

Smart City-Port Relationship: A Circular Port City Development Model for Trieste

Giuseppe Borruso[1(✉)], Andrea Gallo[1,2(✉)], Francesca Sinatra[1(✉)], Ginevra Balletto[3(✉)], and Salvatore Dore[1(✉)]

[1] DEAMS - Department of Economics, Business, Mathematics and Statistics "Bruno de Finetti", University of Trieste, Via A.Valerio 4/1, 34127 Trieste, Italy
giuseppe.borruso@deams.units.it, {andrea.gallo3, francesca.sinatra}@phd.units.it, salvatore.dore@amm.units.it

[2] Department of Economics, Ca' Foscari Venezia University, Dorsoduro, 3246, 30124 Venezia, Italy
and.gallo@unive.it

[3] DICAAR - Department of Civil, Environmental Engineering and Architecture, University of Cagliari, Via Università 40, 09124 Cagliari, Italy
balletto@unica.it

Abstract. Ports as sea-land interface nodes have always been key crossroads for goods and people and for the diffusion of innovation. The recent challenges descending from sustainability need to consider the interaction among the city and its port, particularly in their capacity of playing pivotal roles in shaping the sustainable economic development of their regions, exerting a substantial impact on well-being and overall quality of life, representing an opportunity for implementing Circular City concepts. Achieving this goal depends on the use of appropriate development models for production and consumption, with a focus on interactions within the urban and territorial framework. The implementation of the concepts belonging to the circular economy into the port context, expressed within gateway ports, by their nature strongly embedded within an urban and regional framework, is nonetheless a subject yet to be more deeply investigated. The present research is based on an analysis performed combining different models developed in time to study the city-port relation (Bird's Anyport model) as well as location in space (Weber model of industrial location) within a circular framework. Operationally, a city-port interference and interaction matrix is developed, to analyze the areas of potential development of the circular activities, in particular those related to building maintenance, demolition and reconstruction. These in particular spatial analytical and mapping instruments are also implemented to realize and examine a GIS database for the model's application. The study was implemented to introduce some considerations for the development strategies into the framework of the city-port relation for the study area of Trieste, Italy.

Keywords: First Port-City Relationship · Smart Ports · Smart Cities · Circular Economy

© The Author(s), under exclusive license to Springer Nature Switzerland AG 2024
O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14817, pp. 384–400, 2024.
https://doi.org/10.1007/978-3-031-65238-7_26

1 Introduction

Ports represent strategic nodes of interchange for trade flows at global and regional scales [1], both representing interfaces between the maritime component (foreland) and the land one (hinterland), allowing circulation of goods and people, and representing important drivers of local development. Historically, port activity brought local employment and the dissemination of knowledge created by the sharing and contamination of people and industries in one place [2, 3]. Also, negative externalities and impacts are associated with the presence of ports in urban settings [4, 5]. Despite the fact that the importance of ports to national economies and global trade is clear, there has been a decline in the benefits associated with ports at the local level [6, 7]. These can be summarized in an increase of the negative environmental impacts, the relocation of port-related activities, the decrease in local employment and the increasing use of international - rather than local - inputs. The major drivers of such changes followed globalization and technological innovations, such as naval gigantism, mechanization of port activities, and increased containerization, with a consulting reduction in the number of people directly employed in port work, as well as a higher integration of the supply chain, de facto making ports as crucial nodes in the global supply networks [8–10].

In addition, levels of economic, institutional, and infrastructural integration between ports and cities have declined, with ports serving both consumers and producers over much larger geographic and hinterland areas [11].

In this sense the adoption of circular economy (CE) principles in the port context has become increasingly central to the organization of development processes in port areas. The CE is defined as an economic system that replaces the concept of 'end-of-life' with that of reuse, recycling and the recovery of materials in production/distribution and consumption processes. This can operate at three different process scales: at the micro level - through product and business process innovation - or at the macro level - city, region, nation and beyond -, with the goal of achieving sustainable development [12, 13]. Circular economy principles thus view scrap and waste as resources that can be recycled and reused [14, 15]. Focus on environmental issues is particularly relevant not only in terms of port operations but also with regard to industrial activities in ports and planning and expansion initiatives for ports.

The introduction of these principles in the port environment is a topic currently central to the scientific debate, as well as an issue being tackled by port authorities and also local municipalities proximal to port areas. Nonetheless, several studies focused narrowly on the micro level. From this perspective, this study proposes to investigate the dynamics of development in port-city relations from a circular economy viewpoint applied at the macro level, thus going on to consider waste materials and aggregates as second raw materials to be used within the various port infrastructure development projects.

In this study the port of Trieste is analyzed as a specific case study, taking into consideration what are the main infrastructural work planned by the Port Master Plan and the Strategic Operational Plan of the Eastern Adriatic Sea Port System Authority, and implementing on these development trajectories the considerations about the reuse of secondary raw materials.

The contribution presented, is organized as it follows. In paragraph 2 (Materials) the city-port relations are briefly examined, together with the concept of circular economy and industrial symbiosis. Paragraph 3 (Methods) roots the research into classical models of city-port evolution (Bird) and industrial location (Weber) both updated to host the changes that intervened in more recent times and particularly in hosting circularity concepts. The operational aspects of the symbiosis matrices area also introduced. The analysis of the case study follows in paragraph 4 with a focus on Trieste (Italy) port area analyzing the potentials of introducing circularity in port-related works. Paragraph 5 host results and discussion, followed by conclusions in paragraph 6.

