Integrating Territorialization, Circular Economy, and Industrial Symbiosis: Leveraging GIS for Enhanced Efficiency in Industrial Zones

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Abstract. Territorialization, Circular Economy and Industrial Symbiosis represent key concepts in the context of industrial areas. Present days industrial settings and plans are characterized by a growing attention towards sustainable development, and the processes of territorialization are more and more meant to address a responsible use of natural resources and territory planning in order to maximize efficiency and reduce environmental impact. This challenge involves creating a connection where industrial areas develop clusters, with interconnected business establishing proximity to leverage synergies, share resources, and expertise. Industrial symbiosis and circularity can be facilitated by clusters, which can contribute to sustainability. The purpose of this study is to address circular economy and industrial symbiosis in a spatial analytical framework, proposing a combined methodology of addressing the spatial organization of industrial areas to promote circular activities. A traditional locational analysis method is adapted to circularity and, in this framework, different steps were proposed, involving the use of Geographical Information System (GIS) in the visualization and analysis of an industrial area, with a particular focus on a case study of the industrial area in Trieste. The GIS method enables the mapping of resources, infrastructure, and potential synergies among businesses. The implementation of a geographical database for an initial visual analysis can be a first support to stakeholders in identifying opportunities for cooperation, resource sharing, and optimization of synergy. By adopting this methodology, economic sustainability is not only promoted but also environmental impact is minimized, and a resilient industrial community is established. The importance of this paper lies in highlighting how the GIS approach can help support circular economy policies by providing a foundation for sustainable planning and management of industrial areas.

Keywords: GIS · Industrial Symbiosis · Territorialization · Circular Economy

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O. Gervasi et al. (Eds.): ICCSA 2024 Workshops, LNCS 14817, pp. 369–383, 2024.
https://doi.org/10.1007/978-3-031-65238-7_25

1 Introduction

1.1 Circular Economy and Industrial Symbiosis

The Circular Economy (CE) and the Industrial Symbiosis (IS) play a fundamental role in the promotion of new processes of localization and territorialization of productive activities. Through a case study, the present work will try to investigate the effect that the adoption of circular economic models and the implementation of industrial synergies have on the localization of enterprises activities and their subsequent interaction with the territory.

Over the years, different definitions have been developed for the circular economy. In particular, we want to highlight the one provided by the Ellen MacArthur Foundation (2016): "A circular economy is one that is restorative and regenerative by design and aims to keep products, components, and materials at their highest utility and value at all times, distinguishing between technical and biological cycles" [1]. This is a closed-loop economy that aims to turn generated waste into new secondary raw materials by reusing it.

On the other hand, the Industrial Symbiosis (IS) is a concept that refers to the integration and collaboration between different companies and sectors, with the aim of optimizing the use of resources, the reduction of waste but also improving the overall efficiency of the production system. In relation to the theoretical framework, this concept will be defined through the analysis of the different theories present in the literature. The integration of these concepts is aimed at establishing a more sustainable production/economic system, with the goal of promoting waste reduction and resource efficiency. The use of circular business models can lead to the creation of eco-industrial parks, for instance. However, industrial symbiosis can face obstacles due to lack of information on material flows or distrust of collaboration between competing companies. Consequently, in the literature it appears as the industrial symbiosis is synergistic in the circular transition.

The CE, through the promotion of the re-use and circulation of secondary raw materials and resources, provides new tools for the evaluation and mapping of certain sites. Taking into account social, economic, and environmental impacts, their identification can be achieved through both CE it and localization models. Analyzing the flow of materials in a given area is crucial for identifying opportunities for recycling and/or reuse. Furthermore, this methodological approach promotes the realization of geospatial representations that highlight the possibilities for the development of a given territory, from CE's perspective [2, 3].

Therefore, the present work will focus on the Industrial Zone of Trieste, thanks to the collaboration carried out with the Co.SELAG (Consortium of Local Economic Development of the Giuliana Area). The latter is a public economic body whose function is to promote and improve the creation and development of productive and entrepreneurial activities but also research and innovation-related services within their area of competence.

