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Table of contents

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RE = Restricted to a group specified by the consortium (including the Commission Services)
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Executive summary

Task 5.4.4, titled *"Towards a Circular Metabolism for Urban and Metropolitan Settlements"*, is part of the RETURN project (PE3 – WP4). The task aims to address the challenges of **multi-risk urban contexts through an innovative approach, promoting more sustainable and resilient regeneration models.** It contributes to strengthening the understanding of multi-risk landscapes by supporting the transition towards **circular cities** exploring how the principles of **Circular Urban Metabolism (CUM)** can help to reduce vulnerabilities and enhance resilience through innovative planning and design tools.
The **deliverable DV 5.4.5**, "Evaluation Framework for Monitoring Circularity, Sustainability and Resilience of Urban Metabolism", is structured in two main parts:
The **first part** defines a theoretical framework based on the integration of **CUM** principles and **Urban Political Ecology** (Heynen, Kaika and Swyngedouw, 2006), with the aim of promoting a more integrated risk management in multi-risk contexts, starting from territorial and urban design for sustainable cities (Lucertini & Musco, 2020). The focus is on circularity as guiding paradigm for risk mitigation, also considering the concept of **urban systemic vulnerability** (Task 5.3.3). Through a bibliographic review and theoretical reflection, the deliverable introduces the concept of **Urban Metabolic Risk (UMR)** applied to urban and territorial contexts. **UMR** emerges from the **intertwined and often misaligned dynamics between governance, space, ecology and society**. The first part of the document builds **a conceptual bridge between circular economy and risk mitigation strategies**, drawing on literature review, theoretical elaboration, and best practices at European and international levels.
The **second part** of the deliverable grounds this theoretical framework in the real-life context of **Bagnoli-Coroglio**, a National Interest Site (SIN) in the city of Naples. Bagnoli is an emblematic case of post-industrial transformation, characterized by overlapping ecological, economic and social risks, worsened by stalled redevelopment and implementation delays. The task adopts a multiscalar, diachronic and systemic approach, using **mapping tools and spatial analysis** to bring out **invisible dynamics and temporal misalignments** that have shaped the area's evolution. **The methodology integrates traditional data** (planning documents, environmental indicators, investment flows) **with non-conventional sources** (civic mobilizations, real estate dynamics, ecological signals), offering a **comprehensive interpretive framework** of the ongoing processes. Mapping thus becomes a critical practice—not only for representing the current state of places, but for visualizing tensions, delays, and potential spaces for reactivation.
Thanks to the use of these tools, guiding principles and criteria for the design of the transition of multi-risk contexts toward more circular and inclusive cities will be defined and validated. These principles will be at the base of the **Proof of Concept**, proposed as a flexible and replicable model to guide urban regeneration processes in other multi-risk contexts across Europe.

Research Glossary

The Research Glossary for Task 5.4.4 – intended to be integrated into the RETURN Glossary[1] - has the ambition of defining a field of work by outlining the key terms and central concepts analysed. It provides an overview of the different concepts that are used throughout the deliverable, referencing both foundational and most recent literature. Being the outcome of a transdisciplinary work, this T5.4.4. Research Glossary aims to merge different disciplinary perspectives to have a shared understanding of the most complex concepts that are crossing disciplines. The Research Glossary includes n. 20 terms that have been developed by the participants of the Task to reach these aims.

Brownfield

In the last decades of the previous century, the phenomenon of decommissioning has resulted in a vast range of brownfields across the globe. The European Environment Agency (EEA) defines brownfields as 'land within the urban area on which development has previously taken place' (EEA Glossary). According to the Concerted Action on Brownfield and Economic Regeneration Network (CABERNET) brownfields are sites that: (1) have been affected by the former uses of the site and surrounding land; (2) are derelict and underused; (3) may have real or perceived contamination problems; (4) are mainly in developed urban areas; and (5) require intervention to bring them back to beneficial use' (CABERNET, 2003). Even if no official common definition of brownfields exists in Europe (Morar et al. 2021; Rey, Laprise, Lufkin, 2022) and at the transglobal level, brownfields can be understood as areas, within or close to the urban fabric, which have completed one of their lifecycles —productive, infrastructural, logistic, extractive, etc.— and are in waiting of a new one, strategic soils where to launch innovative processes of urban regeneration. Redevelopment of brownfields is nowadays still a complex issue, even more so in the case of contaminated sites, and simultaneously represents a core opportunity for sustainable urban development.

Circular city

A circular city promotes the transition from a linear to a circular economy in an integrated way across all its functions in collaboration with citizens, businesses, and the research community. This means in practice fostering business models and economic behavior which decouple resource use from economic activity by maintaining the value and utility of products, components, materials and nutrients for as long as possible to close material loops and minimize harmful resource use and waste generation. Through this transition, cities seek to improve human well-being, reduce emissions, protect and enhance biodiversity, and promote social justice, in line with the Sustainable Development Goals. (Circular cities declaration, 2020).

[1] For the RETURN glossary please refer to: DV 5.2.1 - Risk-oriented taxonomy and ontology of urban subsystems and functional models, Appendix 1

Circular Economy (CE)

Circular Economy (CE), defined in more than one hundred ways so far (Kirchherr et al. 2017), it represents an alternative to the current linear economic model which is based on the logic of unlimited growth: 'take, make, waste'. The circular economy proposes a closed loop of resources, which can be reinputted into the consumption cycle as secondary raw materials. CE aims, in this way, to reduce the consumption of virgin resources and to minimize waste by maximizing reuse and recycle processes. It is based on three fundamental principles: eliminating waste and pollution, reusing products and materials, and regenerating nature (Ellen MacArthur Foundation, 2015). In the context of resilient cities, CE can be applied across a wide range of sectors, including waste management, construction, and energy production.

Critical urban context

Critical urban contexts are areas ‹‹where single or interconnected hazards, along with exposure and vulnerability conditions, determine higher risks›› (Sferratore et al. 2024). Higher-risk areas correspond to hotspots where to implement climate-resilient strategies to reduce vulnerability. Multi-risk contexts are therefore identifiable as critical urban contexts for the coexistence of different risk conditions that ask for a systemic approach in terms of risk management, adaptation, and mitigation in synergy with territorial and urban planning.

Circular Urban Metabolism (CUM)

Circular Economy (CE) investigations are closely intertwined with Urban Metabolism (UM) studies, which also encompass the landscape dimension, as well as planning and design approaches (Mazzarella & Amenta 2022). CUM aims to integrate different research fields merging Circular Economy and Urban Metabolism approaches to foster interdisciplinary collaboration in urban planning and management, offering a new framework that simplifies complexity and promotes sustainable cities (Lucertini & Musco 2020).

Co-design

Extending participatory design and co-creation (Sanders and Stappers, 2008), the co-design approach (see also DV- 5.5.2 - City-scale exercise preparation and setup report) enables the creation of a shared language between users and designers, understanding the new product from the viewpoint of all participants (Ardito et al. 2012). Co-design attempts to actively and equally involve all stakeholders in any design process activity, individuating diverse roles for co-design team members: users become co-designers as "experts of their experience" while researchers and professionals become facilitators to ease users' expression of creativity (Dodero et al. 2014).

Environmental Justice (EJ)

The concept of Environmental Justice was introduced in the United States in the 80s (Holifield, 2015) and it has been linking the protection of the environment and public health to the theme of injustice and civil rights. Studies show how the choices of location of environmental hazards were disproportionately located in areas with predominantly minority populations, and they have supported activists in important fights for civil and environmental rights (Bullard,1983;

Sedrez & Biasillo, 2022). EJ underlies the issue of recognition and knowledge of groups and communities in environmental processes and their right in participating in environmental and spatial decisions.

Hazard

A process, phenomenon, or human activity with the potential to cause loss of life, injury, or other health impacts; property damage; social and economic disruption; or environmental degradation. Each hazard is characterized by its location, intensity or magnitude, frequency, and probability of occurrence. Many hazards are socio-natural, influenced by both natural and human factors, including environmental degradation and climate change (UNDRR, 2016).

Health and Environmental Risk Analysis

A site-specific analysis of the effects on human health resulting from prolonged exposure to the action of substances present in contaminated environmental matrices, conducted with the criteria indicated in Annex 1 to Part IV of Part IV, Legislative Decree 152/2006.

Multi-Risk

Risk generated from multiple hazards and the interrelationships between these hazards and considering interrelationships on the vulnerability level (Zschau, 2017).

Orphan sites

A potentially contaminated site where the remediation procedure provided for in Article 244 of Legislative Decree 152/2006 has not been initiated or concluded, for which the person responsible for the pollution cannot be identified or fails to comply with the requirements of Title V, Part Four of the same Legislative Decree (Art. 2, MASE Decree December 29, 2020).

Remediation

Set of measures necessary to eliminate the sources of pollution and pollutants or to reduce the concentrations of the same in the soil, subsoil and groundwater to a level equal to or below the values of the risk threshold concentrations (CSR) (Article 240, Title V, Part IV, Legislative Decree 152/2006).

Territorial Metabolism

Territorial metabolism refers to the recircularization of urban/territorial/regional metabolism paradigm. It promotes synergies between city and hinterland (operational landscapes supplying goods and products) through strategies such as the pooling of resources, the reduction of distances between places of residence and work as well between place of production and consumption (Barles, 2018; Brenner, 1999; Brenner & Katsikis, 2020). It clashes with administrative issues and political-economic barriers (Bortolotti, 2023).

Urban and Territorial Risk

A condition that highlights the weakness and exposure of urban and territorial areas, natural or artificial, to environmental, technological or socio-economic threats. It arises from the interaction between hazards (e.g. natural disasters, economic crises, exposure to pollution), exposure (people, infrastructure, ecosystems and resources within the area) and weakness (ability to resist, adapt and recover from adverse events). This concept is rooted in interdisciplinary approaches, which integrate environmental science, socio-economic analysis, and urban planning to assess and mitigate risks effectively. (IPCC, 2021 Ar.6, Cutter, 2003).

Urban Metabolic Risk (UMR)

The linear urban metabolism characteristic of contemporary cities and territories disperses numerous waste products from political, economic, spatial, ecological, and social production processes across the landscape. These range from the decommissioning of entire urban areas no longer generating value to pollution and contamination associated with production systems. Urban Metabolic Risk refers to the cumulative negative impacts of urban metabolism on territory and communities. The presence of UMR undermines quality of life and creates significant challenges for urban regeneration initiatives. Urban Metabolic Risk is associated with stagnation and prolonged expectation of transformation.

Recognizing **"Urban Metabolic Risk"** as the relationships between the life cycles of cities and risks, requires adopting a **"non-standard" approach**, not hazard-specific (Saja et al., 2019), but rather looking at the systemic and ongoing inefficiency of urban and territorial life cycles, a context-specific approach deeply embedded in local political-ecological process. (Piccirillo et al. 2024)

Urban Metabolism (UM)

This term describes the flows of materials and energy, the endless transactions of inputs and outputs that pass through the urban system (Wolman, 1965). It has been defined as a lens and as a method to read and interpret contemporary cities and for modeling complex urban systems' material and energy streams considering the city as an ecosystem (van Timmeren, 2014). It serves as a metaphor, comparing the dynamic equilibrium of biological organisms as they grow and reproduce to the growth of a city and its outcomes, such as consumption, production, and waste. Resilient cities should have an efficient and sustainable urban metabolism that minimizes environmental impacts and enhances resilience to risks.

Urban Living Lab (ULL)

ULL (see also DV- 5.5.2 - City-scale exercise preparation and setup report) is a dynamic physical and virtual environment for co-designing solutions with stakeholders, including public bodies, private entities, citizens, and other identified subjects. It frames risk not as isolated events but as integral to complex urban processes and multi-risk interdependencies. They serve as multi-actor ecosystems (Engez et al., 2021) applying Circular Economy principles to build resilient, eco-innovative scenarios. ULLs can indeed drive transformative change in sustainability transitions (von Wirth et al. 2019), fostering co-governance and positive community impact.

Urban Political Ecology (UPE)
Urban Political Ecology (UPE) is a conceptual approach that understands urbanization to be a political, economic, social, and ecological process that often results in highly uneven and inequitable landscapes. Cities are seen not as the antithesis of nature but rather as a second nature, representing the dominant form of living in the contemporary age (Cornea, 2019). An urban political ecological perspective permits new insights into the urban problematic and opens new avenues for re-centering the urban as the pivotal terrain for eco-political action (Swyngedouw, 2006).

Urban Regeneration
Urban regeneration is a comprehensive approach that describes an urban-scale transformation process involving both the redevelopment or reuse of buildings and open spaces, and the generation of new social, cultural, and economic opportunities of a public and public-private nature (Pileri, 2020). In contrast to urban expansion, it prioritizes land conservation, community engagement, and environmental sustainability in urban development.

Wastescape
The definition of wastescape has been developed in the framework of the Horizon 2020 Research project REPAiR. Resource Management in Peri-urban Areas (REPAiR 2018). Wastescapes are territories (built entities, infrastructures, and open spaces) that are in a transitional phase, meaning that they are underutilized, abandoned, polluted, or at the end of their planned life cycles, therefore in need of transformation and redevelopment. At the same time, they can be reservoirs of biodiversity so they can be preserved as they are to ensure the preservation of the different species. The lens used to reinterpret wastescapes is to consider them as opportunities for sustainable urban and territorial regeneration, for a better quality of life of all the (human and non-human) inhabitants (Amenta, van Timmeren 2018, 2022).

1 Introduction. Definition, objectives and structure of Task 5.4.4

Task 5.4.4 "Towards a circular metabolism for urban and metropolitan settlements" is part of WP4 of the RETURN project "Multi-risk science for resilient communities under a changing climate", Extended Partnership PE3, "Natural, Environmental, and Anthropogenic Risks," funded by the European Union – NextGenerationEU, National Recovery and Resilience Plan – PNRR (link: https://www.fondazionereturn.it/).
In line with the overall objectives of the project, the Task 5.4.4 contributes to strengthen the understanding and awareness on environmental, natural, and anthropogenic risks - towards a **circular city model** - by interpreting the complexity of their interactions in response to contemporary spatial, environmental, and socioeconomic challenges, imagining intervention strategies aligned with European and global strategic agendas (SDGs, The New Urban Agenda, European Green Deal, etc.).
To define a circular city model, the task 5.4.4 aims to develop an approach based on **circular territorial metabolism in multi-hazard critical urban contexts** to drive the **transition towards a more resilient, sustainable and inclusive city**. The task 5.4.4: (i) systematizes the **circular economy principles applied to risk mitigation measures**; (ii) applies a **circular urban metabolism approach** on a case-study at urban and metropolitan scale to hazard and risk mitigation; iii) proposes **design criteria for reducing risk exposure and enhancing awareness among communities** for circular regeneration processes in multi-risk contexts. To define a circular city in multi-risk contexts, the task intertwines desk research and co-creation activities developed in three phases (please refer to deliverable 5.5.2) (Fig.1) experimented in a real-world setting, such as the test case of Bagnoli-Coroglio Site of National Interest (SIN), in Naples, Italy.

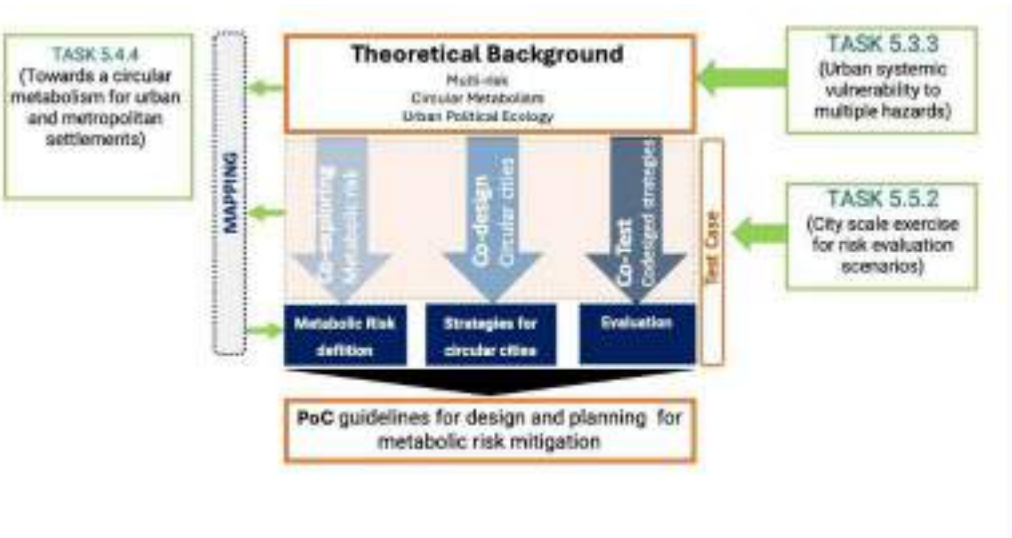


Figure 1 - Structure of the task 5.4.4 and connection with other tasks. Source: authors' elaboration

The deliverable DV 5.4.5 "Evaluation framework for monitoring circularity, sustainability and resilience of urban metabolism" is organized in two parts.
The part 1 of the deliverable studies the challenges and the potentialities of the application of Circular Urban Metabolism (CUM) principles in relation to multi-risk critical urban and territorial contexts, aimed at risk prevention, adaptation and mitigation, in accordance with the

1st WP4 activity report[2]. DV 5.4.5 intends to understand, at different levels and scales, considering the material and immaterial interactions among different overlapping risks, the application of possible circularity approaches in multi-risk critical urban context, starting from the analysis of theoretical approaches and best practices. Additionally, DV 5.4.5 provides, in the first part, a bibliographic review and a theoretical reflection for the definition of the concept of "urban metabolic risk" applied to urban and territorial contexts.
The part 2 of the DV 5.4.5 aims to define fundamental principle for applying CUM theoretical approaches and metabolic risk analysis to critical multi-risk urban and territorial contexts, starting from the test case of Bagnoli SIN area (Naples).
The first part of the deliverable builds a theoretical framework based on the contribution of Urban Political Ecology (Heynen, Kaika and Swyngedouw, 2006) and Circular Urban Metabolism for promoting a more integrated management of risks in multi-risk contexts, starting from territorial and urban design of sustainable cities (Lucertini & Musco 2020), also taking into account the concept of urban systemic vulnerability (task 5.3.3) and delving into the concept of Urban Metabolic Risk (UMR).
The second part of the deliverable aims at defining design principles, based on the test case of Bagnoli. The intervention principles (e.g. co-design tools, co-created scenarios) help to design actions and strategies for risk mitigation also taking into account the sustainable management of local material and territorial resources.
By engaging with multistakeholder and user-centered environments thanks to the Urban and Territorial Living Labs approach (please refer to Deliverable 5.5.2 - City-scale exercise preparation and setup report) in the Bagnoli area—and in alignment with the mid-term activity report of WP4[3], principles for design in multi-risk contexts will be shaped and validated. They will finally converge in the Proof of Concept presented in chapter five of the deliverable.
The aim of the design principles is to orient a (co-)design process able to reduce multi-risks exposure in critical urban and territorial contexts to create safer and more sustainable environments for all also thanks to the definition of co-developed solutions. The design principles are based on circularity to support decision-making processes in Urban Living Lab settings, to enhance the quality of life of settled communities.
Considering the specific objectives of WP4, in which Task 5.4.4 is integrated, the task aims to achieve the following sub-objectives:

[2] Task 4.4 sees UniVE, UniNa, UniFi, EURAC, and Eni Rewind systematizing circular economy principles for risk mitigation. UNIGE, EURAC, and UniFi define indicators for closing the cycle at the urban level and a Circular Action Plan for urban regeneration. System thinking and system dynamic modelling are proposed tools for testing, along with guidelines for reducing risk exposure in regeneration projects at the local scale.
[3] A strategic approach to Comprehensive Risk Management for urban settlements has been discussed and partially elaborated, which is based on the identification and modification of current decision-making processes; A set of key performance indicators (KPIs) has been discussed and defined to work on the assessment and analysis of the current conditions of urban and metropolitan systems and proposed solutions; In cooperation with TS3, current best practices were collected and systematised in order to organise a reference catalogue, also with the aim of using it to define KPIs.
Five case studies and related risks domains were discussed and defined: Bagnoli Coroglio (Risks: anthropic, metabolic, soil pollution), Meisino Park, including disused industrial area and Po Park (Risks: hydrogeological); Bisenzio river basin(Risks: hydraulic, hydreogeological); Functional Urban Area / Cagliari Metropolitan Area and Cagliari Municipality (Risks: hydraulic, Heat waves, air pollution/CO2 emissions); Soccavo (Risks: Heatwaves, UHI); Bolzano (Risks: UHI, Heat waves).

i. systematizing circularity principles to identify risk adaptation and mitigation measures;
ii. monitoring vulnerability (cf. DV 5.3.3) and enhancing circularity, sustainability, and resilience in critical urban contexts to support the transition from a linear to a Circular Urban Metabolism (CUM) with a strong link to the methodological framework of Urban Living Labs (cfr. DV 5.5.2), based on co-creation and inclusion processes;
iii. Defining the concept of Urban Metabolic Risk (UMR) in urban and territorial contexts, also underlying the different factors and elements that make it possible to identify and map it;
iv. proposing design principles to guide the planning of circular and risk-resilient cities, with a practical application case for validating the proposed model: Bagnoli (Naples).

The objectives are achieved through an ecosystemic, multiscale, and transdisciplinary approach, enhancing engagement with the local community and stakeholders involved through Urban Living Labs, and closely examining natural and anthropogenic risks (e.g., soil pollution, etc.).

To this end, the Deliverable, leverages the diverse expertise of the various organizations and research groups participating in the task and proposes the following structure: after this introduction which frames the problem, challenges, and objectives to be achieved in the task (Chapter 1 of the Deliverable); chapter 2 develops a shared understanding of the metabolism of multi-risk territories through the definition of metabolic risk in cities and territories (Chapter 2 of the Deliverable); chapter 3 introduces circular approaches to risk mitigation and adaptation through sustainability- and inclusion-oriented strategies and practices for urban regeneration both in planning and environmental remediation domains (Chapter 3 of the Deliverable); chapter 4 presents the test case of Bagnoli-Coroglio, with descriptions and maps (Chapter 4 of the Deliverable); chapter 5 introduces the result of some tests on the area of Bagnoli (Chapter 5 of the Deliverable); last chapter 6 introduce Design Principles for the regeneration of multi-risk urban and territorial contexts by using the CUM approach for risk mitigation and adaptation strategies (Chapter 6 of the Deliverable).

Part 1. THEORIES AND APPROACHES FOR PLANNING CIRCULAR CITIES

2 Understanding Circular Urban Metabolism (CUM) in multi-risk urban and metropolitan contexts: defining Urban Metabolic Risk

2.1 Circular Urban Metabolism. The challenge of applying Circular Economy and Urban Metabolism principles toward circular cities

Circular Urban Metabolism (CUM) incorporates the concepts of Circular Economy (CE) and Urban Metabolism (UM) in the transformation of cities, by integrating material and landscape dimensions as well as planning and design approaches into urban development (Mazzarella and Amenta, 2022). CUM offers a new framework that simplifies complexity and promotes sustainability in cities (Lucertini and Musco, 2020). Nevertheless, applying the concept of CUM to cities – for understanding and designing urban processes - presents several challenges. The main challenges of CUM implementation to cities include defining the spatial boundaries of resource flows to be considered, the need for up-to-date, open source, and relevant data, understanding the relationships between different flows and the complexity of integrating different disciplines (Lucertini and Musco, 2020).

Cities, understood as complex organisms, are key actors in the management and consumption of resources, energy, human and materials flows, thus representing a crucial node in sustainable development policies. The implementation of sustainable urban projects, the improvement of lifecycle analyses of spaces and materials, the rethinking of resource flows and the adoption of a systemic approach are all necessary elements to integrate the concept of CE and UM into urban development and thus make the transition to circular cities operational.

Circular economy applied to economics - the conceptualization of a regenerative economic system that aims to eliminate or better reconfigure the concepts of waste and pollution by keeping products, components and resources in use for as long as possible, continuously reintroducing them in production lifecycles (MacArthur, 2013) - offers an innovative perspective that recognises the intrinsic value of waste, whether material or immaterial. Transferring this concept to the urban context means that resources previously considered useless or obsolete, such as construction and demolition materials, waste in general, as well as degraded areas or even marginalised communities, can be reintegrated and reclaimed into the city's life cycle, closing or improving otherwise dispersed/fragmented loops. Circular economy principles applied to urban context/settings allow for the assessment of buildings and infrastructure lifecycles, as well as their environmental and urban impacts (Russo, 2018). This operational framework marries quite well the Urban Metabolism metaphor and its application to urban contexts (Wolman, 1965): CE could play a significative role in the implementation of a sustainable UM (Cui, 2022).

UM is known as “the sum total of the technical and socio-economic processes that occur in cities, resulting in growth, production of energy, and elimination of waste” (Kennedy et al.

2007). Inefficiencies in UM create gap in terms of urban and territorial sustainability, amplifying anthropic pressure, vulnerability, conditions of risk such as resources scarcity and marginalization of discriminated communities. In this context, industrial ecology (Ayres, 1989a; Andrews, 2002) provides a useful framework for deepening the concept of UM and the crucial role it can play in territorial planning. Circular Urban Metabolism integrated approach not only improves resource efficiency reducing their environmental impact and promoting their self-sufficiency but also increases the resilience of cities. The introduction of the Circular Urban Metabolism (CUM) concept, generated from the merging of CE and UM, supports the transition toward circular and regenerative metabolism.

Making CUM effective requires a coordinated effort by all stakeholders, together with the implementation of technological tools, innovative policies and strong community support because the CUM application to cities faces several **complex challenges** that go beyond the simple management of resource flows. One of the main difficulties relates to regulatory **fragmentation and the lack of integrated governance** (Piccirillo, Pastena, Vingelli, Russo, 2024). Cities often operate in a context of non-harmonised rules, which makes difficult policies coordination between local, regional and national levels and requires a more cohesive vision and optimised collaboration between the various entities involved.

The **involvement of local communities** is another element to take into consideration. The transition to a circular urban model cannot be effective without the support and active participation of citizens. However, there is often a lack of awareness of the benefits this approach can produce, and decision-making processes risk being perceived as distant or not inclusive. Therefore, raising awareness and encouraging dialogue—placing citizens at the center as agents of change—is essential.

A further challenge is the **cultural and institutional transformation** required to move from a linear to a circular model. This change demands a profound revision of administrative practices, business strategies and citizens daily habits. This is a long process that requires not only time but also investment in training and policies capable of stimulating a new way of thinking, more oriented towards sustainability and collaboration.

Considering the unique characteristics of each city make standardized solutions hard to apply, defining common guidelines proves both urgent and necessary.

Urban contexts are under increasing pressure to meet the needs of a growing population in a limited space which made cities one of the contexts where land consumption is more striking - according to the National System for the Protection of the Environment Report 2022 (SNPA, 2022), more than 70 per cent of global land consumption is related to urban sprawl -, it is increasingly important to develop circular solutions for territories. For example, survey and cataloguing abandoned areas, underused buildings and spaces – namely wastescapes - or unused material resources is a prerequisite to identify potentialities for redevelopment, avoiding urban sprawl and land consumption. This approach maximises the use of existing resources, reduces environmental impact and promotes efficient, sustainable and inclusive urban development. This approach offers the opportunity to rebalance the deranged relationship between built spaces and natural habitats, by recovering and valorising wastescapes as a first strategy.