2 Materials

2.1 The Framework of the Port-City Relationship

City-port relations are characterized by means of a wide set of interdependencies among the evolutions of port and urban forms. This relation is clearly reflected in the evolution of coastal cities, which have often found their development closely linked to the surrounding port activities. Several studies in the literature are aimed at analyzing the development of city-port relations diachronically, that is, as the result of a process of historical evolution [2, 16–18]. Such processes were also coupled with the development of industrial activities, followed then by logistic ones, in these coastal areas, benefitting from the ideal location in proximity of important nodes, shaping the characters of ports and their cities. [4, 19].

The heavy industry was located in areas originally peripheral to major urban centers [19], benefiting of cost efficiency in the access to materials and to the distribution systems. In parallel, urban sprawl with the relocation of businesses to industrial settings in backport areas, resulted in the abandonment of industrial port functions, leaving spaces vacant [4, 20], becoming the object of long-term 'waterfront redevelopment' [21, 23, 24]. Ports however evolved in developing inner harbours and inland terminals, not only affecting the urban dimension of the waterfront, expanding inner industrial and logistics zones to support port activity, with important urban redevelopment processes, and the development of potential conflicts between urban and port uses [22, 23]. Port cities, known as a densely populated area, experimenting with the rapid development of ports and their specialization and expansion, have been facing a wide range of ecological challenges, including environmental pollution, leading to a need for a greater attention to the dangers arising from this co-existence.

2.2 The Future of the Port Beyond the Port: Circular Economy and Industrial Symbiosis Transition

The CE represents a business model within which economic growth is closely related to environmental impact, through the promotion of more resilient production patterns and the use of renewable materials [26]. Attention to environmental impacts is also playing an increasingly important role in maritime transport today, in relation to pollution and emissions from ships that undermine the sustainability of ports and the neighboring

ecosystem [27]. The industrial symbiosis is part of the context of industry 4.0 and has a strategic role in the framework of sustainable development as it facilitates the creation of digital networks, logistics and supply chains through an integrated management of resources. This is done on one side allowing the reduction of waste, by means of processing, reuse, and on the other side favoring the implementation of related businesses in terms of the use of one company's waste or by-product as inputs for other ones. Industrial symbiosis plays a central role in ecological and energy transitions as it becomes a pivotal point in the creation of a circular model [28].

Being ports aggregators of different port and logistics related activities, as well as industrial and service ones, as a consequence, the passage towards a circular economy represents a challenge for the ports all over the world [29]. There are different strategies that can be used in ports, from the reuse of materials and energy to initiatives put in by small enterprises or start-ups [29].

In the last decades, ports have worked to improve their sustainability through Corporate Sustainability (CS), which has become a key factor in defining strategies for the port authorities at the global level. The port management, traditionally geared to profit, is moving towards more sustainable practices, also because of the increased media pressure on environmental issues related to ports. However, the shift to more sustainable practices is hampered by the lack of clear global regulations and the complexity of the public-private dynamics which characterize many port authorities. Ports must balance economic growth with the reduction of negative environmental impacts, considering a wide range of environmental and externalities generated from their activities [30]. In summary, the transition to a circular economy in ports is based on three main pillars: energy recovery, recycling and the creation of new flows of value goods. The industrial symbiosis (IS) emerges as a key strategy, allowing collaboration between ports, industries and cities to reuse waste and materials. Moreover, the adoption of the circular economy in the ports implies a greater attention to all the services, which can influence the circular transitions in industries that use their services. It is important to link the circular economy with industrial symbiosis and port-city dynamics to develop new circular commodity flows. Certainly, the application of the circular economy must extend to processes and infrastructure, influencing spatial planning and product design [29].

3 Methods

The multi-faceted issue of the application of CE principles in the city-port dyad, by implementing the industrial symbiosis on one side, and a renovated city-port symbiosis on another side, implies rooting the research and its applications down into a theoretical framework that combines traditional theories and models within an extended sustainable environment. At the same time the theoretical framework needs to be put in action on real case studies. In such a sense, a workflow and the application of ad-hoc developed instruments need to be implemented and presented.

From the theoretical and methodological point of view, the analysis is performed developing a conceptual model that considers the city-port relationship in the framework of the Bird's Anyport development model, in its evolution of the hybridized functions played within the cities and their ports. The model is integrated with the evolution in

a circular framework of Weber's location theory, expanded to consider circularity in location choices. This is implemented by means of developing an interaction matrix among city-port interferences and interactions, as well as locating in space the potential activities and sites connected to a testbed case study, such as that of the implementation of circular activities in construction in the Trieste port area [31, 32].

Such approach considers circularity in the development of the city-port relationship, as in the recent development regarding the Anyport model [26, 33] presented in Sect. 3.1. These reflections are subsequently extended through the development of a matrix of circularity and industrial symbiosis in the framework of the city-port relationship, presented in Sect. 3.2: this is divided into two sub-sections, the first dedicated to presenting the implications on circularity of spatial location with respect to the places of supply of materials and final destination markets, and the second in which the city-port symbiosis matrix is presented. The methodology presented below is summarized in Fig. 1.