The importance of this study lies in providing an in-depth overview of circular economy practices and industrial symbiosis and providing input for policy makers, entrepreneurs and local stakeholders wishing to promote sustainable localization and territorialization processes, by examining the case study of the Consortium's area. The

adoption of a circular approach and the creation of synergies between companies can contribute to a more resilient economy and better resource management, while promoting local development and environmental sustainability.

1.2 Ports Proximity and the Development of Industrial Areas

Ports have always been important nodes for international trade, and their proximity has led to the development of industrial activities due to their access to different markets.

The development has been influenced by a variety of reasons, including access to raw materials and the advantage of reducing transportation costs, which encourages competitive production. Moreover, the proximity of industrial areas to ports has easily allowed the production export around the world, creating new opportunities.

The economic development of several cities has been greatly impacted by the proximity and connection between industry and port due to their efficiency and connections.

Despite modern times, this connection is still evident in a number of cities where ports are still a crucial part of the local economy.

In spite of this, the existing relationship between ports and industrial areas today is still evolving with globalization and relocation of activities there has been a withdrawal of companies from port areas, while, at the same time, the new industries, in particular those tied to logistics and tourism, continue to emerge near ports. In this sense the port and city's functions are mixing, creating hybridized situations where formerly port-related areas are converted to urban functions, while new urbanized spaces, not always proximal to port areas, but also located in inland, are dedicated to transport, logistic and industrial functions [4].

Therefore, the proximity between industrial areas and ports remains a unique feature for urban economic development, leading to increasing synergies within which industrial areas can progress [5–8].

The paper is organized as it follows: Section 2 Theoretical and methodological aspects; Subsection 2.1 Theories of industrial activity localization; Subsection 2.2 The industrial location theory within a circular framework; Section 3 The application of circular economy's principles.; Subsection 3.1 The study area; Subsection 3.2 Case studies: towards circular economy in the Industrial Zone of Trieste Sect. 4 Result and discussion; Subsection 4.1 Industrial Symbiosis in the Industrial Zone of Trieste; Section 4.2 Circular Economy in the Industrial Zone of Trieste; sub-paragraph Sect. 5 Conclusion.

2 Theoretical and Methodological Aspects

The ratio behind the development of the present research work has its roots within a various as well as articulated theoretical, methodological and operational framework, involving different segments to be integrated and exploited. The research work is in particular aimed at setting a framework for an applied research activity hypotezising and planning the implementation of an industrial symbiosis within an industrial area, revisiting a traditional geographical model of industrial location within a circular economy frame.

2.1 Theories of Industrial Activity Localization

The location of industrial activities is a crucial issue in economic studies, affecting the competitiveness and socio-economic development of regions and countries. Economic space is a set of functional and hierarchical relationships that define the division of labor between the different territorial units. These relationships include economic-functional aspects, where actors act rationally to achieve goals, and aspects of domination or contradiction. The objective of territorial economics is to understand and interpret this complex of relationships [9].

Traditional theories have focused mainly on one of two dimensions: the economic-functional or the domination. However, there are cultural and theoretical premises for a synthesis of the two positions.

Two theories that have profoundly contributed to the understanding of this phenomenon are Alfred Weber's theory of industrial localization and Johann Heinrich von Thünen's model of the spatial distribution of agricultural activities [10].

Weber, in the early 20th century, formulated a theory based on the optimization of production costs. He identified three key factors in the location decision: proximity to raw materials, proximity to consumer markets and accessibility to transport. Companies, according to Weber, try to minimize costs by moving to places that offer an optimal balance between these factors (Fig. 1B). This theory stressed the strategic importance of location decisions in the context of industrial competitiveness [11].

The von Thünen model, developed in the nineteenth century, was originally focused on agriculture, but its concept of concentricity of activities based on transport costs influenced the future understanding of industrial localizations. Von Thünen proposed that agricultural activities should be organized concentrically around an urban center, based on transport costs and land profitability (Fig. 1A). This concept of spatial distribution of activities has stimulated further reflection on the influence of transport costs in economic location [12].

Both models address the issue of economic localization in a complementary way. While Weber focuses on production costs and logistics, von Thünen introduces the concept of distance from the center as a key element in the location decision.