Finally, the transition to circular cities emphasises the necessity of creative frameworks, collaborative tactics, and strong regulations to balance urban expansion with environmental sustainability.

2.2 The impact of Urban Political Ecology and Environmental Justice in defining CUM approach in multi-risk contexts

In multi-risk urban contexts, where exposed elements and risks overlap, interpretative approaches and tools of metabolic urban planning can contribute to investigating the relationships between processes of urban metabolism, such as the production of space and flows, communities, territorial vulnerabilities and risks. According to the theoretical frame of Urban Political Ecology (UPE), urban and territorial metabolism is a socio-environmental process that produces a series of social, political and environmental conditions that can either enable or constrain (Heynen, Kaika, Swyngedouw, 2006) groups and communities living in those territories. From this perspective, implementing mitigation and adaptation processes in multi-risk contexts requires consideration of the entire life cycle of crisis territories and regeneration processes. This expands the scope of urban design beyond achieving optimal spatial configurations to address the dynamics, potentials, and conflicts of the entire transformation process. Prolonged and ineffective regeneration processes can, in fact, undermine the involvement and trust of the communities living in crisis-affected territories, and who bear the social, economic, and spatial consequences. Moreover, it is crucial to consider that metabolic transformation processes are never socially or ecologically neutral, as they produce negative impacts on communities. Embracing a metabolic and systemic approach means going beyond isolated issues such as functional degradation or social marginalization and instead framing them within a broader understanding of territorial dynamics. This allows to identify and analyze a wide range of situations that share a common demand for environmental justice (Palestino, 2022).

Complementary to UPE, the theoretical frame of Environmental Justice (EJ) has also linked the protection of the environment and public health to the theme of unequal access to environmental good as well as inequalities in the exposure to hazard, looking at local scale. Based on grassroots approach EJ supported activists in important fights for civil and environmental rights (Bullard, 1983; Holifield, 2015). The idea of environmental justice expanded overtime to include participation and the ability of local communities to influence decisions that concern their rights. It also emphasizes the importance of recognition and visibility of different groups in environmental processes (Gemmiti et al., 2022).

The EJ movements have contributed to: drawing attention to the intrinsic spatial character of justice; affirming the inseparable relationship that links social justice to the theme of environmental management and plans for sustainable development; and finally manifesting the usefulness of reading development and environmental transformations also in the key of place-based discrimination (Gemmiti et. al., 2022; Nayak, 2019).

At a larger scale, UPE suggests that in urban and metropolitan contexts, global flows of political, economic, social, and ecological processes often result in highly uneven and inequitable landscapes and communities (Cornea, 2019). According to the UPE approach, nature and cities are not to be considered in antithesis or separate from each other. Cities and nature are combined in historical-geographical production processes: the process of urbanization is an integral part of the production of new environments and new natures (Heynen, et al. 2006). In this perspective cities are considered as a second nature (Lefebvre, 1976), representing the dominant form of living in the contemporary age, a "hybrid nature" (Swyngedouw, 2013) which has replaced the previous one and is shaped on the functioning of the socio-economic system varying from "the manufactured and manicured landscaped gardens of gated communities and high technology campuses to the ecological warzones of depressed neighborhoods with asbestos covered ceilings, waste dumps and pollutant-infested areas" (Heynen, et al. 2006). Urban process fundamentally constitutes a political-ecological process, one that shapes the process of production of urban natures (Swyngedouw, Heynen, 2003).

Urban political ecology scholars have regularly used the metaphor of metabolism to designate these complex processes of urbanization of nature. According to historical materialism, metabolism is used to describe the tireless work of human beings in appropriating, using and dumping natural resources (Foster, 2000; Gandy, 2022); these metabolisms contribute to produce enabling social and spatial conditions for strong groups, and to marginalizing more vulnerable individuals and communities.

The different impacts and capabilities of populations to react to a damaging event has to do with the concept of vulnerability characterized by political, economic, social and therefore spatial dimensions (Wisner et al., 2012; Saatcioglu & Corus, 2018). The multidimensionality perspectives (see DV 5.3.3) integrate the root causes and processes that produce vulnerability with observable components. Considering in vulnerability conceptualization these context-dependent factors as underlying risk drivers opens for a shift in the understanding of vulnerability from a focused concept (for example limited to physical resistance of engineering structures) to a more holistic and systemic approach (Schneiderbauer et al. 2017, Sarmiento 2018). Systemic vulnerability of cities is significantly influenced by social inequalities, as disparities in wealth, access to resources, and political power shape how different communities experience and recover from urban risks (Adger, 2006).

For example, in the case of health risks resulting from exposure to pollutants and toxic elements some populations may be more exposed because they are geographically closer to the polluting source. Moreover, even when toxic substances circulate more widely, as in the case of contaminated food or water, some human populations are more vulnerable than others as they do not have access to means of self-protection: e.g. eating organic and expensive food (Wescoat, 2015). The political consequences of industrial contamination have, therefore, frequently been interpreted through the methods of Political Ecology. This framework poses challenge to traditional physical and behavioral methods used to study disasters as it encouraged research oriented on how people are vulnerable to these disasters (Wescoat, 2015). Moreover, by connecting with development studies, Political Ecology helps focus on the geographic and spatial aspects of risk reduction research.

In this frame, criticalities do not lie on an unsustainable city or risk-exposed area in general, but rather there are different urban, environmental and social processes negatively affecting some communities and populations benefiting others (Swyngedouw & Kaika, 2000), confirming inequalities according to class and economic status "social risk position", although risks may bring also a different distributional logic into play and additionally produce new international inequalities (Beck, 1992). This view can also be observed in an urban area exposed to risk or damaged by a hazardous event where the inhabitants of the area, their property, homes and communities may be damaged by the disaster event; while for property developers, a post-disaster reconstruction can represent an opportunity for investments.

From this perspective, processes of spatial-environmental change are, therefore, never socially or ecologically neutral and urban metabolic research for risk reduction needs to consider the question of "who gains and who pays" (Swyngedouw, 2006), and to ask questions about the network of power relations through which deeply uneven spatial and environmental conditions are produced and maintained. Conflicts between interest groups to maintain their spatial privileges can eventually affect the sustainability and efficiency of transformation processes. Therefore, resilient, metabolic-informed urban planning must answer questions of equity and power: who stands to gain, who bears the cost, and whose voices are included in the decision-making process. Recognizing the interests of inhabitants, institutions, stakeholders, and non-humans is vital. Only through inclusive, multi-scale governance transformation pathways can become sustainable, fair, and effective.

2.3 The emergence of Urban Metabolic Risk

Theoretical speculation on Circular Urban Metabolism informed by the Urban Political Ecology and Environmental Justice frameworks suggests a deeper analysis of the existing relationships between Urban Metabolism and risks in multi-risk urban contexts. With this aim, we developed a bibliographic review led to understand the use of an emerging and still unexplored concept: the Urban Metabolic Risk (UMR).

This section presents the methodology and the outcomes of the interdisciplinary and systematic literature review. To effectively addresses the complex research objective, the first step consisted in conducting a thorough investigation of the current knowledge base through a scoping review, following the method proposed by Arksey and O'Malley (2005). This systematic and exploratory methodology is chosen for its ability to provide a comprehensive overview of the existing knowledge by highlighting key concepts, identifying gaps in the literature and delineating areas of uncertainty or controversy. The scoping methodology facilitates the integration and synthesis of a wide range of sources and approaches within a complex, multidisciplinary study.

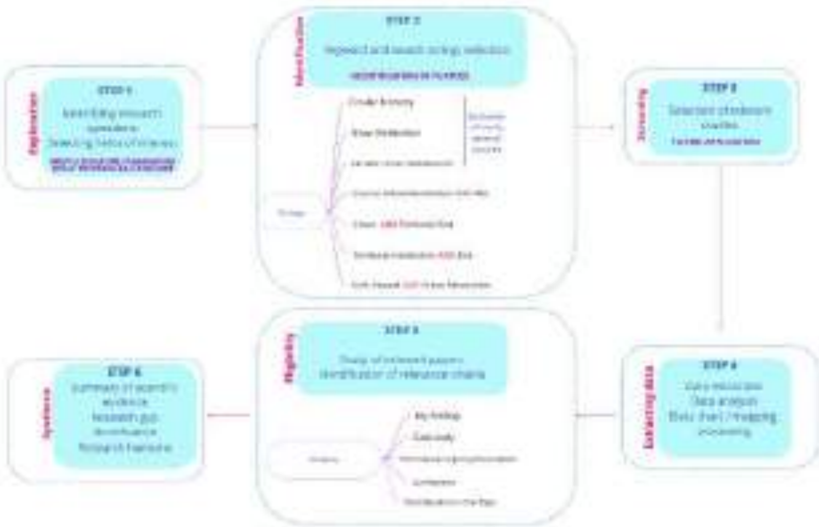


Figure 2 - Flowchart of the scoping review. Source: authors elaboration

The methodology comprises **six different steps**, which can be described as exploration, identification, screening, data extraction, eligibility and synthesis (Fig. 02):

i. The “**Exploration step**” involves selecting fields of interest and identifying the research questions, looking at an early reference literature and the grey literature framework;

ii. The “**Identification step**” consists of identifying and compiling the keywords and defining the search strings useful for exploring the database. This second phase allows for effective structuring of the research tools and focus the investigation on the topics and concepts relevant to the project;

iii. The “**Screening step**” focuses on identifying the subject areas to which the sources belong, followed by the selection of twenty papers of interest to the topics under investigation. This procedure enables limitation of the corpus of analysis to the most relevant contributions, thus ensuring methodological coherence with the objectives of the research project;

iv. The “**Extracting data step**” regards the data extraction and analysis of the selected studies, their mapping and processing;

v. During the “**Eligibility step**”, the structuring of a summary table allows an accurate and comparative assessment of the different selected studies, while defining relevance criteria. The table contains key categories that enable a systematic analysis of the individual contributions. In the first section, the table collects basic information such as the source of the study, the name of the authors or research group, the year and the type (ex: Journal Article, Conference Proceedings, etc.) of publication, to provide a detailed and precise reference for each work included. This is followed by a column dedicated to the topic covered, allowing the thematic area of each research paper to be quickly identified, making it easier to recognize the most important contributions. A further section summarizes each study’s keywords and main findings, providing an immediate overview of the central concepts and relevant results and allowing a direct understanding of the main content. A further column is reserved for specific case studies, detailing the specific contexts to which each piece of research is applied, so that it can be seen how each contribution relates to real situations and provides practical examples. To assess the relevance of each study to the research objectives, the table also includes a section addressing the pertinence and innovation of the contributions. This section is accompanied by a column highlighting the limitations of each study. Methodological limitations are highlighted and areas that could benefit from further research are identified. Finally, the table includes a column outlining the specific contribution of each study to the overarching research theme. This allows to understand how each paper enriches the existing literature and its role in improving and deepening the overall knowledge framework. This organized and methodological structure facilitates understanding and comparison between the different studies selected and identifies any gaps and strengths in the existing literature. The table, therefore, supports an effective synthesis of the information and evidence gathered and encourages critical analysis, which is essential for the subsequent stages of the research process.

vi. Finally, during the "**Synthesis step**" the process is concluded with the graphing and synthesis of the data, which emphasizes both the research gap and the research future horizons.

With the methodological structure in place, the focus shifted towards understanding how the selected literature speaks to the intersection of urban metabolism and multi-risk scenarios. The literature review combined a quantitative data analysis to identify a significant body of scientific literature on urban metabolism in multi-risk contexst with a qualitative filtering phase. This qualitative phase focuses on the selection and in-depth analysis of content extracted from a selection of 20 relevant scientific articles. This rigorous methodological approach results in a comprehensive overview of current research and trends in the field of circular urban metabolism, with a focus on risk management and the promotion of urban sustainability. The main objective of this process is to establish a solid methodological foundation necessary to guide the subsequent research steps in order to answer specific and relevant questions within the study domain.

The literature review has been conducted using the **Scopus indexed web database**, selected for its comprehensive and multidisciplinary coverage to ensure broad access to relevant academic literature and high quality, relevant data. Managed by Elsevier, one of the world's leading academic publishers, Scopus contains more than 75 million documents from 25,000 peer-reviewed journals, books, conference proceedings and other sources of proven scientific value (Scopus.com). The platform covers a wide range of disciplines, including life sciences, social sciences, physical sciences, and health sciences, thus ensuring a multidisciplinary coverage that is critical for contemporary academic research. Scopus, being a database of multidisciplinary scholarly literature, also includes the subject of urban planning by framing it under the subject areas of Urban Studies, Architecture. In addition, the Scopus platform offers rigor in source selection processes, ensuring that only high-quality and scientifically relevant materials are included in the database. Through the analysis of this data, it is possible to identify the most influential publications and understand what lines of research the scientific community is moving along in relation to the selected topics.

Furthermore, the Scopus platform provides rigorous source selection procedures, guaranteeing that the database contains only top-notch and scientifically significant items. The most important papers may be found and the directions the scientific community is taking in regard to the chosen topics can be understood by analysing this data.

Titles and abstracts retrieved from the Scopus database are examined for appropriate sources, followed by the reading of selected articles in full to confirm their relevance.

A set of clearly defined research questions guides the selection of articles with the aim of assessing both the quantity and quality of available evidence (Grant & Booth, 2009). The chosen approach aims to comprehensively explore the research landscape and identify emerging trends, interdisciplinary links and key knowledge gaps in the field of sustainable urban planning, urban metabolism and risk studies.

The initial exploratory phase involves the identification of keywords and the construction of the search strings of interest. The study focuses specifically on three research questions according to which the keywords and strings have been selected:

i. What is the state of the art regarding the integration of risk management and urban metabolism studies?
ii. What thematic nodes, strategies, and tools are emerging as possible integration of the two approaches?
iii. Does the concept of Urban Metabolic Risk provide a key perspective for understanding how risk factors emerge and interact within urban dynamics, shaping planning and design processes?

The aim of the literature review is to confirm whether a **scientifically suitable definition of "Urban Metabolic Risk" exists** by identifying the disciplines that address this topic and the less explored or more promising lines of research.

Keywords selection is a crucial step in efficiently and accurately identifying relevant literature, ensuring a comprehensive overview of the study topic. The search strings selection criteria are relevance, specificity, topicality, and consistency. Keywords were combined using Boolean logical operators (AND, OR) to broaden or narrow the field of inquiry (Boole, 1854).

The systematic and methodical approach to the literature review materializes in the most relevant databases selection, and the application of inclusion and exclusion criteria to filter relevant papers.

The keywords initially explored are circular economy, urban metabolism, and urban circular metabolism. However, the resulting sources were excessively numerous and diverse. For this reason, more targeted search strings have been developed by the research team, namely: “Circular Urban Metabolism AND Risk,” “Urban AND Territorial Risk,” “Territorial Metabolism AND Risk,” and “Multi-Hazard AND Urban Metabolism”. These strings reflect the need to explore the complex relationship between the concept of urban metabolism and the dynamics of risk and sustainability, in a context of increasing urban vulnerability. The research strings cover a broad spectrum of interconnected concepts, allowing the collection of useful information to map current scientific sources that take an integrated approach between circular economy, urban metabolism and risk management and reduction. In the long run, the goal is to promote a more resilient and sustainable urban model.

The investigated search strings, containing keywords linked via Boolean logical operators, provide an initial overview of topics of interest. These topics, widely adopted in many disciplines globally, show an upward trend in scientific production since the early 2000s, with exponential growth since 2010. This increase indicates a strong interest of the scientific community in the advancement of knowledge regarding sustainability and community resilience. As can be seen from the graph below the number of publications in this area has increased exponentially from 2015 to the present This trend highlights a growing interest of academia, the scientific community, and institutions in understanding and managing risks in urban areas and territories. In particular, there is a significant spike in publications from 2020 onward. This increase can be attributed to several factors, including increased awareness of climate change impacts, increased frequency and intensity of extreme natural events, and increasing global urbanization. The COVID-19 pandemic has further accentuated the importance of territorial and urban risk study and management capacity, as it has highlighted the vulnerability of cities to large-scale health emergencies. In addition, the UN Global Assessment Report on Disaster Risk Reduction (GAR) was published by UN Office for Disaster Risk Reduction (UNDRR) in 2022, conducting an in-depth analysis of disaster risks globally, highlighting emerging trends and new challenges, and emphasizing the need for an integrated approach to disaster risk management, including reducing vulnerability and strengthening resilience.

However, some methodological limitations of the study should be acknowledged. The exclusive reliance on the Scopus database, while widely recognized and authoritative, may have excluded relevant contributions from other platforms. Moreover, the interdisciplinary complexity of the topic and the formulation of the search strings—though carefully constructed—might have limited the diversity of perspectives included. These aspects potentially affect the completeness and balance of the proposed analysis.

Furthermore, the Scopus database shows that the majority of publications come from Europe, North America and China, while areas such as Latin America, Africa and South Asia are less involved or completely absent in the scientific reflection on these topics (Fig. 3). This geographical imbalance highlights the need to develop a-spatial methodologies, adaptable and replicable to specific local contexts, in which risks and urban dynamics can be significantly different.

The integration of sources from different geographical areas and disciplinary contexts has enriched the analysis perspective, providing a more global and complete vision of the phenomenon studied.

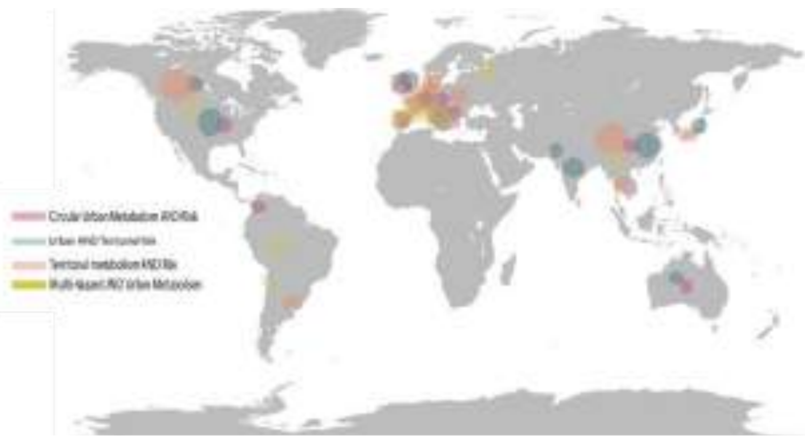


Figure 3 - Geographical distribution of the sources. Source: authors elaboration

2.3.1 The Unexplored Concept of "Urban Metabolic Risk"

The analysis revealed an interesting aspect: the term “metabolic risk” is widely used in medical and health disciplines, where it is synonymous with “metabolic syndrome”. Rather than denoting a single disease, this term describes a constellation of conditions and risk factors that affect human metabolism, such as obesity, diabetes, and cardiovascular disease. The concept of metabolic risk emphasizes the interconnectedness of biological, environmental and behavioural factors in determining people's health status. However, surprisingly, it does not yet have a clear transfer to the city, and in the disciplines of urban planning and architecture the term does not find a definition shared by the scientific community thus highlighting a significant gap in the translation of this approach to the management of urban and environmental contexts (fig. 04)

This lack of enforcement suggests a sectoral approach to risk studies disconnected from an integrated territorial vision. The absence of a holistic, intersectoral vision limits the ability to address the complex dynamics of urban metabolism: the socioeconomic interactions that occur in cities generate residues and fragmentations that contribute to a mosaic of waste.

Hence the need to explore new concepts, such as that of “Urban Metabolic Risk.” This concept, while still underdeveloped in urban settings, could open up new perspectives for analysing and managing unsustainable behaviours and anthropogenic pressures on the land. The idea of Urban Metabolic Risk relies on considering the city as a complex metabolic system, in which the analysis of urban lifecyles becomes central to understanding how cities can be transformed into more resilient and sustainable spaces.

Filtering contributions according to their relevance and connection with the study objectives is the main focus of the selection procedure regarding the top 20 most pertinent publications. Only studies that explicitly address important topics pertaining to territorial and socioeconomic threats are kept after the stringent selection process. Among the chosen subjects, Gerundo, Marra, and De Salvatore's (2020) idea of "**risk of peripheralization**" and other socioeconomic issues are included in the larger framework of UMR. This innovative concept helps to map intricate relationships between hazards and how they affect different regions. It enables a thorough analysis of the ways in which processes such as deindustrialisation, disorderly urbanisation, and peripheralization interact to produce a cascading effect that eventually jeopardises the resilience and sustainability of impacted urban and peri-urban areas. The chosen analysis methodology fosters synergies between planning, urban configuration, and environmental factors while promoting proactive and integrated risk management. This method has worked well for evaluating urban layouts when they are susceptible to important occurrences like **landslides**. This methodology's practical application is shown in the case of Casamicciola Terme (Italy), where design solutions that reduce hazards and promote urban resilience were identified through an examination of pre- and post-landslide urban configurations.

Figure 4 - Synthesis of the main findings. Source: authors elaboration

Methodological Innovations and Patterns in Urban Metabolic Risk Research

From a methodological standpoint, the analysis observed a notable increase in the adoption of multi-criteria evaluation tools. These instruments adeptly integrate a diverse array of multidisciplinary impacts, enriching the analysis of territorial vulnerability by incorporating economic, social, political, and even perceptual dimensions into risk assessments. This fosters a more holistic grasp of urban dynamics and the intricacies of urban metabolism. Geographic Information Systems (GIS) serve as a prime example of such tools (Caprari & Malavolta, 2024). When embedded within decision support systems, GIS have proven exceptionally effective for territorial analysis and risk modelling (Minciardi et al., 2006). They simultaneously facilitate knowledge creation (through the visualization and comprehension of risks) and the development of adaptation and mitigation strategies (Lara et al., 2021), effectively bridging the divide between scientific inquiry and practical implementation.

Scenario development, encompassing both predictive and transformative approaches, emerges as an invaluable asset in studies that construct models and practices for multidisciplinary urban risk management. These scenarios provide crucial foresight into potential urban futures, aiding decision-makers in navigating urban risks with a clear understanding of both short- and long-term implications.

Across diverse approaches and risk categories, a significant emphasis is placed on the regulation of building activities (Font, 2020; Battisti et al., 2023). This regulatory aspect remains critical for both the genesis and amelioration of certain risk factors, and it mirrors the inherent uncertainty and complexity associated with transformations in the built environment. This also necessitates considering the critical timeframes inherent in planning, the dynamics of negotiation between public and private sectors, and the potential for conflicting interests within vulnerable territories.

It is particularly noteworthy that, despite the wide geographical diversity of the case studies we examined, several recurring aspects and factors consistently surfaced. These point to common characteristics of a linear metabolism within urban areas, including widespread environmental pollution, the exclusion of communities from decision-making processes, and the abandonment of urban areas and infrastructure. Such commonalities suggest the existence of potential cross-cutting patterns that could be relevant across a broader spectrum of urban contexts exposed to metabolic risk. Future research could further investigate these patterns to uncover shared underlying mechanisms and develop more unified strategies for managing urban risks and fostering more resilient, sustainable cities.

2.3.2 *Identified limitations*

While acknowledging the validity of the methodology used, the study is not without some critical aspects. One important aspect concerns the decision to rely exclusively on the Scopus database. Although it is a widely recognised and respected resource for its reliability and coverage, the use of only one database may have excluded relevant contributions from other platforms, such as Web of Science or Google Scholar. Several studies have highlighted the advantages of combining several databases to obtain a completer and more varied overview: the decision to limit the search to Scopus may have reduced the diversity of perspectives and affected the overall representation of the phenomenon analysed.

Another limitation concerns the choice of keywords and the construction of search strings. Despite the careful selection of terms and the combination of keywords such as 'circular urban metabolism AND risk' and 'multi-hazard AND urban metabolism', the breadth of the concepts covered resulted in a large number of results, often too diverse. This necessitated a more targeted selection, but at the same time limited the inclusion of some relevant studies that could have been found using other string formulations or alternative terms.

Another limitation is the interdisciplinary complexity of the issue. Integrating concepts such as urban metabolism, risk management and circular economy is a major methodological challenge. The need for a truly holistic approach requires the consideration of multiple disciplines, often characterized by different languages and methodologies, this complexity can make a coherent and comprehensive synthesis a difficult result. This can lead to a loss of specificity or the adoption of oversimplifications that risk not to fully capture the urban phenomena complexity.

2.4 Urban Metabolic Risk, a definition

The term "**metabolic risk**" is so far widely used in the medical field and disciplines related to health, often identified with the concept of "metabolic syndrome". Applying this concept to urban and territorial disciplines may help to develop an integrated approach for a more effective management of territorial and environmental risks. However, the concept of metabolic risk has not yet been used in urban and architectural disciplines, highlighting a broader fragmentation and a sectoral and non-integrated approach of urban policies for mitigation and adaptation of territorial risk in multi-hazard contexts. Several studies tried to suggest a more integrated approach to risk management. In the pursuit of a comprehensive and integrated understanding of risk, the UN Office for Disaster Risk Reduction (UNDRO) had already, in the 1970s, shifted away from viewing disasters as isolated incidents and recognized the socially constructed nature of risk (White, 1945), arising from a complex interplay of factors such as the vulnerability of exposed elements and their underlying physical, economic, and environmental conditions (Peduzzi, 2019).

The UN's **Sendai Framework for Disaster Risk Reduction** (2015–2030) (UNDRR, 2015) seemingly aligns with this approach, transcending the distinction between “natural risks” and “anthropogenic risks” and identifying eight categories of risks, including environmental, technological, social, and geological risks, with specific techniques and strategies for measurement and mitigation outlined for each. Such an approach struggles to account for the relationships between urbanization processes and the metabolism of the biological and non-biological components of risk, as the metabolisms that support and maintain urban life—such as, for example, water, food, computers, or movies—combining physical and social processes as infinitely interconnected (Latour 1993; Latour and Hermant, 1998; Swyngedouw, 1999). In this regard, Urban Political Ecology highlights that processes of spatial-environmental change are, therefore, never socially or ecologically neutral and this is why urban metabolic research for risk reduction also needs to consider the question of "who gains and who pays" (Swyngedouw, 2006). For this reason, the analysis of the transformation process governance, which is significantly more complex in a multi-risk context, is relevant for the definition of the Urban Metabolic Risk.

The close correlation between planning, urban development, and multi-hazard risk management represents one of the challenges faced by urban planning (Kamalrathne et al., 2022), which must establish risk-sensitive urban development. This requires an inclusive, adaptive, and integrated governance process (Roslan et al., 2021), responsible local leadership, improved risk data and monitoring, compatible urban development, and an innovative post-transformation management model. Addressing and jointly managing multiple hazards while promoting sustainable development of the area demands a coordinated and cooperative approach among various actors and entities, with multidisciplinary expertise at different scales. There is increasing recognition of the need for new forms of risk management and decision-making processes in multi-risk contexts. The concept of multi-risk governance implies a sociopolitical landscape that is increasingly stratified and diversified, where a multitude of actors, each with their own expertise and assessments, draw upon a diversity of knowledge (Sakic Trogrlic, 2024). This does not correspond to traditional hierarchical structures but constitutes polyarchic frameworks (Renn, Klinke & Schweizer, 2018). Although international policies and guidelines for risk reduction and management provide a global action plan (e.g., the Sendai Framework for Disaster Risk Reduction 2015-2030), risk management ultimately remains a local issue, with local and national entities playing a crucial role in collaboration with a broader stakeholder base. It is therefore essential to engage various stakeholders to understand their needs and identify the challenges they face (Komendantova et al., 2016), particularly to reduce conflicts that tend to slow down or even halt ongoing processes.