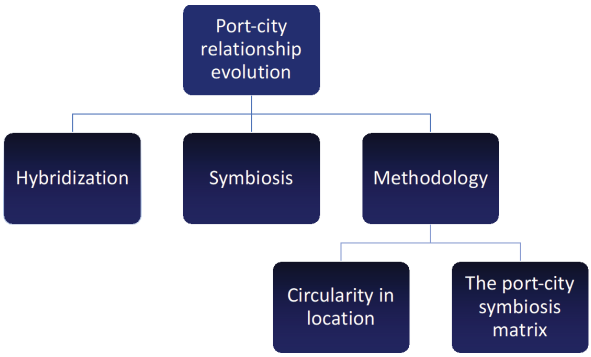


Fig. 1. Framework of the evolution of port-city relationship and methodology: circularity in location and port-city symbiosis matrix

3.1 Ports and Their Evolution. The Anyport Model with Hybridization

Port's evolution as previously introduced in paragraph 2.1 was synthesized and modeled within a model developed by Bird [17, 34] in which the evolutionary stages of cities and ports were considered as common to 'any' city and port - from that, the name 'Anyport' - and therefore presenting similarities among the different contexts. The evolution in ports was summarized by Borruso (2022) [34] in a proposal to evolve furtherly from the Anyport model, summing up a further stage of development, that of the hybridization of the functions, both from the port and from the city points of view. The evolutionary path taken by the city-port dyad in time led to different moments of alternatively tightening and loosening of the relations between the two parts. The latest stage in the model of development followed by ports, that of specialization, seemed to mark an important divide between ports and cities, given the exchanged and modified role of ports of playing their function servicing more a hinterland consisting on the port regions and even farther destinations, in case of the gateway ports, and servicing the maritime foreland, in case of hub ports.

The more recent evolution of ports, however, which was named as that of 'hybridization', seems to be changing and renewing the existing relationship between ports and their cities, as functions tend to be more mixed. This happens not just within the terminals, but also in the former port areas, as on the urban waterfront, where urban and port functions mix and coexist - cruise ships and passengers use often same parts of the city as citizens and city-users - or as in the peripheral and semi-peripheral areas of the city, where port-related functions are more and more moved in order to free valuable space on the docks. Dry ports and inner terminals in fact move far from the shoreline and docks, to allow handling, warehousing, train composition and other transport and logistics-related operations [25, 34].

3.2 Circularity in Location and the Port-City Symbiosis Matrix

As from the previously mentioned considerations, mixed functions in different areas, both proximal to the waterfront and in inner areas, have recently taken place and challenge urban and port development, in terms of positive and negative externalities. The analysis of the port and city evolution in terms fostering circularity in the economic development towards sustainability, there is a need to observe the different spatial subjects, as urban areas, waterfronts, peripheries, semi peripheries, suburbs and the proximal port and port related areas, within a broader planning and programming framework capable of considering together circularity and hybridization.

Circularity in Location. As a matter of example, there is the need to develop circular development synergies in the port and urban sphere in relation to the development of planned major infrastructure works. Such elements appear as belonging to an innovative perspective within the theoretical framework of a circular economy of construction and manufacturing, particularly in terms of recycled aggregates as secondary prime materials, thus reevaluating a traditional model of industrial location considering contemporary circumstances. This implies inserting circularity within Weber's studies on industrial location [17], revisiting the ideal location of manufacturing facilities connected to transport costs from and to energy, materials and marketplaces. From the original model, that foresaw the minimization of transport costs by locating manufacturing plants near either to raw material and energy sources or to markets, according to their weight into the final products and the relative transport costs. In a circular economy framework, the spatial separation among 'resources', 'energy', and 'market' becomes quite naive, as second prime materials are inserted as resources, and the same 'market' can become a place of origin of resources - in case we consider reusing and recycling of materials. Furthermore, the same plants can be located in proximity of the 'market' - i.e., a demolishing and reconstructing building or compound can represent a 'market', being the place where a new construction will be done, a place of origin of 'materials' and, also the preferred location for a batching - treatment plant - a 'firm' in Weber's theory [27, 31]. This led to the definition of an extended version of the model, to include, as materials' locations, the places of origins of recycled construction waste [35]. In such a sense, proximity becomes important and relevant particularly to foster a functional and locational integration both within the same production system and among different productions involving reuse of waste and byproducts. Apart from the theoretical framework of the 'extended Weber

locational model', a necessary stage is that of locating in space the potential places of origins of the materials involved in the circular production: attention is to be paid to the port itself as a generator, for example, of secondary raw materials. For this reason, the approach will be linked to the methodology used for the MEISAR –"Materials for Sustainable Construction and Infrastructure: The Recycled Aggregates"- project. The circular economy's key principles can be applied effectively with clusters that involve companies that recycle construction and demolition waste, quarries, and batching plants.

The port-city symbiosis matrix. The research begins by integrating various analyses, such as investigating and organizing planning tools at both a strategic and urban level and linking them to industrial and logistical organizational aspects in a circular perspective.

The methodological approach aims to generate a synthetic matrix that encompasses planning and governance tools, while also incorporating spatial dimensions and circular objectives. In addition, the approach aims to develop a synthetic matrix that takes into account the different planning and governance tools, spatial dimensions, and the existence of circular purposes.

Planning tools have an impact on a range of space-related issues, including development and approval state, spatial and administrative dimensions, overall characteristics of the application (industrial, urban, port/logistics, etc.), and the presence of circular shares in relation to the aforementioned spatial features and frameworks.

The outcome is a matrix for evaluating urban-port performances that provides a synthetic picture of their summaries and characterizations, in order to exploit the coexistence of planning and integration tools or potential conflicts arising from the different uses of urban and port areas (Fig. 2).



