across the border. Hence, cross-border infrastructure (cf. pipelines) is needed. Most likely, within the near future, these industrial symbiosis projects linked to circularity will only increase in impact. The question remains, though, if it will also go beyond the port area and connect to the region.

For the port of Zeebrugge, our analysis did only find four relevant circular activities. On the one hand this is not really surprising, because Zeebrugge is foremost a throughput port, focusing on logistical processes and less on manufacturing processes. In Zeebrugge, three companies are related to recycling activities, linked to their historical presence going back more than a century. More recently, the port authority is building wind turbines within its port area, explaining the one activity related to the intra-port level or area, and energy recovery as a focus.

Considering the port of Ostend's small size in cargo throughput, this port developed quite a few initiatives, mainly in energy recovery and recycling. Little is known about the investment size or subsidy levels of these projects, but it is clear from the initiator perspective that most projects are privately embedded and facilitated by the PA in its area.

As an inland port, but capable of receiving maritime vessels and therefore legally categorized as a seaport, the port of Brussels is characterized by a large number of CE initiatives, both initiated by its companies and by the PA itself. Most initiatives are situated in the recycling activity and in relationship with the city of Brussels and its region, which reflect an urban mining focus, but intra-port and port-city energy recovery projects are also well developed.

4.3. Results: Mapping of CE Initiatives of Five Ports in the Transition Framework

In Table 1, some key figures (throughput and port area) and the main CE variables collected per port are presented.

Table 1. Overview of circular initiatives of Belgian ports.

	Antwerp	**Ostend**	**Brussels**	**North Sea Port**	**Zeebrugge**
Throughput (2019) (a)	240.000.000 ton	1.600.000 ton	5.200.000 ton	71.400.000 ton	45.800.000 ton
Port area (b)	12.068 ha	658 ha	107 ha	9.100 ha	2.857 ha
Number of initiatives	65	14	49	19	4
Number of initiatives initiated by the port authority	28	2	13	5	1
Number of supported initiatives by public subsidies	27	4	18	8	1
Total budget public subsidies	193.954.287 €	3.423.565 €	48.692.476 €	100.000.000 €	not known
Strategic focus	Energy hub	Recycle vs. Energy hub	Recycling hub	Energy hub	Energy hub
R-strategies	Reduce, recycle	Recycle, recover	Recycle	Reduce, recycle	Reduce, recycle

Sources: (a) [48], (b) [49].

Taking all results together, as shown in Table 1, it is clear that the larger diversified port hubs, Antwerp and North Sea Port, have more CE activities in absolute number, as well as in relative size. The medium-sized port of Zeebrugge has as few as four initiatives to report. The port of Ostend, a small niche port amongst others involved in off-shore windmill projects, has a relatively large number of initiatives, almost all situated in the port area itself. The inland port of Brussels also has a large number of CE projects, and here we observe a more balanced spread over the three strategic pillars, which is also geographically more extended.

Translating these results to our framework, most ports concentrate their CE initiatives in the lower-left side of the framework in Figure 4. Within the colored circles and squares in Figure 4, the mentioned numbers are referring to the found number of different initiatives or projects existing in the ports.