Sustainable development objectives in the regeneration of disused industrial sites highlight the importance of remediation through a "sustainable" approach, capable of seizing environmental, economic, and social opportunities linked to the reuse of contaminated sites (Tonin & Bonifaci, 2020), aiming for an appropriate balance between economic well-being and the natural environment. This relationship between remediation and planning calls for a methodological rethinking in the definition of various projects, ensuring simultaneous and continuous dialogue between areas to be remediated, remediation classes, remediation systems, and urban planning. This synergy is crucial to limit waste, accelerate timelines, and reduce costs.

In considering the interaction between risks and urban planning, it is essential not to overlook the inherent risks of the area's transformation process (Tedd, Charles & Driscoll, 2001). These include risks to the population, such as the potential loss of memory and collective identity; risks to the natural environment, as ecosystems that have emerged during the period of abandonment may not be preserved; and risks to the built environment, where developments might disregard the architectural and urban character of the area, its history, and its territorial context. Instead, they may be primarily focused on economic viability and structural stability. Finally, one of the risks related to post-transformation is that of management (Leger, Balch & Essex, 2016). Management thus represents another crucial issue, as the risk of gradual return to degradation and abandonment following the transformation is very high. From the decommissioning of entire urban areas that no longer serve a purpose or generate value, to cases of pollution and contamination linked to production systems, the life cycle of cities can contribute to increasing the vulnerability of settlements and communities, and therefore the exposure to risk factors. These impacts include wasted landscapes, marginalized communities, waste, and pollutants, progressively and incrementally exposing communities and territories to the impacts of health, environmental, and social risks. Urban metabolic risk refers to the cumulative negative impacts of urban metabolism on territory and communities. The presence of metabolic risk undermines quality of life and creates significant challenges for urban regeneration initiatives. Urban Metabolic Risk is associated with stagnation and prolonged expectation of transformation.

Recognizing 'metabolic risk'—the relationships between the life cycles of cities and risks—requires adopting a 'non-standard' approach, one not focused solely on disastrous events (hazard-specific) (Saja et al., 2019) but also the potentials of the places. Instead, it emphasizes a context-specific approach, deeply tied to understanding urban metabolism, its form, its relationships, and the resources of the communities inhabiting it. Within the RETURN research project, defining the concept of metabolic risk means placing the local contexts and communities facing adverse events at the forefront. It involves examining how the outcomes of risks—be they social, environmental, or climatic—overlap and materialize.

2.5 Circular city Evaluation Framework: Metabolic Risk indicators

The concept of resilience applied to wastelands is now a methodological and operational challenge of growing importance for urban design and sustainable planning.

The most recent scientific literature has devoted increasing attention to the assessment of urban transformations with reference to intermediate scales, such as districts or neighborhoods. An analysis of the case studies addressed in the literature reveals significant heterogeneity in the methods used, the types of contexts analyzed (former industrial areas, contaminated sites, disused port areas) and the variety of indicators used, ranging from environmental to infrastructural, social and ecological indicators. This plurality reflects the need for flexible and multidimensional tools capable of responding to the complexity of urban systems in transformation.

Rocha et al. (2024) emphasize how the circular economy can offer a useful framework for guiding territorial decision-making processes, proposing an integrated combination of environmental, social and economic indicators. Marzani and Tondelli (2024), on the other hand, emphasize the importance of GIS-based decision support systems and multi-criteria approaches, identifying ecological connectivity and public accessibility as key factors for assessing the regenerative potential of post-industrial contexts in particular.

The district scale, in particular, appears to be the most suitable for conducting granular and contextualized assessments. Several authors, including Nocca, De Toro & Voysekhovska (2021) and Capolongo et al. (2020), have developed evaluation frameworks geared towards this scale, adopting indicators related to land use, pollution, energy efficiency and soft mobility. Similarly, authors such as Ariyaningsih et al. (2023) and Mateus et al. (2023) have proposed systemic approaches based on urban metabolism, linking material and energy flows with regeneration strategies.

These approaches are accompanied by a growing focus on the social dimension of resilience. Stakeholder participation, scenario co-creation, perceptions of safety and community cohesion are increasingly recognized as essential elements for assessing and activating effective regeneration processes. Resilience cannot simply be imposed through technical standards, but must be built collectively, valuing social capital and local adaptive practices.

In the context of this research, the objective was to build an Evaluation Framework capable of spatializing the resilience potential of wastescapes, identifying priority areas for intervention and providing replicable tools for the selection and monitoring of transformation hotspots. The framework developed is based on a selection of criteria derived from scientific literature, reinterpreted in an operational key to guide circular and adaptive planning. It is a set of metabolic indicators that focus not so much on critical issues as on the latent opportunities in degraded urban systems.

The proposed approach integrates spatial analysis, quantitative data and multi-criteria assessments with a specific focus on the ecological, social and economic potential of wastescapes. The use of GIS technologies and predictive models allows for a dynamic and articulated representation of the territory, useful not only for diagnosis but also for the design of future scenarios. Each criterion is associated with specific data sources and detection techniques, ranging from satellite photo interpretation to participatory surveys.

Finally, this framework is proposed as an operational tool to support strategic decisions and guide circular and inclusive regeneration policies. Resilience, understood as the systemic capacity for adaptation and transformation, is thus reconfigured as an emerging quality of urban space, its infrastructure, ecosystems and communities. In this way, the concept of "metabolic risk" becomes a key to recognizing not only the signs of degradation in wastescapes, but also the traces of a possible regenerative future.

2.5.1 Resilience potential in wastescapes

Starting from the state of the art, a methodological framework has been developed for the analysis, evaluation and mapping of the resilience potential of wastescapes in multi-risk urban contexts.

Said analysis on wastescapes potential, can be used to prove that the condition of industry delocalization (loss of functions) is acting differently in the three dimensions of Sustainability:

i. on the social level, it is rising community expectations, leading to either a sense of dispossession (in case of brand-new development, not accessible to existing communities) or a sense of loss and deprivation in some occasions (in case of prolonged abandonment; see later in this document, on the Bagnoli case);

ii. on the economic level, it is causing a standstill in the estate market and rising the developer expectations (to be met in normative and planning instruments);
iii. on the environmental level, it is related to the existence of latent ecological resources, to be assessed.

The composition of these three dimensions, with their specific indicators can help us determine the actual ‘resilience potential’ in wastescapes, to orient and guide future strategical interventions. Indeed, even in a condition of prolonged standstill, the indicators can demonstrate that wastescapes can be characterized by an unexpressed capital of resources (matter, nature, space) at a multidimensional level. Then the use of adequate indicators can highlight previously mentioned resilience potential based on social-ecological and cultural conditions, linked to social-economic but also more-than-human capital.

Phase One in this analysis included a literature review to explore current methodologies for assessing resilience potential in multi-risk urban contexts (GIS - MCDA). GIS-MCDA (Geographic Information Systems - Multi-Criteria Decision Analysis) is an integrated approach that combines the potential of Geographic Information Systems (GIS) with Multi-Criteria Analysis (MCDA) methods to support complex spatial decision-making processes. GIS enables the management, visualization and analysis of georeferenced spatial data, while MCDA provides a methodological framework for evaluating alternatives on the basis of multiple (environmental, social, economic, etc.), even conflicting criteria. The integration between GIS and MCDA makes it possible to assess spatial scenarios taking multiple indicators into account simultaneously, assign different weights to criteria according to specific priorities or objectives, map the results in a visual and interpretable manner, highlighting areas of greatest potential or risk. This combination is particularly useful for analyzing complex urban systems, identifying intervention hotspots and supporting sustainable planning and regeneration strategies, as in the case of the wastescape resilience study.

The literature analyzed in Phase One emphasizes the urgent need for integrated, adaptive strategies that address environmental, social, economic, and spatial factors.

Starting from the state of the art, Phase Two involved developing a methodological framework for analyzing resilience potential at a multidimensional level, with particular application to the specificities of wastescapes, based on the indicators that emerged as most relevant from Phase One and related to the relationship between resilience and urban metabolism.

The evaluation framework adopted is based on a structured approach that allows for the analysis of the territory from an integrated and multidimensional perspective, paying particular attention to the interactions between physical, environmental, social, economic and cultural factors. The framework is based on a matrix of criteria divided into three main macro-areas: ‘General’, ‘Physical and Non-Human’ and ‘Human’. Within each area, the criteria are organized according to spatial analysis geography, i.e. the specific areas of territorial intervention considered relevant for sustainability.

Each criterion is described in operational terms, associated with one or more dimensions of sustainability – environmental, economic, social or cultural – and accompanied by measurable indicators, chosen for their ability to provide an objective and quantifiable picture of the conditions of the context. To support the analysis, the framework also identifies the main data sources and technologies that can be used for mapping and spatial representation of the

indicators, ensuring that qualitative and quantitative assessments can be integrated into decision-making processes.
In the “General” macro-area, the framework takes into account, for example, the technical and financial sustainability of the public sector through the analysis of the availability of publicly owned space, measured in square meters. A further general criterion concerns the capacity to adapt and manage multi-risk environments, assessed through the presence of urban planning projects or tools specifically aimed at preventing and mitigating environmental risks.
In the “Physical and Non-Human” area, particular importance is attached to the quality of the natural and landscape system, considering the presence and continuity of agricultural and silvo-pastoral areas, landscape components and green and blue infrastructure. The indicators used include, for example, the surface area of green spaces, land use types and the length of ecological corridors. Also in this area, a further criterion concerns the quality of life for all species, which analyses the ecological suitability of urban and peri-urban environments for biodiversity, using indicators such as the NDVI vegetation index, the presence of habitats and the distribution of species.
Another central component of the framework is the assessment of urban compactness, measured through the land cover index and proximity to built-up areas accessible within an average time of 15 minutes. Closely related to this criterion, the framework also considers the accessibility of public space, analyzing the distance from public transport infrastructure, such as railway stations or intermodal hubs, as well as the presence of soft and sustainable mobility networks.
In the “Human” macro-area, the criteria focus on the social and cultural dimensions of sustainability. Multi-actor cooperation is assessed on the basis of the presence of care networks, local public services and third sector actors, with indicators such as the number of active organizations in the area or proximity to social and health care facilities. This is complemented by the criterion of social cohesion and inclusion, which takes into account the presence of spaces and initiatives dedicated to inclusion, such as educational campaigns, intergenerational activities or participatory projects, assessed through levels of civic participation and the number of initiatives promoted.
A further element of analysis is the sustainability of human resources, with reference to the promotion of skills and training, both in the public and private sectors. This criterion is measured by the number of active training projects and the degree of involvement of local actors in educational or professional development programs. The framework also addresses the issue of resource efficiency, assessing the capacity for self-production of energy from renewable sources and the presence of water reuse and filtration facilities, through indicators such as the amount of self-produced energy or the area served by water recovery systems.
Finally, the criterion relating to non-extractive projects is considered, i.e. initiatives located near sites dedicated to the reuse of raw materials or the production of organic waste, with the aim of promoting circular economies and reducing the consumption of natural resources. In this case, indicators may include the distance from composting plants, recovery centers or sustainable manufacturing facilities.
To support the entire framework, various information sources and technical tools are used, including cadastral data, urban planning tools, mobility plans, direct observations,

environmental surveys (such as those by ISPRA, ARPA and Corine Land Cover), as well as remote sensing technologies and satellite data. The integration of quantitative indicators, spatial criteria and diverse data sources provides a detailed picture of the potential and critical issues of the territory, helping to guide planning and design choices towards sustainable, resilient and inclusive models.

This structure allows for an integrated reading of territories, with the aim of guiding urban transformations towards more sustainable, resilient and inclusive models. Each criterion is designed to be georeferenced, measurable and updatable over time, promoting integration between planning, design and monitoring.

The chosen approach combines traditional multi-criteria evaluation with spatial analysis by defining multiple criteria, but also defining a geographic location. This spatialization allows us to identify the weight on the final decision that the selection of a specific area plays with respect to the investigated territorial complex.

The district scale, already utilized in the RETURN project, is identified as an ideal level for implementing effective interventions, offering detailed insights into territories, hotspots, and unexploited resources that can foster transformation.

This spatialization is fundamental to identify specific intervention hot-spots in which the presence of latent resources is greater, for the implementation of circular strategies, aimed at valorizing these urban areas, through recovery, sustainable management and the integration of ecological and social practices that can reduce risks and promote greater long-term sustainability.

The starting point to re-input them into the system as ecological resources, is assessing through the framework their current condition of ‘criticality’, degradation, and waiting conditions, connotating them as resource-spaces (Amenta & Attademo, 2023), an interesting starting point to define a regenerative approach to cities and territories (Amenta & van Timmeren, 2022).

The re-conceptualization of wastescapes as Resource-Scapes is strictly related to the ‘resilience potential’. In the mapping of wastescapes, the interpretation of the relationship between proximities to certain activities or to certain areas at risk is fundamental. In a multi-risk context, the large amount of wastescapes is the indicator of a currently vulnerable city, but also of latent valuable resources.

Furthermore, the evaluation can be structured into three phases—ex-ante, in-itinere, and ex-post—enhances flexibility, allowing for targeted planning, impact assessment, and strategy adjustments during implementation. Engaging local stakeholders in later stages to define resilience indicators promotes participatory governance, ensuring community needs are integrated. Thus, resilience can be conceived not only as a technical attribute but also as a social and cultural process, benefiting from active community involvement and co-evaluation.

Therefore, the methodological framework could be used to identify, monitor and assess:

i. in the ex-ante phase (before the application of the strategy), the possible impacts of future strategies and the socio-spatial factors that can contribute to reverse the condition of landscapes prone to Metabolic risk (e.g. categories of wastescapes), showing ecological degradation and biodiversity loss, social and spatial fragmentation;

ii. in the in-itinere phase (temporary use strategies), the presence of latent resources in the period of abandonment and their potential for valorisation, triggering further processes of landscape rehabilitation and social, economic and environmental regeneration;
iii. in the ex-post phase (after the application of the strategy), the reached level of circularity, considering all its dimension (social, economic and environmental).

The proposed methodology advances resilience mapping and assessment, providing tools for future scenario analysis and territorial planning. It emphasizes spatialization, highlighting the importance of space, morphology, and social connections. Each criterion relies on specific data sources and collection technologies, sometimes including direct methods. Specifically, this analysis of the 'resilience potential' can be integrated with the mapping activities (also developed in Task 5.5.2), spatializing the indicators identified in this methodological framework. The framework developed is not only a tool for analysis and monitoring but also a support for defining guidelines for mapping areas with high resilience potential for identifying regenerative and circular strategies.

In a subsequent phase, it will be essential to integrate the contribution of local stakeholders in defining the weights assigned to resilience indicators. Co-evaluation is, in fact, an essential step in building participatory governance capable of taking into account the needs and expectations of the communities involved. In this sense, resilience cannot be considered a purely technical quality, but must also be understood as a social and cultural process.

2.6 The risk associated with contaminated sites and criteria for circular and sustainable remediation

The management of contaminated sites is closely intertwined with the metabolism of the city, either because several contaminated areas are located within urban boundaries or because dismissed and contaminated industrial sites on the outskirts of the city pose an objective risk to human health and the environment of the surrounding areas. In recent decades, many of these industrial sites have been incorporated by urban expansion, to the point of becoming part of the consolidated city; in many cases we were faced with areas with enormous economic and commercial potential, whose redevelopment projects were completed despite often costly reclamation expenses. Urban planners and architects have begun to discuss the opportunities offered by these spaces (Dansero et al., 2001), often imagining them as new urban centralities of the 21st century. As a consequence, some of the most interesting European and American urban projects of the last decades are precisely related to transformations of former industrial areas (brownfields), for example: the Lingotto in Turin, the Docklands in London, the High Line in New York, and the Pobelnou neighbourhood in Barcelona, in a logic, however, of a still linear and unsustainable economy.

The scenario has radically changed in recent years, suggesting that the mechanism of reclamation and redevelopment should be rethought, integrating environmental protection with the economic feasibility of projects and the long-term planning of the areas themselves.

At the European level, the European Environment Agency (EEA) estimates 2.8 million potentially contaminated sites. These were recorded by 23 Member States in 2016 as 1.38 million, of which 69% were defined as contaminated sites following the characterization phase and only 8.3% were remediated in the same year (EEA, 2024). Therefore, to date the number of potentially contaminated sites is estimated to have doubled since the last update, carried out in 2016. These data highlight the critical situation in Europe, where more than 60 % of soils are in a poor state, negatively affecting human health, the economy, climate and society (European Commission, 2023). Exposure of humans to contaminants from contaminated land may result in many types of health damage ranging from relatively innocent symptoms such as skin eruption or nausea, on up to cancer or even death. Human health protection is generally considered a major protection target, but improving soil health is also essential for disaster prevention and management. This is ever more important as climate-induced extreme weather events, such as droughts, floods, and wildfires are becoming a more frequent reality in Europe. Depollution and decontamination of soils will also greatly improve the health of citizens, especially of vulnerable groups, who are proven to be disproportionally affected by pollution. Consequently, the Soil Monitoring Law proposed by the Council of the European Union in June 2024, with the main goal of achieving good soil quality by 2050, emphasizes the importance of a healthy soil and the need to use a step-by-step risk-based approach. This methodology allows member states to set priorities for action, considering potential risk, socio-economic aspects and current and future land use. Furthermore, in order to be able to better manage potentially contaminated sites at the European level, the ministers agreed in this bill to establish national lists of potentially contaminated sites (CoE, 2024). The main issue inherent to the management of contaminated sites at EU level concerns the absence of common legislation standardizing the procedure in Europe and, consequently, the lack of correct and consistent identification of the risks associated with such sites (EEA, 2022; Panagos et al., 2013; Wcisło et al., 2016).

The procedure of Risk Analysis was developed in the mid-1980s in America, to provide assistance to operators in the evaluation of intervention priorities for environmental protection (Gorla, 2019). Risk assessment includes two different activities, i.e. the exposure assessment and the hazard assessment. The combination of these is called the risk characterization, which results in an appraisal of the contaminated land. Starting from presence of a pollutant source via different migration routes, pollutants can reach the receptor or target. It is therefore necessary to identify the relationships within the system between the following three elements: sources, pathways, and targets (Swartjes, 2015). Thus, the exposure assessment covers a smart combination of calculations, using exposure models, and measurements in contact media and body liquids and tissue.

The hazard assessment, which is different for contaminants with or without a threshold for effects, results in a critical exposure value. Good human health risk assessment practice accounts for tiered approaches and multiple lines of evidence. Specific attention is given here to phenomena such as the time factor in human health risk assessment, suitability for the local situation, background exposure, combined exposure and harmonization of human health risk assessment tools.

The Environmental Health Risk Analysis represents an advanced procedure, both from a technical and scientific point of view, for assessing the degree of pollution of a site and for defining the intervention priorities to be implemented within it (Di Molfetta & Rajandrea, 2012) but also present some limitation (Swartjes, 2015). Regarding risk assessment, as in any

scientific field, it is essential to use an internationally standardized approach to achieve greater transparency, comparability and validity of the data and assessments implemented through Risk Analysis (Chartres et al., 2019). Qualitative and quantitative risk assessments are the basis for deciding on the most sustainable course of action among different alternatives, be they safety measures, remediation or environmental restoration (Theodore & Dupont, 2017).
In Italy, the reference legislation on contaminated sites is Legislative Decree 152/2006, Part IV, Title V, which defines procedures, criteria and methods for environmental remediation and restoration. Under Article 240 of Legislative Decree 152/06, two threshold values are defined for concentrations of pollutants in the environmental matrices soil, subsoil and groundwater: the first is represented by the Contamination Threshold Concentrations (CSC), above which the site is potentially contaminated and site characterization and site-specific Risk Analysis are required. The second limit value is represented by the Threshold Risk Concentrations (CSR), which are determined on a case-by-case basis at a potentially contaminated site, based on the results of the Characterization Plan and through the site-specific Risk Analysis. The CSRs constitute the levels of acceptability of the site. If they are exceeded, the definition of the area of interest changes from potentially contaminated site to contaminated site. When this condition occurs, it is necessary to proceed with remediation or safety works, identifying the CSR as the remediation target and, consequently, it is mandatory to reach a concentration below this limit in the different contaminated environmental matrices, whether soil, subsoil or groundwater (Legislative Decree 152/06, 2006). The human risk assessment and the ecological risk assessment are the subject of WP4.4 “Multi risk assessment, and proof of concepts” of VS4.

2.6.1 Criteria and standard for circular remediation and sustainable requalification

The sustainability assessment in the context of remediation processes, and the criteria and methodologies associated with them, represent a meeting point between this Task and Task 4.5.4 ‘Sustainable Remediation’ of WP5 in VS4, where criteria for sustainable remediation measurements are outlined.
Remediation of contaminated land has been considered in past decades as an intrinsically sustainable action (Bardos et al., 2011), since it contributes to the objectives of sustainable development by aiding in the preservation of land as a valuable resource, averting the spreading of pollution in air, soil, and water, and alleviating the demand for development on pristine greenfield sites. The primary motivations for remediation revolve around diminishing risks to human health and the environment, in fact in most countries management of contaminated land is risk-based. Besides the primary impacts associated with the state of the site, however, secondary impacts are associated with the site remediation itself (Lesage et al., 2007). In fact, remediation endeavors typically entail adverse consequences, such as the utilization of fossil fuels (resulting in CO2 emissions), generation of waste, and substantial on-site disturbances in the form of noise and dust (Bardos et al., 2011; USEPA, 2008). Thus, the final objective of sustainable remediation is to ensure that while reducing the potential for harm from land contamination, also unintentional consequences are avoided (Hadley et al., 2009).
The interest in the sustainability of remediation has been growing since the early 2000s, following this evidence that, although such activities on the one hand generate positive impacts

correlated to the removal of contamination and reduction of environmental health risk from the site of interest and its redevelopment, they also generate negative impacts. The latter affect all aspects of sustainability and mainly concern the costs of intervention, the use of raw materials and energy, the production of waste, dust, noise and traffic (Alshehri et al., 2023).
At the European level, let alone the Italian level, there are no standardized methodologies for assessing the sustainability of remediation, but several countries have included in their administrative procedures the need to assess the most sustainable intervention by considering both environmental and economic and social aspects indicating or suggesting particular indicators.
Following the review made in Task 4.5.4 (VS4) of the European and non-European situation regarding the methodology used to assess the sustainability of remediation, the main functions of five different software and tools (ASTRA, SRT, SiteWise GSR Tool, SURE) used for estimating the sustainability of remediation alternatives has been investigated. The final output of Task 4.5.4 (VS4) will be the implementation of a sustainability assessment methodology and a check list to support data collection for sustainability assessment of the remediation. For more details see Deliverable DV 4.5.6- Assessment of remediation methodologies performances. However, what DV 4.5.6 does not deal with in detail are the methodologies for evaluating the circular economy performance of the remediation, which is instead investigated in this section.
Circular economy has been defined in almost as many ways as demonstrated by Kirchherr et al, 2017 (Valenturf & Purnell, 2021). The common denominator in all these definitions is the objective of making better use of available resources and reducing waste production (Valenturf & Purnell, 2021). In addition, the circular economy should lead to the regeneration of the environment by contributing to the sustainability of the entire system, optimizing the social, environmental and economic values of materials, products and services (Ellen MacArthur Foundation, 2021).
The definition considered in this discussion comes from International Technical Standard ISO 59004 ((ISO), 2024). Circular economy is defined as "a systemic approach to maintain a circular flow of resources, by recovering, retaining or adding to their value, while contributing to sustainable development". This concept is summarized in Figure 5.

Figure 5 - Circular economy through a sustainable perspective (Valenturf & Purnell, 2021)

In opposition to the model take-make-dispose that characterized a linear system of resources exploitation, circular economy suggests the 4R model, Reduce-Reuse-Recycle-Recover based on Reduction of waste, raw materials and energy, Reuse of a good for as long as possible and Recycling of discard (Aiguobarueghian, Adanma, Ogunbiy, & Solomon, 2024). The linear system of resource use is no longer practicable and requires a more sustainable approach, based on minimizing the extraction of natural resources, maximizing waste prevention, and optimizing the environmental, social, material and economic values throughout the lifecycles of materials, components and products (Valenturf & Purnell, 2021).
One of the main topics of the European Green Deal, in relation to the new agenda for sustainable development, concerns the adoption of the new circular economy action plan (CEAP) in March 2020. The new action plan announces initiatives along the entire life cycle of products: it targets how products are designed, promotes circular economy processes, encourages sustainable consumption, and aims to ensure that waste is prevented and the resources used are kept in the EU economy for as long as possible (European Commission, s.d.).
The scientific literature about circular economy (CE) provides principles and actions associated with circular economy that evolved over time (Suárez-Eiroa, Fernández, Méndez-Martínez, & Soto-Oñate, 2019) and should be integrated into organizational strategies to support continual progress towards increasing circularity ((ISO), 2024). The CE principles should act as rules, capable of describing a 'must be' and outlining a clear and operational measurement pathway, and to objectively support the development of the strategic circular economy model over time (Ente Italiano di Normazione, 2022).
Fundamental principles of circular economy, reference for future implementations, refer to:
Circular economy; - the 10 R;

i. the 6 principles of the standard BS 8001:2017;
ii. the 3 principles of the Ellen MacArthur Foundation.
iii. the 7 operating principles developed by Suarez-Eiroa;
iv. the 8 operating principles developed by UNI/TS 11820: 2022
v. the 6 principles of ISO 59004 Circular economy - Framework and principles for implementation.

The last two standards were created to provide standardization of the circularity assessment to produce a common strategy for monitoring circular processes in organizations. The main objective is to adopt a clear and neutral, concrete and replicable circularity measurement system (Ente Italiano di Normazione, 2022).
From an international point of view, the main goal of the working group ISO/TC 323 "Circular economy" is the standardization in the field of Circular Economy in order to develop frameworks, guidance, supporting tools and requirements for the implementation of activities of all involved organizations, to maximize the contribution to Sustainable Development ((ISO), 2024). The standards are:
- ISO/CD 59004 - Circular economy - Framework and principles for implementation
- ISO/CD 59010 - Circular economy - Guidelines on business models and value chains
- ISO/CD 59020 - Circular economy - Measuring circularity framework
On a national level instead, the circularity assessment was evaluated by the working group UNI 057 in the available standards:

- UNI/TS 11820:2022 Measuring circularity - Methods and indicators for measuring circular processes in organizations
- UNI/TS 11821:2023 Collection and analysis of circular economy best practices.

In particular, the Italian standard UNI/TS 11820 and the international standard ISO 59020:2024 are recently published in order to create a common strategy for monitoring circular processes in organizations in order to create an objective model that should be able to measure the circularity of a given process through the assessment of specific indicators.

Indeed, these two standards give a set of indicators for measuring circularity at the micro (individual organization, local authority) and meso level (group of organizations, inter-organizations, industrial or territorial clusters, industrial areas and districts, production and material chains, territories, regions, metropolitan areas, provinces metropolitan areas, provinces) (Ente Italiano di Normazione, 2022).