Fig. 2. Framework of Port City Symbiosis. Port and urban planning and the planning tools. – Source: Personal Elaboration [25]

4 Case Study. Port City Hybridization as a Driver of Circular Economic Development: The Case of Trieste

4.1 Port of Trieste, Waterfront, and Future Development

The Port of Trieste, located at the northern tip of the Adriatic Sea, serves as a crucial logistical node for intra-Mediterranean trade and strategic connections between Central-Western Europe and the Middle East. Functioning as an international port, it handles a

significant portion of its traffic through global routes [37]. In 2023, it ranked as Italy's top port in terms of cargo volume, managing over 57 million tons of goods, with 65% comprising liquid bulk commodities, primarily petroleum products. Recent years have witnessed notable growth and heightened commercial activity at the Port of Trieste, capitalizing on its inherent geographic advantages, including a seabed depth of approximately 18 m and a well-developed railway network connecting to logistics hubs across Central and Eastern Europe [38].

The analysis on potential circular activities in port areas is performed considering the development trajectories of the port of Trieste, the Port Master Plan provided by the Port Network Authority of Eastern Adriatic Sea, that manage the ports of Trieste and Monfalcone, was taken into consideration in Fig. 3 the Trieste port's expansion framework as in the port master plan is presented in order to identify the planned areas of development in the short to medium term.

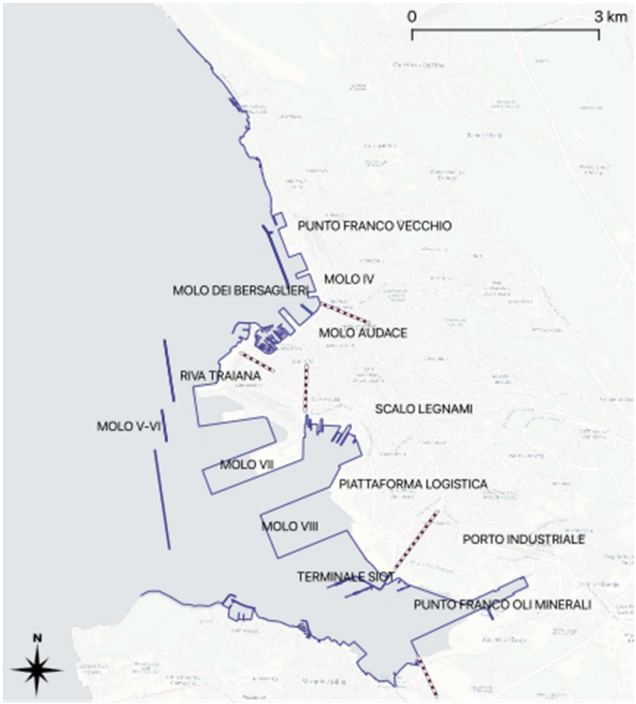


Fig. 3. Port of Trieste, coastline, and future development Source: Personal Elaboration on Port Authorities data

In particular, the area located close to the Logistic Platform (Piattaforma logistica in the map) is earmarked as the first strategic infrastructure to be realized, both as the root for the development of the new container terminal Pier VIII (Molo VIII) and for the development of land infrastructures supporting the road and rail connections supporting the logistics activities of all the terminals. The realization of Pier VIII, while not forthcoming in the short run, represents the pivotal strategic work for the expansion

of the productive capacity of cargo handling by the Port of Trieste, with a quay with an estimated size of about 88 thousand square meters, a length of 860 m and a width of 100.

Other works either planned or ongoing include the construction of a new multipurpose terminal in the southern part of the port, in an area that was historically occupied by 'l'Aquila' refinery plant, and the expansion of Pier 'VII', the current container terminal at the Port of Trieste. The design of these works is presented in Fig. 4 below.

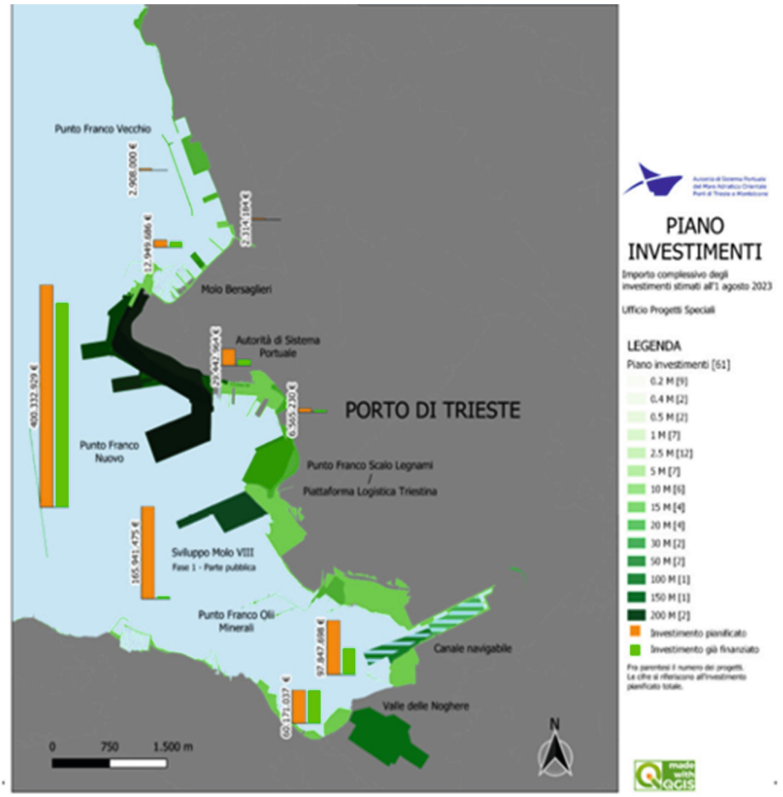


Fig. 4. Investment from the Three-Year Port Plan 2021–2024 – Source: Port Authority of Trieste

4.2 Investments from the Three-Year Operating Plan

To implement circularity within the port framework, the starting point is the plan of investments allocated in the framework of the three-year operating plan, divided into 6 different items, which are: rail infrastructure, port infrastructure, investments in energy and environment, investments in green ports, allocations for heritage conservation, and finally other planning services (Table 1).

