Implementing industrial ecology in port cities: international overview of case studies and cross-case analysis

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Abstract:

The aim of Industrial ecology (IE) is to optimize resource and waste management by densifying interactions between different stakeholders occupying a common geographic area. This article considers ports, understood as platforms of circulation and transformation of the main material and energy flows, as interesting laboratories for the implementation of IE. It addresses the role and capacity of ports to foster the implementation of IE in port cities and to contribute to the optimization of resource and waste management in coastal areas.

This article presents the result of a research project, carried out from September 2011 to September 2012, consisting of an international inventory of innovative resource management initiatives in port areas in North America, Europe, Africa and Asia. 18 port-based industrial complexes were visited, enabling the identification, documentation and analysis of 23 port IE initiatives. Cross-case analysis was carried out following a 3 step methodology: 1/ definition of the research boundaries; 2/ qualitative data collection by means of interviews and a literature review; 3/ data analysis in order to build a typology of port IE contribution to the implementation of IE in port-city areas. The validation of these results is led through a theoretical saturation process.

The case studies analyzed can be classified into 9 patterns based on temporal and spatial characteristics of P-I initiatives. They provide some insights on the ports' influence on local IE dynamics: as areas of testing and implementation of industrial symbiosis, ports can constitute exemplary self-sufficient areas, likely to boost the development of other local eco-parks; as drivers of local economic development, ports act as levers for the implementation of sustainable policies at a regional scale; as nodes in a global port network, ports can develop inter-port by-product exchanges and utility sharing. Ports question the relevance of geographical proximity in IE.

Key-words: Industrial ecology; industrial symbiosis; port; port city; cross-case analysis

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1. Introduction

The coastal zone, covering 8% of the world's surface area may account for as much as 25% of global primary production (Turner *et al.,* 1996). Demographic trends have combined with major socioeconomic trends to produce a growing concentration of urban development and port-based industry in these areas. In 2010, 65% of cities with populations above 1.3 million were located along the world coast (Vallega, 2001). Within these coastal zones, ports have essentially been defined as gateways linking a home region to the rest of the world via international transport (Bird, 1983). They constitute logistic nodes playing an important role in the management and co-ordination of material and information flows, at the interface between land and water transport, within a global supply chain network (Carbone and De Martino, 2003). They are platforms of transit, storage, collection and distribution as well as industrial processing for the main material and energy flows (Van Klink, 1994). As nodes in a global transportation network, the functions of ports have generally been considered as exogenous and eccentric to the coastal and urban landscape (Bird, 1983). In major European seaports, port functions have been dissociated from city functions. While in the traditional port city, port and urban functions are located together and interpenetrate each other, with the development of huge industrial port complexes, the port functions has migrated outside the city, toward peripheral urban areas or greenfield sites (Hoyle, 1989). Spatial and functional segregation between ports and cities has thus become more marked in many port cities in the world (Hayuth, 1989). However, this trend must be qualified. Lee *et al.* (2008) describe the stages of evolution of Western and Asian port-city interfaces since ancient medieval times. Resulting from these evolutions, they contrast two extremes of port-city relationships: on the one hand, 1/ a "general port city" model where the port has been separated from the city and, on the other hand, 2/ a "global hub port city" where the port development is integrated within the urban core. It therefore becomes necessary to enhance port-city relationships and reappraise new opportunities for synergies between these two main functions of coastal zones. For Merk (2013), the core question of these coastal areas addresses the capacity of ports to continue providing added value to cities, and fostering urban prosperity and well-being.

Ports have both negative and positive impacts upon their local urban context. Several ports are sites for resource-intensive industries that benefit from the proximity of loading and unloading vessels. Port-related activities are generally heavy-industry activities such as refineries, chemical plants, steel and coal production, paper and paper pulp processing, aerospace and renewable energy generation (Merk, 2013). As a result, they are currently experiencing intense and sustained resource, environment and health pressures. In terms of resource depletion, the level of energy consumption of port-based industrial complexes is illustrated by energy-intensity: for instance, while only representing 0.02% of the total surface area of France, the Marseille-Fos port-based industrial zone consumes the oil equivalent of approximately 4.5 million tons per year, i.e. 3% of national energy consumption (Rodrigues, 2012). Terrestrial activities in port areas also contribute to soil and sediment contamination, together with air pollution, negatively impacting public health (Miola *et al.*,2009), and use up land, provoking the degradation of natural habitats and biodiversity (Darbra *et al.*, 2004). According to the European Sea Ports Organization Environmental Survey, one of the major environmental issues in seaports remains port waste management (European Sea Ports Organisation, 2013). On the other hand, the creation of added value by ports and port-related activities can be substantial, in terms of direct impacts including jobs and income generated by the port, indirect impacts generated by the supply of goods and services and the catalytic impact generated by the capacity of port to drive economic productivity, growth and attractiveness (Merk, 2013). For Brooks and Cullinane (2007), the global evolution of port governance toward public-private organization reveals the desire of governments to garner greater local efficiency, effectiveness and responsiveness from ports. For instance, in 2007, the added value of the Antwerp port cluster contributed to 2.9% of the national gross domestic product (GDP) and represented 15.5% of regional GDP (Merk *et al.*, 2011). This added value of industrial port development is fostered by synergetic cluster effects measured though the intensity of economic linkages between sectors within the port area (Merk, 2013).

In this context, port cities are interesting laboratories for the implementation of industrial ecology (IE). IE seeks to optimize resource and waste management by densifying interactions between different stakeholders occupying a common geographic area. Industrial symbiosis, as a way to implement IE, has been defined as engaging traditionally separated industries in a collective approach to competitive advantage involving physical exchange of materials, energy, water and by-products, thanks to the synergistic possibilities offered by geographic proximity (Chertow, 2000). Industrial symbiosis supposes the evolution of coordination between economic actors (Baas and Boons, 1997). As areas concentrating high resource depletion, pollutant emissions and human population density, port cities constitute a real challenge with regard to reducing pressures on the environment and society. As logistic nodes centralizing material and energy flows and concentrating major operations in the value chain, they directly concern issues of optimization and integration of flow management and represent major drivers for the implementation of IE. As synergetic clusters, they benefit from an existing culture of linkages and partnerships between sectors which can be propitious to IE initiatives (Cohen-Rosenthal, 2000; Boons and Howard-Grenville, 2009).

Port cities do not appear as a stand-alone issue in IE literature: some IE articles refer to seaports but mostly as case studies amongst others (Baas, 2000; Fleig, 2000; Park and Won, 2007; Boehme *et al.*, 2009). It would appear that little mention is made of the specific characteristics of IE initiatives carried out in port-based industrial complexes. The IE measures implemented in port areas cover a broad range of initiatives, including: collaborative approaches to air or water pollution at watershed scale (Boehme *et al.,* 2009; Cameron, 2010; Booth and Loh, 2012), collaborative dredged material management at regional scale (Abriak *et al.,* 2006, Junqua *et al.,* 2006; Stern, 2009; Port of Long Beach, 2011), resource and energy optimization together with waste recycling between firms (Otsuka, 2006; Royston, 2009), and port-city cooperation over recycling facilities (Fujita, 2006; Higushi, 2004). While individual case studies are indispensable for revealing the variety of industrial symbioses, comparative research at international scale may cast more light on similarities and differences in IE initiatives in varying contexts (Lombardi *et al.*, 2012).

This article is a first trans-continental study of IE initiatives in ports, emphasizing IE theory, policy and implementation transfer, and replication in other port contexts. It presents the result of a research project, carried out from September 2011 to September 2012, consisting of an international inventory of innovative resource management initiatives in port areas in North America, Europe, Africa and Asia. 18 port-based industrial complexes were visited, enabling the identification, documentation and analysis of 23 port IE initiatives (hereafter designated as P-IE initiatives). By identifying patterns for the definition and planning of IE initiatives in port areas, this article addresses the role and capacity of ports for fostering the implementation of IE in port cities and contributing to the optimization of resource and waste management in coastal areas. The core question is how do ports contribute to the planning and implementation of IE in port-city areas?

2. Research framework and methodology

The case study methodology consists in identifying recurrent phenomena among a number of situations (Collerette, 2004), using a “pattern-matching” logic (Yin, 1984). Eisenhardt (1989) assigns two functions to the case study approach: a deductive function that tests theories using case studies to assess a *priori* models, and an inductive function that generates theories using recurring patterns of case studies to generalize postulates. In practice, case study methodology cannot dissociate these two functions. The process is highly iterative, comparing the emerging framework with the evidence from each case in order to shape and sharpen hypotheses and confirm the relevance of patterns and models (Eisenhardt, 1989). As a result, the case study methodology can be understood as a succession of codified intellectual processes: definition of the research boundaries, categorization of the constitutive dimensions of the studied phenomena, identification of patterns by linking these dimensions, validation of these patterns by means of the case studies (Mucchielli, 2006). Starting from the definition of boundaries for this analysis, we are then able to select cases in order to collect data mainly of qualitative nature, though interviews performed on site and a literature review. The core of our research is the analysis of data, coupling within-case analysis and a cross-case search for patterns. Fig. 1 presents the general methodological framework presented in the following sections.