Integrating these approaches could provide a more comprehensive view of the spatial dynamics of economic activities, considering both industrial and agricultural aspects.

The theories of Weber and von Thünen provided essential conceptual foundations for understanding the strategies of localization of industrial activities. The integrated analysis of these models can enrich the understanding of spatial dynamics of economic activities, helping to develop more effective and sustainable industrial policies.

Classical theories of localization and applied economic geography have studied industrial localization primarily in static terms, emphasizing transportation costs and differential economic characteristics of geographical areas.

These approaches consider space as an exogenous data and enterprises adapt to its characteristics. The analysis of spatial domination has focused on power relations at the international, interregional and intraregional levels, often in a Marxian context. A theoretical synthesis is necessary, integrating micro and macro spatial approaches and overcoming the static conception of space. The next sections will examine three lines of

thought: localization economics, localization policy analysis, and localization political economics.

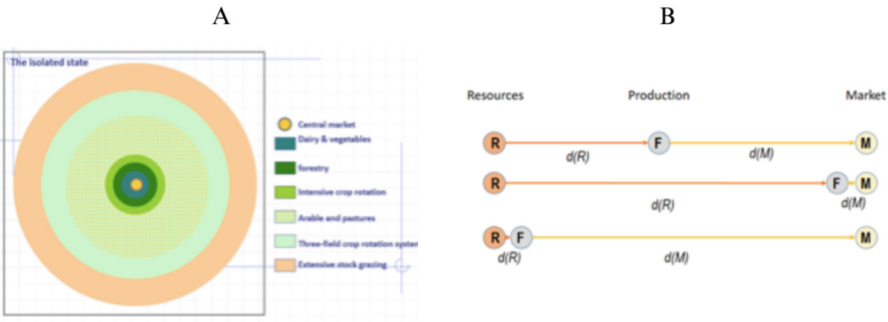


Fig. 1. A: Von Thünen's model of land use. Source: Von Thünen J.H. (1826) [12] B: Location à la Weber in the simplified model (along a line). Source: Balletto et al. (2019) after Weber (1909).

2.2 The Industrial Location Theory Within a Circular Framework

An extension of the classical Weber's model of industrial location can be to-date adapted to host circularity, as studied and applied to the case of construction and demolition waste in the MEISAR project [14]. The idea is that of minimizing transport costs related to materials, energy and products extended to recycled waste in the twofold nature of waste and potential secondary raw materials. This implies a change of paradigm, as the place of production, whose location is central in the original Weber's theory, becomes also a place of origin of second raw materials. The same production plant can be de facto localized in close proximity to the places of production of waste. Furthermore, waste processing plants - in their journey towards becoming secondary raw materials - can be the object of location choices and minimization of costs, by the consideration of the 'to & fro' waste-materials' transport costs (Fig. 2). It is therefore needed a high level of flexibility in realizing mobile plants. The traditional non-circular location model needs to be reconsidered in order to correctly quantify the quantity of waste produced and its percentage of reinsertion into a circular - symbiotical - production process. An estimation of the overall production costs need therefore to be performed, where externalities of production, waste production and reuse can be estimated. In this sense, the modified model could be interesting for both considering new locations for processing waste, and also for favouring rise of new business given the proximity of the different activities.

A consequence of that is the need to correctly and precisely map the potential actors involved in the process. This requires a deep work of data organization and harmonization, also by means of geographical analytical and sharing tools (GIS software and geographical sharing packages).