Table 1. Summary of investments divided by macro-categories Source: Port Network Authority of the Eastern Adriatic Sea, Three-Year Operating Plan 2021–2024.

Categories	Amount ('000 Euro) Three Year Operating Plan 2021–2024
Railway Infrastructure	284.266 €
Port Infrastructure	243.393 €
Energy and Environment	33.952 €
Green Ports	35.231 €
Heritage conservation	19.043 €
Supplies of Services	7.260 €

5 Results and Discussion

Circular economy issues have been tackled following different steps that will need more in-depth analysis. The analysis in particular produced three main results in terms of obtaining the 'building blocks' of circularity in port-city relation. In the present stage, the most promising part of issuing circularity action is relatable to construction activities, that imply considering waste from demolition as potential sources of secondary prime materials and therefore capable of activating circular economic interaction and symbiosis.

5.1 Identification of the Investments and Their Potential in Circularity

When considering the Three-Year Operating plan and the investments, specifically, in this phase, the focus will be on the investments included under the heading "Port Infrastructure". This item has been explored in depth because, from the perspective of circularity of production processes, we can identify demolition and waste disposal as a source of secondary raw materials to be processed in waste treatment plants. At the same time, the construction of new infrastructure works implies a demand for construction raw materials. Under a circularity profile then, it could be hypothesized that demolition works, dredging and the production of large amounts of waste, could generate waste materials flows that once processed, would be transformed into raw materials to be used in the construction of new infrastructure works such as the construction of the new yards and dock as presented in Table 2. Under this perspective, and following the Meisar approach [39], the locations of caves, batching plants, landfills, recycling plants, quarry concessions and waste treatment plants close to the port context were considered, due to highlight not only the places of origin of the different raw materials, but also the locations where it could be processed in order to re-integrate it into circular construction production cycles.

Thus, we can see that most of the investments included in the Port of Trieste's Three-Year Operational Plan are aimed at improving logistical and environmental efficiency. In particular, for the share of investments aimed at increasing rail traffic through the implementation of systems related to this mode of transport, to investments in 'green ports' but also with a series of investments aimed at improving energy performance and

Table 2. Summary of investments in infrastructure Source: Port Network Authority of the Eastern Adriatic Sea, Three-Year Operating Plan 2021–2024.

Categories	Amount (‘000 Euro) Three Year Operating Plan 2021–2024
Port Infrastructure	
Extraordinary maintenance work on the dock at the Scalo Legnami behind the I extension and the extension of Pier II - Prog. 1897	1.501,95 €
Extraordinary maintenance work on the facades of warehouses Nos. 85–86-87–88-89 and interior warehouse No. 87 handed over to the Guardia di Finanza	1.450,00 €
Partial resurfacing work at the port of Monfalcone	1.350,00 €
Work on the construction of a new electrical cabin in the New Free Point of the Port of Trieste - Prog. 1900	2.800,00 €
Extension work on the root of Pier VI of the New Free Point of the Port of Trieste - Prog. 1801	18.307,21 €
Completion of the “east” forecourt at the former San Marco Arsenal: repaving and preparation of new sheds in the remaining area between the sea and the property boundaries	3.000,00 €
Extraordinary maintenance work on the facades of warehouses Nos. 85–86-87–88-89 and interior warehouse No. 87 handed over to the Guardia di Finanza	1.450,00 €
Renovation work on the facade and roof of Warehouse No. 41 - Trieste Maritime Station at the Bersaglieri Pier - Prog. 1838	2.760,00 €
Consolidation works of the South Rizzo Dam of the port of Trieste - Prog. 1816	6.724,00 €
Intervention components in the project of infrastructural and functional modernization of the container terminal at Pier VII in the Port of Trieste - Prog. 1949	100.500,00€

(*continued*)

Table 2. (*continued*)

Categories	Amount ('000 Euro) Three Year Operating Plan 2021–2024
Port Infrastructure	
Preparatory works for the establishment of logistic and industrial activities in the Noghere area, with a view to integration with the Noghere port terminal under construction	60.000,00 €
Partial dredging of the Noghere Terminal in the Port of Trieste, including dredging of the service channel and connection to the road system - Prog. 1948	45.000,00 €

the creation of a system of cold ironing of the docks aimed therefore at lowering the polluting emissions of ships at the docks, which we remember to be the main item of impact in terms of emissions in port contexts for a share that averages between 70 and 80% of total port emissions [4]. Also important in the plan are works to upgrade buildings and warehouses in the port context, aimed at increasing the port's energy efficiency.

5.2 Circularity in Location

With reference to the potentials of realizing local industrial symbiosis, considering the case of construction and reuse of first and second raw materials, an example of a workflow for reorganizing data for realizing symbiosis is proposed. At present locating in space the monetary values implied that can be involved in a circular process does not seem feasible, being the planned projects not yet in an advanced stage of implementation and, therefore, the materials' requirements not being clear at present.