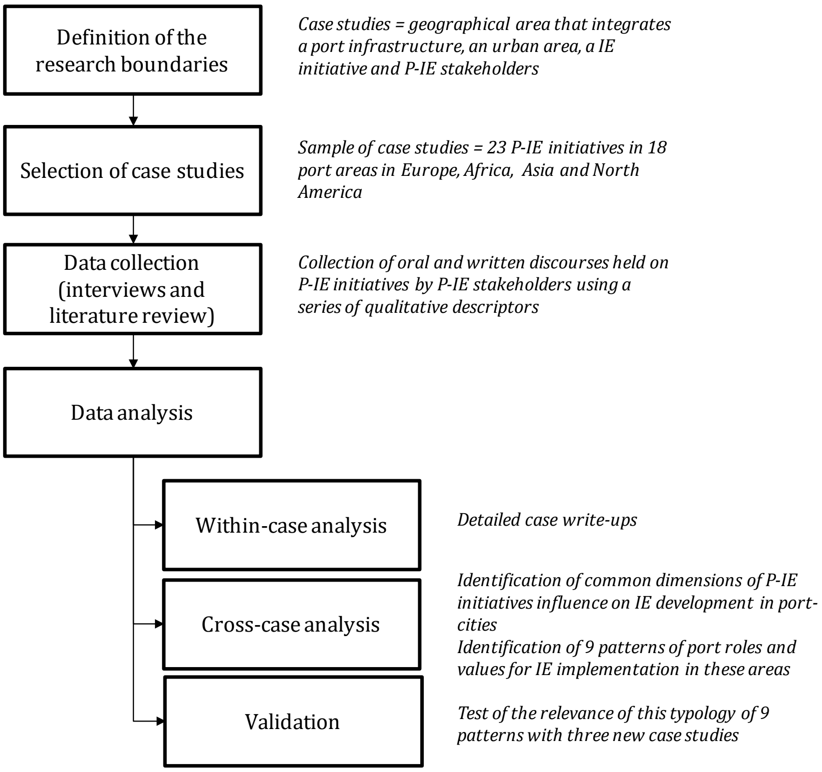


Fig. 1: Methodological framework of the case study analysis

2.1. Definition of the research boundaries and selection of case studies

The sampling framework is theoretically guided by the research question, which addresses the role and capacity of ports to foster the implementation of IE in port cities. The research boundaries must guide the selection of the sample in order to group together case studies that have common characteristics and can provide data to answer this research question (Mucchielli, 2006). The case study is the unit of this analysis (Miles and Huberman, 2003). In order to fit with the scope of this research focus, case studies are defined as geographic areas that combine:

- A port infrastructure with a logistic function of transit, storage, collection and distribution as well as industrial processing for the main material and energy flows (Van Klink, 1994) between land and water transportation. Ducruet *et al.* (2013) define 8 types of ports considering the linkages occurring between the port infrastructure and the host territory: for instance, metropolitan and industrial port regions are characterized by important demographic, economic and port concentrations, handling more international traffics than world average. Metropolitan port regions are richer, more densely populated and service-oriented, whereas industrial port regional are dominated by production and transformation activities. Productive and bulky port regions are large regions with high GDP and lower international and general cargo traffic than world average. Bulky port regions are specialized in solid bulk traffics, while productive port regions are richer and more industrialized than average, handling more imports and liquid bulk. Deprived port regions are defined by poor economy performance and higher specialization in primary activities.

Finally, traditional port regions are characterized by a smaller size and a specialization in solid bulk traffics and primary sector ;
- An urban area with historical or current links with this infrastructure, Ducruet (2004) identifies 9 types of port-city models, from coastal port town to world port city depending on city size and port traffic;
- A number of industrial symbiosis initiatives referring to Chertow (2000)'s taxonomy material exchanges within a facility, firm, or organization; among firms collocated in a defined eco-industrial park; among local firms that are not collocated; and among firms organized ''virtually'' across a broader region. Three types of industrial symbiosis can occur: by-product exchanges, utility sharing or facilities management optimization, and cooperation on issues of common interest such as sustainability planning (Chertow *et al.,* 2008; Meneghetti and Nardin, 2012);
- An informal or formal organization of P-IE stakeholders (Table 1) that are both port stakeholders (Van Klink, 1998; de Langen, 2006) and IE stakeholders (Baas and Boons, 1997; Chertow, 2000; Brullot, 2009; Cerceau *et al.*, 2013).

Table 1: Definition of P-IE stakeholders

Port stakeholders (Van Klink, 1998; de Langen, 2006)	**IE stakeholders (Baas and Boons, 1997; Chertow, 2000; Brullot, 2009; Cerceau *et al.*, 2013)**		**P-IE stakeholders**
Port authority, local government, national government	Local authorities, decentralized state services and agencies	→	Port authorities, local authorities, national government
Port specific activities (transshipment, ship repair), port related activities (manufacturing, distribution, wholesale), final users of the port (import, export)	Companies, professional networks	→	Companies
Local associations	Networks, consulting agencies	→	Network stakeholder
	Universities, research institutes	→	Research stakeholder

The sampling strategy consists in identifying case studies that gather these characteristics on the basis of a literature review and interviews with port network organizations (Worldwide Network of Port Cities AIVP, International Association of Ports and Harbors, Port Management Association of Eastern and Southern Africa) and IE communities (National Industrial Symbiosis Program). It follows an iterative and investigative logic, working in progressive "waves" as the study progresses (Miles and Huberman, 2003). Finally, the sample is composed of 23 P-IE initiatives taking place in 18 ports. Each P-IE initiative constitutes what is hereafter called a "case study". These case studies are identified, documented and analyzed by means of individual or collective interviews of 67 P-IE stakeholders (Table 2).

Table 2: P-IE initiatives case studies, sample of the case study analysis

Port-city areas	P-IE initiatives case studies	Type of port region (Ducruet *et al.,* 2013)	P-IE stakeholders Interviewed (number)
Europe			
Port of Fos-Marseille (France)	IE strategy	-	Port authority : 2
Zeeland Seaports (Netherlands)	Biopark Terneuzen Hidden Connections	Productive port region	Port authority : 1
Port of Rotterdam (Netherlands)	Bioport of Europe	Metropolitan port region	Port authority :2 Research stakeholder: 2
Port of Antwerp (Belgium)	Antwerp Sustainable policy	Industrial port region	Port authority : 1
Port of Brussels (Belgium)	Brussels' collaboration and urban integration	-	Port authority : 2
Port of Bristol (United Kingdom)	Bristol Industrial ecology approach (NISP)	Productive port region	Network stakeholder : 2 Research stakeholder: 2
Ports of Galicia (Spain)	Integrated fishing waste	Industrial port region	Port authority : 1

	management in Ports of Galicia		Network stakeholder: 1
Africa			
Port of Jorf Lasfar (Morocco)	OCP Eco-industrial symbiosis	-	Company: 3 Research stakeholder: 3
Ports of Morocco	Integrated shipping waste management among Moroccan ports	Traditional port region	Company: 1
Port of Bejaïa (Algeria)	Cevital eco-industrial synergies	-	Port authority : 4 Company: 3 Local authority:1
Asia			
Port of Osaka (Japan)	Eco-industrial synergies of Osaka Gas Co. Osaka Bay Phoenix Project	Metropolitan port region	Port authority : 1 Local authority: 4 Company: 3
Port of Kawasaki (Japan)	Kawasaki recycling port Kawasaki eco-town	Metropolitan port region	Local authority: 4 Network stakeholder: 1 Research stakeholder: 5
Port of Tianjin (China)	Tianjin Port symbiosis	Bulky port region	Port authority : 4 Network stakeholder : 2
Port of Ningbo (China)	Ningbo Port symbiosis	Bulky port region	Local authority : 4 Research stakeholder: 1
Port of Ulsan (South Korea)	Ulsan Port symbiosis	Industrial port region	Port authority: 3
Port of Map Ta Phut (Thailand)	Map Ta Phut Eco-industrial estate	-	Company : 1 Research stakeholder: 1
North America			
Port of New York / New Jersey (United States)	NY/NJ Harbor Consortium NY/NJ Dredged materials reuse	Metropolitan port region	Research stakeholder: 1
Port of Long Beach (United States)	Collaborative dredged material management (Long Beach)	Deprived port region	Port authority: 1

The representativeness of the qualitative analysis sample cannot be assessed on statistical grounds (Miles and Huberman, 2003). It deals with theoretical saturation defined as the phase of qualitative data analysis in which the researcher has continued sampling and analyzing data until no new data appear and all concepts in the theory are well-developed (Morse, 2004). The sample's relevance must be assessed in terms of its capacity to develop and consolidate a theorization process (Paillé, 2004).