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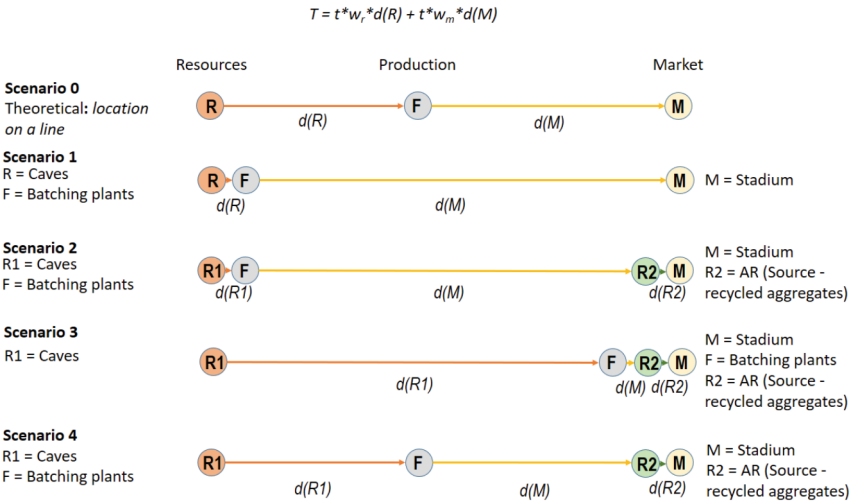


Fig. 2. The Weberian localization model of batching plants in a circular economy: case study of a stadium demolition and demolition. Source: Balletto et al. (2019) [13]

3 The Application of Circular Economy's Principles

An application is proposed, considering a case study based on the industrial area of Trieste (Italy). The idea is that of taking into the consideration the industrial activities based in this area proposing possible applications of circular economy and industrial symbiosis.

3.1 The Study Area

The area under study corresponds to the Industrial Zone of Trieste, specifically the area of competence of Co.SELAG that includes portions of the municipalities of Trieste, Muggia and San Dorligo della Valle. Located in the region of Friuli-Venezia Giulia and consequently in north-eastern Italy, the study area is a strategic point not only for its geographical position but also from an industrial and logistical point of view, given its proximity to the borders of Slovenia, Austria and Croatia and being the port a crucial hub for international trade.

The ultimate goal of the Consortium is to contribute to economic growth and the creation of jobs within its territory, trying to promote the technological development and competitiveness of local businesses [15, 16]. The Consortium has been charged, through the regional law n. 3 of 20 February 2015, to manage the industrial area that was previously under the responsibility of the Agency for the Industrial Zone of Trieste (EZIT). This transition occurred following the liquidation of the EZIT at the end of 2015, definitively concluding the procedure in April 2019.

It is important to underline that the management of the legacy of EZIT represents a great responsibility, with the aim of preserving its memory and continuing to develop the Industrial Area of Trieste. The history of the EZIT dates back to the early post-war period,

when it was established as the "Coordinating Body for the Industrial Development of Zaule".

The Co.SELAG is charged from the Region Friuli Venezia Giulia to conclude the procedure of liquidation of the Agency for the Industrial Zone of Trieste (EZIT) that was in course from 2015. With the conclusion of the procedure of liquidation, this new consortium structure, with a participation of 52% from the Authority of Harbour System and 48% from the municipalities of Trieste, Muggia and San Dorligo of the Valley-Dolina, is now able to resume its activities and attract new entrepreneurial initiatives to revitalize the area.

It is important to note that Co.SELAG plays a strategic role both in terms of logistics and real estate and is also committed to the integration with the waterway and management of FREEeste, the area formerly belonging to Finnish marine technology firm Wärtsilä's production plant, now an inner harbor and free zone part of Trieste Port Authority. In this perspective, the port becomes a key player in the industrial policy of the territory, in which the governance model unites the port itself, logistics and manufacturing.

The strategic position of this industrial area, crossed by important road, highway and railway connections, allows joining the port of Trieste with the European net, making it a fundamental node. Moreover, an important road axis crosses the area, connecting northern Italy to Istria region – part of Slovenia and Croatia - through the Rabuiese border, serving important tourist traffic and regional freight offices.

Companies located in the industrial area of Trieste have faced challenges related to the scarcity of space, but recently there is a growing interest by companies of international importance towards the opportunities offered by this industrial area. These positive signs indicate its potential for growth and continued development.

Co.SELAG focuses on the adoption of CE and IS to address the problems related to environmental sustainability, through the launch of an initiative to revitalize the industrial area of its competence. This is an economic public body which also takes into account existing environmental issues and challenges. In fact, it develops several projects in collaboration with both the FVG Region and the European Union.