A further step in setting the framework for circularity is georeferencing the potential economic subjects that can be involved, to optimize location. To do that, we propose the construction of a MEISAR_Map, recalling a previously implemented project [30, 38] in this context linked to Weber's theory, adapting it in a circular perspective, applying this model to the case study of the Port of Trieste, placing the attention on the port as generator of raw and second materials. The importance of a spatial constraint cannot be overstated, as the distance between the plants and the location where secondary raw materials are used must not exceed 30 km.

Both fieldwork and surveys were necessary to accurately position the elements in space, ensuring they were harmonized within a unified reference system.

Different sources for geocoding points were used. Landfills were derived from the Friuli Venezia Giulia website. Data were updated to 2024 and organized to be displayed on a Google MyMaps platform, called "MEISAR_Map_FVG", to keep all of the authors and participants of the MEISAR project up-to-dated on the different stages of the research (Fig. 5).

The MEISAR_Map_FVG is not a proper GIS - Geographical Information System, nonetheless it is based on preparatory work involving data preparation, organization, and elaboration of geographical data from multiple sources, by means of the QGIS platform. Considering the data realized and loaded onto the MEISAR_Map, we georeferenced all the players at regional level involved into the different processes of production, quarries, batching plants, waste disposal sites (Fig. 2).

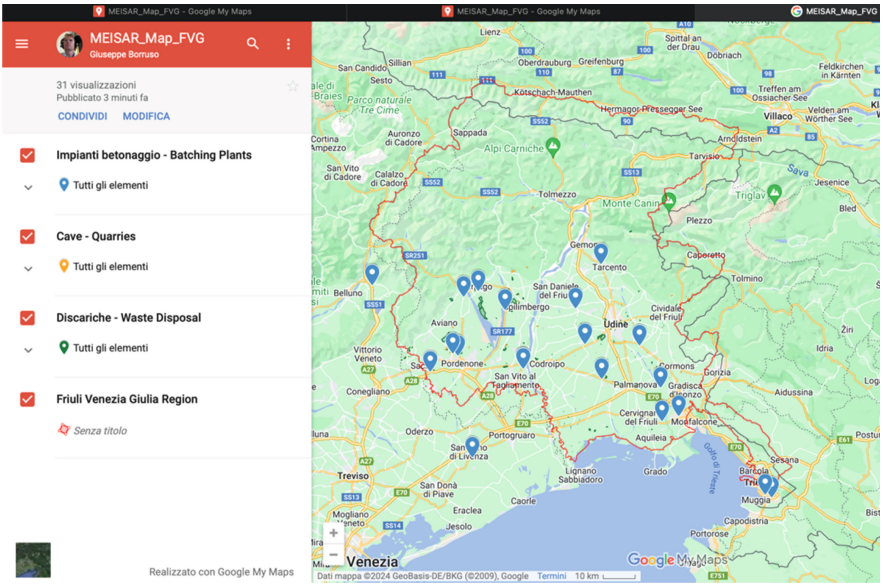


Fig. 5. The Meisar Map for the Friuli Venezia-Giulia Region https://bit.ly/Meisar_Map_FVG - Source Author's elaboration in Google MyMaps

5.3 The Port City Symbiosis Matrix

A further step in the evaluation and planning of circular actions in the city-port framework is that of considering a matrix where urban planning tools and the different port and city spatial components are matched. The above-mentioned analytical matrix is therefore filled considering overall planning tools insisting on the different areas of the port-city dyad. The planning tools are related to port and urban planning, the mobility plans and the industrial ones, including also the specific case of the Free Zones.

Considering the different levels of adoption of the planning instruments, the port and city of Trieste at present are characterized by a wide set of instruments usable and applicable to produce their effect over territories, and considering the different levels, as (urban) waterfront, port areas and extensions, semi-periphery and periphery. In most of the sub-areas considered, plans appear to be in an advanced stage of adoption, while only periphery appears still little covered by the ordinary urban planning tools, particularly in terms of transport topics (Fig. 6)

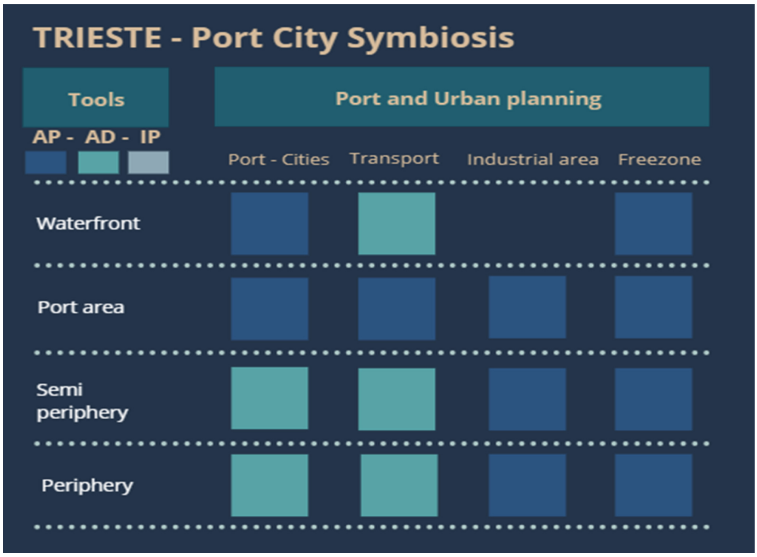


Fig. 6. The Port-City symbiosis matrix – Trieste - Source: Author's elaboration [25]

6 Conclusions

Given the complex framework in which ports find themselves within the circular transition, applying circular strategies and trying to mitigate the negative effects caused by port activities on the ecosystem constitute a crucial node.