2.2. Data collection

Early in the data collection process, case study analysis needs to cope with the overwhelming volume of data. Data collection must gather elements that highlight the particular role and value of ports for IE planning and implementation in port-cities: when did the port stakeholders intervene in the IE process? To what extend are port stakeholders involved in the IE initiatives? What is the centrality of the port area within the boundaries of the IE project? How does the port strategy integrate IE objectives? Etc. Cases are studied using a range of qualitative descriptors to collect and organize such elements. The selected descriptors (Table 2) consider industrial symbiosis case studies literature as well as insights from the research objective itself. This common analysis grid participates in a replication strategy (Yin, 1984) which will allow a cross-case comparative analysis.

Table 3: Within-case descriptors used for the analysis of each case study

Within-case descriptors	Collected information	References
Period	Main dates of the IE approach	Bossilkov et al, 2005
Boundaries	Geographic perimeter of the IE's implementation (port city, port-based industrial complex, port region, port network)	Argawal and Strachan, 2006; Van Klink, 1998.
Major environmental	Environmental issues motivating the implementation of IE (availability	Argawal and Strachan, 2006

issues	of resources, land pressure, air pollution, water pollution, waste management)	
Type of synergies	Characterization of industrial symbiosis	Bossilkov et al, 2005; Argawal and Strachan, 2006; Gibbs and Deutz, 2007
Involved stakeholders	Stakeholders involved in the P-IE approach (international institutions, central government, local authorities, port authorities, firms, academics)	Gibbs and Deutz, 2007; Argawal and Strachan, 2006
Coordinating structure	Identification of an IE leadership embodied in a dedicated structure	Bossilkov et al, 2005
Financial support	Identification of financially involved stakeholders	Gibbs and Deutz, 2007
Link with port development strategies	Highlights of port strategic orientations correlative to IE objectives and principles	
Communication	Level of communication of the IE approach (data transparency among stakeholders, local communication, international diffusion)	Bossilkov et al, 2005

Data collection is mainly of qualitative nature. It was performed by means of individual or collective interviews performed on-site and a literature review in order to gather both oral and written discourse on the P-IE planning objectives.

Interviews were conducted using a semi-directive approach. The first part of the interview allowed the P-IE stakeholders to express themselves freely so as to present the P-IE initiatives as they intended. The second part consisted in covering a series of complementary themes and questions in order to make sure all within-case descriptors had been filled in (Table 4). Interviews were transcribed by means of a systematic qualitative note-taking process (Paillé, 2004) in order to record both the exchanges and the researcher's observations that occurred during the interview. The literature review concentrated on the analysis of written discourse produced by P-IE stakeholders (articles, presentations, posters, communication brochures, etc.). It followed the same analysis grid, in order to prepare and complete data collected through interviews. The collection and analysis were static, considering the planning objectives as they were communicated during the period 2011-2012. The analysis was based on publicly available information.

Table 4: Interview guidelines (abstract of the interview led in Ulsan, South Korea)

Within-case descriptors	Collected information
Boundaries	What is the geographic organization of Ulsan coastal area? How far is Ulsan industrial park from the port? What definition would you give of this whole region in terms of circular economy? And, in your opinion, what specific role of coastal areas in the development of EIP in South Korea?
Type of synergies	How many synergies occur between Ulsan industrial park's companies and port area companies? What material links are developed with the maritime industry (concerning the management of shipping waste, sludge for instance)? Are or can they be integrated within the petrochemical ecosystem network?
Involved stakeholders	Do you know what are the main missions and skills of the Port authority, and/or the different port stakeholders? Do they play an important role in local and territorial development? How can these missions and skills contribute to the implementation and development of synergies? In terms of governance, what are the role and the function of the Port Authority (and the local government) in Ulsan's organization, planning and implementation? What are their implication and participation at the different steps of its development?
Link with port development strategies	To what extent is the EIP approach integrated in the economic development, attractiveness and competitiveness of the port area?

2.3. *Data analysis*

Having defined the research boundaries, the next step consisted in analyzing collected data in order to identify recurrent patterns for the roles and values of ports for IE planning and implementation in port-cities. Data analysis began with a within-case study. It involved detailed case study write-ups for each case study producing a stand-alone description (Eisenhardt, 1989), using a common analysis grid (Table 3). From these descriptions, the objective was to confirm whether IE was implemented, consciously or not, in port-cities and to present the diversity of P-IE initiatives carried out in Europe, North America, Asia and Africa.

In order to help the emergence of common patterns among this staggering volume of data, data analysis was continued by means of cross-case analysis. Through the study of discourse collected through the interviews of port stakeholders involved in IE initiatives together with the literature review, the first aim was to categorize the constitutive dimensions of the influence of P-IE initiatives on IE development in port-cities. P-IE discourse was compared to the prospective framework (Godet, 2004; Genet *et al.,* 2005) and port literature (Raimbault *et al*., 2010; Ducruet, 2008; Van Klink, 1998), in order to clarify the various levels of their temporal and spatial dimensions. On the basis of these temporal and spatial dimensions, a P-IE typology was elaborated by identifying the different patterns of port role and value for local IE implementation. In order to test the theoretical saturation (Morse, 2004) of this model, we ensured that these different patterns can be used to describe any other current case study. This typology was tested with two P-IE initiatives that are not part of the sample: the P-IE initiatives of Kalundborg (Denmark) and Kwinana (Australia).

3. Within-case studies: overview of IE initiatives in ports

Our research reveals that new visions and practices are emerging in ports worldwide, ranging from pragmatic synergies between firms developing pooling of utilities and facilities, to the integration of IE within port strategic policy and prospective. Using the common within-descriptors analysis grid, Table 5 presents a global overview of the main features of P-IE initiatives in Europe, Africa, Asia and North America, based upon publicly available information gathered through the interviews and literature review.

3.1. European P-IE initiatives case studies

IE cases in Europe are relatively numerous in ports: P-IE initiatives are inventoried in the Netherlands, Belgium, United Kingdom, Spain and France. In France for instance, with the expansion of the port city of Marseille and the development of port-based industrial complexes further to the west – Etang de Berre from the 1920s and Fos from the 1960, the implementation of energy intensive companies and the Liquified Natural Gas (LNG) terminal led to the development of by-products exchanges, More recently, the Port of Marseille-Fos considers IE as an attractiveness factor for the establishment of new businesses and the evolution of the Port's mission toward local energy production and supply. Initial studies were carried out in 2004 and 2005 (Junqua *et al.,* 2005, 2006; Junqua and Moine, 2007), enabling the identification and modeling of potential synergies and new activities. Research projects contribute to enhancing IE approaches in Marseille (Mat *et al.,* 2012; Mat and Cerceau, 2011). Other projects such as VASCO and SALINALGUES aim at capturing or reusing CO_2, for microalgae production in particular.

The Port of Rotterdam's IE approach is one of the oldest P-IE initiative cases inventoried. The first initiatives were launched in 1990 by companies, mobilized with regard to environmental issues in response to tighter regulation, with the support of the Universities of Rotterdam and Delft. A first research program (INES Program 1994-1997) led to the analysis of materials and energy flows and to the detection of 15 opportunities for synergies. Joint systems for compressed air, waste water circulation and bio-sludge reduction system were selected for further feasibility studies (Baas and Huisingh, 2008). A second research program (INES Program Mainport 1997-2004) extended the scope of study and governance approach to consider the establishment of "Vision 2010", a strategic plan for the region ROM Rijnmond

(Baas and Boons, 2007). Nowadays, “Port Vision 2030” embodies the integration of IE in the Port authority’s strategy, focusing on the reuse of CO_2 and the limitation of GHG emissions across the port-based industrial complex, in order to lead the industrial transition to a "bio-based industry" through denser clustering of industrial activities in Rotterdam. This culture of rational use of energy also associates the urban component of the port area. Bringing focus on the articulation of port, industrial and urban needs, the Rotterdam Climate Initiative is a multi-stakeholder approach involving the Port Authority and the City of Rotterdam in the optimization of energy management, for instance with the construction of a 26 km long pipeline to provide heat from the port area to 50,000 homes (Baas and Boons 2007).

The Port of Antwerp considers IE approaches as an attractiveness factor for the establishment of new businesses. Relationships developed between companies and flows exchanges opportunities are presented as a real vector of competitiveness and business efficiency. The Port Authority acts as a stakeholder for 1/ funding synergies (for instance, shared funding audits on energy consumption for 500 companies), 2/ leading projects for the pooling of equipment or services (for instance, the construction of a deionized water plant for petrochemical industries), 3/ mediating between the city, companies and institutions on structuring projects for sustainable development in the port area (for instance, the development of a network of waste heat recovering for the city and businesses, and the implementation of a network for the exchange of CO_2 between the companies in the chemical sector) (Delhove, 2012).