The UNI/TS 11820 "*Measuring circularity - Methods and indicators for measuring circular processes in organizations*" – available from November 2022 – anticipated the publication of the ISO specification (ISO/DIS 59020), available from 2024. The standard aims to provide a method and a taxonomy of indicators for assessing, through a rating system, the level of circularity of an organization or group of organizations, including public institutions, regardless of type, size and the supplied products or the provided services. The national standard provides a set of circularity indicators that can be applied at both the micro level (single organization) and the meso level (group of organizations). The set is composed of 71 indicators grouped into six categories, encompassing material resources, energy and water, waste and emissions, logistics, products and services, and human resources, assets, policies and sustainability. The indicators are also divided into core (that must be filled in), specific (of which at least 50% must be filled in) and rewarding indicators (for which filling in is not compulsory). The indicators are also defined by a quantitative, semiquantitative or qualitative scale. In general, the level of circularity is defined with a measurement system on a 100 basis that has no minimum threshold for circularity. The calculation of each indicator is given by a ratio, so that a normalized circularity index value between 0 and1 can be obtained.

The preliminary steps to the assessment involve the definition of the system boundaries, the data quality requirements and the type of assessment (and the relative indicators set). After collecting data and evaluating the indicators, the circularity performance can be calculated for each indicator category. The results can be visualized on a radar chart encompassing all 6 categories.

The standard ISO/DIS 59020 provides a framework of environmental, social, and economic indicators to assess the circularity performance of a selected system. The results of this assessment are intended to be used to support the transition towards a circular economy. The framework is applicable to multiple levels of an economic system, from regional, inter-organizational, organizational, to the product level. The framework also relies on inputs from a variety of complementary methods.

The framework consists of three main steps. The boundary settings step, which includes the definition of the system in focus, the circularity aspects to be measured, data quality requirements and the pre-selection of complementary methods of assessment. The data acquisition step, where general circularity indicators are used for data collection (they can serve

as a basis to form more detailed, sector specific measurement methods, when required). The circularity assessment and reporting step, in which the results of the circularity measurement are evaluated in a comprehensive statement about the circularity performance of the system in focus. The standard provides a set of core circularity indicators that can be supplemented by additional ones (also derived from complementary methods) to meet the goal and the scope of the circularity measurement and assessment.
In the European context, Standards developed by the European Financial Reporting Advisory Group (EFRAG) have recently been issued to enable small and medium-sized (SMEs) enterprises to provide information on risks and opportunities related to environmental, economic and social (ESG) practices through sustainability reporting, in order to understand the positive or negative impacts of their activities (European Commission, 2023).
These standards development refers to a regulatory framework of Corporate Sustainability Reporting Directive (CSRD - 2022/24642). (European Parliament, 2022). The CSRD requires large companies and listed small and medium-sized enterprises (SMEs) to include in a separate section of their annual report the information on risks and opportunities related to their environmental, social and economic (ESG) practices, necessary for understanding the company's impact on sustainability issues and the information necessary for understanding how sustainability issues affect the company's development, performance and position (European Commission, 2023). The new Corporate Sustainability Reporting Directive (CSRD) replaces the EU's pre-existing ESG reporting program, the Non-Financial Reporting Directive - Directive 2014/95/EU, 'NFRD'
These disclosures must be reported in accordance with the ESRS - European Sustainability Reporting Standards, promoted by EFRAG and coming into force as of July 2023. The ESRS are the first set of European sustainability reporting principles that companies must use in their sustainability reporting. Information on these topics will have to appear in the annual reports together with the financial data and will also be subject to audit verification (European Commission, 2023).
The first set consists of 12 Standards: two Cross Cutting General Standards and ten Topical Standards (Environmental, Social, Governance) divided precisely by topics: 5 environmental, 4 social and 1 on governance.
ESRS E5 "*Resources Use and Circular Economy*" is the last standard of Environmental part of Topical Standards and specifies disclosure requirements regarding both the company's use of resources and CE strategies implementation together with the related risks, impacts and financial effects (European Commission, 2023).
The standard is constituted by two sections, one comprising disclosures related to impact, risk and opportunity management (referred within the ESRS as IRO) identified through the necessary double materiality assessment at the base of the sustainability report, and a second section concerned with metrics and targets (European Commission, 2023).
The objective of the standard is to maximize and maintain the value of resources, products and materials by creating a system that enables renewability, optimal long-term use or reuse, refurbishment, regeneration, recycling and biodegradation.
The objective of the ESRS E5 is to enable stakeholders of the sustainability statement to understand the actions the company is taking to decouple its economic growth from the use of

resources and the plans it must adapt its business model to the CE principles. The standard establishes reporting requirements on resource inflows, resource outflows and waste. Concerning its resource inflows, the company should report information on the weight of technical and biological products and materials used during the reporting period, the percentage of biological materials used to manufacture products and offer services that originate from a sustainable supply chain (with additional information on the used certification system and on the application of the cascading use principle), and the weight of reused or recycled secondary components and secondary intermediate products and materials used (including packaging). About its resource outflows, the company should report information on the expected durability of products placed on the market compared to the industry average, the reparability of products, and the ratio of recyclable content in products and packaging. Concerning the produced waste, the company should report information on the total amount of generated waste, non-disposal waste, waste for disposal, and non-recycled waste.

Given the nature of the ESRS E5 standard – unlike the other analyzed standards – it does not provide a methodology nor indicators for calculating circularity performance.

Information obtained from the study of such technical standards are also applicated in the field of remediation of contaminated sites.

In the field of environmental management, the remediation of contaminated sites is a critical sector that requires interventions and strategies that could have a double purpose. On one hand, there is the reduction of contamination by removal or reduction of the contaminants in environmental matrices, on the other hand, the decontamination cannot be the only purpose, it must be connected with the protection of the ecosystem and the public health while also contributing to the redevelopment of these areas and to urban renewal (Ferber, Grimski, Millar, & Nathanail, 2006).

Contaminated sites refer to areas where, because of past or ongoing human activities, an alteration of the qualitative characteristics of the environmental matrices soil, subsoil and groundwater has been determined to be a risk to human health (ISPRA, s.d.). Some of these sites are part of the so-called "brownfields". The United States Environmental Protection Agency, U.S. EPA defines Brownfields as "*The lands that have been once used industrially or commercially and are now abandoned and inactive, and the possibility for their redevelopment is very complicated due to environmental pollutions*" (EPA, 2002). These areas are often characterised by contamination considered 'historical' caused by industrial activities in the past (SuRF-UK, 2010).

These situations are particularly complex to manage in terms of sustainable spatial planning and urban development. In fact, contaminated sites are often an integral part of a vulnerable urban area but also a part of territory and citizens historical memory.

The concepts of brownfield development and urban regeneration are closely correlated toward accomplishment of sustainable urban development so that both concepts have been respectively structured around environmental, social and economic issues (Mehdipour & Nia, 2013) as shown in Table 1.

Remediation (Environmental display)	Revitalization (Social display)	Reintegration (Economic display)
- Protects biodiversity - Improves air quality - Minimizes stormwater runoff - Reduces greenhouse gas emissions - Reduces heat island effects - Lessens urban sprawl	- Provides more integrated community involvement - Cuts down long-term risks to human health - Increases the quality of life - Appreciates local culture and heritage - Promotes public safety - Aesthetically creates more pleasing urban space	- Increases land value - Reduces energy consumption cost - Enlarges employment and investment rate - Increases the average income - Encourages regional industries

Table 1 - Main benefit of Brownfield redevelopment.

The adoption of circular approaches could offer new opportunities for optimizing resource use, minimizing waste, and promoting the regeneration and reuse of materials and resources, thus effectively embedding the operating principles of circular economy.

Activities, resources (water, energy, materials, human resources, etc.) but also the specific remediation technologies are the main objective of the circularity assessment for the remediation of contaminated sites which are part of an urban multi-risk setting. In this context, knowledge concerning the application of the circular economy and the available standards may be useful to develop a new methodology applicable to the remediation of contaminated decommissioning sites with specific indicators to enhance the redevelopment of an urban context from a circular and a sustainable perspective.

2.6.2 Selection of circular indicator to evaluate the remediation project

Circularity assessment of remediation processes on contaminated sites is a developing issue. However, the absence of research and studies specifically exploring how to integrate CE principles into remediation practices represents a significant knowledge gap in the scientific literature.

Recent studies provide a set of suitable indicators for assessing circularity in the context of contaminated sites remediation, according to the provisions from the latest standards on circularity assessment. Indicators have been selected from two recent standards for circularity assessment: the Italian UNI/TS 11820:2022 and the international ISO 59020:2024.

Indicators have been selected to evaluate circularity assessment for both ex-ante and ex-post phases of remediation processes. Ex-ante phase regards the stages of intervention design and is aimed to choose the best applicable technologies. Instead, ex-post phase concerns the phases following the start of the remediation procedure, with the aim of pursuing monitoring aimed at continuous improvement.

The methodology of evaluating and selecting indicators from the two standards is summarized in the following Figure 6. This study was carried out from a working group of experts in remediation technologies designed, Life Cycle Assessment and Multi Criteria Decision Analysis.

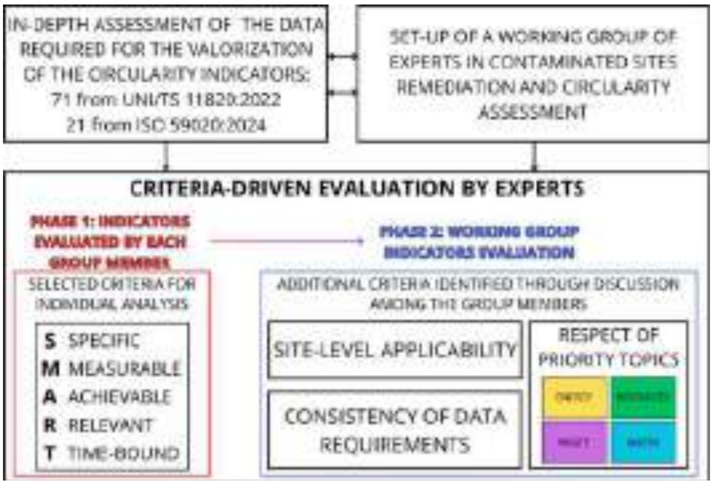


Figure 6 - Methodology for the selection of circularity indicators applicable and relevant to the contaminated sites remediation sector

The selection of indicators follows different phases of evaluation:

Phase 1: analysis of formulation and data requirements for the assessment of the 71 indicators of the UNI/TS 11820:2022 standard and the 21 indicators of the ISO 59020:2024 standard, to serve as a knowledge base for the WG members.

Phase 2: individual assessment of each indicator by all experts in the WG, based on the SMART criteria.

SMART criteria (Doran, 1981) are applied to check for data to be:

i. Specific: defined and focused on specific aspects of the remediation process
ii. Measurable: quantifiable, so progress towards improved circularity can be tracked
iii. Achievable: realistically measured given the available resources
iv. Relevant: meaningful and with a clear relationship to the intended outcome of the assessment.
v. Time-bound: with a clear measuring timeframe and measured at a specific time

The evaluation for both *ex-ante* and *ex-post* phases was carried out with a qualitative approach consisting of three possible outputs:

Y (YES) for an indicator deemed useful for assessing circularity of remediation activities;

N (NO) for and indicator not deemed useful for such purpose;

M (MAYBE) if further discussion was deemed necessary to debate issues of relevance or applicability of an indicator.

Phase 3: the results of the previous phases are a set of indicators which were further evaluated considering other aspects:

Site-level applicability: identifying if an indicator does not focus on overall organisation management;

Priority thematic area: identified in resources, energy, water, and waste;

Data availability: accessibility of data for a specific thematic area at the remediation site level;

Agreement in Phase 1 based on the prevailing number of positive or negative evaluations given for each indicator.

The methodology presented above has been applied to the indicators available in the UNI/TS 11820:2022 standard as shown in Table 2, where are shown the indicators selected by the working group followed by the number of Y, N, M ratings acquired as applicability in the ex-ante and ex-post assessments.

Indicator number	Description	Y ex-ante	N ex-ante	M ex-ante	Y ex-post	N ex-post	M ex-post
Indicators related to material resources and components							
1	Self-produced secondary material resources, compared to total raw and secondary material resources	2	2	4	6	0	2
2	Raw materials and secondary material resources purchased and/or acquired from local suppliers compared to total raw materials purchased and/or acquired	1	3	4	5	1	2
4	By-products and/or secondary material resources (input) compared to total material resources (input)	1	3	4	6	0	2
Indicators related to energy and water resources							
11	Self-produced electrical energy from renewable sources and/or recovery processes compared to total electrical energy consumed	6	1	1	7	1	0
12	Self-generated thermal energy from renewable sources and/or recovery processes, compared to total thermal energy consumed	6	1	1	7	1	0
15	Amount of water from recovery and/or recycling compared to total water demand	7	0	1	8	0	0
Indicators related to waste and emissions							
16	Municipal and/or special waste sent to landfill compared to total waste produced	5	0	3	7	0	1
Indicators related to logistics							
22	Waste treated at local recovery plants compared to total treated waste	6	0	2	7	0	1
Indicators related to product/service							
30	Value of supplies from suppliers with product and/or service and/or organisational sustainability and/or circularity certifications in year n compared to the total value of supplies in year n	0	4	4	5	2	1
31	By-products generated in year n compared to total production residues generated in year n	1	6	1	2	1	5
32	Value of products and/or services placed on the market that have product and/or service sustainability and/or circularity certifications in year n compared	0	7	1	0	5	3

	to the total value of products and/or services placed on the market in year n						
34	**Value of procured products and services related to circular business models in year n compared to total procured products and services in year n**	1	5	2	3	1	4
41	**Value of products and services (excluding raw materials) procured from local suppliers in year n compared to the total value of products and services (excluding raw materials)**	1	1	6	6	0	2
46	**R&D investments related to circular economy principles in years n and/or n-1 and/or n-2 compared to total R&D investments in years n and/or n-1 and/or n-2**	0	4	4	2	2	4
06. Indicators related to human resources, assets, policies, and sustainability							
64	Goods and infrastructure (e.g. computers, vehicles, furniture, buildings, land) purchased by the organisation based on the lowest life-cycle cost criterion in relation to the total purchased goods and infrastructure	3	2	3	4	1	3
65	Goods and infrastructures with circular end-of-life management solutions compared to the organisation's total goods and infrastructures	6	0	2	7	0	1

Table 2 - Assessment results for the circularity indicators of the UNI/TS 11820:2022 standard. In bold and blue are the indicators selected for both the ex-ante and ex-post phases. In bold and red the indicators selected for the ex-post phase only. The original descriptions of the indicators are provided in Italian, while the English translations are an original elaboration by the authors. Further details on the indicators are available in the text of the standard.

The most represented category in both assessment phases is “02. Indicators related to energy and water resources,” while the least represented is “06. Indicators related to human resources, assets, policies, and sustainability” (although with different percentages). It can be noted that the average relevance percentage for the ex-ante phase (22.3%) is lower than the average relevance percentage value for the ex-post phase (26.2%). The higher alignment of the UNI/TS 11820:2022 circularity indicators with the ex-post assessment phase is consistent with the standard purpose of supporting the sustainability reporting of companies which better reflects the ex-post phase where remediation activities have already started and partially or totally implemented.

The same methodology has been applied to the indicators available in the ISO 59020:2024 standard, as shown in Table X, which includes a description of the indicators selected, followed by the number of Y, N, M ratings assigned by the experts of the WG for their applicability in the ex-ante and ex-post assessments (Table 3).

Indicator category	Circularity indicator	Y *ex-ante*	N *ex-ante*	M *ex-ante*	Y *ex-post*	N *ex-post*	M *ex-post*
Resource inflow	**Average percent reused content of an inflow (X)**	7	0	1	8	0	0
	Average percent recycled content of an inflow (X)	8	0	0	8	0	0
	Percent actual reused content derived from outflow (X)	1	2	5	7	0	1
	Actual % recycling rate of outflow (X)	0	2	6	6	0	2
Energy	**Average percent of energy consumed that is renewable energy**	8	0	0	8	0	0
Water	**Percent water withdrawal from circular sources**	2	0	6	7	0	1
	Percent water discharged in accordance with quality requirements	2	2	4	7	1	0
	Ratio (onsite or internal) water reuse or recirculation	3	2	3	8	0	0
Economic							
ADDITIONAL CIRCULARITY INDICATORS (FROM ANNEX B)							
Additional energy indicators	**Percent energy recovered from residual, non-renewable and non-recoverable resource outflow**	8	0	0	8	0	0
Additional water indicators							
Additional economic indicators							

Table 3 - Assessment results for the circularity indicators of the ISO 59020:2024 standard. In bold and blue are the indicators selected for both the ex-ante and ex-post phases. In bold and red the indicators selected for the ex-post phase only. Further details on the indicators are available in the text of the standard.

The most represented category in both assessment phases is “Energy” (although it only has one indicator), while the least represented categories are “Economic”, “Additional water indicators”, and “Additional economic indicators” in both assessment phases, and only for the ex-ante phase “Resource outflow” and “Water”. As already discussed for the previous standard, it can be noted that the average relevance percentage for the ex-ante phase (27.8%) is lower than the same value for the ex-post phase (45.8%), indicating a stronger suitability of the ISO 59020:2024 standard in supporting non-financial reporting activities which mainly cover the ex-post phase.

As result of the application of the proposed expert-based methodology, a total of 25 circularity indicators has been identified as suitable for the circularity assessment of the remediation activities both in the ex-ante and in the ex-post phases. The indicators derived from the UNI/TS 11820:2022 standard are 16, of which 11 for both phases and 5 only for the ex-post phase. The indicators derived from the ISO 59020:2024 standard are 9, of which 4 for both phases and 5 only for the ex-post phase. It can be noted that all indicators suitable for the ex-ante phase assessment are also suitable for the ex-post phase assessment, while there are additional indicators only suitable for the ex-post phase. This is because all the circularity aspects that can be assessed before the start of the remediation activities can also be evaluated during such

activities, whereas some other circularity aspects can be assessed once the activities have begun. All the selected indicators are consistent with the identified priority thematic areas (i.e. resources, energy, water and waste). The topic of resources is the most diverse: in addition to quantity and quality, aspects such as sourcing, possibilities for reuse as by-products (rather than waste) and economic value related to circularity are also considered.
The selection of useful indicators for circularity assessment of a remediation projects could provide useful suggestions for the definition of strategies, actions and guide line for a sustainable and efficient remediation and resources' management in order to develop a new integrated approach for contaminated sites management and to develop the concept of a resilient city and to improve the habitability of urban spaces.
The next step for the refinement and consolidation of the selected indicators requires their application to a suitable case study, where all the circularity indicators can be calculated.
This is an essential step to better understand their suitability and relevance to the contaminated sites remediation sector as well as to potentially identify any possible critical issues related to data availability.
Indeed, the key criterion for valuing indicators and making the analysis reliable turned out to be the availability of the data, which, directly or indirectly, must be accessible as of the drafting of the remediation project. The specificity and completeness of the data also turn out to be crucial, as the circularity assessment is based on inventory data on site management and not on impacts.
Based on the experience in the field of contaminated site management and on the knowledge of the type of data available in the ex-ante phase at the remediation project, a further selection of a group of indicators was made before actual application to a case study. The selection was made for both the circularity indicators chosen and reported in this chapter, as well as for the sustainability indicators.
From this point of view, following the final output of Task 4.5.4 (VS4) with the implementation of a sustainability assessment of the remediation (for more details see Deliverable DV 4.5.6- Assessment of remediation methodologies performances), the objective for this Task is to create a framework as a decision-support tool that, through the use of specific indicators, aims to direct project choices in favour of identifying the best solution to maximise environmental, social and economic benefits through a shared decision-making process with stakeholders (Surf Uk, 2015), but also to evaluate circular economy performance, which currently represent one of the major contributions to sustainable development policies (United Nations, 2015).
The following table (Table 4) shows the sustainability and circularity indicators selected for application to the case study described in the chapter 4.3. In the Appendix 1 there is a description of the selected indicators in the table 4.

Sustainability Indicators	
ENVIRONMENTAL INDICATORS	Mineral resource scarcity (LCA midpoint)
	Solid waste production
	Global warming (LCA midpoint)

	Cumulative Energy Demand (LCA midpoint)
ECONOMIC INDICATORS	Expected duration of intervention
	Construction costs physical capital used in the intervention
	Intervention operating costs
	Increase in land value following reclamation
SOCIAL INDICATORS	Health impacts on workers and residents in communities adjacent to the remediated site
	Equity across genereations and populations
	Negative externalities for residents and stakeholders
	Human capital (i.e., investment in training, experimentation, research and development)
Circularity Indicators	
	(UNI 1) Self-produced secondary material resources reused in the process, compared with total used secondary material resources
	(UNI 18a-18b) Disposed urban and/or special waste compared to total generated waste
	(UNI 24a-24b) Urban and/or special waste treated at local valorization facilities compared to total treated waste
	(UNI 32) Generated by-products compared to total generated production waste

Table 4 - Sustainability and circularity indicators.

2.7 Analysis of the current context of remediation of contaminated sites in Italy

This chapter examines the regulatory framework and current practices related to environmental remediation and site decontamination in Italy. It provides a comprehensive overview of the key national regulations, starting with the Legislative Decree 152/2006 and other relevant laws related to characterization and remediation interventions. The study explores the process involved in site remediation with the objective of its valorization, including the definition and application of screening values. Through this analysis, the study highlights the challenges to promote sustainable remediation practices in contaminated sites.

2.7.1 SIN former industrial areas as critical hotspots

An illustrative example of a multi-risk condition in urban areas, where the combinations of various types of risks and their relationships with urban metabolism are deeply interconnected, is represented by post-industrial territories. These are areas of industrial decline depleted, disused, and often polluted by waste from past production cycles. Such conditions can lead to environmental degradation and pollution, with severe impacts on ecosystems and human populations. These wastescapes also pose significant challenges for urban regeneration processes. On one hand, there is a pressing need for remediation to reduce public exposure to health risks. On the other, these areas face difficulties in tackling and completing complex and

lengthy planning and implementation processes due to constraints in resources, governance, and techniques. Moreover, the challenge of identifying compatible and potentially simultaneous uses during the remediation process adds an additional layer of complexity.
Contaminated sites refer to areas where past or ongoing human activities have released pollutants periodically altering natural soil properties up to existing standards (Araneo F. et al. 2023). Potentially contaminated sites can often be found in post-industrial areas due to the production models and processes that have taken place there.
In Europe it's estimated that 60-70% of soils are estimated to be degraded due to human use practices: 21% of soils have limits for cadmium above the danger threshold for humans and 83% of soils have at least one pesticide residue (European Commission, 2020).
From an administrative perspective soil protection, unlike air and water, does not yet have dedicated EU-wide legislation. The European Commission's 2006 Soil Framework Directive Proposal was definitively withdrawn in 2014. However, since then, various aspects of soil protection have been integrated into other sector-specific regulations and/or policies not directly related to soil. Legislative fragmentation contributes to multiply procedures and processes for soil regeneration.
From this perspective, contaminated and exposed sites should be considered as ecosystem environments that are not fully resilient, because they often lack the capacity to provide biodiversity, have mineralized soils with high levels of pollution and elements from anthropogenic contamination that have deprived them of their capacity to provide ecosystem services (Johnson, Lewis, 2007). The Intergovernmental Panel on Climate Change (IPCC) defines **land degradation** as "a negative trend in land conditions caused by direct or indirect human processes - including anthropogenic climate change- expressed as a long-term reduction and loss of at least one of the following: *biological productivity, ecological integrity or human value*" (IPCC, 2021). Working to clean up these polluted soils is therefore a priority; in fact, the European Green Deal calls on EU member states to create a toxic-free environment that requires urgent remediation and clean-up initiatives.
In Italy, a **National Interest Site (SIN)** refers to areas designated for environmental remediation due to significant pollution that poses high risks to human health and the environment (D.l. 152/2006). The issue of contaminated sites was first introduced by Italian legislation with the "Ronchi Decree" No. 22 of 1997. Subsequent regulations that identified most of the contaminated National Interest Sites (SIN) were Law No. 426 of 09/12/1998, and Law No. 179 of 31/07/2002. Today, the main regulatory reference is Legislative Decree 152/2006, known as the "Environmental Code," which, in Part IV, Title V, establishes the administrative and technical procedures for the remediation of contaminated sites. Over time, various regulatory updates have modified the criteria for SIN classification, leading some of them to be downgraded to Regional Interest Sites (SIR). SINs are managed by the Ministry of the Environment and Land Protection, now called the Ministry of Ecological Transition (MiTE). These sites are classified according to specific criteria, including the presence of pollutants such as heavy metals, hydrocarbons, hazardous substances that may originate from industrial activities and improper waste disposal or other sources of contamination. A site is classified as a SIN when it shows a high level of contamination and its environmental impacts extend beyond the local area, often affecting large populations or significant natural resources

(Scaini et al., 2023). The remediation of SINs involves the active participation of government agencies, local authorities, private entities, and strict regulatory frameworks that ensure thorough and sustainable remediation efforts. These sites are often located in urban or industrialized areas, making urban planning and regeneration particularly challenging in these contexts. Currently, **there are 42 SIN areas in Italy** (Isprambiente, MASE, feb 2025) (Fig. 7). The total land area of SINs covers just under 149,000 hectares, accounting for 0.49% of the country's surface area, while the total marine area extends over 77,000 hectares (Araneo et al. 2023).

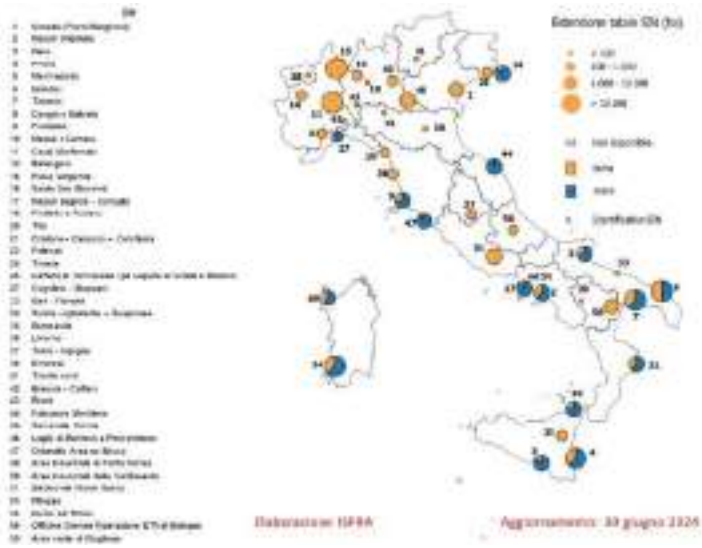


Figure 7 - Distribution of National Interest Contaminated Sites (SIN) across Italy Source: https://indicatoriambientali.isprambiente.it/it/siti-contaminati/siti-contaminati-di-interesse-nazionale

In Italy, environmental remediation of contaminated site, is beset by several challenges, these include the high cost of materials and operating techniques, the lengthy permission and implementation process for interventions and, in certain situations, the difficult interactions with regulatory authorities.

The revitalization of brownfields and former industrial areas is becoming increasingly urgent because they pose a danger to public health and safety and hinder urban transformations. Among the hazards to which urban areas are subjected, pollution and soil contamination are directly linked to urbanization, land use and the cities' life cycles. Process industry, transport, urban sprawl, agriculture, illegal dumping or landfill without adequate resource recovery are indeed currently reported among the main sources of pollutants (Zhang, Wang, 2020) causing the direct release or indirect deposition of organic and inorganic pollutants (including heavy metals, mineral oils, and polycyclic aromatic hydrocarbons) into the soil, with hazardous effects on the environment and human health (UNDRR, 2020; Grifoni et al., 2022).