The first one "APEA" (Ecologically Equipped Production Areas), a project promoted by individual regional consortiums that aims to apply the principles defined in the circular economy within production areas, in order to obtain data on environmental status and energy consumption [15].

The second one "Eco Industrial Park Network for the Alpine Regions Leveraging smart and Circular Economy" (ECOLE) represents the second project which is implemented to try to find a solution to the problems faced by industrial parks in be-coming integrated circular eco-industrial (EIP).

In collaboration with the Regional Administration FVG and the agency ARPA FVG, APEA is designed as an undefined industrial area, consisting of at least two companies with different production vocations, as industry, crafts, trade and agriculture. Characterized by an integrated management of infrastructure and resources, APEA aims to optimize the organization of activities to reduce environmental impact. The primary objective of the APEA project is to improve environmental, industrial and social performance, in line with EU directives, promoting sustainable environmental economic

development and implementing a management model that increases the competitiveness of the companies involved.

On the other hand, the ECOLE project represents a key action aimed at spreading and promoting sustainable development within Industrial Parks. The importance lies in the fact that the project suggests and provides guidelines and a structure to be followed in order to establish Eco-Industrial Parks contributing to the creation of more resilient and sustainable industrial areas [16].

This poses a challenge as it mainly affects industries and also infrastructure providers, industry agencies, business support organizations and public authorities. Since Industrial Parks today have a negative image as polluters and a lack of CE implementation in their value chain and daily activities, cooperation is essential to accelerate this transition, and this is what is proposed within the use of a community approach by establishing an action plan for the implementation of the tools collected in the pilot sites. The project aims to transform industrial parks into more circular, resilient and sustainable EIP in the Alps, able to deal with climate and economic crises [17].

More in depth, the development of this project in the Industrial Zone of Trieste, concerns the realization of a platform which will have the purpose of monitoring energy, water, soil, and waste (etc.) consumption in order to implement and promote strategies of IS.

The two projects have in common the imposition of constraints and objectives aimed at:

- Reduction of environmental impact: involves reducing emissions and waste generated by the same industrial activities through, for example, air monitoring to ensure compliance with environmental standards or the adoption of low carbon technologies.
- Waste management: The projects call, in the case of waste, for improved waste management through separate collection and recycling within the area under consideration. It also seeks to limit the generation of hazardous waste and to encourage responsible waste management.
- Energy efficiency: The objective is to reduce energy consumption through the adoption of specific measures. Incentives for the use of renewable energy sources, the promotion of cogeneration and heat recovery are crucial to improving the overall energy efficiency of the industrial park.

3.2 Towards Circular Economy in the Industrial Zone of Trieste

As part of this study, the data used was provided by the Consortium itself, which allowed the data to be processed in aggregate form. Indeed, within the Co.SELAG a geographical database process implementation has been started, in order to prepare a cognitive tool regarding the real company assets. Localization can provide a "spatial" idea of their location and spatial distribution.

The data provided concerns the companies that are part of the study area, which have been provided in the form of an excel file containing the following information: name, address, contacts, sector type and ATECO code, type of activity established, the size of the company and finally the number of employees.

In the future, the database can be extended with the inclusion of additional company information and data, not only to implement projects to reduce environmental impacts and implement the logic of circularity.

In order to conduce a more in-depth analysis of the study area, the excel file was analyzed. The analysis started from the number of companies present in the industrial area which amounted to 895. Since the main objective of the paper is to understand what the synergies within the study area could be, it was decided to carry out an even more targeted analysis using a series of filters available within the excel file.



Fig. 3. Included sectors in the analysis. Author: Sinatra F. (2024)

As a first filter, it was analysed the column called "Sector 1" within which the macro-areas of belonging companies were taken into account, as we note in Fig. 3 there were 13 different sectors.

In the analysis, have been excluded sectors as the wholesale, retail trade, transport and logistics, gaining a sample of 382 companies. Subsequently, it was applied a second filter regarding the "Business Size" excluding only micro enterprises, obtaining a sample of companies equal to 243.