As an attractiveness and competitiveness factor, IE is also a relevant means for European ports to develop in areas constrained by a lack of land, “Not In My Back Yard” effects and environmental regulation. Zeeland Seaports applies IE by optimizing resource management, in order to convert these regulatory and social pressures into opportunities for the development of the port-based industrial complex. The Terneuzen Biopark embodies this IE approach. Within a cluster, companies have spontaneously developed eco-industrial synergies (CO_2, water and biomass synergies). The Warm CO_2 initiative collects the thermal and CO_2 surplus of Yara to feed agricultural and horticultural greenhouses. The Port Authority appropriates this dynamic through its sustainable development strategy (Zeeland Seaports, 2011 (a)). The implementation of a multi-utility provider (Interreg IV PATCH project), a pipeline network, will enlarge and systemize the range of flows exchanged (Zeeland Seaports, 2011 (b)).

3.2. North-American P-IE initiatives case studies

Case studies analyzed in North America do not systematically refer to the concept and vocabulary of IE. However, there are initiatives carried out by North American port authorities that fall within the sphere of IE. In the Port of Long Beach, for instance, a land development project provides a Port-to-Port collaborative response to the problem of managing contaminated dredged material on the Californian coast. The Middle Harbor Project required 7 million cubic meters of material to cover 50ha of sea, of which 3 million could not be provided locally. Six Californian ports and marinas proposals were finally accepted for the quality of their materials and their ability to meet the project schedule. This port-to-port symbiosis enabled 1.3 million cubic meters to be diverted from landfill (Port of Long Beach, 2011)

The harbor basin of New York / New Jersey is another emblematic example of P-IE initiatives in North America. The first application of IE tools (flow analysis, mass balance) in this area dates back to the early 1990s (Rod *et al.,* 1989). In 1997, the New York Academy of Science set up a working group of 70 institutions to evaluate the relevance of applying IE tools in the port area of New York / New Jersey. The Harbor Consortium was constituted to apply a renewed governance system involving multiple port stakeholders (industrial, public, scientific, institutional) and articulate different jurisdiction levels (municipal, state, federal). Results at a watershed scale allow targeting policies to prevent pollution by sectors of economic activity. Among objectives pursued by port stakeholders are 1/ the reduction of contaminants flows (mercury, cadmium, PCBs, dioxins, PAHs and suspended solids) from unidentified sources of pollution scattered throughout the watershed (Boehme *et al.,* 2009), 2/ the implementation of a regional plan for sediment management by in and ex-situ treatment technologies coupled with remediation and recovery opportunities (Stern *et al,* 2009).

3.3. Asian P-IE initiatives case studies

There are numerous cases studies in Asia. Indeed, China is recognized world-wide known for having inscribed IE principles in its National Development Plan with the Circular Economy Promotion Law, and for implementing it in its “National Pilot Eco-Industrial Park Program”. The implementation of the Circular Economy approach is a major feature of the recent Chinese 5-year plan. Several examples of implementation are underway, especially in ports. For instance, since the early 2000s, the Ningbo Beilun region has been a pilot territory for the national circular economy strategy. In 2005, industrial symbioses in the Ningbo chemical zone led to its certification as “Circular Economy Pilot Park” (Wang *et al.*, 2008). The Ningbo Beilun District Authority, in charge of the development of a coastal industrial zone of Ningbo, is currently promoting a strategy for emission reduction and efficient energy use. There are several short-term projects that directly refer to circular economy principles: for instance, 1/ the use of the cold generated by the LNG regasification unit in an air liquefying process to reduce power consumption by 56%, 2/ the recovery of the gaseous by-products of a Ningbo metallurgical company to extract 60% of the hydrogen resources required by plastic and steel producers across the area and 3/ the recovery of solid metallurgical by-products by opening an integrated sorting treatment center for reusing the waste produced by the metallurgical industry (powder coke for example), in the construction and production of high-performance magnets (Beilun District, 2012).

South Korea has also initiated an extensive program of experimentation and diffusion of IE in its industrial parks, including ports. Some port cities such as Ulsan have developed a symbiotic network, resulting in the development of more than 70 synergies, exchanges of utilities and pooling of equipment, contributing to significant reductions of impacts on the environment (Park and Won, 2007).

Japanese ports are also intersting laboratories for IE experimentation at various scales: from the company located in the port-based industrial complex to the port region. Japan has national programs that have adopted IE principles. During the 1990s, Japan launched its "Eco-Town Program" aimed at developing the concept of "zero-emission" in 26 territories, mostly port-cities, to build a society based on a resource recycling economy (Fujita, 2011). The port city of Kawasaki is one of the most successful examples. The project began in 1997 with concrete synergies concerning waste management, energy and water recovery, and a significant limitation of impacts on the environment (Maki, 2009). Japan has also launched the "Recycling ports" national program which aims at developing a recycling-based society build on a flow distribution network around port areas, creating logistical recycling bases and pooling resources, infrastructure and technology. 18 ports have already been identified as part of this program. Osaka Bay remains the most emblematic example of this multi-scale approach of IE: the Osaka Bay P-IE initiatives take place 1/ at the firm level with, for instance, the thermal utilities exchanges developed by Osaka Gas Co. on the LNG terminal with a petrochemical plant and a refinery (Otsuka, 2006); 2/ at the port area level with the implementation of the “Recycling Port” program in order to raise Osaka port to the status of national recycling hub; 3/ at the port city level with the “Eco-Town Program”; at the port region level with the Osaka Bay Phoenix Project creating a wide urban, industrial and port waste collection and recycling network among 195 municipalities and 4 ports in order to build 4 off-shore disposal sites contributing to port land development (Higushi, 2004).

3.4. *African P-IE initiatives case studies*

Industrial symbioses in African ports are more difficult to identify due to poor communication at international level. The African case studies analyzed reveal spontaneous collaborative resource management initiatives, developed in order to optimize waste and by-product management (environmental connotation) and promote local anchorage (socioeconomic connotation) for major economic activities in port areas. The inventoried and documented P-IE initiatives were carried out by major Moroccan and Algerian industries. The port area of Bejaia, in Algeria, is tackling many environmental issues, such as port-based industrial waste management, including organic waste produced by a major industrial site located on the Port. In order to reduce its outputs, Cevital has developed an eco-industrial synergy with local producers of soap, paint and mastic in order to collect and recycle acid oils and acids.

The Office Chérifien des Phosphates (OCP), a major stakeholder in the Jorf Lasfar port area in Morocco, has developed an ambitious environmental management system whose actions benefit not only the OCP but also the local communities. The OCP has implemented a series of collaborations with local stakeholders (neighboring towns, businesses, etc.) to optimize water and energy consumption and better integrate its activities into the local context. These synergies include, in particular, the valorization of surplus thermal energy, enabling the port-based industrial site to move toward energy self-sufficiency and providing energy to a sea water desalination unit to power both the desalination process and part of the nearby town of El Jadida. The optimization of washing cycles on the upstream extraction site enables the recycling of 85% of water in a closed circuit and the reuse of treated water from the Khouribga wastewater treatment plant, leading to a significant reduction in groundwater consumption by the mining site.

Table 5: Main features of P-IE initiatives

P-IE initiatives	Period	Boundaries	Major environmental issues					Type of synergies			P-IE stakeholders involved						Coordinating structure	Financial support	Link with port development strategies
			Availability of resources	Land pressure	Air pollution	Water pollution	Waste management	By-product exchange	Utility sharing	Cooperation	Port authority	Local authority	National authority	Companies	Network stakeholders	Research stakeholders			
Europe																			
Port of Fos-Marseille (IE strategy)	2004-…	Port area	X		X	X	X	X			X	X		X		X	-	Port authority, companies	IE as a driver for energy transition
Zeeland Seaports (Biopark Terneuzen)	2005-…	Port area	X	X				X	X		X	X		X			Biopark project agency	Port authority, Companies	IE as a lever for resilience of port development
Zeeland Seaports (Hidden connection)	2010-…	Port network	X		X		X		X		X	X		X	X	X	INTERREG consortium	European Union, Port authority, Companies	IE as a lever for resilience of port development
Port of Rotterdam (Bioport of Europe)	1994-…	Port area and Port region	X	X	X			X	X		X	X	X	X		X	EBB → Deltalinqs	National government, Port authority, Companies	IE integrated in the "Port Vision 2030" strategy
Port of Antwerp (sustainable policy)	2000s-…	Port area	X	X	X			X	X		X	X		X			-	Port authority, companies	-
Port of Brussels (collaboration and urban integration)	2010-…	Port area and Port region	X	X				X	X		X			X			-	Port authority, companies	-
Port of Bristol (IE approach)	2009-…	Port region	X		X			X	X		X	X	X	X	X	X	NISP	National government, local government, companies	IE as a lever for port development
Ports of Galicia (Integrated fishing waste management)	2007-…	Port network					X	X		X	X		X	X			CETMAR	International institutions, national government	-
Africa																			
Port of Jorf Lasfar (OCP eco-industrial symbiosis)	2008-…	Port region		X		X	X	X			X	X	X	X			Economic interest group (OCP, Port, National Port Agency)	National government, companies	IE as a lever for company's development and territorial anchorage
Ports of Morocco (integrated shipping waste management)	2000-…	Port area and Port region				X	X		X		X	X	X	X			Economic interest group PROGRES	National government, local authority, company	Ship waste management
Port of Bejaïa (Cevital eco-industrial symbiosis)	2005-…	Port area				X	X	X	X		X	X		X			-	Company	-
Asia																			
Port of Osaka (Osaka Gas Co.)	1972-…	Port area	X		X		X	X	X					X			-	Company	-
Port of Osaka (Osaka Phoenix	1990-2027	Port region		X			X		X	X	X	X	X				Osaka Bay Regional	National government, Local authorities, Port	Off-shore land development for port