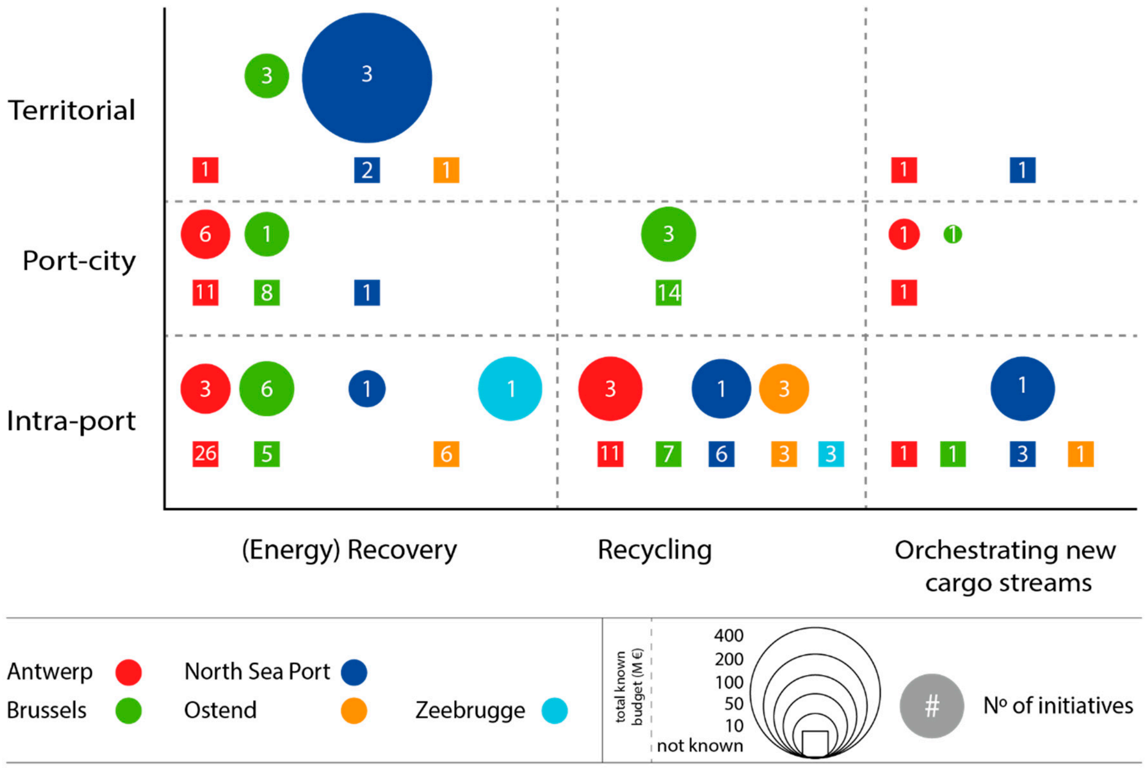

Figure 4. Mapped circular initiatives for five Belgian (sea)ports (source: compiled by authors).

5. Discussion

Considering the fact that larger port hubs have more means and firms to support initiatives, taking all the results together, as shown in Table 1, it is clear that larger diversified ports have more CE activities in absolute number as well as in relative size. However, it is apparent that for many projects the total budget is unknown, and for approximately a quarter of the projects, at least, public subsidies are keeping them alive.

Arguably, the port of Brussels stands out, especially considering its small size. We detected many circular activities, although they are in most cases on a relatively small scale and related to existing cargo streams within and between port and city. This is not a surprise, taking into account that the port of Brussels is a true urban port, understood as being located in a dense urbanized region. This lends itself to more cooperation between urban processes (e.g., building materials, bio-based flows) and the logistical and processing processes in the port areas. The CE will bring increasingly localized and closed material flows, coming with a considerable logistical challenge to make this possible, especially in spatial terms. Hence, the city of Brussels, having a maritime port area at its heart, has many advantages to really develop the more urban centered circular processes. This is confirmed by the type of circular activities. In Brussels, the majority of circular activities deal with recycling activities, while in the other Belgian ports, energy is more important, which deals with larger-scale processes and industrial activities.

What we also see is that ports that focus on energy activities tend to deal with higher budgets. This is to some level quite logical, because these energy activities are on a larger scale and involve more (capital-powerful) actors. Nonetheless, Brussels does not have the smallest budget involved—on the contrary. The city of Brussels is the largest city in Belgium (around 1 million inhabitants) and the capital of Belgium and Europe. Hence, the potential for urban circular activities is relatively higher than in the other Belgian cities. In other words, although we found that recycling activities tend to involve less money than energy and industrial symbiosis activities, following the large amount of recycling activities in Brussels, they account for the third largest budget involved in Belgian ports.

Overall, the port of Antwerp takes the lead in number of activities, activities that are supported, as well as the involved budget. Second is North Sea Port, then Brussels, Ostend and finally Zeebrugge. Zeebrugge is a greenfield port, focusing on logistical processes, cross-channel feedering and trans-shipment, and so far did not manage to attract nor initiate many CE initiatives.

What clearly differs thus is the overall focus of the different ports. Brussels and to a smaller extent Ostend focus on recycling, while the largest Flemish seaports of Antwerp, North Sea Port and Zeebrugge focus much more on energy activities. However, increasingly—following the more recent date of the respective initiatives of our dataset—activities are moving towards the lower- and mid-right side of the framework. In other words, this confirms our hypothesis that slowly the circular transition is getting more mature and will—most likely—increasingly cross port areas and borders and reach out to the surrounding urban environments, similar to what occurred with energy activities. It is however very clear for every port that the orchestration of new CE-based cargo streams is still a lower priority or evolved at a slower pace. The fact that many of the studied ports do not control many information links on their cargo flows, or develop strong data-relationships with their shippers in their hinterland, may be a bottleneck for developing these more complex, yet important and sustainable CE initiatives.