Since the cells which do not contain any information about the companies' sector were also considered, the corresponding 98 companies were analyzed trying to understand what their activities could be. The ATECO code, allowed to identify it. Infact, ATECO code constitutes in fact a type of classification of economic activities at national level. As a matter of fact, it is an alpha-numerical combination that defines the main activity carried out by the company and which is conferred at the time of enrollment in the Register of Companies [18].

Consequently, companies which could potentially be involved in the creation and/or implementation of circular strategies and industrial symbiosis were 146 companies.

Subsequently, a detailed analysis of the identified companies was carried out excluding the small ones which did not have a very large production, obtaining a final sample of 101 enterprises (including companies that own multiple production facilities).

On the practical side My Maps was used, which is an application that allows the development of an interactive mapping, in order to organize and obtain a geospatial representation of data. This tool was functional for data collection and also for their analysis through the QGIS software [19].

4 Result and Discussion

The Industrial Area of Trieste represents a meaningful example of how its strategic geographic position, combined with a series of logistic, economic, and structural factors, can favor its increase and development.

The map provided gives a clear overview of the locations of the companies and their surroundings, allowing a better understanding of the arrangement of industrial activities. This is essential to identify potential synergies between companies, encouraging collaboration and maximising the use of shared resources.

Moreover, the use of Geographic Information System (GIS) mapping systems is a valuable tool for evaluating access to markets, resources and infrastructure. This approach can significantly contribute to the sustainable planning of the industrial area of Trieste, allowing an optimal management of resources and an intelligent design of infrastructure. The present study has therefore tried to develop a mapping of the aforementioned area through the use of QGIS that emerges as a fundamental geographic informative tool for the analysis of the distribution of the activities carried out within the boundaries of the Consortium (Fig. 4).

The methodological approach used is therefore similar to the one developed in the MEISAR "Materials for Sustainable Construction and Infrastructure: the Recycled Aggregates"- project, based on the core principles of the circular economy. One aspect of this project was the introduction of cluster analysis in which it is essential to take into account the spatial constraint, where the distance between the plants and the place where secondary raw materials are used must not exceed 30 km. The MEISAR Map (Fig. 5) allows the construction of a map that binds to Weber's theory in circular view. [14].

4.1 Industrial Symbiosis in the Industrial Zone

Given the willingness and interest of the Consortium in encouraging sustainable practices in its territory, the latter has carried out a series of interlocutions with its companies in order to evaluate the opportunities for the expansion of production sites.

With reference to the dialogue with one of the companies present in the territory, a need for the use of lemon processing by-products, generated by the processing of liqueurs, has emerged. Until then, the lemons were used exclusively for the outermost part of the skin, while the rest of the product, despite being intact, was no longer used, thus becoming a waste of production for the company.

Consequently, the Consortium has explored the production system of the Industrial Area of Trieste through ad hoc interviews with companies involved in the food sector and which were interested in the waste production of the liquor factory.

After identifying the company that was interested in participating, the team began working together to assess the potential for synergy between the two realities and repeat it in the future.