project)																	Offshore Environmental Improvement Center	authorities	area extension
Port of Kawasaki (Recycling port)	2003-..	Port network	X				X	X	X	X	X	X	X				Ports and Harbour Bureau	National government, local government, port authority	Functional definition of the port in terms of waste management
Port of Kawasaki (Eco-town)	1997-...	Port region	X	X	X	X	X	X	X	X	X	X	X	X	X	X	Zero-emission industrial complex association Liaison center for creation of industry and environment	National government, local government, port authority, companies	-
Port of Tianjin (Port symbiosis)	2005-....	Port area	X		X	X	X	X	X		X			X			-	Port authority, companies	IE as a lever to become the 1st world ecological port
Port of Ningbo (Port symbiosis)	2000-...	Port area	X		X	X	X	X	X		X	X	X	X	X	X	Ningbo circular economy promotion association	National government, local authority	-
Port of Ulsan (Port symbiosis)	1995-...	Port area and port region	X		X	X	X	X	X		X	X	X	X		X	Ulsan Eco-center, Korean Industrial Complex Corporation	National government	IE as a lever to become one of the most environmentally efficient port in the world
Port of Map Ta Phut (Thailand)	1998-...	Port area	X				X	X	X				X	X		X	Eco-center	National government	-
North America																			
Port of New York / New Jersey (Harbor consortium)	1980-...	Port region				X				X	X	X	X	X		X	Harbor Consortium	National government, port authority, companies	Pollution prevention
Port of New York / New Jersey (Dredged Material reuse)	1998-...	Port region				X	X	X	X				X	X		X	-	National government, companies	-
Port of Long Beach (Collaborative dredged material management)	2011-2012	Port network	X			X	X	X		X	X	X	X				-	Port authorities	Land extension for port development

4. Cross-case analysis: IE patterns for P-IE initiatives

4.1. Constitutive dimensions of P-IE initiatives

The objective is to highlight to what extent and in what ways P-IE initiatives deliberately or spontaneously influence local IE implementation. The analysis of the oral and written discourse produced by P-IE stakeholders revealed that this influence can be characterized through its temporal and spatial dimensions: to what extent do P-IE initiatives participate in local planning or development? To what extent do P-IE initiatives spread their influence spatially? A cursory look at Table 6 reveals the diversity of timeframes mentioned in discourse on P-IE initiatives. Some discourse refers to short-term timeframes, emphasizing "demonstration projects" in the port-city of Antwerp, or "conducted within two years" in the port-based industrial area of Ningbo. Other discourse demonstrates medium-term objectives for the P-IE initiatives, focusing on the time required for evolution, innovation and optimization. Finally, some discourse targets long-term ambitions. For instance, the P-IE initiative of the Port of Rotterdam is defined as a "vision" for 2030.

On the basis of the analysis of this discourse, it is possible to state that different temporal references echo the strategic prospective tool box (Godet, 2004; Genet *et al.,* 2005):

- the "*operational planning*" level describes IE approaches conducted as a short-term reaction to a declared urgent situation, for instance industrial pollution and health safety issues, in order to resolve and better control the flows concerned. In discourse, this appears through references to short-term timeframes ("short term projects") and occasional opportunities ("uniquely"), for instance;
- the "*technical planning*" level concerns IE approaches performed as a medium-term strategy precaution in response to forecast changes which would cause higher costs if not prevented. It can be detected through references to optimization processes ("evolution of process"), innovation ("innovative strategy"), and continuous improvement ("work in progress", "learn from the past");
- the "*strategic planning*" level characterizes IE approaches intended to achieve long-term ambitions in order to provoke required changes among stakeholders. It is formalized in discourse by a long-term timeframe vision, plan or projection ("in 2030").

Table 6: Temporal influence of P-IE initiatives on local IE implementation

Port IE approaches	Temporal influence of P-IE initiatives	Sources
Europe		
Port of Marseille/Fos	**IE strategy** : « the industrial ecology study aims at *identifying new ways of development and diversification of activities* »	Junqua and Moine, 2007
Zeeland Seaports	**Biopark Terneuzen:** "Biopark Terneuzen is *a work in progress*"	Zeeland Seaports, 2011 (a).
	Hidden Connections: "Zeeland Seaports aims to *promote itself in the market* as a sustainable port"	Zeeland Seaports, 2011 (b).
Port of Rotterdam	**Bioport of Europe:** "the *vision* of the port of Rotterdam and industry *in 2030* must be, above all, ambitious"	Port of Rotterdam, 2011
Port of Antwerp	**Antwerp's Sustainable policy :** "*demonstration projects* to maintain a dynamic of sustainable development"	Interview
Port of Brussels	**Brussels' collaboration and urban integration**: "the European C2C BIZZ program extends *over a period of 4 years* (2011-2014)."	Fremault, C., 2012
Port of Bristol	**Bristol IE approach:** "Provide *economic benefits* to the port and its tenants and neighbors, [...], reduce environmental impacts such as diverting waste from landfill and CO2 reduction."	Royston, K., 2009.
Ports of Galicia	**Integrated fishing waste management:** "*Improve sea water and coastal quality* by a correct use of fishery equipment and the improvement of fishing waste recycling"	3R Fish White Book, 2011
Africa		
Port of Jorf	**OCP Eco-industrial symbiosis:** "de*velopment of new services in a competitive context*".	OCP, 2011.

Lasfar		
Ports of Morocco	**Integrated shipping waste management among Moroccan ports:** "Proposes professional chain for recycle and reduce to *ship waste producers in demand*".	Interview
Port of Béjaia	**Cevital eco-industrial synergies: "**diversification strategy"	Interview
Asia		
Port of Osaka	**Eco-industrial synergies of Osaka Gas Co.:** Osaka Gas carries out *complete 3R (reduce, reuse, recycle) activities* for various processes in its energy business", through the "*evolution of the LNG Cold use process*"	Otsuka, T., 2006.
	Osaka Bay Phoenix Project : "[…] ensure the *long-term safety* of waste storage sites in port areas, […], to improve the functionality of the ports using off-shore reclaiming land."	Higushi, 2004.
Port of Kawasaki	**Kawasaki eco-town:** "*building* a sustainable society where industrial activities are *in harmony with the environment*"	Fujita, 2006.
	Kawasaki recycling port: "part of the basic plan for *establishing the recycling-based society*"	Higuchi, 2012.
Port of Tianjin	**Tianjin Port symbiosis:** integration of circular economy principles as a *lever for competitiveness* (to attract foreign investment)" as part of 5-year plans.	Interview
Port of Ningbo	**Ningbo Port symbiosis :** "Development strategy in order to reduce emissions and energy use" with 10 major *projects conducted within 2 years.*	Beilun District, 2012.
Port of Ulsan	**Ulsan Port symbiosis:** "*Working toward a green port*" as a factor of competitiveness	Interview
Port of Map Ta Phut :	**Map Ta Phut Eco-industrial estate:** "Decreasing environmental impacts and demand of natural resources, *improvement of business performance*, improvement of quality of life", but "since 2009, the question is *how to build the concept again*".	Charmondusit *et al.,* 2007; Interview
North America		
Port of New York/New Jersey	**Harbor Consortium:** "Apply the analytical tools of IE, […] identify and *implement strategies and policies to prevent* the continuing loading of 5 contaminants."	Boehme et al. 2009.
	Dredged materials reuse: "to solve *sediment related problems*" by "*develop[ing] and demonstrate[ing]* technologies"	Stern, E. 2009.
Port of Long Beach	**Collaborative dredged material management:** "*Opportunity* to uniquely dispose of contaminated material".	Port of Long Beach, 2011.