The observation that limited information is available on the budget and on the extent and prospected timing of subsidies does raise some questions on the funding continuity and the sustainability of these initiatives in the longer run. In fact, very few initiatives are confirmed as building upon a positive business case today.

6. Conclusions

In this paper, we developed a framework to indicate the maturity level of the circular transition of ports, through their portfolio of circular initiatives in which the port authority either takes the lead, partners or facilitates by offering space. We mapped all current CE initiatives based on the strategic focus of the project in the CE transition, and on the symbiosis level and geographical outreach of each initiative or project. We find that the studied Belgian ports almost all focus on the lower-left side of the framework. This is rather natural for seaports with a large industrial development area. Only the inland port of Brussels has a stronger focus on recycling, but being close to a large metropolitan area, this is also a more expected development for this port. In line with this observation, we could conclude that the CE provides especially interesting new strategies for urban ports such as Brussels. During recent decades, the growth and success of ports were mostly based on a growth of throughput and land leasing. However, this is problematic for ports that have a lack of space or are locked-in in a densely populated area, such as Brussels. The CE transition provides a way to turn this disadvantage of being located within or close to large urban metropoles into an advantage. The CE strives for more closed, but also more local material flows. Hence, urban areas with industrial and logistical (maritime) areas within their centers have a clear advantage to realize their CE potential. For Brussels, we thus expect, based on their context and front runner position in CE, that increasingly they will be able to move more quickly towards the right side of the framework, but still very much linked to urban activities.

For the larger-scale circular activities, ports that already host huge industrial and energy processes have more intrinsic potential for intensified symbioses [50]. We observed that so far the focus has been on pure energy processes (e.g., transforming CO_2 into fuels). However, these energy processes will increasingly blend into more 'clear' circular processes, whereby waste from one organization becomes input for another, without the current intermediary step of transforming waste into energy before being used by a new actor, such as in the Ecluse project in Antwerp. The Steel2Chemical project in the North Sea Port can be seen as an example here, whereby CO_2 is not being transformed into fuels which only then can be used by actors, but is directly being transformed into a commodity (cf. naphtha) that can be used to make plastics. As a result, new cargo streams in and through the port will occur, and hence we foresee that circular activities within ports will move towards the right side of the framework.

Of course, we should not underestimate the crucial role of the port authority in facilitating the emergence of circular activities within their ports. Despite the fact that the CE potential may depend on the present type of activities, it is still important that actors are networked, ideas are exchanged and funding is provided to proceed. The port authority plays an important role in this process. From this perspective, we can conclude that the ports of Brussels and Ostend really 'jumped' on the circular bandwagon and have successfully put themselves on the map as circular ports. Zeebrugge, on the other hand, and although it is a clear logistical greenfield port, until now has not succeeded in doing the same. Next, both North Sea Port and the port of Antwerp are increasingly positioning themselves as places where circular activities can—and should—emerge. The question, however, remains how sustainable the initiatives are in terms of their business case, and how the PAs also realize the importance of the third CE pillar of orchestrating new CE cargo streams. Their history and economic profile play to their advantage. Different than for example the port of Zeebrugge, North Sea Port and the Antwerp seaport are more industrial ports, already having many industrial clusters and related supporting infrastructure. The potential to further increase circular symbioses is there; the question is if this potential is fully recognized and exploited. To conclude, all ports can embrace more partnerships and clustering, as well as benefit from better understanding the importance of data and capturing information on their traffic flows to and from their hinterland. Hence, they could co-create with shippers and other actors the cargo streams of tomorrow and play a lead role in the CE transition.

Despite these insightful results, our study also indicated future research is necessary on the role of each actor, on the developed business models for the CE initiatives, and on how the results for Belgian ports relate to the CE transition in other ports in Europe and beyond.

Author Contributions: E.H. had the initial idea for the paper and set out the main lines and structure, and subsequently with K.V.d.B. wrote the paper. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Acknowledgments: OVAM/Circular Flanders commissioned a study in 2018 to Architecture Workroom Brussels (AWB) and 1010au to explore circular projects undertaken by multiple city ports in Northwestern Europe. The results have been widely communicated and will lead to more specific valorization studies together with ports and business partners from summer 2020. The initial explorative study and the workshops organized during this trajectory, under the leading project role of Walter Tempst, were an important source of inspiration to both authors for this research paper.

Conflicts of Interest: The authors declare no conflict of interest.

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