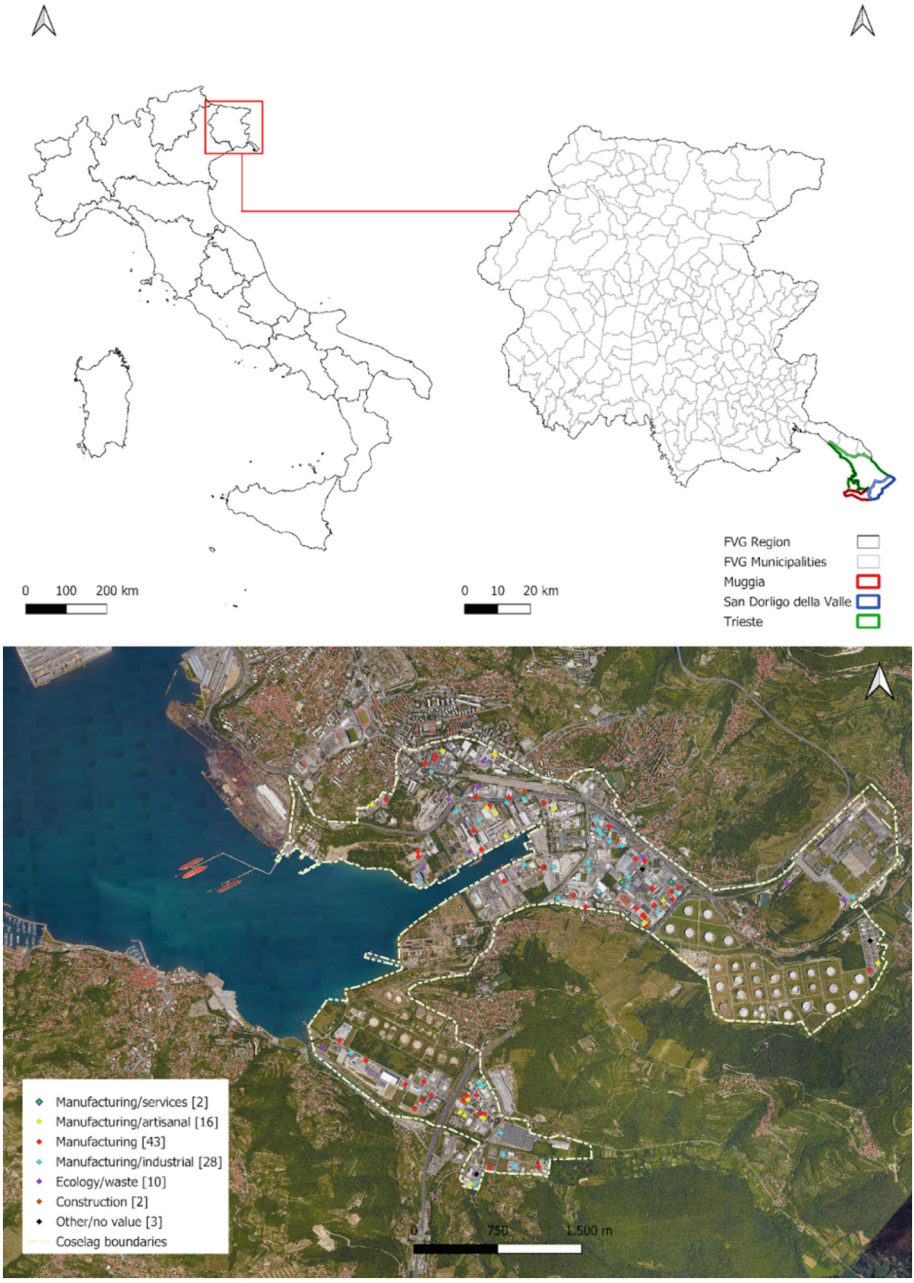


Fig. 4. District of the Industrial Zone's companies (Personal Elaboration, 2024)