Concerning the spatial influences of P-IE initiatives, Table 7, which was compiled on the basis of interviews with port stakeholders involved in IE initiatives and a literature review concerning those case studies, shows that P-IE initiatives are characterized by interventions within various boundaries: "the port and the city", "the site", "the city", "the watershed". On the basis of the analysis of this discourse, it is possible to state some initial provisional results: the port area is structured as a platform where the circulation of flows is organized. As a fixed infrastructure and area, this platform acts as a pole that centralizes flows in order to irrigate and drain a much wider area (Raimbault *et al*., 2010). This centrality of the port area can have multiple dimensions, from local to global (Ducruet, 2008). Van Klink (1998) proposes, as a synthesis of this diversity, a broad definition of the port's geographic area of influence. Depending on the focus given to their historical functional and spatial development, "port" can refer to the port area, the port city, the port region or the port network. These different scales can also highlight the perimeter of influence of P-IE initiatives on the local implementation of IE:

- the *port area* known as the port-based industrial complex, designated in discourse as "the port area", "production plants" or "terminal";
- the *port city and* the *port region* covering the perimeter of the port as well as surrounding areas, understood as different geographic entities such as the "city" or "town", the "coastal area", the "hub", the "watershed or "the bay";
- the *port network* understood as a borderless and discontinuous area defined by interactions between the port and other locations, and designated by P-IE stakeholders as "network", "canal zone" or "industrial cluster".

Table 7: Spatial influence of P-IE initiatives on local IE implementation

Port IE approaches	Spatial influence of P-IE initiatives	Sources
Europe		
Port of Marseille/Fos	**IE strategy**: "industrial ecology and competitive intelligence are complementary tools to support the sustainable development of an *industrial area*"	Junqua and Moine, 2007
Zeeland Seaports	**Bipoark Terneuzen:** "a logical extension of its overall management and development of the port *areas of Terneuzen and Visslingen*"	Zeeland Seaports, 2011 (a).
	Hidden Connections: "The development of a *uniform pipeline network* to promote sustainable industry in the *Ghent-Terneuzen canal zone*"	Zeeland Seaports, 2011 (b).
Port of Rotterdam	**Bioport of Europe:** ""Rotterdam's industrial complex will have *integrated with industries in Antwerp, Moerdijk, Terneuzen and Flushing* by 2030, effectively creating one big, world-leading petrochemical complex: Europe's Industrial Cluster. More *interconnecting pipelines* will have been built for that purpose."	Port of Rotterdam, 2011
Port of Antwerp	**Antwerp's Sustainable policy :** "BASF's Verbund structures and high-*efficiency power plants*" and "add value *as one company* through efficient use of our resources" through "intelligent *interlinking* of production plants"	BASF, 2012.
Port of Brussels	**Brussels' collaboration and urban integration**: "An innovative approach to improve their environmental performance by creating inter-firm synergies" and "industrial ecology synergies with neighboring businesses in the industrial area" [...] "on industrial parks Mercator Galilei and Technopark, located in Neder-over-Heembeek and managed by the SDRB "	Fremault, C., 2012
Port of Bristol	**Bristol IE approach:** open the boundaries: from the "port estate" to the "*industrial estate*" by "*identifying synergies*"	Interview
Ports of Galicia	**Integrated fishing waste management:** "participate in a global *network of stakeholders* committed to understanding, preventing, reducing and managing marine debris, "foster *inter-sector collaborative actions*" such as the "emergence of companies *producing new design products by transforming fishing nets*"	3R Fish White Book, 2011
Africa		
Port of Jorf Lasfar	**OCP Eco-industrial symbiosis:** "Federate subcontractors by developing joint venture on a project development and implementation of industrial ecology" around the extraction and production sites OCP"	Donsimoni, 2012
Ports of Morocco	**Integrated shipping waste management among Moroccan ports:** "PROGRES disposed 5 centers grouping products collected in the main cities of the Kingdom."	Serfati, A, 2012
Port of Béjaia	**Cevital eco-industrial synergies: "**Implementation of power plants to supply its food complex"	Interview
Asia		
Port of Osaka	**Eco-industrial synergies of Osaka Gas Co.:** "sharing the utilities with neighboring companies, and by further promoting the use of LNG cold" on the "LNG receiving *terminal* of Osaka Gas"	Otsuka, T., 2006.
	Osaka Bay Phoenix Project : "on the Kinki District, "construct, by reclaiming part of Osaka Bay, stable, long-term sites for appropriate final waste disposal"	Higushi, 2004.
Port of Kawasaki	**Kawasaki eco-town:** ""a new *town-building project*"[…] "through mutual *cooperation* among a number of different enterprises and recycling facilities in the *coastal area*" […] "*whereby companies use wastes and by-products from one industry as useful resources in another*"	Fujita, 2006.
	Kawasaki recycling port: ""construction of a *comprehensive network distribution system centering around harbors*", promoting "nation-wide *recycling facilities*"	Ports and Harbours Bureau, 2006
Port of Tianjin	**Tianjin Port symbiosis:** facilities on the basis of aggregate industrial needs in order to maximize the overall energy performance of the area	Interview
Port of Ningbo	**Ningbo Port symbiosis :** on the *District of Beilun* (*Ningbo chemical industrial zone*), "resource recycling-type use", "business cycle-type production", "industrial circulating type combination" in order to build "an eco-industrial chain network», "a symbiotic system based on *flows exchange*"	Beilun District, 2012.
Port of Ulsan	**Ulsan Port symbiosis:** "Ulsan as the hub of industrial symbiosis activities in Korea" by the "development of the symbiotic network"	Park and Won, 2007
Port of Map Ta Phut :	**Map Ta Phut Eco-industrial estate:** "implementation of the *Eco-industrial Estate* concept to industrial sectors" through "*by-product exchanges*"	Charmondusit *et al.,* 2007
North America		
Port of New York/New Jersey	**Harbor Consortium:** "a diagnosis led on the "NY / NJ Harbor *watershed*" also designated as "NY/NJ Harbor *Estuary*"	Boehme *et al*., 2009.
	Dredged materials reuse: "Orientate toward a regional management with *a system-based (watershed) approach*" in order to "*transform sediments into a sealeable beneficial use product*"	Stern, E. 2009.
Port of Long Beach	**Collaborative dredged material management:** "expand the opportunity of *reuse of dredged material* to *other local ports*"	Port of Long Beach, 2011.

4.2. Contributions of P-IE initiatives to local IE implementation

The cross-case analysis of P-IE initiatives highlights that the role of P-IE initiatives in the local implementation of IE can be characterized through its temporal and spatial influence. Linking these two dimensions allows the identification of 9 patterns of P-IE contribution to the implementation of IE in port-city areas (Table 8).

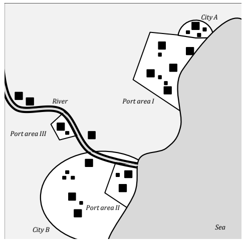
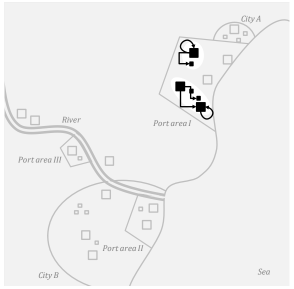
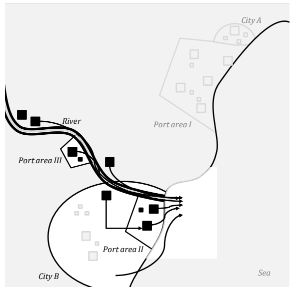
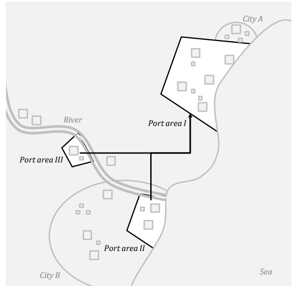
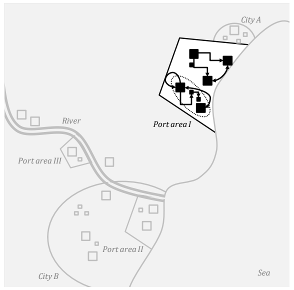
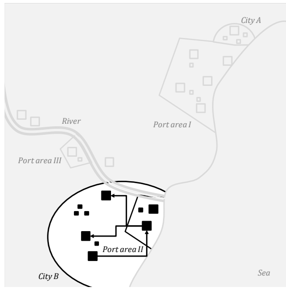
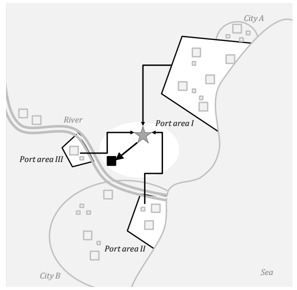
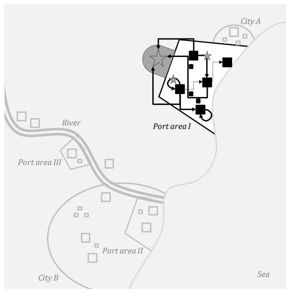
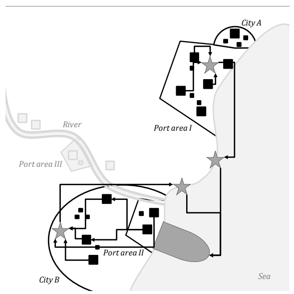
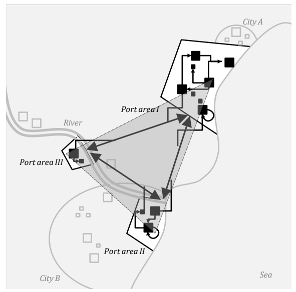
		PORT AREA	PORT CITY AND REGION	PORT NETWORK
 Fictitious coastal area, including the mouth of a river, three port-industrial areas, two urban areas and P-IE stakeholders.	OPERATIONAL PLANNING Short-term reaction to a declared urgent situation	**1 - Plot** 	**4 - Watershed** 	**7 - Outlet** 
Key P-IE area of influence Excluded area of P-IE area of influence P-IE stakeholders Other local stakeholders	TECHNICAL PLANNING Middle-term strategy of precaution in response	**2 - Complex** 	**5 – Port-city interface** 	**8 - Network** 
Flows New activity or infrastructure New area emerging from the local influence of P-IE initiatives	STRATEGIC PLANNING Long-term ambitions in order to provoke needed changes	**3 - Ecosite** 	**6 - Eco-region** 	**9 - Eco-cluster** 