These are areas whose previous life cycle has ended due to changing socio-economic and environmental dynamics. As highly contaminated sites, they have been decommissioned and currently remain subject to restrictions pending environmental remediation interventions. However, these areas have the potential to be transformed into valuable resources for sustainable and resilient urban development. They are characterized by a range of risks, including environmental, health and socio-economic threats, making them exemplary case studies for understanding how to rehabilitate multi-risk territories. The aim is to explore how these areas, can be reintegrated into the circular metabolism as secondary raw materials. Regeneration efforts for SINs must aim to transform them into resilient, adaptive, and sustainable urban spaces, positively contributing to the quality of life of citizens and addressing the challenge of climate change (Lucertini, 2020). This approach aligns with contemporary urban planning goals that emphasize sustainability, risk reduction, and the reintegration of waste into the production cycle to ensure, that future urban development minimizes negative impacts and promotes a more efficient use of resources.

2.7.2 Regulatory framework

The main national regulatory reference for defining the technical-administrative process for the remediation of contaminated sites (procedural steps, roles, timelines, and penalties) is represented by Title V (Remediation of contaminated sites) of Part Four of Legislative Decree No. 152 of April 3, 2006 (Environmental regulations).

In the context of the remediation procedure for Contaminated Sites of National Interest (SIN), assigned to the competence of the Ministry of Ecological Transition pursuant to Article 252 of the aforementioned legislative decree, it has often been necessary to define technical guidelines or operational protocols by supporting technical bodies, as well as the issuance of specific circulars and/or guiding documents by the competent Authority, usually to clarify cross-cutting issues that affect the progress of administrative proceedings.

The table below (Tab.5) presents an updated overview of the main technical-normative documents produced by the competent Authority or by the technical support Entities in addition to the regulations referred to in Part Four, Title V (Remediation of contaminated sites) of Legislative Decree No. 152 of April 3, 2006 (Environmental Regulations).

Date	**Object**	**Issuing regulator body**	**Notes**
02.03.2008	Criteri metodologici per l'applicazione dell'analisi assoluta di rischio ai siti contaminati - Revisione 2	APAT	Latest revision of the guidelines for risk analysis in contaminated sites, drawn up by the working group coordinated by APAT and made up of representatives of ISS, ISPESL and the System of Environmental Agencies (ARPA/APPA).
02.03.2008	Criteri metodologici per l'applicazione dell'analisi assoluta di rischio ai siti contaminati - Revisione 2- APPENDICI	APAT	Appendices (17) of the latest revision (no. 2 of 2/3/2008) of the guidelines for AdR in contaminated sites, drawn up by the working group coordinated by APAT and made up of representatives of ISS, ISPESL and the System of Environmental Agencies.
01.06.2008	Documento di riferimento per la determinazione e la validazione dei parametri sito-specifici utilizzati nell'applicazione dell'analisi di rischio ai sensi del d.lgs. 152/2006	APAT, ISPESL	Technical reference for the determination and validation of site-specific parameters which, as part of the risk analysis pursuant to Legislative Decree no. 152/2006, must be determined exclusively through direct checks and/or investigations.
01.06.2009	Appendice V - Applicazione dell'analisi di rischio ai punti vendita carburante	ISPRA	Guidelines for the application of risk analysis to the specific case of fuel outlets. Prepared by the (restricted) working group ISPRA, ISS, ISPESL, ER Region, FE Province and ARPA (Lazio, Lombardy, Marche, Tuscany, Piedmont, Sicily, Valle d'Aosta and Veneto)
22.10.2009	Decreto del Ministero della Difesa 22 ottobre 2009 (Procedure per la gestione dei materiali e dei rifiuti e la bonifica dei siti e delle infrastrutture direttamente destinati alla difesa militare e alla sicurezza nazionale)	Ministero della Difesa	Regulation of the procedures for the remediation of sites, possibly polluted, where waste materials are stored pursuant to the decree of the Minister of Defence adopted on 6 March 2008

11.01.2013	Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare 11 gennaio 2013 (Approvazione dell'elenco dei siti che non soddisfano i requisiti di cui ai commi 2 e 2-bis dell'art. 252 del d.lgs. 3 aprile 2006, n. 152 e che non sono più ricompresi tra i siti di bonifica di interesse nazionale)	MATTM	Approval of the list of sites that are no longer included among the remediation sites of national interest
14.05.2014	Richiesta chiarimenti in merito all'applicazione della normativa su terre e rocce da scavo	MATTM (DG TRI, Divisione VII)	Clarifications on the regulatory interpretation of the practical aspects related to the management of excavated soils and rocks and backfilling materials (small-scale sites subject to EIA/IEA procedures, on-site reuse in remediation projects). **Note:** "to be verified".
18.11.2014	Linee-guida sull'analisi di rischio ai sensi del D.Lgs. 152/2006 e ss.mm.ii. - Trasmissione testo condiviso	MATTM (DG TRI, Divisione VII)	Transmission of the final text (6 pages) of the document Guidelines for the application of site-specific risk analysis, relating to the points examined and approved during the meetings of the special working group set up at the Ministry of Environment
12.02.2015	Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare 12 febbraio 2015, n. 31 (Regolamento recante criteri semplificati per la caratterizzazione, messa in sicurezza e bonifica dei punti vendita carburanti, ai sensi dell'articolo 252, comma 4, del d.lgs. 3 aprile 2006, n. 15)	MATTM	
19.02.2015	Linee-guida sull'analisi di rischio ai sensi del D.Lgs. 152/2006 e ss.mm.ii. - Testo condiviso trasmesso con nota prot. MATTM n. 29706/TRIdel 18/11/2014 - Errata corrige	MATTM (DG STA)	Errata corrige of the text of the Guidelines for the application of site-specific risk analysis, document already transmitted with note MATTM Prot.0029706/TRI of 18/11/2014
20.11.2015	Art. 252 co.6, D.Lgs.152/2006 - Autorizzazioni e nulla osta accessori ai progetti di bonifica e messa in sicurezza operativa e permanente	MATTM (DG STA)	Operational indications to the Administrations responsible for authorizations and ancillary clearances to POB/MiSO and MiSP
08.06.2016	Decreto DG STA 8 giugno 2016, n. 351 (Approvazione della procedura per la derivazione dei valori di riferimento in aree marine e salmastre interne alla perimetrazione dei SIN Proposta ISPRA - CNR - ISS (ottobre 2015))	MATTM (DG STA)	Approval of the document (October 2015) prepared by ISPRA, ISS and CNR for the definition of the concentration values of pollutants in the materials resulting from the dredging activities referred to in Art. 5-bis, paragraph 2, letter d, of Law no. 84/94
15.07.2016	Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare 15 luglio 2016, n. 172 (Regolamento recante la disciplina delle modalità e delle norme tecniche per le operazioni di dragaggio nei siti di interesse nazionale, ai sensi dell'articolo 5-bis, comma 6, della legge 28 gennaio 1994, n. 84)	MATTM	Definition of the methods and technical standards of dredging operations in port and coastal marine areas located within SIN, also for the purpose of reusing dredged materials
28.07.2016	Istanza di autorizzazione allo scarico all'interno dei SIN e riparto delle competenze	MATTM (DG STA, Divisione III)	Clarifications on the allocation of competences for discharge authorizations for interventions relating to areas within SIN
10.01.2017	Decreto DG STA 10 gennaio 2017, n. 1 del 10/1/2017 (Bando per il finanziamento della progettazione preliminare e definitiva di interventi di bonifica di edifici pubblici contaminati da amianto, annualità 2016)	MATTM (DG STA)	Call for the financing of the preliminary and final design of remediation interventions of public buildings contaminated by asbestos, as prepared by the MATTM Decree no. 276 of 25/11/2016

01.02.2017	ISPRA - Manuali e linee guida - 146/2017 Criteri per la elaborazione di piani di gestione dell'inquinamento diffuso	ISPRA	Guidelines for the preparation of regional plans referred to in art. 239 paragraph 3 of Legislative Decree no. 152/2006: indications for the characterization and perimeter of diffuse pollution scenarios, as well as for the definition of management paths shared by the competent subjects.
10.01.2011	Disciplina delle matrici dei materiali di riporto. Chiarimenti interpretativi	MATTM (DG RIN)	Interpretative clarifications on landfill matrices following Presidential Decree 120/2017, with reference to the management of excavated earth and rocks in contaminated sites.
23.01.2018	Obblighi del proprietario non responsabile della contaminazione e onere probatorio. Inquinamento diffuso	MATTM (DG STA, Divisione III)	Definition and sharing of common guidelines on the obligations of the non-responsible owner, burden of proof and diffuse pollution, following requests for clarification by the Authorities
13.03.2018	Banca dati ISS-INAIL (Allegato 1) - Caratteristiche chimico-fisiche e tossicologiche delle sostanze elencate nell'Allegato 5 Titolo V Parte IV del D.Lgs. 152/2006 Aggiornamento di marzo 2018	ISS, INAIL	Latest version (March 2018) of the ISS-INAIL database of chemical-physical and toxicological properties to be used for risk analysis. Transmitted to the MATTM (DG STA) and ISPRA with INAIL note no. 1810 of 4/4/2018
16.03.2018	Banca dati ISS-INAIL (Allegato 2) - Documento di supporto Aggiornamento di marzo 2018	ISS, INAIL	Description of the criteria adopted for the preparation of the latest version (March 2018) of the ISS-INAIL database of chemical-physical and toxicological properties to be used for the risk analysis, with indications for its correct use. Transmitted to the MATTM (DG STA) and ISPRA with INAIL note no. 1810 of 4/4/2018
07.09.2018	Banca dati ISS-INAIL(marzo 2018)per l'applicazione della procedura di anlisi di rischio sanitario-ambientale. Trasmissione resoconto tavolo tecnico del 18 luglio 2018	MATTM (DG STA, Divisione III)	Clarifications relating to the application of the health-environmental risk analysis procedure following the publication of the new ISS-INAIL database (March 2018)
16.11.2018	Linee Guida SNPA n. 15/2018 (Metodiche analitiche per le misure di aeriformi nei siti contaminati)	SNPA	Document prepared by the SNPA Working Group 9bis to define the procedure for validating data from direct measurements of aeriforms (in risk analysis); technical indications for the sampling of aeriforms in order to assess the extent of the volatile fraction of contamination and emission of vapours from soil and/or groundwater: soil gas survey (Appendix 1), flux chambers (Appendix 2).
16.11.2018	Linee Guida SNPA n. 16/2018 (Metodiche analitiche per le misure di aeriformi nei siti contaminati)	SNPA	Document prepared by the SNPA Working Group 9bis to define the procedure for validating data from direct measurements of aeriforms (in risk analysis); illustrates the analytical methods to be used for the measurements of aeriforms in contaminated sites on the different supports available (solvent desorption vials, thermal, canisters).
16.11.2018	Linee Guida SNPA n. 17/2018 (Procedura operativa per la valutazione e l'utilizzo dei dati derivanti da misure di gas interstiziali nell'analisi di rischio dei siti contaminati)	SNPA	Drafted by the SNPA Working Group 9bis to define a procedure for the validation of data from direct measurements of aeriforms (to be used in risk analysis): it illustrates a step-by-step approach for the assessment of soil gas data, the criteria underlying the definition of threshold values for soil gases, as well as for the assessment of the related risk.
01.03.2019	Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare 1 marzo 2019, n. 46 (Regolamento relativo agli interventi di bonifica, di ripristino ambientale e di messa in sicurezza, d'emergenza, operativa e permanente, delle aree destinate alla produzione agricola e all'allevamento, ai sensi dell'articolo 241 del d.lgs. 3 aprile 2006, n. 152)	MATTM	Regulation of interventions for the safety, reclamation and environmental restoration of areas intended for agricultural production and livestock subject to events that may have caused, even potentially, contamination.

06.02.2020	Nota Tecnica di indirizzo per il Sistema Nazionale per la Protezione dell'Ambiente: utilizzo dei software per l'analisi di rischio sito-specifica dei siti contaminati	SNPA	Technical note drawn up in September 2019, approved and transmitted by SNPA Council Resolution no. 68 of 6 February 2020: it provides clarifications on the use of SW for the AdR in order to standardize the technical guidelines within the SNPA, as well as to provide useful information to designers and homogeneous evaluation criteria.
14.10.2020	Decreto DG RIA 14 ottobre 2020, n. 130 (Definizione del formato della modulistica da compilare per la presentazione dell'istanza per l'approvazione del Piano di caratterizzazione di aree ricadenti all'interno dei perimetri di SIN)	MATTM (DG RIA)	Definition of the application format for the submission of the Characterization Plan of areas falling within the perimeters of SIN (Annex 1), as well as the minimum contents of the plan itself (Annex 2) **NB: Replaced by DG RIA Decree 20 July 2021, no. 114**
29.12.2020	Decreto del Ministero dell'Ambiente e della Tutela del Territorio e del Mare n.269 del 29/12/2020 (Programma nazionale di finanziamento degli interventi di bonifica e ripristino ambientale dei siti orfani)	MATTM	It regulates the criteria and methods of transfer to the beneficiaries of the resources for the implementation of the remediation and environmental restoration of orphan sites, as defined in art. 2.
30.03.2021	Decreto DG RIA 30 marzo 2021, n. 46 (Definizione del formato della modulistica da compilare per la presentazione dell'istanza di avvio del procedimento di valutazione di cui all'art. 242-ter, comma 2, del d.lgs. 152/2006, nel caso di interventi ed opere di cui all'art. 242-ter, comma 1, del medesimo decreto legislativo, da effettuare in aree ricomprese in SIN, anche in presenza di interventi ed opere che non prevedono attività di scavo ma comportano occupazione permanente di suolo)	MATTM (DG RIA)	Approval of the forms for the submission of applications for the initiation of the evaluation procedure pursuant to art. 242-ter, paragraph 2, of Legislative Decree no. 152/2006, to be submitted to the MiTE, as well as the minimum contents of the technical documentation to be provided, in the case of interventions and works referred to in art. 242-ter, paragraph 1, even in the presence of interventions and works that do not involve excavation activities but involve permanent occupation of land (defined in Annex A, which is an integral part of the decree)
10.05.2021	Interventi ed opere di cui all'articolo 242-ter, comma 1, del decreto legislativo 3 aprile 2006, n. 152. Chiarimenti.	MiTE (DG RIA)	Clarifications in relation to the applications for the initiation of the evaluation procedure referred to in art. 242-ter, paragraph 2, of Legislative Decree 152/2006, for interventions/works that the proponent considers to be among those referred to in paragraph 1 on the basis of the fact that they involve "a reduction in environmental impacts compared to the existing structure" (ultimately, it is clarified that this condition applies only to thermoelectric plants)
19.05.2021	Decreto DG RIA 19 maggio 2021, n. 72 (Definizione del formato della modulistica da compilare per l'istanza di approvazione del Progetto Operativo di Bonifica, di Messa in Sicurezza Operativa e Permanente, di aree ricadenti all'interno dei perimetri di SIN)	MiTE (DG RIA)	Approval of the application form for the start of the procedure for the approval of the POB/MiSO/MiSP for areas included within the SIN (Annex 1), as well as the minimum contents of the documentation to be attached (Annex 2). **NB: Replaced by DD DG RIA no. 137 of 18/8/2021**
19.05.2021	Decreto DG RIA 19 maggio 2021, n. 73 (Definizione del formato della modulistica da compilare per la conclusione del procedimento nel caso di contaminazione inferiore alle Concentrazione Soglia di Contaminazione in aree ricadenti all'interno dei perimetri di SIN)	MiTE (DG RIA)	Approval of the forms for the submission of applications for the conclusion of the characterization procedure for areas included within the SIN in the case of concentrations below the CSCs (Annex 1), as well as the minimum contents of the documentation (Results of the Characterization Plan) to be attached (Annex 2)
19.07.2021	Decreto DG RIA 19 luglio 2021, n. 113 (Definizione del formato della modulistica da compilare per la presentazione dell'istanza di avvio del procedimento di valutazione di	MiTE (DG RIA)	Approval of the forms for the submission of applications for the start of the procedure for the evaluation of interventions and works in areas included within the SIN referred to in art. 242-ter, pursuant to paragraph 3, of Legislative Decree no. 152/2006

	cui all'articolo 242-ter, comma 3, del d.lgs. 3 aprile 2006, n. 152, nel caso di interventi ed opere che ricadono nel campo di applicazione dell'articolo 25 del DPR 13 giugno 2017, n. 120, nonché nel caso di interventi ed opere che non prevedono scavi ma comportano occupazione permanente di suolo)		(Annex A), as well as the minimum contents of the documentation to be attached (Annex B), whether the interventions involve excavation activities or involve only permanent occupation of land. In practice, these are the interventions referred to in Article 25 of Presidential Decree no. 120 of 2017 and those that do not involve excavations but involve permanent occupation of land.
20.07.2021	Decreto DG RIA 20 luglio 2021, n. 114 (Definizione del formato della modulistica da compilare per l'avvio del procedimento di approvazione del Piano di caratterizzazione di aree ricadenti all'interno dei perimetri di SIN)	MiTE (DG RIA)	Approval of the application form for the start of the procedure for the approval of the Characterization Plan of areas included within SIN (Annex 1), as well as the minimum contents of the documentation to be attached (Annex 2), in line with Article 252, paragraph 9-quarter, of Legislative Decree 152/2006, introduced by Article 37 of Decree-Law No. 77 of 2021. **NB: replaces the previous DD DG RIA no. 130 of 14 October 2020**
18.08.2021	Decreto DG RIA 18 agosto 2021, n. 137 (Definizione del modello dell'istanza da compilare per l'avvio del procedimento di approvazione del Progetto Operativo di Bonifica, di Messa in Sicurezza Operativa e Permanente, e dei contenuti minimi della documentazione tecnica da allegare, in aree ricadenti all'interno dei perimetri di SIN)	MiTE (DG RIA)	Approval of the application form for the start of the POB/MiSO/MiSP approval procedure for areas included within SIN (Annex 1), as well as the minimum contents of the documentation to be attached (Annex 2), in line with art. 252, paragraph 9-quarter, of Legislative Decree 152/2006, introduced by Law no. 108 of 29 July 2021. **NB: replaces the previous DD DG RIA no. 72 of 19 May 2021**
22.11.2021	Decreto ex DG RIA 22 novembre 2021, n. 222 (Elenco dei siti orfani da riqualificare in funzione dell'attuazione della misura M2C4, investimento 3.4, del Piano Nazionale di Ripresa e Resilienza)	MiTE (ex DG RIA)	Approval of the list of orphan sites to be redeveloped on the territory of the Regions and Autonomous Provinces. As specified in paragraph 2 of Article 1, *the individual sites and related interventions to be carried out for the redevelopment of orphan sites ... will be defined in the (publishing, NDR) Action Plan referred to in art. 17 of Decree-Law no. 152 of 6 November 2021, within the limits of the economic resources provided for the M2C4 measure, investment 3.4, of the PNRR.*
22.12.2021	Decreto ex DG RIA 22 dicembre 2021, n. 269 (Definizione del modello di istanza da compilare per l'approvazione del documento di Analisi di Rischio sanitaria e ambientale sito specifica e dei contenuti minimi della documentazione tecnica da allegare, relativi ad aree ricadenti all'interno dei SIN)	MiTE (ex DG RIA)	Approval of the application form for the start of the procedure for the approval of the Health Risk Analysis document (Annex 1) and the minimum contents of the technical documentation to be attached (Annex 2), relating to areas falling within the perimeters of the SIN, pursuant to art. 252, paragraph 9-quarter, of Legislative Decree 152/2006, introduced by Law no. 108 of 29 July 2021.
23.02.2022	Decreto DG USSRI 23 febbraio 2022, n. 15 (Criteri di ammissibilità degli interventi nei siti orfani da realizzare con le risorse del PNRR (misura M2C4, investimento 3.4) per l'adozione del Piano d'azione e check-list di verifica)	MiTE (DG USSRI)	Definition and adoption of the eligibility criteria for interventions in orphan sites and commitments (art.1) for the purpose of adopting the Action Plan provided for by art. 17 of Legislative Decree no. 152 of 2021 as part of the M2C4 measure, investment 3.4, of the PNRR, in accordance with the technical instructions referred to in note no. 21 of 14 October 2021 of the MeF; approval of the check-list (art. 2 and annex A) for the verification of the eligibility for funding of the interventions

Table 5 - Updated overview of technical-normative documents supporting the remediation procedure

2.8 Analysis of the current context of waste management in Italy

The purpose of the chapter is to analyze the flow of 5 types of waste that are typically encountered in brownfields sites regeneration and, more broadly, in the proper management of anthropized areas: municipal waste, asbestos-containing waste, waste consisting of soil and rock, CDW, and sludge from civil wastewater treatment, performing the following targeted insights:

- Italian and European regulatory context for these types of waste;
- Analysis of the main critical issues in the management of these types of waste in Italy;
- Performance of a reconnaissance analysis of the national context of the 5 waste streams (also taking into account the total waste production in Italy) with possible indication of present plant capacities;
- analysis of plant needs and identification of critical areas. An analysis of possible transport to foreign plants was also performed for each of the 5 indicated streams;
- Reconnaissance of plants in Italy and Europe, by type of treatment, disposal and recovery, with an indication of their technical characteristics; in this context, a mapping of the plants present for the treatment of the types of waste indicated and an analysis of their characteristics was carried out where data were available in the databases indicated below;
- Analysis of the movement of these wastes in Italy and to foreign countries in terms of environmental and economic impacts;
- Analysis of the planning and average capacity and as well as the location of new landfills and the time horizon in which they are to be operational, particularly for special hazardous wastes whose material recovery cannot be technically carried out;
- Analysis of the main tariffs by macro-type of waste: transport, disposal and waste recovery in the national and European context;
- Analysis of the national and European regulatory environment with reference to possible impacts on the target market (EU Taxonomy, Green Deal, Sector Directives, etc.);
- analysis of how sustainability principles are applied in waste management regulations/directives (EU directives, national laws, technical standards, guidelines);
- focus on how waste legislation affects the application of sustainability;
- review of sustainability assessment tools in waste management and how they work with possible inclusion of some example case studies.

The base year for the study is 2022 and the following sources have been consulted:

Italian context: ISPRA reports, regional databases, ISTAT, trade associations, research institutions, environmental foundation studies available online;

European context: officially recognized European databases such as those of the EC, European Parliament, EEA, European research institutes, European trade associations.

In particular, the analysis highlighted critical issues, good practices, and prospects for improvement in the context of circular economy and environmental sustainability.

Methodology

The analysis was conducted through the processing of official data from national public sources (ISPRA, ARERA) and European sources (Eurostat, OECD), complemented by regulatory and

technical references, mainly related to the Italian national context and the European community.
For each waste stream, depending on the sources reviewed and on the accessible data at the time of the study, the following aspects were examined: produced volumes, management methods, plant distribution, operational critical issues and the regulatory framework of reference.
The approach has been comparative between the Italian and European context, with particular attention to the objectives of recovery and reduction of landfill disposal.
Results and conclusions
Construction and demolition waste (C&D) (EER 170101, 170302, 170405, 170904)
In Italy, C&D waste production reached about 80 million tons in 2022, with a recovery rate of 79.8%, exceeding the EU target of 70%. At the European level, the average recovery rate is 89%, with significant differences among member states. Main critical issues related to the recycling and reuse of C&D materials relate to the lack of trust in the quality of recycled materials, lack of regulatory guidance, greater economic competitiveness of virgin materials, and the lack of clarity regarding REACH obligations related to material management.
Asbestos-containing waste (EER 17 06 01*, 17 06 05*, 15 02 02*, 16 01 11*, 15 01)
Management of waste containing asbestos represents a matter of great environmental and health relevance. In 2022, Italy produced 243,000 tons of waste containing asbestos, primarily managed through landfill disposal (89.8%). There are only 17 authorized landfills, with an uneven geographical distribution. The main critical issues relate to the lack of disposal sites and the need to identify new destinations, the absence of homogeneous data at the national level, and the need to develop new technologies for the inertization of asbestos, alternatives to disposal. At the European level, data on asbestos are often aggregated with other types of mineral waste and specific statistics have not been identified.
Excavated earth and rocks (EER 17 05 03*, 17 05 04)
Excavated earth and rocks constitute a significant portion of C&D waste. In Italy, in 2022, over 18.5 million tons were produced, with a recovery rate exceeding 80%. However, for soils containing hazardous substances, management is more complex and often involves export to Germany. At the EU level, only 35% is recycled, while 25% is still disposed of in landfills, and the remaining 40% is used as filling material. At the national level, authorization for new sites for the disposal of hazardous soils would be necessary, and in general, it would be appropriate to develop treatment technologies for the reuse of hazardous soils. The analysis conducted showed that the methods of data collection at the national level (essentially through MUD) do not allow for specific assessments of soils coming from remediation sites.
Urban waste
Urban waste management represents a crucial challenge for Italian and European cities. In 2022, urban waste production in Italy exceeded 29 million of tons, with still fragmented management and a significant infrastructural deficit in the Center-South. 52% of urban waste produced is sent to material recovery facilities for the treatment of separate collections. 18% of urban waste produced is incinerated, and the same percentage is sent to landfill disposal. Intermediate treatments of selection and bio stabilization, co-incineration, home composting, and use for landfill cover account for a total of 9% of the urban waste produced in Italy. Finally,

the export of urban waste was equal to 3% of the total production in 2022, with main destinations in Germany, Austria, and the Netherlands. In light of what has been observed also at a European level, where strong differences in waste management among the various member states can be seen, the main critical issue remains the difficulty of closing the waste cycle at the territorial level. Due to, especially, vertical fragmentation (numerous operators upstream and downstream in the chain) and horizontal fragmentation (operators have a local action radius at the municipal level) of the sector operators.

Sludge from the treatment of civil wastewater EER 19 08 05

In 2022, about 3 million tons of sludge were managed in Italy, of which 54.2% was sent for disposal operations and 43.4% was subject to recovery operations. The remaining 2.4% remained in stock at the end of the year. The main methods of reusing sludge appear to be: land application in agriculture, composting, anaerobic digestion, and incineration with energy recovery. The latest update of EU Directive 91/271/EEC related to the management of this type of waste mandates the adoption of advanced treatments for the removal of micro-pollutants and the use of energy from renewable sources to power the plants with a load equal to or over 10,000 equivalent inhabitants. It is emphasized that the development of emerging technologies aimed at nutrient recovery and the production of innovative materials such as bioplastics, bricks, activated carbon, and glassy materials is underway: it is therefore confirmed that it is essential to continue promoting research and innovation in this sector to ensure sustainable sludge management.

2.8.1 Innovative circular materials and construction techniques for environmental sustainability

The efforts towards an increased circularity in the construction industry pass through the proposal of a sort of “passport” for building materials (Rau & Oberhuber, 2022), to keep track of their genesis, use, and future re-use, recycling, and – ultimately – disposal. The use of materials should comply with the expected resource availability within a civil work’s lifetime (Cristiano, 2018), to avoid prospective shortages. The collection and disposal of construction and demolition waste undergo informal activities that make more sustainable approaches quite difficult to imagine and to implement (Cristiano *et al.*, 2021). An often underexplored aspect of circularity lies in the fact that efforts seem to be focused in finding a new life to waste, but the overall human economy is far from being circular, at present it is perhaps undergoing some “rounding-off”, with recycling anyway requiring additional materials and energy at every round, and with the “spinning speed” of economic rhythms that are still quite far from being addressed in a slow-down perspective (Cristiano *et al.*, 2020), since the acceleration of the economic throughput is still at the basis of human economies, pursuing monetary profit more than (or instead of) ecological sustainability.