If the port cities of the future are to be sustainable, ports must aim to reduce their negative am- environmental impacts as much as possible while increasing local economic and social benefits. City-port interaction in relation to waterfront development and industrial development are key strategies through which ports can generate significant economic benefits for the backwater area [7].

So, we can highlight how city-port relations represent an eloquent example of symbiosis between economic processes and relative physical places. Urban evolution has influenced port planning and vice versa, creating a spatial and temporal continuum in which cities and ports influence each other, adapting to the changing needs of commerce and society [27, 28].

The paper showed how practices such as optimization of the use of resources, reduction of the amount of waste, materials recycling and the adoption of more resilient and green technologies can improve both ports' operational efficiency and reduce greenhouse gas emissions and pollutants.

Consequently, this approach also leads to economic efficiency, through the creation of long-term benefits and rise of new business opportunities in fields as sustainable material management and resource savings.

Despite this, collaboration between port authorities and different stakeholders involved is essential in order to develop ad hoc strategies which take into account needs and challenges of local communities, maximizing the benefits for both economy and environment systems.

Acknowledgments. This publication was produced while attending PhD programme in Circular Economy at the University of Trieste, Cycle XXXVIII, with the support of a scholarship financed by the Ministerial Decree no. 351 of 9th April 2022, based on the NRRP - funded by the European Union - NextGenerationEU - Mission 4 "Education and Research", Component 1 "Enhancement of the offer of educational services: from nurseries to universities" - Investment 4.1 "Extension of the number of research doctorates and innovative doctorates for public administration and cultural heritage".

Conceptualization, methodology, formal analysis, materials and resources, data curation and validation: all authors .

Disclosure of Interests.. The authors have no competing interests to declare that are relevant to the content of this article.

References

1. Hoyle, B.S., Pinder, D.A.: European Port Cities in Transition. Belhaven Press, London (1992)
2. Vallega A.: The Changing Waterfront in Coastal Area Management. FrancoAngeli, Milano (1992)
3. Hoyle, B.: Global and local change on the port-city waterfront. Geogr. Rev. **90**(3), 395–417 (2000)
4. Saz-Salazar, S.D., García-Menéndez, L., Merk, O.: Port–city relationship and the environment: literature survey and methodological approach for project appraisal in presence of environmental externalities. J. Urban Planning Dev. **141**(3) (2015)
5. Hall, P.V., Jacobs, W.: Why are maritime ports (still) urban, and why should policy-makers care? Marit. Policy Manag. **39**(2), 189–206 (2012)
6. Musso E.: Città portuali: l'economia e il territorio. FrancoAngeli, Milano (1996)
7. Musso E., Ghiara H.: Ancorare i porti al territorio. Dai traffici alla marittimizzazione. McGraw-Hill, Milano (2007)
8. Vallega A., Geografia delle strategie marittime. Dal mondo dei mercanti alla società transindustriale, Mursia, Milano (1997)
9. Balletto, G., Borruso, G., Campisi, T.: Not only waterfront. The port-city relations between peripheries and inner harbors. In: Gervasi, O., Murgante, B., Misra, S., Rocha, A.M.A.C., Garau, C. (eds.) Computational Science and Its Applications–ICCSA 2022 Workshops: Malaga, Spain, July 4–7, 2022, Proceedings, Part V, pp. 196–208. Springer International Publishing, Cham (2022). https://doi.org/10.1007/978-3-031-10548-7_15
10. Vallega A.: Porti e regionalizzazione: un paradigma sistemico, in "Bollettino della Società Geografica Italiana **10**(8), 577–594 (1979)
11. de Langen, P., Sornn-Friese, H.: Ports and the circular economy. In: Green ports, pp. 85–108. Elsevier (2019). https://doi.org/10.1016/B978-0-12-814054-3.00005-0