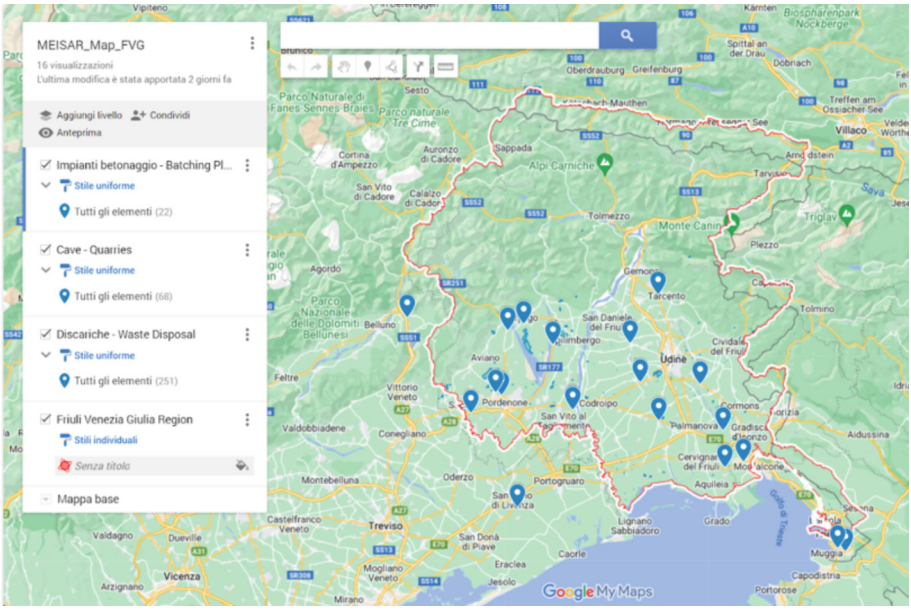


Fig. 5. The MEISAR Map FVG

Then, thanks to the development of this IS strategy, unused parts were categorized as by-products, stored, and in most cases, given as a gift to individuals for food use, to farmers for agricultural purposes, or, at worst, disposed of as waste.

As stated by the interviewee, the study of symbiosis has been highly advantageous in multiple ways, including environmental and economic ones, in this context. Firstly, this synergy has allowed the company to remove lemons continuously without having to find someone to give them away or occupy warehouse space. It turned out to be an optimal choice from the ethical and environmental point of view since, as indicated by the interviewee, dispose of lemons was seen as a real waste.

4.2 Circular Economy in the Industrial Zone of Trieste

As part of this research, a meeting was organized with the entrepreneur of a company located within the consortium's district which carries out the activity of "storage, processing by volume adjustment, the treatment of special waste, sorting, shredding and volumetric conditioning of special waste similar to urban. Construction and operation of plants for the production of heat and electricity. Management of areas, warehouses, terminal yards, handling, storage, storage, distribution, and handling of goods in general. Management of commercial warehouses of products or goods in general.

The interview was carried out due to the fact that the company began the demolition works of one of their buildings which occupies approximately 26,000 m^2.

From the waste generated by this demolition, the company will try to recover most of the reusable material, for the construction of their new plant that will rise a few kilometers

from the old. In doing that, the company is taking different steps to implement the circular economy practice, as:

- The analysis of all the materials present as iron, asbestos etc. obtaining a detailed mapping of the whole area.
- Strip-out operations, which take place during demolition and involve the preventive removal of all elements from the building structures, which must be handled differently. This phase enables the effective management of waste materials by directing them towards the proper disposal and recovery processes, preventing dangerous waste from being mixed with inert and recoverable materials [19]
- Remediation of asbestos in other areas and then the cement analysis in order to establish their typology.

The demolition of the area mentioned will only take place after these interventions are completed.

5 Conclusion

In the near future, it is expected to focus more research on synergies between companies within the Industrial Area of Trieste, trying also to have a more in-depth collaboration within the related companies. This implies the study of the possibilities of exchange of by-products, resources and skills between the different companies present in the territory.

The primary objective will be to identify how these synergies can contribute to the creation of a more robust and sustainable local economic ecosystem.

With a greater focus on synergies research, the aim is to promote greater efficiency in the use of available resources and to reduce the environmental impacts associated with industrial activities. This approach can not only lead to a better management of resources, but also to a greater competitiveness of companies in the industrial area of Trieste.

Through closer collaboration between companies and a sharing of resources and skills, it is hoped to create a more dynamic and resilient economic environment. This could encourage the development of new business opportunities and innovation, thus helping to consolidate Trieste's position as an important industrial and commercial hub in the region.

The limit of this work lies in its evolution. In fact, it is a developing project which, through its implementation, will enable us to obtain more precisely data to assess the benefits of this approach in an industrial area. In addition, it will provide us with an holistic view of the positive implications that can be achieved, paving the way for future decisions and actions to promote good circular practice.

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".

• a period of study and research at Co.SELAG - Consorzio di Sviluppo Economico dell'Area Giuliana.

Conceptualization, methodology, formal analysis, materials and resources, data curation and validation: all authors. In particular: Sinatra wrote Sects. 1.1, 3, 4 and 4.2; Borruso wrote Sects. 1.2 and 2; Primiceri wrote Sects. 4.1 and 5.

Disclosure of Interests. The authors have no competing interests to declare that are relevant to the content of this article. Confidential collaboration with the project companies does not allow the dissemination of localization and quantitative analysis of the case studies developed.

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