2.8.2 Towards a Circular and Resilient city

Our cities today face several challenges: those of environmental, energy, and cultural transition to achieve sustainability in urban areas.

The role of cities, as is well known, is very important on an international level.

According to the United Nations, by 2050, 68% of the world's population will live in cities and therefore cities and their inhabitants will be increasingly exposed to various risks.

Cities, therefore, play a crucial role in the transition, serving as hubs of innovation and new ideas. This transition requires a shared strategy and the integrated management of various existing planning tools. Such an integrated process is necessary to overcome some of the major gaps, including those related to policy implementation (characterized by the absence of a strategic tool); regulations (unclearly defined standards); awareness (cultural barriers, inadequate information); financial resources (lack of public funding and/or private investments); and capacity (shortages of technical solutions and technological expertise).

Regarding the first gap (policy implementation), starting from the Rio de Janeiro Summit in 1992 and the Paris Agreement in 2015, various strategies and tools have been developed over the years with a focus on sustainability, understood as a genuine balance among the environmental, social, and economic dimensions.

Since its theorization in the late 1980s and early 1990s, sustainability has become a reference point for the development of communities and urban areas. The widely accepted definition of sustainability is from the Brundtland Commission, which has defined it as "… the development that meets the needs of current generations without compromising the ability of future generations to meet their own needs" (Bruntland, 1987). In general, sustainability is focused on increasing people's quality of life with respecting three key elements: the economic, environmental, and social well-being, both for the present and the future generations (Pirlone et al., 2020).

Today, the current economic model is experiencing a crisis, proving incompatible with the availability of natural resources. Therefore, the transition to a circular approach emerges as one of the best solutions from an environmental, social, and economic sustainability perspective (Paoli et al., 2023).

This contribution aims to operationalize existing strategies through the development of a tool capable of ensuring effective governance.

In 1992, the Environmental Action Plan was introduced within Agenda 21 in Rio de Janeiro, and in 2015, Agenda 2030 and its Action Plans were introduced in Paris.

This research proposes a specific **Action Plan: A Plan for a Circular and Resilient City**. This tool aims to provide a comprehensive vision of objectives and actions to improve urban sustainability levels. Such tools can complement existing urban plans, making them even more effective in addressing current challenges.

Key aspects to be considered in this new Plan are the concepts of circularity and resilience.

It is necessary to close the cycle at the city level.

So far, the closure of the waste cycle has been properly explored and implemented, but the vision needs to be broader if we want to transform current urban realities into circular and sustainable cities. Therefore, a dedicated Plan is needed to address the closure of the urban cycle.

Another fundamental aspect is resilience. Resilience, as we know, represents the ability of an urban system to adapt to external stress or events. Initially, it was introduced to address natural risks. Today, urban resilience tackles various types of risks, including those caused by human activities, such as environmental risks (e.g., waste management) or climate change, which can intensify existing natural events.

Resilience focuses on the response of systems (differentiated in environmental, social, and economic systems) to both extreme disturbances and persistent stress. Urban resilience has become an important objective for cities. Urban resilience refers to "the ability of an urban system—and all the ecological and socio-economic networks that make it up on a temporal and spatial scale—to maintain or quickly return to the desired functions in the face of a disturbance, adapting to change" (Collier et al., 2016). Sustainability and resilience are both used to describe a system (Pirlone et al., 2020).
The new Action Plan aims to deepen not only the aspect of circularity but also that of resilience, to achieve true sustainability.
A sustainable city is, in fact: a circular city designed to regenerate, a resilient city capable of adapting to both natural and anthropogenic external events, and a smart city that uses ICT tools. This tool must also be participatory to be sustainable. The role of the various stakeholders becomes fundamental in the new proposed Plan to define shared objectives and actions.
Therefore, the new circular and resilient Action Plan introduces new participatory sustainable actions, also aimed at the sustainable regeneration of the city.
From an urban planning perspective, as is well known, there has been a shift from the concept of recovery (recovery of the urban fabric) in the late 1970s, to the concept of urban renewal (which focused on quality of life) in the 1990s, to regeneration, which began in the 2000s, and finally to recycling parts of the city (with the application of the circular strategy). This last phase involves integrating recovery and renewal, while also introducing the concept of participation from various stakeholders.
Urban regeneration is carried out through actions aimed at the recovery and requalification of urban space, limiting the land's use with a view to environmental sustainability. It has the primary aim of improving the quality of life of the people, through an intelligent use of urban spaces, without losing focus of the peculiarities of the context. It represents a circular and sustainable practice, as it operates improvements on the environmental sphere, reducing the consuming of soil, the anthropic and energy impact on the ecosystem, social, creating new places of gathering, and economic, bringing value to places (Pirlone et al, 2022).
The European Union promotes and funds urban regeneration, as well as circularity and approaches aimed at urban resilience, addressing issues such as reducing land consumption and the sustainable redevelopment of urban areas.
Even Italy with the Green New Deal 2020-2023 fund in the 2020 State Budget, has made available 4.2 billion euros to "realize economically sustainable projects that have as their objective the decarbonization of the economy, the circular economy, urban regeneration, sustainable tourism, adaptation and mitigation of risks on the territory deriving from climate change and investment programs and projects of an innovative nature and with high environmental sustainability" (Pirlone et al, 2022).
A circular approach considers topics of urban planning: transport systems, water, sanitation, waste management, disaster risk reduction, access to information, education and capacity-building in a circular way, planning a sustainable urban development and regeneration that close the production cycles (Pirlone et al, 2022).
Therefore, circularity and resilience represent an opportunity to regenerate the territory and create urban realities with a higher quality of life for their inhabitants.

3 CUM approaches and practices for regeneration: toward adaptation and mitigation of urban metabolic risk

This chapter examines the regulatory framework and current practices related to environmental remediation and site decontamination in Italy. It provides a comprehensive overview of the key national regulations, starting with the Legislative Decree 152/2006 and other relevant laws related to characterization and remediation interventions. The study explores the process involved in site remediation, including the definition and application of screening values. Additionally, it presents a detailed survey of contaminated sites in Italy, including regional censuses and the national inventory of contaminated sites (SIN). The research also reviews the most widely used decontamination technologies in the Country. Through this analysis, the study highlights the challenges and advancements in Italy's efforts to address environmental contamination and promote sustainable remediation practices.

In the face of growing environmental pressures, social inequalities, and increasing exposure to urban risks, **Circular Urban Metabolism (CUM)** approach offers a strategic framework to support the sustainable transformation of cities. By promoting the circularity of material, energy, and ecological flows, as well as the involvement of local communities CUM strategies foster more efficient and regenerative use of resources, contributing to urban resilience and climate adaptation. However, the bibliographic review highlighted that metabolic processes — which involve material flows but also processes of urban transformation and new life cycles – are deeply embedded in power relations that shape access to resources, exposure to risk, and spatial injustice. From this perspective, a strategy for developing circular cities must not only aim at technical efficiency but also address the socio-environmental inequalities produced by dominant urbanization models. This means recognizing cities as hybrid socio-natural systems, where metabolism is not neutral but actively constructs uneven urban landscapes. Chapter 3 will explore both spatial planning and ecological strategies for remediation and regeneration of cities and brownfields with particular reference to possible use of NBS and Gentle remediation Options to avoid the production of soil waste throughout the remediation process, as well as well the definition of a new tool designed to enhance the circularity and resilience of a city.

3.1 A gentle approach: ecological value and role of vegetation in brownfield remediation and redevelopment

The management of historical contamination (e.g. brownfields and orphan sites) presents several challenges, both in terms of site characterization (including risk assessment) but also considering the following steps required for site remediation and redevelopment. Contaminated sites release potentially toxic compounds into soil, air and water, and can restrict economic development and decrease property values and the attractiveness of communities. Such sites are often located in urban industrial areas and lower income communities; however, they offer potential for urban re-development through land recycling after remediation (EA, 2022).

Traditional remediation technologies typically require high energy and resource input, and can result in loss of land functionality and cause secondary pollution; in this sense, there is a growing interest in the use of alternative methods (such as those indicated with the terms Gentle

Remediation Options and Nature Based Solutions) applied to remediation and conversion of brownfield sites to public greenspaces and site redevelopment.
The term **Gentle Remediation Options (GRO)** indicates risk management strategies or technologies that result in a net gain (or at least no gross reduction) in soil function as well as achieving effective risk management (Drenning et al. 2022). The term **Nature Based Solution (NBS)** refers to actions "inspired by, supported by, or copied from nature" (van den Bosch and Sang, 2017); according to the European Commission, NBS are "solutions that are inspired and supported by nature, which are cost-effective, simultaneously provide environmental, social and economic benefits and help build resilience. Such solutions bring more, and more diverse, nature and natural features and processes into cities, landscapes and seascapes, through locally adapted, resource-efficient and systemic interventions" (European Commission, 2017).
GRO and NBS are umbrella concepts that can be used to capture nature based, cost effective and eco-friendly treatment technologies, as well as redevelopment strategies that are socially inclusive, economically viable, and with good public acceptance (Song et al., 2019, Drenning et al. 2022). In last years, several studies have investigated the theorical framework of these approaches and their benefits (environmental, social, and economic) in a wide variety of applications (Song et al., 2019; Faivre et al., 2017; Raymond et al., 2017; Drenning et al. 2022), including their use in the urban environment (van der Jagt et al., 2017, Kabisch et al., 2016, Greksa et al. 2024, Bona et al. 2022) but also their application in land reclamation (Song et al., 2019, Hou et al., 2014, Hou et al., 2018, Hou et al., 2016, 2023; O'Connor et al., 2017, Zhang et al., 2018).
As indicated in Song et al. (2019), these approaches offer great potential for application in the field of contaminated land remediation and brownfield redevelopment; this is an area of huge significance due to the need to optimize high cost associated with remediation activities with respects to net benefits and overall sustainability. Specifically, the use of NBS at brownfield sites holds much promise because it has a number of beneficial sustainability implications, including an increased human well-being (by providing space for recreational and social activities, education etc), optimization of cost-benefits (also in term of management and control actions), increased resilience to social and environmental changes, improved air quality, reduced noise, protection or reclaiming ecological habitats, and lowered life cycle environmental footprint of remediation operation. Additionally, vegetation, as a component of NBS, helps to address a variety of climate-related difficulties and vulnerabilities and is considered an important component for its contribution in the delivery of ecological functions and related ecosystem services.
However, despite the progress made in successful green alternatives (such as GRO and NBS) in the remediation practice area, many regulators are still hesitant towards their application as current policies set remediation targets based on total contaminant removal or destruction, rather than risk reduction to acceptable levels (Drenning et al., 2022). As stated by Drenning et al. (2022), the inherent uncertainties and long timeframe potentially required for green alternative to achieve such remediation targets pose challenges to their widespread adoption. Thus, **site remediation is often based on conservative target-based risk assessments, leading to over-designed, invasive, and unnecessary risk management solutions that entail large costs to society.**

Additionally, it is worth noting that the remediation community traditionally relies upon human health risk assessment (HHRA) to derive cleanup standards that are suitable for future use, while an evaluation of ecological values and ecological risks is not always required or admitted by legislation. With special regard to Italy, the legally binding procedure to assess contaminated sites (Legislative Decree 152/2006, 2006) requires the evaluation of risks to human health posed by contaminants in soils and groundwater, whereas the consideration of ecological receptors potentially linked to relevant exposure pathways is not required and assessment of ecological values is not specifically required (Bizzotto et al. 2022). The lack of a regulated and officially recognized approach in Italy to the application of Ecological Risk Assessment in contaminated sites has led, in some cases, to the elaboration of assessments that have proved to be biased or unsatisfactory with respect to the remediation objective and reuse of sites (Bizzotto et al. 2022).

Under this context, vegetation (including both urban greening and spontaneous vegetation) is a relevant component of various NBS and represents valuable support in mitigating and contrasting issues related to climate changes and anthropic pollution, providing several services and functions. A proper knowledge and assessment of main vegetation attributes (i.e. traits) represents therefore an essential step in order to improve their benefits (such as stormwater retention, cooling, habitat for biodiversity and mitigation of air pollution, phytoremediation) and to support the creation and design of more sustainable spaces and landscapes, considering also future challenges related to the climate change; this is especially relevant in cases where there is the will and/or the need to optimize the land reclamation/redevelopment activities taking also into account and valuing existing ecological components and related ecosystem services.

This chapter aims to summarize key concepts related to plant succession and ecology, as well as to present ecological functions and services delivered by existing vegetation in area to be redeveloped, in order to illustrate the benefits provided by the existing biodiversity (evaluating also potential issues due to the presence of invasive species), to foster awareness and support for local ecology, to support engagement with the local community and to provide a different perspective on land reclamation under a circular economy approach.

3.1.1 Ecological succession and spontaneous vegetation in contaminated sites: a short introduction

Ecological succession is a fundamental concept in ecology; this term indicates the process by which the mix of species (e.g. plant community) and habitat in an area replace (or “succeed”) one another over time. The changes can take decades or only years, depending on many factors such as the existing plant community, climate, seed dispersal and soil type. Each plant community creates conditions that subsequently allow different plant communities to thrive. Succession stops temporarily when a “climax” community forms; such communities remain in relative equilibrium until a disturbance restarts the succession process.

Generally, the initial phase of plant succession (e.g. colonization of a bare substrate) is characterized by the presence of pioneer species (such as weeds and grasses), that can grow in poor soil conditions and disturbed sites. Often, pioneer plants are fast-growing, have a variety of adaptations which facilitate dispersal (e.g., windborne seeds), and can quickly establish themselves in cracks and empty lots.

As pioneer species modify the environment (e.g., improving soil quality), more species can establish themselves (such as herbaceous plants and shrubs), introducing more structure and habitat. As the environment continues to change, more complex communities develop and, depending on the environmental conditions, shrubs and young trees may take root. In the absence of further disturbance, the ecosystems may eventually reach a more stable state (e.g., in a temperate environment, usually a forest).

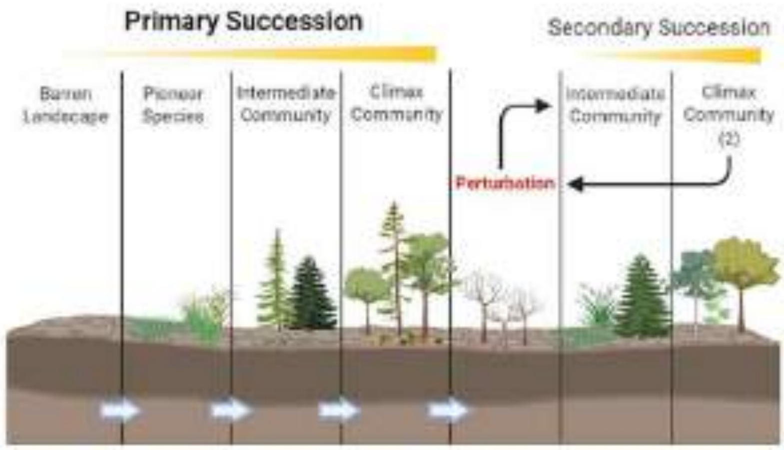


Figure 8 - Model of ecological succession

The model of ecological succession (Fig. 8) describes the stages of primary succession (left) that occurs through pioneer species which colonize an initially uninhabited landscape from an environmental reservoir secondary succession (right) that occurs through locally resident species following a perturbation that disrupts the normal steady state and results in the formal of a stable, but different climax community. As the perturbations, however minor, are constantly occurring, even a relatively "steady-state" community is constantly in a dynamic state of flux, and moving toward a desired equilibrium, which may never be truly reached.

In the context of contaminated sites and brownfields, former industrial sites often have environments that are unfavorable for plant growth, such as impermeable land surfaces, toxic contaminants in soil and groundwater, and a lack of seeding plants in the nearby environment. However, historical contaminated sites can also experiment, along years, recolonization by spontaneous vegetation, or can form valuable ecological habitats, such as wetlands, breeding areas, thus introducing ecological values and creating "unexpected" (and, in some cases, unwanted or underappreciated) successional landscape also in contaminated area.

As reported by Salgueiro et al. (2020) and Whisenant (1999), the conceptual model of state transition from a highly degraded state (e.g., area with absence of soil and other alteration) to a fully restored environment typically includes two main constraints (Fig. 9):

i. The first barrier is controlled by abiotic limitations (e.g., lack of soil, unstable substrates, steep slopes, contamination, erosion etc). At this stage, restoring soil properties and landforms are necessary to reinstate soil functions, thus preventing erosion, water drainage or retention, and nutrient leaching, which ultimately will determine vegetation settlement. These processes can also occur naturally but with a time scale that often is not compatible with human needs; in this sense, human intervention can serve to significantly speed up the process and to drive the overall restoration process.

ii. The second barrier is introduced by a biotic barrier. Ecosystem functioning relies on the interplay within and between the biotic and abiotic components of an ecosystem, that is, ecological processes. Reinstating ecological processes will allow the system to regulate itself without the need for active intervention.

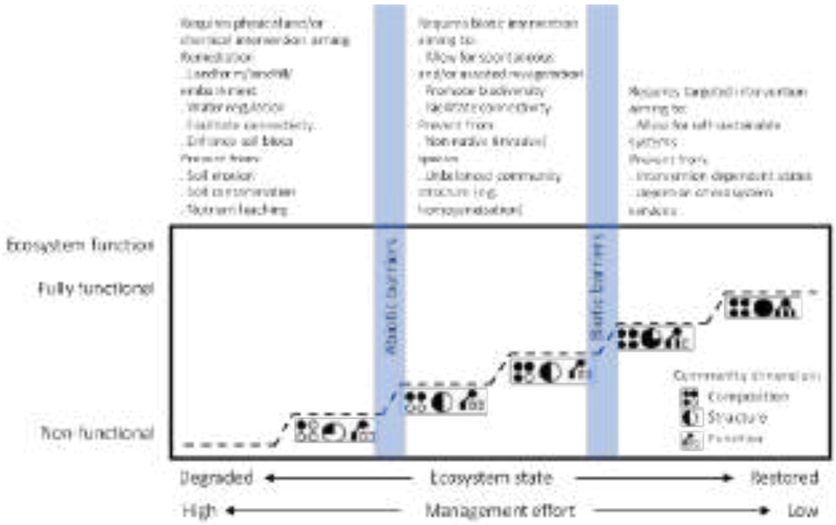


Figure 9 - Conceptual model of state transition along a degraded to restored gradient from a highly degraded state (e.g., an exploited quarry area) to a fully restored environment. Source: authors elaboration on Salgueiro et al., 2020.

In the conceptual model of state transition horizontal dashed line signals the different hypothetical equilibrium states along the gradient; diagonal dashed line signals transition between states. Each state transits to a more or less functional system (with increasing complexity of the community dimensions); two main barriers may exist in the restoration process, due to abiotic limitations (e.g. lack of soil) or biotic limitations (e.g. unbalanced process in the revegetation). The intensity of these constraints may vary between site condition and overall restoration target. Overcoming these barriers can be either promoted by spontaneous (supported by ecological succession when barriers can be naturally overcome) or active intervention (if barriers are naturally constrained).

As recognized in the scientific literature (Salgueiro et al., 2020), a restored site does not have to specifically mimic the pristine situation, but to be fully functional (hosting self-sustainable communities for long term with minimal or no intervention). Similarly, Drenning et al. (2022) reported that, with regard to contaminated soils, the ultimate objective of any remediation process is not only to remove the contaminants from the soil (or, instead, break exposure pathways) but also to restore soil functioning and quality.

In this sense, spontaneous revegetation is environmentally friendly in that it reduces weeding, watering, and soil amendment requirements. It is affected by both pollution patterns and environmental effects, although the most relevant drivers affecting natural revegetation are strongly dependent by site specific condition. In literature there is also conflicting evidence showing that other environmental effects (e.g. soil structure and depth, nutrients, water availability etc) can be more influential than soil contamination level in determining plant diversity and abundance (Song et al. 2019, Adamo et al., 2015).

3.1.2 Functions and services provided by vegetation and possible application in site remediation and redevelopment

Vegetation provides multiple benefits, due to their ability to store carbon, regulate water flow, increase air quality, support in noise reduction, microclimate regulation and, more generally, determine positive impacts on biodiversity and cultural values. However, unsuitable use of vegetation in urban context can also introduce disservices, although the perception of these disservices can also be strongly influenced by several factors (such as age, education, cultural values, attitudes, health conditions, knowledge of the person making the evaluation and context of reference) (De Groot 2006, Roy et al., 2012, Semeraro et al. 2021).

In this sense, the use of vegetation in redevelopment plans and in urban areas should be strongly connected to the overall environmental factors as well as local policy, social context and its dynamics.

As example, Salmond et al. (2016) reviewed ecosystem services (defined as subset of ecological functions that are directly or indirectly linked to human benefits or wellbeing) provided by street trees, concluding that the relationships between the bio-physical properties of vegetation and human benefits are both complex and context-dependent. While some of the biophysical functions of trees can be summarized and described 'in general', the particular meanings, values and societal implications of vegetation in urban areas for a particular setting need to be evaluated scientifically and justified politically in place.

As recognized in literature, urban greening initiatives should be pursued through a process where the multiple meanings of vegetation (cultural as well as scientific) can be articulated and deliberated together (Salmond et al., 2016); in this sense, listing potential societal benefits provided by vegetation can represent a starting point for conversation with affected stakeholders, to support a meaningful engagement from diverse community voices and perspectives considering specific and local needs and desires.

Under this context, the tables below summarizes main ecological functions that can be developed considering the use of vegetation (as part of NBS) in anthropic areas, and the relative benefits (Tab. 6) or disservices (Tab. 7) that may derive from them; specifically, the Table 1 illustrates the link between ecological functions, ecosystem services and benefits for human health (adapted and modified from Semeraro et al., 2021, Greksa et al. 2024, De Groot 2006, De Groot et al. 2012).

The benefits provided by vegetation can help mitigate environmental pollution and risks related to human activities but can be used also to contrast current climate-related vulnerabilities, regulate microclimate, improved human health, and, more generally, to manage different environmental and climate-related problems.

Ecological Processes	Ecosystem Services°	Possible Benefits
Energy flow from solar radiation into edible plants and animals	1—Food	Fruits, Small scale subsistence
Biomass production, photosyntesis	3—Raw material	Fiber, timber, leaves to be used in compost production etc
Influences on material and energy flow of the ecosystem in biogeochemical cycles (CO_2, ozone layer etc.)	7—Air quality regulation	Reduction of respiratory and cardiovascular illnesses and allergies, Evacuation of air pollutants (e.g., particulate matter, CO_2, nitrogen dioxide, carbon monoxide and sulphur dioxide), Carbon sink, Reduction of carbon footprints, Dust mitigation/reduction
Evapotranspiration	8—Climate regulation	Evapotranspiration, Increase of shade and thermal comfort, Reduction of heat-related illnesses, Reduction of greenhouse gas emissions, Mitigation of heat flux (including urban heat island effect), Reduction of urban energy consumption (e.g., for climate conditioning), Reduction of carbon footprints, Decrease of cooling and heating, Reduce stormwater temperature impacts, Wind speed reduction, Noise reduction
Increase of surface albedo		
Plants influence on microclimate		
Plants contribute to runoff reduction through the interception of rainwater and evapotranspiration; assimilate toxins and pollutants into their stems and roots, Plants create conditions for different biological and physicochemical processes, By slowing down water flow and enabling silt to fall out of it, plants help remove sediment and offer mechanical filtration, Plants absorb nutrients in the tissues and root system and provide space for the growth of bacteria	11—Water and soil treatment 9—Moderation of disturbance events	Reduction of disturbance events and stormwater volume, Increased water retention, Decrease of the burden of the water treatment facilities, Discharge rates, Recharge groundwater by infiltration, Flood prevention, Improvement of wastewater quality, Phytoremediation, Prevention of water and soil pollution, Prevention of eutrophication, Improvement of organic degradation and prevention of erosion, Increase in pollutant degradation
Filtering, retention and storage water, Enhancement of water infiltration into soil	10—Water regulation	
Accumulation of organic matter, Plant roots continuously fracture the filter media's surface	12—Erosion prevention 13—Maintenance of soil fertility (including soil formation)	Maintenance of soil productivity, Retention of soil nutrients, Organic waste and compost production, Prevention of surface clogging and soil degradation, Soil stabilization, Support soil formation
Living space suitable for wild plants and animals' growth and reproduction, Plants provide food, shelter, and reproductive sites for pollinators and other creatures, Plants create microclimates for flora and fauna, Seed production	14—Pollination 15—Biological control 16—Maintenance of life cycles of migratory species 17—Maintenance of genetic diversity	Support biodiversity and genetic diversity, Provision of habitat for insect and animals, Implementation of vegetation biodiversity and improved landscape, Propagation of plant adapted to site specific conditions (eg. Metal tolerant, etc)
Attractive landscape elements	18—Aesthetic information 19— Opportunities for recreation & tourism 20—Inspiration for culture, art and design 21— Spiritual experience 22— Information for cognitive development	Promotion of green lifestyles, Increase of community engagement, Provision of recreational green spaces, Aesthetic appreciation, Increased inspiration, Increased recreational activities, Improve the quality of physical function and/or health, Cultivating psychological well-being, Constructing Community and building social bonds, Reclaiming the city, Cultural identity

°considering the TEEB classification (from 1 to 6 provisioning services; from 7 to 15 biological services; from 16 to 17 habitat services; and from 18 to 22 cultural and amenity services). The table was structured following the ecosystem services classification and the link between ecological processes and benefits developed by de Groot et al. (2006, 2010).

Table 6 - Example of the main ecosystem services and main roles provided by vegetation in urban/industrial areas. Source: authors elaboration on Semeraro et al. 2021, Greksa et al. 2024, De Groot 2006, De Groot et al. 2012).

Ecosystems functions	**Disservices**	**Example**
Photosynthesis	Air quality problems	Emission of the volatile organic compounds (VOCs), Concentrations of particulate matter (PM)
Vegetation biomass growth	Blockage of landscape view	Limit of the scenic views by trees located in front of the windows of the buildings
	Cost related to maintenance	Cost for planting, irrigation, pruning, street cleaning, green waste etc
Flow of floral gametes such as pollen	Allergies and/or intoxication	Allergic reactions
Plants aging	Accidents	Break up of trees and branches falling in roads causing damage of matter and people
Dense development of the plants	Fear and stress	Dark green areas perceived unsafe, fears of crime/disease/insects etc
Decomposition and biomass root fixation	Damages to infrastructure	Breaking up of pavements, Drip sap or sticky residue on streets/parked cars, causing drainage problems
Habitat provision for animal species	Habitat competition with humans, Abundance of undesired species, Introduction of invasive species, Contamination of crops with pathogenic organisms or residues of agrochemicals and other pollutants through contaminated soil, water or air	Animals/insects perceived as scary, unpleasant and/or disgusting, Animal species can be vectors of diseases (e.g., avian influenza, rabies), Population development of invasive species
Water supply	Decrease in water quality/quantity inappropriate drawing of water sources threat of local water sources or underground water contamination due to uncontrolled treatment of fertilisers, pesticides or rich manure from animals	Amount of water used for plant growth, Water pollution
Soil erosion	Poor environmental conditions of land, further depletion of soil quality	Use of fertilisers that can alter the quality of the soil

Table 7 - Potential disservices related to vegetation. Source: Roy et al., 2012, Semeraro et al., 2021.