12. Dore, S., Gallo, A.: Circular Economy and Reverse Logistics: an analysis of sustainable business models. In Gervasi O., Murgante B., Misra S., Rocha, A.M.A.C., Garau C. (eds), Computational Science and Its Applications – ICCSA Workshops 2023, LNCS vol. 14110, pp. 495–511. Cham: Springer Nature, Switzerland (2023). https://doi.org/10.1007/978-3-031-37123-3_34
13. Courtens, F.M., Haezendonck, E., Dooms, M., Verbeke, A.: Accelerating the circular economy transition process for gateway ports: the case of the Port of Zeebrugge. Marit. Transp. Res. **4**, 100088 (2023)
14. Morgan, F.W.: Ports and Harbours. Hutchinson, London (1954)
15. Sellari, P.: Geopolitica dei trasporti. Editori Laterza, Milano (2018)
16. Hayuth, Y.: Intermodal transportation and the hinterland concept. - Tijdsch. Econ. Soc. Geogr. **731**, 13–21 (1982)
17. Bird J.H.: Seaports and Seaports Terminals. Hutchinson, Londra (1971)
18. Hoyle, B., Charlier, J.: Inter-port competition in developing countries: an East African case study. J. Transp. Geogr. **3**(2), 87–103 (1995)
19. Goss, R. O.: Advances in Maritime Economics. CUP Archive (1977)
20. Vigarie, A.: Maritime industrial development areas: structural evolution and implications for regional development. In: Hoyle, B.S., Pinder, D.A. (eds.) Cityport industrialization and regional development: spatial analysis and planning strategies, pp. 23–36. Pergamon, Oxford (1981)
21. Soriani S.: La transizione postindustriale della portualità tra dinamiche di mercato e vincoli-opportunità territoriali in Soriani S. (eds.), Porti, città e territorio costiero. Le dinamiche della sostenibilità, Bologna, Il Mulino, pp. 19–65 (2002)
22. Hoyle, B.S.: The port-city interface: trends. Probl. Examples Geoforum **20**, 429–435 (1989)
23. McCalla, R.J.: Separation and specialization of land uses in Cityport waterfronts: the cases of Saint John and Halifax. Can. Geogr. /Le Géographe can. **27**(1), 48–61 (1983)
24. Norcliffe, G.B.: Industrial change in old port areas, the case of the Port of Toronto. Cah. de Géographie du Québec **25**(65), 237–253 (1981)
25. Borruso, G.: Balletto: The Port-City Relations in the Era of Hybridization. In: Gervasi O., Murgante B., Misra S., Rocha, A.M.A.C., e Garau C. (eds), Computational Science and Its Applications – ICCSA Workshops 2023, LNCS vol. 14110, pp.594–607, Springer -Verlag, Berlin (2023). https://doi.org/10.1007/978-3-031-37123-3_41
26. Circular economy: definition, importance and benefits. https://www.europarl.europa.eu/topics/en/article/20151201STO05603/circular-economy-definition-importance-and-benefits. Accessed 2 Feb 2024
27. Paulauskas, V., Filina-Dawidowicz, L., Paulauskas, D.: The method to decrease emissions from ships in port areas. Sustainability **12**(11), 4374 (2020)
28. Balletto, G., Sinatra, M., Sinatra, F., Borruso, G.: Industrial Symbiosis and Circular Urban Practices. In: International Conference on Innovation in Urban and Regional Planning, pp. 14–24. Cham: Springer Nature Switzerland (2023). https://doi.org/10.1007/978-3-031-54096-7_2
29. Haezendonck, E., Van den Berghe, K.: Patterns of circular transition: what is the circular economy maturity of Belgian ports? Sustainability **12**(21), 9269 (2020)
30. Stein, M., Acciaro, M.: Value creation through corporate sustainability in the port sector: A structured literature analysis. Sustainability **12**(14), 5504 (2020)
31. Balletto, G., Borruso, G., Mei, G., Milesi, A.: Strategic circular economy in construction: case study in Sardinia, Italy. J. Urban Planning Dev. **147**(4) (2021)

32. Balletto, G., Borruso, G., Mei, G.: Location theory and circular economy. Demolition, constructions and spatial organization of firms–an applied model to Sardinia Region. The case study of the New Cagliari Stadium. In: Gervasi O., Murgante B., Misra S., Rocha, A.M.A.C., e Garau C. (eds), Computational Science and Its Applications–ICCSA 2019: 19th International Conference, Part III 19, pp. 535–550, Saint Petersburg (2019)
33. Bird J.H.: Ports, then and later, In: Charlier J., (eds.), Ports et mers. Mélangers maritimistes offerts à André Vigarié, Paradigme, pp. 157–170, Caen (1986)
34. Borruso, G.: Port-City relationship in the era of hybridization. A development model. J – Reading – J. Res. Didactics Geogr. **11**(2), 125–137 (2022)
35. Weber, A.: Theory of industrial location. San José State University Department of Economics, San Jose, CA, USA (1909)
36. Rodrigue, J.P., Notteboom, T.: Foreland-based regionalization: integrating intermediate hubs with port hinterlands. Res. Transp. Econ. **27**(1), 19–29 (2010)
37. Borruso, G., et al.: Rail ports as nodal gateways in the sea–land connections and the challenges of sustainable globalized markets: the case of Adriafer and the port of Trieste. In: Gervasi O., Murgante B., Misra S., Rocha, A.M.A.C., e Garau C. (eds), Computational Science and Its Applications – ICCSA Workshops 2023, LNCS vol. 14110, pp. 425–441, Springer -Verlag, Berlin (2023). https://doi.org/10.1007/978-3-031-37123-3_30
38. Tadini, M., Borruso, G.: Sea-rail intermodal transport in Italian gateway ports: a sustainable solution? The examples of La Spezia and Trieste. In: Gervasi O., Murgante B., Misra S., Rocha, A.M.A.C., e Garau C. (eds), Computational Science and Its Applications – ICCSA Workshops 2022, LNCS 13381, Springer-Verlag, Berlin, pp. 156–172 (2022)
39. Balletto, G., Borruso, G., Mei, G., Milesi, A.: Economia circolare, gestione dei rifiuti da costruzione e demolizione e produzione di Aggregati Riciclati. Il progetto MEISAR–Un'applicazione alla Sardegna. Boll. dell'Associazione Italiana di Cartografia. **170**, 178–200 (2020)
40. Gallo, A.: The logistic carbon footprint: a dynamic calculation tool for an indicator of the sustainability of logistic processes with a case study on the Port of Trieste. In: Gervasi, O., Murgante, B., Misra, S., Ana, M.A., Rocha, C., Garau, C. (eds.) Computational Science and Its Applications – ICCSA 2022 Workshops: Malaga, Spain, July 4–7, 2022, Proceedings, Part V, pp. 109–123. Springer International Publishing, Cham (2022). https://doi.org/10.1007/978-3-031-10548-7_9