Table 8: Patterns of P-IE initiative contribution to local IE implementation

4.2.1. *The port as an self-sufficient exemplary area*

Some P-IE initiatives attempt to limit negative externalities and to optimize resource management among port-based industrial activities. These approaches thus consider that P-IE initiatives must focus on the development of the port area's IE potential. The role and value of the port for IE is thus confined within the boundaries of the port area.

P-IE initiatives on *port-based industrial plots* (pattern 1) involve the implementation of collaboration between neighboring firms to reduce short-term environmental and regulatory constraints on their activities. In the port of Ningbo, this approach results in 10 major projects to foster by-product exchanges and utility sharing to be conducted in the next two years so as to reduce emission flows and energy consumption (Beilun District, 2012). On the coastal site of Map Ta Phut, byproduct exchanges contribute to reducing the environmental impact and demand for natural resources (Charmondusit *et al.*, 2007). The company Cevital in the Port of Bejaia area is diversifying its business by building a power plant enabling energy flow circulation within the food complex (Interview). In the port of Antwerp, the project aims at developing flow exchanges between production sites (Interview). Industrial ecology is seen as one solution amongst others for the environmental management of the port-based industrial plots.

The *port-based industrial complex* approach (pattern 2) provides a medium-term optimization solution for industrial processes to anticipate changes and maximize the environmental and economic gains related to synergies between businesses. Biopark Terneuzen is defined as a "work in progress" to benefit companies ("Eliminate storage and disposal costs," "lower environmental taxes", "optimize generation costs," "Improve Profitability") (Zeeland Seaports, 2011). The evolution of the "LNG cold use process" led by Osaka Gas Company also assumes a gradual optimization to share utilities with neighboring firms (Fujiwara *et al.,* 2011).

This *eco-site* approach (pattern 3) ranges over the long term in order to strive towards the self-management of externalities generated by port-based industrial activities through the implementation of an eco-industrial development plan.

4.2.2. *The port as a driver for local implementation of IE*

Other P-IE initiatives aim at developing interactions between the port and the city, and further with the whole region. These approaches thus enhance the local role and value of ports in IE local implementation. As outlets of major pollutant emissions, ports constitute a lever for removing, reducing and transforming pollutants. As neighbors of major urban areas, ports open their administrative boundaries by developing industrial symbiosis at the interface between port-related activities and industrial activities. As drivers of local economic development, ports act as a lever for the implementation of sustainable policies at regional scale.

The *watershed approach* (pattern 4) involves the implementation of short-term multi-stakeholder collaborations, to reduce and prevent pollutant emissions that flow into the port from various sources and accumulate in sediments. For Lifset (2000), the New York port area is like a bathtub: water comes in through the faucets and flows out through the drain. The amount that comes in must add up to the amount that leaves plus any water that remains pooled in the tub. In the port area of New York / New Jersey, the diagnosis tools of industrial ecology were implemented in order to promote actions of pollution prevention, such as the recycling of boat oils (Boehme *et al.,* 2009).

The *port-city approach* (pattern 5) plans technological innovations to optimize the medium-term circulation of flows and the use of infrastructures in the port-city interface. It contributes to enhance the global positioning and sustainability of industrial activities. In Brussels, the C2C BIZZ program is spread over four years and develops an innovative approach to improve environmental performance by fostering inter-firm synergies (Fremault, 2012). In New York / New Jersey, processes are developed and tested in order to produce municipal compost and road layers from sediment (Stern, 2009, Stern *et al,* 2011). The Office Chérifien des Phosphates, based at the Jorf Lasfar port site, set up a "disruptive and innovative strategy to launch its profound transformation" (OCP, 2011), including the establishment of joint ventures around a project development and implementation of industrial ecology.

The *eco-region approach* (pattern 6) aims at a better functional organization of flow circulation and infrastructure development at regional scale. Within the framework of the Kawasaki Eco-town project, this approach is defined as "a new town building project [...] through mutual cooperation among a number of different enterprises and recycling facilities" (Fujita, 2006). In Osaka Bay, the goal is to "construct [...] stable, long-term sites for appropriate final waste disposal" (Higushi, 2004).

4.2.3. The port as a node in an inter-port IE network

Lastly, some P-IE initiatives develop inter-port by-product exchanges and utility sharing. These patterns contribute to emphasize that despite the competitive environment context between ports, the national and international issues in terms of resource and waste management require new forms of collaboration between stakeholders within port areas. Cooperation between ports and port firms should not be considered as impediments to the revitalization of port's economic base but rather as necessary preconditions (Van Klink, 1998).

The *outlet approach* (pattern 7) takes advantage of an opportunity to share and reuse flows generated by port-related activities located in different port areas. The Middle Harbor Project Long Beach, as a port-to-port response to the problem of contaminated dredged material management, is thus defined as an "opportunity to uniquely dispose of contaminated material" (Port of Long Beach, 2011).

The *network approach* (pattern 8) plans the development of new activities and processes at the interface between the stakeholders within a same sector. In Galicia, the objective is to optimize the management of waste from the fishing industry by promoting "the emergence of companies producing new design products by transforming fish nets" (3R Fish White Book, 2011). In Morocco, PROGRES is developing a "professional supply chain to recycle and reduce ship wastes" (Serfati, 2012).

The *eco-cluster approach* (pattern 9) aims at a functional specialization of the port-based industrial activity thanks to infrastructures interconnecting ports for flow management: "the vision of the port of Rotterdam and industry, in 2030, must be, above all, ambitious "(Port of Rotterdam, 2011). In the framework of the National Port Recycling program in Japan, Kawasaki develops the "construction of a comprehensive network distribution system centering around ports" (Port and Harbours Bureau, 2013). The ambition of the port is to become the hub of by-products exchanges across a nation.

4.3. Validation of P-IE patterns

The cross-case analysis led to the identification of 9 patterns for the contribution of P-IE to the implementation of IE in port-city areas. These patterns are tightly linked to the sample of case studies selected for this analysis. The validity of these results must be assessed in terms of their capacity to provide a relevant framework for the analysis of new case studies (Morse, 2004).

Kalundborg (Denmark) is considered as the paradigmatic model for IE. Being very well documented in IE literature (Ehrenfeld and Gertler, 1997; Coté and Cohen-Rosenthal, 1998; Ehrenfeld and Chertow, 2002; Jacobsen, 2006), it has not been included in the sample of case studies in this research project. However, the validation process gives an occasion to check the relevance of the P-IE initiatives typology with this exemplary case study. Kalundborg industrial symbiosis complex is located in a geographic area combining a port infrastructure with an oil terminal, an urban area and a complex web of symbiotic interactions among collocated companies including a power plant, an oil refinery, a pharmaceutical company, a producer of plasterboard and a soil remediation company (Jacobsen, 2006). The spatial influence of the Kalundborg industrial symbiosis complex covers the port-based industrial zone but also spreads into the municipality of Kalundborg and toward farming land and companies located over a wider region (Domenech and Davies, 2011). It is described as an evolutionary process in which a number of independent by-product exchanges have gradually evolved in an industrial symbiosis complex (Jacobsen, 2006). As a result, Kalundborg can be representative of a port-city approach (pattern 5), characterized by a progressive optimization of the circulation of flows through the development by-product exchanges within an industrial symbiosis network at a local scale.