With special regard to contaminated sites, colonization of spontaneous vegetation (also in case of ephemeral/ruderal/stress tolerant species or even invasive species) can therefore provide several ecological functions, for example supporting the pedogenesis process, enhancing soil stabilization, supporting contaminant sequestration and degradation, reducing erosion and increasing water retention and energy capture process, etc… Therefore, although the presence of vegetation can be simply considered an extemporaneous factor, to be erased to allow traditional soil remediation activities, it is also important to underline that proper management should facilitate the creation of a self-repairing landscape, enhancing the delivery of functions and services necessary for ecologic and socioeconomic sustainability.

Among the other advantages, the use of vegetation in land reclamation and developing brownfield sites holds great promises for global climate change mitigation. As example, a study conducted in San Francisco indicates that brownfield redevelopment offers the mitigation equivalent to 14% of the city's annual GHG emissions (Hou et al., 2018b).
With regard to site remediation, Drenning et al. (2022) explored the application of **phyto-management strategies** to support risk management and mitigation at contaminated sites. Authors reported that phyto-management has been demonstrated to be an effective strategy for sustainably managing and monitoring risks posed by a wide variety of contaminants, improving soil functions and ecosystem services, and generating profits where local conversion chains are present to value biomass. Phyto-management strategies include both *phytoextraction* (aimed to remove contaminants), *phytostabilization* (which intends to minimize the uptake of contaminants, sequestering the pollutants in soil and reducing contaminant bioavailability) and *phytodegradation* (Drenning et al., 2022, Song et al., 2019). Another possible application of vegetation in land remediation and mitigation actions is *phytocapping*, that is establishment of perennial plants on a layer of soil placed over landfills; plants are used as ‘bio-pumps’ and ‘rainfall interceptors’ and soil cover as ‘storage’ of water, in order to minimize water percolation into the waste (Venkatraman & Ashwath, 2009).
While the economic aspect is undoubtedly important for long-term sustainability of these strategies, the wider environmental benefits generated in phyto-management, especially at larger sites, are becoming increasingly salient in the modern context of widespread environmental degradation, biodiversity loss, rising sea levels, climate change and other challenges to meet a sustainable development.
However, the use of phyto-management and other gentle approaches is often under discussion and many regulators are hesitant towards their application as current policies set remediation targets based on total contaminant removal or destruction, rather than risk reduction to acceptable levels (Drenning et al., 2022). Improved communication is needed to support risk reducing strategies that emphasize a risk-based perspective instead of focusing exclusively on total amounts of soil contaminants; in this sense, it is also worth to note that, often, a critical aspect to be evaluated in site-specific risk assessment is the effective bioavailability of contaminants, i.e. the readily available fraction of a contaminant that can cross cell membranes to enter the organism. Due to the complexity in determining this factor, often risk assessments rely on ultra-conservative assumptions, leading to invasive and large remediation plans.
To support the decisional process, Drenning et al. (2022) recently developed a generic risk management framework considering GRO, illustrating the connections between risk mitigation mechanisms, risk objects, and GRO strategies (Fig. 10). In summary, authors identified three main risk mitigation mechanisms linked to phyto-management (and other similar approaches):
bioavailability and solubility reduction,
source removal – plant uptake, degradation, volatilization, and
secondary effects by vegetation cover for plant-based GRO.
The relative risk reduction time for these strategies has been estimated to be mostly similar, because the time required for the onset of risk mitigation is dependent on the time it would take for vegetation to establish or for amendments to alter soil properties. Based on literature review,

vegetation establishment can be separated into different time ranges depending on plant species (Fig. 10):

i. Quick – soil amendments and fast-growing species like grasses, herbaceous species and annuals crops can provide risk mitigation within 6-8 weeks;
ii. Medium – shrubs take longer to establish and can provide wider, more lasting risk mitigation within 1-2 years;
iii. Slower – trees provide the most extensive risk mitigation with roots able to reach down to deeper soil layers but even fast-growing tree species like willow and poplar can take from 2 to years to establish.

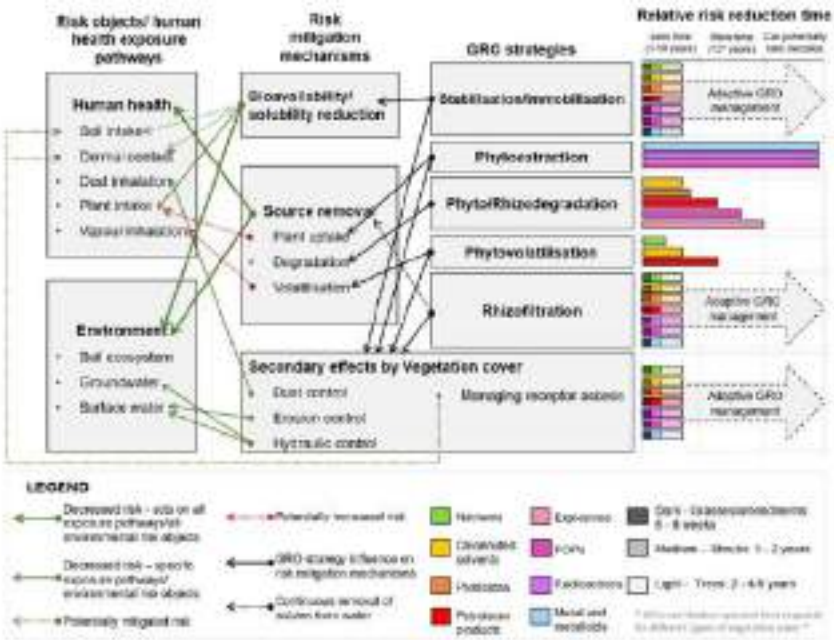


Figure 10 - Risk management and communication framework for GRO. Source Drenning et al. 2022

In the risk management and communication framework for GRO, as developed by Drenning et al. (2022), columns indicate specific information on risk objects, risk mitigation mechanisms, GRO strategies and a bar chart depicting relative risk reduction time for each GRO strategy. Relative times for stabilization/immobilization, rhizofiltration and vegetation cover are based on literature. Adaptive GRO management is needed for all GRO strategies during their implementation, and includes long-term monitoring, watering, etc. for upkeep and to ensure the risk reduction is maintained over time.

Similarly, Song et al. (2019) evaluated the application of NBS solution in brownfield remediation and redevelopment, concluding that integrating revegetation of contaminated soil with landscape architecture can be an effective NBS for brownfield redevelopment. For this, designers must understand the spatial distribution of soil contaminants and soil properties like pH and organic matter content. Contaminant enriching plant species may be used for contaminant removal at heavily polluted areas, whereas native species tolerant of contaminant toxicity can be used to cover the majority of moderately polluted areas. Institutional or engineered controls can be put in place to limit public site access in order to prevent the risk of direct contact, i.e. dermal and ingestion related exposure (Song et al. 2019). For example, authors indicated that raised pathways maybe used to separate human activities from the contaminated media. Under this context, Table 8 reports a summary of the main benefits provided by use of vegetation and, more generally, application of other NBS in brownfield remediation and redevelopment (modified from Song et al. 2019).

Nature based remediation technologies	Advantages			Disadvantages
	Social benefits	Economic benefits	Environmental and ecological benefits	
Contaminated land remediation				
Constructed wetlands	Improve aestethics, create meeting/ socializing space	Enhance flood control, ease drainage system burden	Create a healthy ecosystem, low life cycle environmental footprint, reduce flood risk	Challenges in operation, slow time period for remediation, require space
Phytoremediation	Improve aestethics, bring in health benefit	Enhance flood control; lower remediation cost. Further strategies can be used to enhance the economic viability;e.g. seedlings, grasses or shrubs may only be planted at strategically selected small areas, which can nurse subsequent plant succession in surrounding areas	Create a healthy ecosystem, improve air quality, low life cycle environmental footprint, reduce direct exposure pathway (contact with soil), dust suppression, carbon sequestration potential	Slow contaminant removal or sequestration
Phytocapping	Improve aestethics, bring in health benefit	Enhance water control, reduce water infiltration and thus cost related to eluate management	Improve air quality, reduce direct exposure pathway, dust suppression, carbon sequestration potential	Depending by the species, cost for maintenance
In situ bioremediation	Fast removal of contaminant	Lower capital expenditure	Low life cycle environmental footprint, lower global warming potential, air pollutant emissions, and ecotoxicity than other physical or	Potential toxic byproducts

			chemical remediation techniques	
Green synthesis for nanoremediation	Reduce use of toxic chemicals, fast removal of contaminants	Lower operating expenditure	Low life cycle environmental footprint, carbon sequestration potential	Difficulty in large-scale manufacturing
Stabilization with biochar, green mulch and compost	Eliminate waste, improve aesthetic	Lower operating expenditure, enhance flood control, dust suppression	Low life cycle environmental footprint, improve air quality, carbon sequestration potential	Risk in contaminants release with time goes and soil condition change
Brownfield redevelopment				
Revegetation and integration with landscape architecture	Improve aesthetics, provide leisure and recreational opportunities		Create a healthy and stable ecosystem	Extra cost for maintenance, Slower time period
Converting brownfield sites into greenspace	Improve public health, aesthetics, social interaction; increase area for public recreation	Enhance flood control, Reducing costs of building envelopes	Low life cycle environmental footprint, create a healthy ecosystem;	No income, extra cost for maintenance
Converting brownfield sites into green industrial heritage park	Education, culture preservation, increase area for public recreation	Improve local economy, low remediation cost, Improve life cycle cost	Low life cycle environmental footprint, Enhance evaporative cooling	High maintenance cost
Ground source heating and cooling	Meet the community heating and cooling demand	Lower heating and cooling costs, eligible for government subsidy	Low life cycle environmental footprint	High construction cost due to below ground excavation
Nature Preserves	Improve aesthetics, provide leisure and recreational opportunities		Maintain urban biodiversity	No income, extra cost for maintenance
Additional benefits provided by	adiabatic cooling, energy	improvement in the resilience of urban systems,	Protecting/providing/enhancing ecological features and biodiversity, mitigation	Possible concern for environmental

vegetation in brownfield redevelopment	efficiency improvements, creating space for socializing, pluvial flood reduction etc, improving environmental justice and social equality°	with socioeconomic benefits in the long term; promoting urban regeneration in declining former industrial centers.	of climate induced impacts, carbon sequestration; regulation of storm water runoff, reduction of 1) energy footprint of urban sewer systems, 2) negative impact of urban heat islands, 3) noise and air pollution, etc.	justice (e.g. in case of "green gentrification")°° Cost for maintenance
° E.g. improving environmental conditions for people living in deprived communities. Contaminated sites often represent locally unwanted land uses, and they are often associated with deprived/neglected communities where disadvantaged or marginalized people reside. The systemic cleanup and environmental upgrade of these sites could create new jobs and reduce social/behavioral problems, thus greatly improve the long-term livability and environmental quality of such local communities.				
°° E.g. as sites become remediated and redeveloped, often high-end commercial and residential buildings with green spaces are built, leading to wealthier residents moving in and the local community being displaced. This so-called "green gentrification" represents a concern for environmental justice (Anguelovski, 2016). A holistic approach to remediation with prudent decision-making based on green and sustainable remediation principals may help provide nature-based solutions that work for all.				

Table 8 - Summary of the main benefits provided by NBS in brown field remediation and redevelopment. Source: authors elaboration on Song et al. 2019.

3.2 Actions for designing the Circular City. An Action Plan for Urban Regeneration and Resilience[4]

This chapter aims to propose a new tool designed to enhance the circularity and resilience of a city. In the following paragraph we propose a possible structure for an Action Plan for a Circular and Resilient city. Then we focus on one of the operational tools on which the Plan is based: circularity and resilience indicators. Finally, we describe the circularity and resilience actions that the Plan considers closing the urban cycle and improving adaptation to natural or anthropogenic events. These actions also contribute to the sustainable regeneration of our cities.

[4] The contribution is the result of a shared reflection between the authors (Pirlone F., F. Paoli, I. Spadaro) and part of the research was developed within the framework of F. Paoli's doctoral thesis entitled "Proposal for a Participated Urban Circular Action Plan. The case of the city of Genoa".

3.2.1 Structure of the Action Plan

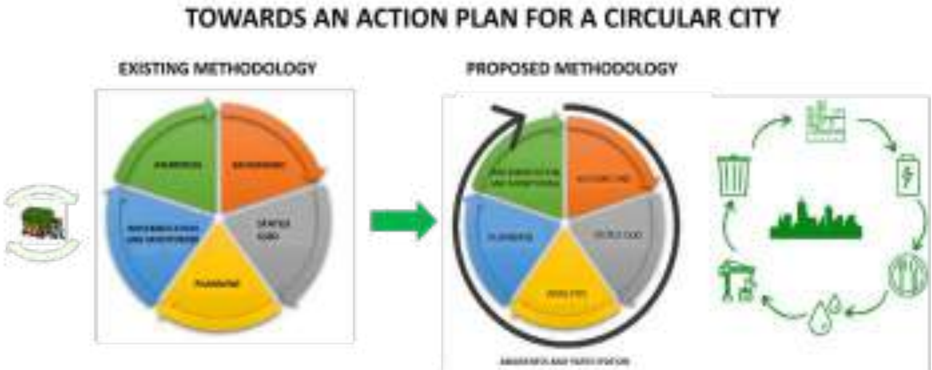


Figure 11 - Phases of an Action Plan and Resilient city. Source: authors elaboration

This paragraph proposes the structure of the Action Plan for a Circular and Resilient city, with circular, sustainable, and resilient objectives and actions, also aimed at urban regeneration (Fig. 11). This research seeks to concretize the proposed strategy through a tool that can give substance to all the guidelines and visions produced in the fields of circularity and resilience, which often remain at the level of good practices without contributing to the necessary global vision. Therefore, it aims to create a regulatory-level plan that gathers and communicates the circular themes that must integrate and coordinate with each other, ultimately contributing to a resilient vision of the city. This Action Plan must define a forward-looking program, developed together with economic operators, consumers, citizens, and civil society organizations. It should also present a series of interconnected initiatives designed to establish a strategic framework for the city, one that is consistent in which sustainable products, services, and business models will be produced, transforming existing consumption models.

The preparation of the Plan starts from a methodological approach developed within the framework of several European projects focused on sustainable waste management. Specifically, this initial research aimed at structuring a Sustainable Waste Management Plan at the urban level within the Mediterranean basin (Project MED3R 2012-2015). The methodology led to the definition of the structure of such a Plan, but more importantly, to the development of guidelines for its compilation.

Therefore, based on these guidelines, applied and modified according to new needs, the necessary phases for defining the Action Plan for a circular and resilient city have been structured (Fig. 12).

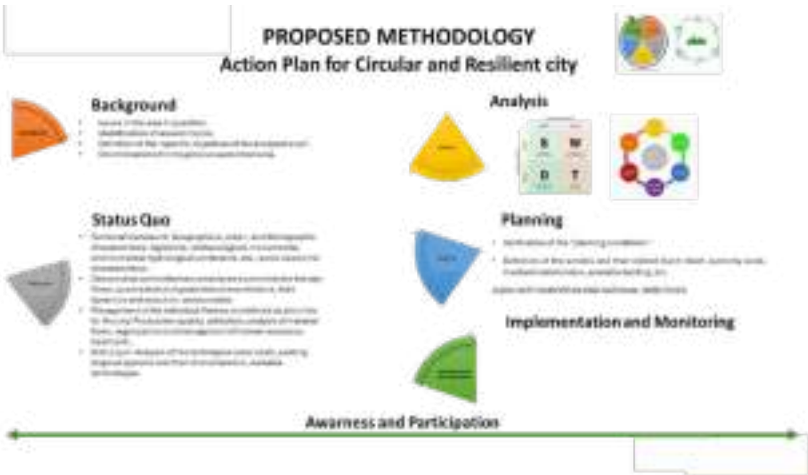


Figure 12 - Insight on the phases of the Action Plan. Source: authors elaboration

The first phase, "Background", includes a study of the issues in the area in question and the identification of relevant topics. This is followed by the definition of the "specific objectives of the analyzed area" and the determination of homogeneous watershed areas, meaning the definition of "homogeneous collection basins", which are areas with similar characteristics and behaviors regarding the actions planned for the development of a Circular and Resilient City.
The second phase, "Diagnosis of the status quo", is based on the collection of information about the territory. A precise understanding of territorial characteristics and various dynamics is necessary to create a priority scale for the interventions to be carried out. Indeed, planning must focus on identifying, within the specific territorial context, the best solutions that can ensure optimal performance and the achievement of the set objectives. This phase is essential both for drafting the actions of the Action Plan and for defining indicators aimed at monitoring the progress of the established objectives. The information to be included in this chapter can be summarized as follows for each theme being analyzed:
Territorial framework: Geographical, urban, and demographic characteristics, legislative, archaeological, monumental, environmental, hydrological constraints, etc.; socio-economic characteristics...
General data on the themes considered as priorities for the city: Flows, quantitative and qualitative characteristics, their dynamics and evolution, various notes.
Management of the individual themes considered as priorities for the city: Production-quality, collection, analysis of material flows, organization and management of human resources, treatment...
Status quo: Analysis of the techniques used, costs, existing disposal systems and their characteristics, available technologies.
The third phase carried out the analysis of the status quo, which must take into account a series of considerations that depend both on the municipal regulatory framework and higher-level regulations, as well as the characteristics of the area under examination, and any existing best practices and actions already implemented in the area. Specifically, the specific objectives of municipal plans for regional and national development, the strengths and weaknesses of current policies, and the opportunities and constraints of the territory being examined must be considered. This phase concludes with the "evaluation of objectives". Through a SWOT and

PESTEL analysis, the strengths, weaknesses, opportunities, and threats are identified, and based on these, proposals and recommendations are formulated.
The fourth phase represents the core of the new Action Plan. It focuses on “Planning” and begins with the verification of the "planning conditions." The goal is to define actions and their related Gantt chart, a priority scale, involved stakeholders, available funding, etc. In general, all actions defined in this chapter must align with European and national directives and should be consistent with the key priority identified by the European Union, which is prevention and therefore waste reduction at the source. It is also important to establish connections with existing tools in the territory and, most importantly, to intersect the various themes present in urban realities.
The fifth phase relates to “Implementation and Monitoring”, which should begin once the Plan has been approved and made operational. In this chapter, it is necessary to identify the indicators that serve as tools for verifying and controlling the activities of the Plan. All categories of indicators should have been defined in the previous chapters to assess both the pre- and post-implementation context of the Plan.
Finally, phase 6, “Awareness and Participation”, is not the last in chronological order, but it is transversal to all the phases. The importance of a participatory approach is fundamental to achieving full consensus and collaboration from the actors of the quintuple helix (public administration, citizens, universities, businesses, and the third sector). Through the involvement of these five types of actors and a participatory process based on information, communication, awareness-raising, and training, it is possible to create an open, circular, and resilient governance system, and therefore a sustainable one. In this process, the population plays a key role.
To close the life cycle of the city, it is essential to initially consider which themes are a priority for the specific city, the indicators to be considered, and the best practices needed to close the life cycle of each specific theme. Subsequently, these best practices must be systematized to achieve urban closure.

3.2.2 Action Plan and indicators of circularity and resilience

An Action Plan for a circular and resilient city must consider several aspects, both technical and social in nature (Fig. 13).
This section delves into a fundamental technical tool for the objectivity of the Plan: the indicator tool.
Indicators provide a synthetic measure, typically quantitative, corresponding to a variable, or composed of multiple variables, capable of summarizing the trend of the phenomenon it refers to.

Figure 13 - Action Plan - Aspects to be considered. Source: authors elaboration

In general, indicators can be categorized according to the dimension they measure, for example, using the DPSIR framework (Driving forces, Pressure, State, Impact, and Response). This framework was adopted by the EEA (European Environment Agency) to propose a general reference structure and an integrated approach in the environmental reporting processes conducted at any European or national level. It allows for representing the set of elements and relationships that characterize any environmental issue or phenomenon, linking it to the set of policies directed towards it. Indicators are also crucial at various stages of a Plan. Initially, they are essential in the knowledge and analytical phase, then in defining objectives and selecting the best actions, and finally in monitoring the Plan and the actions and best practices outlined within it

Of particular interest in this case are the sustainability, circularity, and resilience indicators. Regarding the former, a prerequisite on the path toward sustainability is the need to measure the impacts of urban activities and monitor the progress of the local Agenda 21 (as an important component of the UN Summits in Rio and Johannesburg). In general, since the adoption of the Aalborg Charter in 1994, there has been reflection on the necessity of indicators to measure progress towards sustainability. Various measurement tools focused on assessing and evaluating progress towards sustainability have been developed internationally, and several initiatives are underway at the European level (ECI - Common European Indicators, EEA Environmental Indicators, etc.). In recent years, there have also been efforts regarding local-scale indicators. Urban sustainability indicators are tools that allow urban planners, city managers, and policymakers to evaluate the socio-economic and environmental impact of current urban projects, infrastructure, policies, waste management systems, pollution, and citizens' access to services. They help diagnose problems and pressures, thus identifying areas that could be addressed through good governance and science-based responses. Moreover, they enable cities to monitor the success and impact of sustainability interventions.

How to measure circularity and resilience in urban contexts? This is one of the questions most posed in literature today, and the answer is far from straightforward.

In general, some indicators for circular cities have been identified (Saidani et al., 2019), however, it is often not possible to apply them (lack of data, inability to compare and monitor)

(Douma et al., 2015). Therefore, it is important to consider circularity indicators that, although not designed to be applied directly to the city, can still provide a good framework for some of its areas. It is essential to capture the important aspects of a city in its various sectors of activity and, for each of them, identify indicators that are universal and allow comparison between different sectors and case studies (Cavaleiro de Ferreira & Fuso-Nerini, 2019). In the context of circular cities, we need to define what we consider relevant and think about what can be measured and is worth measuring (European Academies' Science Advisory (EASAC), 2016). The indicators described in the literature and those proposed in circularity initiatives cover at least environmental, social, economic, and cultural aspects. However, the characteristics related to the circularity and resilience of a city are not fully measurable and therefore require specific indicators that may be subjective and qualitative. Although each Member State is subject to binding EU sustainability and circularity goals, there is currently no set of shared circular indicators at the national or European level. The lack of a widespread and participatory implementation strategy makes it difficult to achieve these goals. It is necessary to create a shared base of data and knowledge, measuring the flows, the effectiveness of actions taken in urban areas for closing the loops, their resilience, and providing the city with a clear view of the policies in place while ensuring the involvement of relevant stakeholders.
The research begins by reviewing existing indicators commonly referenced in the literature and official documents from cities that have endorsed initiatives like the Circular City Declaration. It then proposes a framework of indicators to evaluate urban circularity and resilience.
Drawing on databases of existing indicators and conducting a detailed analysis, the study identified 26 indicators suitable for diverse urban settings, despite various challenges noted. The selection criteria prioritized indicators frequently cited in multiple sources, emphasizing those already well-established in both academic and official contexts. Additionally, indicators with clear, quantifiable units of measurement—facilitating monitoring—were given precedence. Lastly, their relevance to urban applications was ensured by categorizing them into key thematic areas, an approach shaped by the findings of the analysis (Paoli et al., 2022).
Subsequently, the resilience of these 26 indicators was assessed with respect to three selected risk types:
Anthropogenic risk: This refers to artificial situations caused by human initiatives and activities that expose groups of people to threats such as pollution, communication failures, and general life and survival issues.
Environmental risk: This refers to natural and/or artificial situations in which there is a certain probability that a phenomenon, once a specific threshold is surpassed, will result in losses in terms of human lives, property, production capacity, and will have harmful effects on the natural environment.
Health risk: This refers to situations in which there is the potential for an external element to cause harm to the health of the population.
In particular, all these circular 26 indicators (Fig. 14) were considered resilient because, through their quantification, it is possible to assess the increase or decrease in urban resilience in response to the selected risk types. These risk types are the root causes of the major issues linked to the linear externalities produced by the current linear city model (e.g., waste,

emissions, noise, congestion, etc.), which correspond to linear risks associated with the increasing demand for resources and the decreasing availability of those resources.
The indicators are structured to be first quantified at the neighborhood level and then scaled up for application at the urban level. To support this, a database of indicators has been developed, organized into priority sectors relevant to the urban context, such as waste management, mobility, and energy. This approach facilitates the evaluation of impacts within each sector. The ultimate goal is to create an integrated perspective that addresses the city’s interconnected challenges. To achieve this, it is crucial to analyze the interrelations between these sectors.

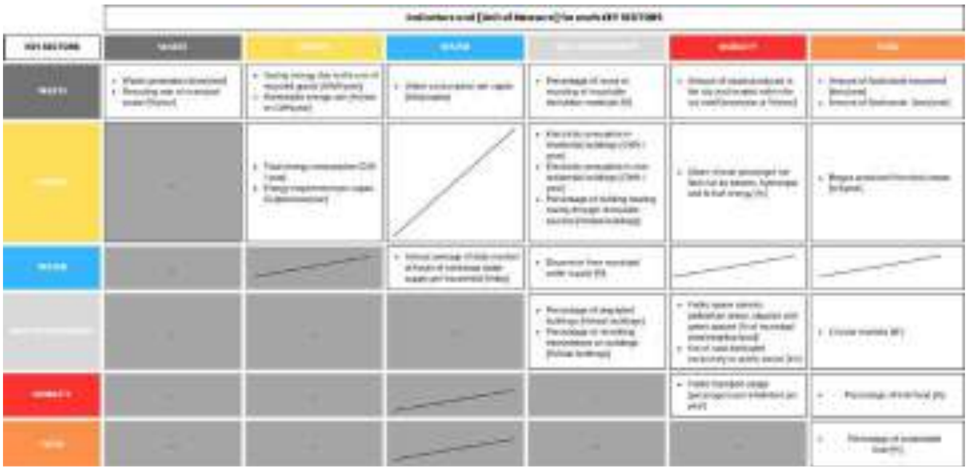


Figure 14 - Proposed circularity and resilience indicators

The motivation for this work and the creation of the dataset was to identify indicators as generic as possible, so that through the systematic use of this tool the circularity of any urban reality can be determined, providing an appropriate differentiation regarding the various key sectors under consideration, which involve different issues and needs (Paoli et al., 2022). Moreover, it also evaluates their resilience in relation to a series of specific risk types.

3.2.3 Action Plan and circular and resilient actions

A key role in the planning phase is the definition of strategies and actions to be implemented to achieve the goal of contributing to the creation of a circular and resilient city. It is important that these actions are sustainable in terms of environmental, economic, and social impact, as well as effective, meaning they should be adapted to the specific area where they will be applied. Lastly, they must be participatory, giving participation a strategic role in engaging key stakeholders in relation to the goal to be achieved. Therefore, in the transition toward a circular and resilient city model, best practices are essential for efficiently managing resources and closing their cycles while adapting the territory to potential risks.
Urban planning plays an important role in proposing and combining actions capable of closing the loop, even across different priority sectors, and initiating a process of sustainable urban regeneration (Fig. 15).
When discussing circularity, the connection to the issue of waste is immediate, along with actions specific to this sector. For example, Refuse, Rethink, Reduce, Reuse, Recontain, Repair, Recondition/Regenerate, Repurpose, Recycle, and Recover can help extend the life and maximize the recovery of resources, products, as well as urban spaces and infrastructure. To

close the urban life cycle, a possible strategy is first to close the cycle of individual priority sectors in a city presented before: Mobility, Waste, Built Environment, Water, Energy, Food, and then propose interrelations among them.