The Kwinana industrial area, in Western Australia, has also not been included in the sample of analysis. However, this new case study fits with the scope of this research focus. Indeed, the Kwinana industrial area is a geographic area that integrates a port infrastructure including oil and grain loading terminals and a concentration of heavy industries ranging from manufacturing and construction facilities through to high technology chemical plants and large resource processing industries, such as titanium dioxide pigment production and alumina, nickel and oil refineries. It is located 40km south to the urban area of Perth (van Beers and Biswas, 2008). In 2007, 47 regional synergies had been inventoried in the Kwinana industrial area, 32 of these were qualified as by-product synergies and 15 involved shared use of utility infrastructure (van Beers, 2007). These P-IE synergies involved P-IE stakeholders such as an industrial gas producer and supplier, a cogeneration plant, a refinery, etc. Since 1991, the core industries have been organized in the Kwinana Industries Council which seeks to foster positive interactions between member industries, government and the boarder community (van Beers and Biswas, 2008).

The energy recovery initiative carried out in the Kwinana industrial area enables the identification of collaborative opportunities between industries located within different clusters in close proximity (van Beers and Biswas, 2008). The spatial influence of this initiative is thus concentrated within the port-based industrial area. These set of on-site and collaborative recovery opportunities are now subjected to technical, economic and environmental assessments and follow-up work will be required to achieve their implementation (van Beers and Biswas, 2008). The time schedule of this P-IE initiative corresponds to technical planning within a continuous improvement process. As a result, Kwinana's energy recovery initiative stands for a port-based industrial complex approach (pattern 2), which aims at providing solution for industrial processes to maximize environmental and economic gains related to energy recovery.

Another P-IE initiative targets the development of large scale reuses of inorganic by-product. The inorganic by-products available in Kwinana could be used to supply the growing demand for already scarce building and construction materials in Western Australia. Opportunities have been studied in order to find opportunities in cement manufacturing, agricultural applications and soil amendments, at a regional scale. This collaborative approach in Kwinana with industry, government, Kwinana the Industries Council, and the community is ongoing and working towards achieving a sustainable solution for the large volume of inorganic by-products and avoiding the mining of "virgin" building materials (Van Beers *et al.*, 2009). This P-IE initiative represents an eco-region initiative (pattern 6), which targets a better functional organization of inorganic by-product circulation and reuse at a regional scale.

5. Discussions

5.1. Co-existence of P-IE patterns

The cases provide the identification of 9 patterns of P-IE initiatives, defining the role and the value of port in the implementation and development of IE in port-city areas. These patterns are not exclusive; they constitute stages in a continuum of P-IE definitions. They can co-exist within a same port-city area. For instance, in Osaka (Japan), the complex approach developed by Osaka Gas Co. on the LNG terminal co-exists with the eco-region approach structured by the Osaka Bay Phoenix project. In Terneuzen (The Netherlands), by-product exchanges between firms are concomitant with the development of a network approach in the Ghent-Terneuzen canal zone: the complex approach embodied in the Terneuzen Biopark is applied together with the eco-cluster approach developed by the Hidden Connection project. In these contexts, the issue may be the relevance and conditions for a better articulation of these different patterns co-existing in the same port-city area.

5.2. Conditions of emergence of these different patterns

The port's role in the implementation of IE can also evolve, and patterns of P-IE initiatives can follow one another in time, designing a P-IE trajectory. For instance, in France, the P-IE initiative in Marseille-Fos has evolved from the implementation of collaboration between neighboring firms within port-based industrial plots (pattern 1) in the 1970s, to the development of a P-IE complex strategy (pattern 2) in the early 2000s. Nowadays, the development of a new metropolitan area aims for the extension of P-IE boundaries toward the development of synergies within the port-city interface (pattern 5).

It questions the conditions of emergence of these different patterns: why and how is the role of the port for IE implementation defined and why and how does it evolve over time? This article argues that ports play an active role in IE implementation in port-city areas. However, the local context could also influence the port's involvement and intervention in the local IE implementation. The within-case analysis reveals that a common representation of environmental issues (resource scarcity, land availability, pollution, etc.) often justifies and legitimates the implementation of P-IE initiatives: in New York / New Jersey, the P-IE initiative provides an answer to water pollution; in Jorf Lasfar, industrial symbiosis aims at reducing industrial pressure on water resources. It also highlights the necessity of a progressive involvement of different P-IE stakeholders: in the port of Rotterdam, industrial initiatives, coordinated with research implication, progressively associated the Port authority and the City of Rotterdam to the P-IE initiatives. The Chinese National Pilot Eco-Industrial Park Program challenges the implication of industrial stakeholders to develop industrial symbiosis in the port-city of Ningbo. These results echo research works carried out on the social embeddedness of industrial ecology (Boons and Howard-Grenville, 2009). These works highlight the fact that material and energy flows exchanges are tightly embedded in local social networks (Ashton, 2008). This local network is based on 1/ a *structural dimension* drawing the morphology of the network; 2/ a *cultural and political dimension* defining the way stakeholders are organized and the way they behave and 3/ a *cognitive dimension* constituting the system of meaning (Ashton and Bain, 2012). For instance, the cases could provide insights into how a top-down approach regulated by government planning or a bottom-up approach regulated by market laws could condition the emergence of specific patterns. They could also highlight the impact of the organization of P-IE stakeholders on the evolution of P-IE toward one pattern or another. Cultural and geographic trends could also be pointed out.

These P-IE patterns are defined on the basis of P-IE stakeholders' current understanding and representation of the main objectives of the P-IE initiatives. IE being in constant evolution, through innovation and invention of new practices in terms of by-product exchanges and utility sharing, P-IE patterns also need to evolve, following this continuous improvement process of P-IE trajectory.

5.3. P-IE initiatives and proximity for industrial symbiosis

Finally, P-IE initiatives, and especially port network approaches of IE (patterns 7, 8 and 9) question the notion of proximity in IE. For Chertow (2000), the key to industrial symbiosis are collaboration and the synergistic possibilities offered by geographic proximity. Beaurain and Brullot (2011) highlight the benefits of the scientific proximity field on industrial ecology analysis: industrial symbiosis presuppose geographic, institutional and organizational proximity among stakeholders. For P-IE initiatives, geographic proximity should no longer be evaluated in terms of Euclidian distance; the kilometric metric does not constitute a key factor for the development of industrial port symbiosis. The notion of proximity must be adapted to P-IE initiatives, by considering the degree of natural, logistical and infrastructural connectivity between ports and port-cities. Indeed, by-product exchanges and utility sharing occur, within a broader scale, between distant port-related activities or port-cities infrastructures, connected by natural or artificial networks. For instance, a P-IE initiative is currently developed on the Ghent-Terneuzen canal zone. In France, the challenge for the ports of Le Havre, Rouen and Paris is to develop industrial ecology across the Seine axis, developing synergies between large group facilities in several port-based industrial areas, between companies of the same sector (projects are carried out on the construction sector) and between stakeholders in different sectors.

6. Conclusion

This paper sought to provide an overview of P-IE initiatives at an international scale and ports' contribution to the planning and development of IE in port-cities areas. It aims at highlighting to what extend and in what ways P-IE initiatives deliberately or spontaneously influence local IE implementations. A cross-case analysis has been carried out following a 3 step methodology: 1/ definition of the research boundaries; 2/ qualitative data collection thanks to interviews and literature review; 3/ data analysis in order to build a typology of P-IE contributions to the implementation of IE in port-city areas. Our research revealed that new visions and practices, echoing to IE principles, are emerging in ports worldwide, ranging from pragmatic synergies between firms developing polling of utilities and facilities, to the integration of IE within port strategic policy and prospective. 18 ports, in Northern America, Asia, Africa and Northern Europe, were involved in the construction and validation of our proposals.

The cross-case analysis highlighted that the role of P-IE initiatives in the local implementation of IE can be characterized through its temporal and spatial influence. The temporal influence has been identified at different prospective levels: 1/ as a short-term reaction to a declared urgent situation, 2/ as a medium-term strategy precaution in response to forecast changes or 3/ as long-term ambitions in order to provoke required changes. The spatial influence defined different perimeter of influence of P-IE initiatives on the local implementation of IE: 1/ the port area, 2/ the port city and port region, 3/ and the port network (connected at a national or international scale). Linking the spatial and temporal dimensions allowed the identification of 9 patterns of P-IE contribution to the implementation of IE in port-city areas, from a port-based industrial plots approach (pattern 1) to an eco-cluster approach (pattern 9) aiming at a functional specialization of the port-based industrial activity thanks to infrastructures interconnecting ports. The validity of these patterns has been assessed by their capacity to provide a relevant framework for the analysis of Kalundborg (Denmark) and Kwinana (Western Australia), two case studies that were not included in the analysis's sample.

As a general conclusion, our research reveals that ports can greatly contribute to shaping IE development by fostering the implementation of industrial symbiosis. As area of testing and implementation of industrial symbiosis, ports can constitute self-sufficient exemplary area, likely to boost the development of other local eco-parks; as drivers of local economic development, ports act as levers for the implementation of sustainable policies on a regional scale; as nodes in a global port network, ports can develop inter-port by-product exchanges and utility sharing.

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