When considering **good practices to promote circularity and resilience**, particularly in response to climate change and water-related challenges (such as drought and extreme hydraulic events like flash floods and stationary regenerative storms), a possible solution is to encourage the installation of cisterns for rainwater storage (recovery) and its reuse for irrigating green areas or cleaning outdoor spaces. **Recovering water** to restore natural ecosystems in cities would positively impact the quality of public spaces and air, reducing atmospheric pollution. Moreover, the same practice, through the creation of retention basins, can help slow down flood peaks that urban drainage systems must manage during heavy rains. Cisterns, combined with greenery (nature-based solutions), also contribute to mitigating hydraulic risks. This example clearly demonstrates how closing the life cycle of a sector generates a circular output that, if well planned, can be repurposed to foster resilience and territorial regeneration.

There are numerous combinations of best practices that can be implemented to close the urban cycle. Best practices can address various stages of the production cycle: sourcing, design, production, distribution, consumption, collection, and recycling.

Examples of best practices/actions for waste management include recycling, implementing separate waste collection systems, raising awareness about proper waste management, and investing in advanced recycling and material recovery technologies.

In terms of sustainable mobility, promoted actions include developing infrastructure for efficient public transport, encouraging cycling and outdoor activities, and implementing car- and bike-sharing systems.

For energy, **planning distributed and effective energy systems** that are both resilient and renewable is essential. Actions include investing in renewable energy sources such as solar and wind, which can be resiliently integrated with the existing structures in the area, promoting energy efficiency in buildings and infrastructure, and developing community renewable energy projects.

For water and water resources, actions include implementing advanced water resource management technologies and reducing water waste through efficient irrigation systems, among other measures.

For food, it is crucial to implement actions that create a balance in the urban bioeconomy, such as returning nutrients to the soil through composting and promoting production systems that encourage “local value loops”, minimizing waste and transportation impacts.

In the proposed research, a database of circular best practices across seven identified sectors was developed after reviewing current literature. These actions aim to close life cycles across sectors while enhancing resilience—defined as the ability to respond to changes through prevention strategies like knowledge, flexibility, and inclusiveness. The database, implemented in Excel, is designed for easy sharing, updating, and replicability in other urban contexts. It also supports administrations in selecting actions, engaging stakeholders, and identifying funding channels to make circularity economically advantageous.

Figure 15 - Action Plan and actions. Source: authors elaboration

In the research, best practices are organized based on different urban components where interventions can occur artefacts, mobility infrastructure, green spaces, and urban furniture. For artefacts, potential practices include using low-impact, recyclable materials; selective demolition with material passports for reuse; incorporating recycled content in structural elements; improving energy efficiency and utilizing alternative energy sources; installing green roofs or walls; and designing buildings in a modular, flexible way; building on the built. Many of these actions can also be applied to mobility infrastructure (roads, bike lanes, pedestrian paths), which should be accessible, affordable, and clean. Key practices promoting circularity and resilience in roads include using recycled or low-impact materials (e.g., replacing asphalt), installing systems to generate energy from alternative sources, and creating modular infrastructures that speed up road construction and improve the resilience of their maintenance or modification. One of the most strategic areas for achieving the goals of the research is green spaces, ranging from parks and gardens to green roofs and urban farms. It is crucial that these spaces are planned to create green infrastructures and greenways that help restore nature and biodiversity. Indeed, a well-planned local/regional/national green infrastructure network can strengthen the connectivity between artificial, natural and semi-natural areas – linking for example, parks, agricultural landscapes, forests, wetlands – supporting wider biodiversity targets. In this context, the nature-based solutions play a key role in addressing three types of risks: anthropogenic, environmental, and health risks (as defined in section 3.4.3). Finally, to make our cities more circular and resilient, urban furniture interventions can be considered. Possible best practices include installing smart canopies that integrate energy production systems for reuse (e.g., to charge electric vehicles) and green panels to improve air quality and reduce noise. These canopies can serve both as shelters for people waiting for public transport and as charging stations for electric mobility users. Additionally, providing free Wi-Fi in these locations could be a useful enhancement.

The following table (Tab. 9) describes some best practices that can be implemented in various parts of the city, along with information on their potential impacts, priority topics involved, and examples of their application. This is designed to provide those interested in a specific practice with the opportunity to explore it further and assess its adaptability to their urban context.

GOOD PRACTICE/DESCRIPTION	IMPACTS	PRIORITY SECTORS	EXAMPLES
ARTEFACTS			
Rebrick 'Market uptake of an automated technology for reusing old bricks': Project for the recycling of used bricks through the automated sorting of demolition waste, followed by separation and cleaning. 	More sustainable management of demolition waste, specifically bricks, which, as modular elements, are inherently flexible and resilient in their uses. Thanks to Rebrick, they become easier to recycle. This approach simultaneously promotes the creation of green jobs and contributes to sustainable production and eco-friendly development in the construction and architecture sectors. It is estimated that reusing bricks saves 2 kg of CO_2 emissions per brick. Furthermore, each recycled and reused brick in the construction phase allows for a reduction of 0.5 kg of CO_2 emissions compared to a non-recycled one.	Built Environment, Waste, Energy	Denmark
Traveling museum: created using recycled and recyclable materials, specifically containers arranged in a checkerboard pattern stacked on top of each other in the ports of Venice, New York, Los Angeles, and Tokyo to host photography exhibitions. 	A best practice that breathes new life into containers: a traveling museum (2004-2005) showcasing the works of Canadian photographer Gregory Colbert. It was constructed using 150 repurposed shipping containers, cardboard tubes, gravel, pebbles, and wood. The structure was resiliently assembled on-site to adapt to the available space. The multicolored metal walls supported an iron roof coated in PVC, which was also used to seal the gaps between containers, protecting visitors from strong winds. Designed for transience, every material was chosen for easy transport or reuse. The installation created a striking impact, blending art with the transitory and rugged character of the port environment. It demonstrated how ports can serve as venues for art and carriers of a message of environmental sustainability.	Built Environment, Waste	Nomadic Museum: conceived in Italy and developed by Japanese architect Shigeru Ban
MOBILITY INFRASTRUCTURES			
SolaRoad: An infrastructure project aimed at transforming public roads into a source of clean and renewable energy. The initiative involves repaving road surfaces with photovoltaic cells capable of converting incident solar energy	In addition to replacing asphalt (see the impact of Plastic Road), the energy produced by photovoltaic roads can be used for street lighting, traffic signals, integrated LEDs displaying road-related messages (e.g., "slow down," "danger,"	Mobility, Waste, Built Environment, Energy	Netherlands: A cycling path from Amsterdam to Krommenie and Wormerveer (length: 25 km),

into electricity. The surface is coated with tempered, non-slip glass and arranged with a slight incline, allowing rainwater to wash the surface and enhance efficiency. 	"stop"), powering electric vehicles, and supplying electricity to nearby homes. A 1.6 km stretch of four-lane road is estimated to provide energy for 400 households. Moreover, this technology can serve additional functions, such as heating road surfaces to melt ice or snow, improving safety and accessibility in winter conditions. This innovation also changes public perception of roads, transforming them from sources of pollution into generators of clean energy. Weaknesses: high costs, limited energy efficiency, and challenges related to the end-of-life disposal of solar panels.		the first example of a concrete track incorporating solar cells. United States: The *Solar Roadways* project
Plastic Road: A sustainable modular infrastructure that uses recycled plastic as the primary material for constructing road surfaces. At the end of their lifecycle, the elements that make up the road can be recycled and reused. 	This solution allows for the replacement of bituminous asphalt, currently used for road surfaces, with recycled plastic. Asphalt produces an average of 27 kilograms of CO_2 per ton produced, and by absorbing heat, it contributes to global temperature rise. Additionally, in many countries, including Italy, removed asphalt is disposed of in landfills as non-recyclable special waste. By replacing traditional pavements with Plastic Roads, it is estimated that CO_2 emissions can be reduced by 72%. This approach also reduces construction time and, in particular, the management and maintenance of the infrastructure, making it more resilient to future interventions. The modules are designed with cavities inside to allow for the passage of pipes and cables, as well as to facilitate rainwater drainage and mitigate the risk of flooding and aquaplaning on the surface. Weaknesses: High costs.	Mobility, Waste, Built Environment, Water	Netherlands: Rotterdam, the creation of two cycling paths in Zwolle (length: 30 meters, made from recycled plastic equivalent to 218,000 cups or 500,000 bottle caps) and Giethoorn
GREEN SPACES			
Rain gardens: “Sponge Garden” It consists of a public garden that, in addition to hosting vegetable plots, flowers, and compost bins, serves as a space to experiment with new solutions for rethinking green spaces in a way that allows for the absorption, drainage, and storage of water.	Green space helps reduce air, water and noise pollution, provides protection from flooding, droughts and heat waves and much more and enhancing the services that urban ecosystems provide. Urban green spaces: • play a key role for climate change adaptation helping to address	Water, Urban Environment, Food	

	the Urban Heat Island effect and protect against flooding, while also contributing to reducing emissions and capturing carbon. • have an aesthetic value and provide space for recreation, social exchange, educational purposes and reconnecting people with nature. • helps reduce and remove different types of pollution by filtering air particles, purifying water and reducing noise. This can improve human and environmental health and well-being.		
Water squares: Spaces designed to be publicly accessible, such as recreational areas intended for families or sports activities, which, in the event of rain, become reservoirs for rainwater. These spaces serve a dual purpose: on one hand, they prevent the overload of the sewage system, and on the other, they allow for the storage of rainwater in underground reservoirs, which can later be reused. 			
URBAN FORNITURE			
Viva Smart Bench: Urban furniture benches entirely made from recycled plastic, Wi-Fi connected and equipped with photovoltaic panels. 	This urban furniture helps conserve new resources as it is entirely made from recycled plastic. The Wi-Fi connection can be used to provide real-time information on mobility services, traffic, CO_2 emissions, weather conditions, and more. The photovoltaic panels (60W power) are useful for providing energy to charge bikes (10W power / up to 80% efficiency) or electronic devices through the USB ports (2 ports at 5W and 2.2W).	Mobility, Waste, Built Environment, Energy	Italy
Community fridge: are one tried and tested way of stopping good food ending up in the bin. They're housed in public, accessible places, making surplus perishable food freely available to members of the public. Surplus food is provided by local businesses or members of the public and is then available for collection by people who need it. They work on an honesty basis. 	The British town of Frome has created a huge communal fridge in a converted_Reuse public toilet building, inspired by the Spanish "Solidarity Fridge" initiative. It will cut food waste, build stronger bonds within the community and provide people with nutritious, perishable food items. Anyone is free to donate or take food, and thousands of items have been redistributed since the project began in June 2016. Businesses are encouraged to get involved as food from certified kitchens can be stored in the fridge with no health and safety concerns—but households can also contribute, subject to a few restrictions.	Waste, Built Environment, Food	UK - Frome

Table 9 - An extract of Best Practices in Circularity and Resilience. Source: authors elaboration.

The definition of circular and resilient best practices should be both top-down, from administrative bodies, and bottom-up, from various stakeholders. Participation plays a strategic role in shaping the Action Plan, not only for collecting or proposing best practices but also for sharing and raising awareness among all involved actors, ultimately engaging the main actor—the population—around which a city should be designed.

This synergy of individual and collective behaviors, economic decisions, political choices, and technological development can transform current urban areas into truly circular, resilient, and therefore sustainable cities (Fig. 16).

Figure 16 - Towards an Action Plan for a Circular and Resilient City. Source: authors elaboration

Part 2. PRINCIPLES FOR CO-DESIGNING AND PLANNING CIRCULAR CITIES

4 Applying CUM approach for the regeneration of a multi-risk contexts: the test case of Bagnoli

4.1 Bagnoli: a multi-risk context

Located in the western area of the city of Naples, the district of Bagnoli constitutes a critical urban context due to the overlapping of risk factors linked to both its territorial morphology and its productive history.

Bagnoli is located on top of the Phlegrean Caldera[5], occupying an area surrounded by the dense nineteenth-century urban fabric of the Giusso neighborhood to the north-west, important urban attractions such as the exhibition centre and park Mostra d'Oltremare, the Maradona soccer stadium, and the Federico II University campus – all located in the confining district of Fuorigrotta – to north-east, the Cavallegeri d'Aosta Rione to the east, the imposing hill system of Posillipo and the Sports Park to the south and the island of Nisida and the sea to the west. Bagnoli's coastal position and its proximity to the Phlegrean volcanic cratersand the Posillipo hill make the area exposed to both climatic and geophysical risks, because of the overlapping of the volcanic and hydrogeological risk and the coastal erosion and flood hazard. Moreover, the massive past industrial activity has left high rates of soil and water pollution that represent a further environmental risk factor.

Because of high levels of pollution (De Vivo, 2007) the Bagnoli-Coroglio Site of National Interest (SIN) has been inaccessible for more than thirty years. The appointment of the Extraordinary Commissioner of Government for the environmental remediation and urban regeneration of the Site of National Interest Bagnoli-Coroglio in 2014 introduced a unique opportunity to manage an inter-institutional process of redevelopment of the brownfield, a privileged observatory to understand how to effectively guide the process of environmental and urban regeneration in the contaminated former industrial site. The Bagnoli-Coroglio SIN provides a compelling case study for RETURN research. The long state of abandonment and the contextual conditions have led to a multi-risk urban context of multidimensional nature, where environmental degradation, anthropogenic hazards, and socio-health risks converge (Polese & Tocchi, 2024). The multiplicity of risks in the area results in complex interactions between them, and it is this interrelation that makes multi-risk contexts particularly critical, not only to manage emergencies, but also to plan land use and mitigate risks. The occurrence of a catastrophic event can trigger further events, generating a cascade effect that is difficult to manage. For example, an earthquake could damage toxic waste containment facilities, causing

[5] The Phlegrean Fields - from ancient Greek φλέγω, phlégō, "burning", literally "Burning Fields" - is a vast area of volcanic nature in the Metropolitan City of Naples, namely a caldera, active for more than 80,000 years. With a diameter of 15-18 km, the caldera is made up of numerous craters and small volcanic buildings - at least twenty-four -, some of which have effusive or hydrothermal manifestations.

pollutants to be dispersed into the soil and surrounding waters. This domino effect amplifies negative impacts on the population and ecosystem, further complicating rescue operations and post-disaster recovery (Gill & Malamud, 2014). Therefore, in multi-risk contexts such as the Bagnoli-Coroglio SIN, it is essential to adopt integrated approaches for risk assessment and management, considering the possible interactions and synergies between various hazards (Kappes et al., 2012). These risks overlap with other hazards related to geo-morphologic conditions of the environment, such as hydrogeological flood, and volcanic risks.

The complexity of managing overlapping risks makes Bagnoli an ideal laboratory for the RETURN project, which aims to develop and test new design principles for risk mitigation in critical multi-risk contexts through the lens of circular urban metabolism. This approach, combined with circularity principles, seeks to minimize the use of new resources, reduce environmental impact and lower exposure to risks by actively involving local communities in the co-design of sustainable solutions. The selection of Bagnoli-Coroglio SIN for RETURN research as a case-study highlights the site's potential to significantly contribute to understanding and managing multi-risk dynamics in critical urban contexts, thanks to stakeholder engagement and the adoption of a multidisciplinary approach to develop innovative adaptation and mitigation methodologies.

The complexity of Bagnoli makes the area ideal to test the efficacy of the RETURN design and planning principles and their adaptability and usefulness in similar situations across the country, in order to enhance urban resilience in critical urban contexts.

In the following paragraph it will be described first the different imaginaries that the area of Bagnoli has covered in the history till to arrive at the recent year with the industrial myth first and the with the dismantling the project of the future Bagnoli as city of the science (4.1.1), then we will analyse the impact that metabolic risk may have on communities (4.1.2).

4.2 The former industrial area of Bagnoli-Coroglio Site of National Interest (SIN) and its critical urban context

The district of Bagnoli, located in the western area of the city of Naples in Italy, is a former industrial site, covering approximately 120 hectares, that had been definitively closed in 1993. The coexistence of environmental, anthropic and natural risks makes this area an ideal laboratory for assessing the feasibility of new risk mitigation principles combined with circularity principles. Its complexity, beyond its degraded and abandoned condition, is given by the overlapping of different risks that makes it a field of experimentation to elaborate and test some guiding principles for the development of a Proof of Concept (PoC) useful as a tool in decision processes.

A variety of both anthropogenic and natural risks invest this fragile coastal territory close to an active volcanic system. Due to contamination, in 2001 the former ILVA industrial area was perimeter-zoned by the Ministry of the Environment and Protection of Land and Sea (MATTM) decree on 31 August 2001 and subsequently by MATTM decree on 8 August 2014 as the 'Bagnoli- Coroglio' Site of National Interest (Sito di Interesse Nazionale). According to the Italian legislation, the Sites of National Interest for remediation (SIN) are highly contaminated areas with an elevated ecological and sanitary risk (art. 252 D.Lgs. 152/06) and represent an opportunity to implement new preservation and mitigation strategies.

According to the law's safety objectives, prior and complete environmental remediation is required for carrying out any type of intervention or activity in a SIN area.

In Italy, the environmental remediation of the SIN areas is, currently, a long and complex process which encounters difficulties both in technical and social and economic terms.

In Bagnoli the first tasks of this process were undertaken after the dismissing of the production activities in 1993. In 1994 CIPE has raised funds for remediation work with the approving of the *Environmental Recovery Plan. Project of technical operations for the reclamation of disused industrial sites in the high environmental risk area of the Bagnoli production and employment crisis zone* drawn up by Ilva in Liquidazione S.p.a. In 1996, the company Bagnoli s.p.a. was founded with the aim of carrying out the remediation, but the works were limited to the demolition and dismantling of the industrial plants (Coppola, 2020). In 2002, new funds were used to establish the company for urban redevelopment named "Bagnoli Futura s.p.a." with the same aim of initiating soil remediation activities. In 2013, however, due to heavy debts and the seizure of the areas for environmental fraud, Bagnoli Futura declared bankruptcy (Piscopo, 2022). The Ministry of the Environment and Protection of Land and Sea (MATTM) decree of 8 August 2014 officially delimited the Bagnoli Coroglio SIN site. Subsequently, art. 33 of Law Decree n. 133 of 12 September 2014 (Sblocca Italia decree), converted into Law n. 164 of 11 November 2014, was approved enacting provisions on the environmental reclamation and urban regeneration of the areas of the Bagnoli-Coroglio SIN. Law n. 164 contains both the provision of a new implementing institution named Invitalia s.p.a. (the National Agency for Attracting Investment and Enterprise Development) and the introduction of the figure of the Government Extraordinary Commissioner for Environmental Remediation and Urban Regeneration. The Commissioner and the Invitalia s.p.a. have formalized their commitment to carry out the 'programme of environmental rehabilitation and urban regeneration of the area of significant national interest Bagnoli-Coroglio' within the 'Extraordinary Commissioner - Invitalia Convention'. Newly conducted investigations on the types of contaminants in terrestrial and marine areas detected zinc and tin lead for the surface soil, and mercury, copper and arsenic, on both land and sea areas. High above-normal traces of polycyclic aromatic hydrocarbons (PAH), heavy hydrocarbons and traces of polychlorinated biphenyls (PCB) are also present throughout the site. In the deep soil, the potential contamination trend substantially follows the surface soil. In groundwater, contamination by organic compounds and metals such as iron, manganese and, in rare cases, nickel was detected (https://bonifichesiticontaminati.mite.gov.it/sin-17/).

The entire SIN area has been divided into sub-lots with respect to the pollutants present, and reclamation action has been assigned a period in which it must be completed. First soil characterization investigations have been completed. The remediation technologies identified, supported by demonstration tests, are divided into off-site technologies such as soil washing and thermal desorder and in-situ remediation technologies such as chemical oxidation and bio-phytodepuration (Invitalia, 2021).

While the regeneration project of brownfield sites has inevitably to face the legacy of contamination and pollutants left behind by industrial production to ensure safety for future users of the area, it is also necessary to consider the remediation project as part of the design process and not as an activity that postpones the use of land.

4.2.1 Immaterial values the landscape of Bagnoli

In the early years of the new millennium, the Bagnoli neighborhood experienced widespread degradation, partly due to the ongoing stalemate over the future of the large disused industrial area, that threatened to turn Bagnoli into an abandoned district (Leone 2002, Coppola 2020). The media attention focused on the abandoned industrial area overshadowed the historic neighborhood of Bagnoli, Rione Giusso, the core of the working-class district of Bagnoli. This area appears to be suspended in time and space, as poignantly described in Rea's text: "I am a displaced man among many displaced men. In Bagnoli, there are as many as you want" (Rea, 2002).

Yet, despite being "an anomalous suburb west of Naples" (Cardone 1989), Bagnoli has never been a peripheral district but one of the liveliest neighborhoods in the Municipality of Naples. To honor and revive the memory of the neighborhood, the Bagnoli Labs[6], active since 2016, has focused on the local community and brought to light the diverse identities that have characterized the neighborhood over time (agricultural, seaside, working-class, and international). As the poet Anna Scala recalls:

"Bagnoli was a quiet neighborhood, it felt like a village, but there was also a certain social vibrancy due to the workers who upheld labor principles and a certain international flavor brought by the Americans at the NATO base. We admired the emancipation of American women driving big cars, taking their children to school, sports, and parties, and we dreamed of emulating them. In Bagnoli, there were farmers from the estates, gentlemen in Liberty-style villas, engineers and workers from Italsider, and Americans from NATO."

Between History and Myth

The earliest references to the area are of a mythological nature: the coast between Posillipo and Pozzuoli is described as the "land of the Cyclopes" (Bernard 1955). The legend of Nisida is narrated by Matilde Serao (1881) in *Leggende Napoletane* (Neapolitan Legends), while the remains of the Seiano Cave are one of the most significant Roman relics in the Province of Naples.

Today, Nisida is no longer an island but a peninsula, as the former Chiuppino islet, later renamed *"Lazzaretto"*, became part of the mainland connection. Fittingly, Edoardo Bennato (perhaps Bagnoli's most famous resident) sang in his 1980s hit: *"Nisida is an island, but nobody knows it."*

Touristic Bagnoli.

Until the early 19th century, the area round Bagnoli was considered a swampy, sparsely frequented region, primarily used for hunting expeditions. Between the late 1800s and early 1900s, however, Bagnoli developed a touristic identity liked to bathing and thermal baths. This identity was gradually overshadowed by increasing industrialization, which led to Bagnoli identification as a working-class district.

[6] Bagnoli Labs has been institutionalized at Department of Architectur DiARC of the University Federico II of Naples

The Duca di Noja Map shows the area before the urbanization that began in the late 19th century (fig. 17), one of the pioneers of its urbanization was the Scottish-born engineer Lamont Young. This extraordinary and eclectic genius, who lived in Naples at the end of the 19th century, devised a grand project for a metropolitan railway system encircling the entire city. He also designed the *Rione Venezia* in the Campi Flegrei, an extraordinary urban invention. In Young’s vision, this project could have transformed Naples into a modern and cutting-edge European city.

Figure 17 - Map of rural Bagnoli from the XVIII century. Source: Duca di Noja

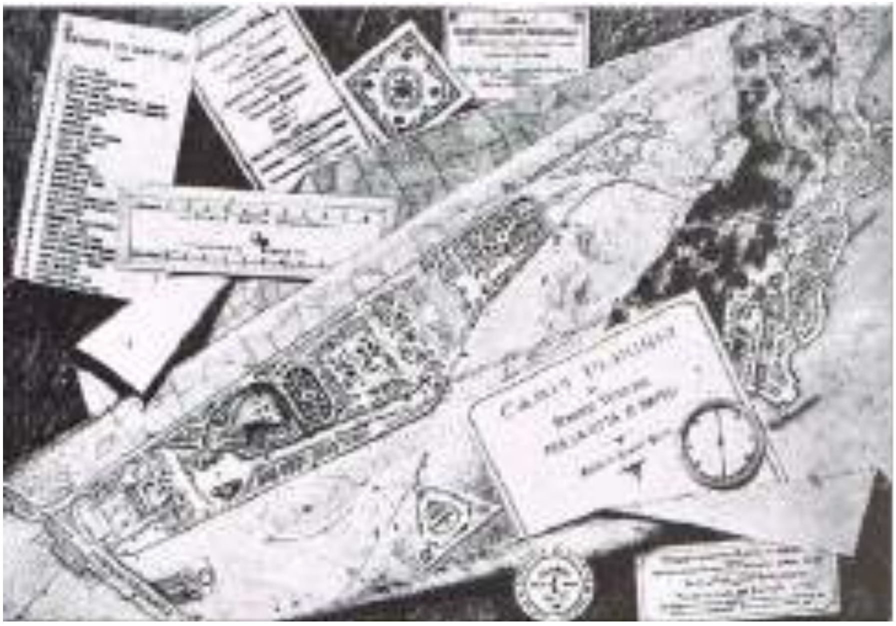


Figure 18 - Venezia neighborhood project in Bagnoli (Lamont Young, 1883) Source: Alisio, 1993

The new district was envisioned to emerge between Santa Lucia and the Campi Flegrei area, connected by a system of streets and canals (Fig. 18). This included a spectacular underground canal, 1,940 meters long, consisting of a 12-meter-wide navigable channel flanked by two 6-meter-wide roads linked by three pedestrian metal bridges. The canal was designed to pass beneath the Posillipo hill, run through Fuorigrotta, and end in Bagnoli, which Young identified as an ideal hub for tourism and seaside activities on a European scale (Alisio, 1993).

Young's decentralization project required the construction of an underground metro system to overcome the limitations of building new roads. Bagnoli was to serve as the starting point of the metro network. However, the project was not understood or supported at the time. The Naples Municipality gave Young an extremely short timeframe to find investors and execute his plan. Despite this, Young's extraordinary vision inspired the foundation of the original residential core of Bagnoli, known as *Rione Giusso*, named after Marquis Candido Giusso, who brought it to fruition.

The 1886 *Giusso Project* aimed to integrate railways, thermal baths, and the sea through a predominantly tourism-focused urban development plan. The district was designed with a north-south orthogonal layout, featuring two-story houses with gardens, located at least 30 meters away from the street. It also included detailed regulations for greenery and open spaces, both public and private.

Rione Giusso became a summer retreat for Neapolitans (*Bagnoli balneare*), necessitating a high standard of urban quality to cater to its purpose.

International Bagnoli

Between 1937 and 1943, significant projects were undertaken in Bagnoli, including the construction of the *Mostra delle Terre d'Oltremare*, the Riding School, designed by Carlo Cocchia between 1938 and 1939, and finally the *Collegio Costanzo Ciano*, which later became the NATO headquarters and is now the *Parco San Laise* (Fig. 19). These projects, examples of Fascist architecture, were intended to transform the western area of Naples into a hub for exhibitions, tourism, and commerce.

Figure 19 - Detail from the 1939 General Regulatory Plan of Naples

The complex is notable for hosting the NATO military base in Bagnoli for nearly 60 years, from 1954 to 2012. It is a site of great interest in terms of landscape, urban planning, and architecture. Originally conceived as a significant social initiative, the Collegio was intended to be a boarding school for abandoned boys. The goal was to house and educate around 2,500

young minors—referred to as "children of the people"—to train them for work and military service in line with Fascist ideology. However, this grand social project was never fully realized.
The initiative was supported by the Banco di Napoli, the city's most prominent bank, to celebrate the 400th anniversary of its founding. The Collegio was designed by Francesco Silvestri, an architect previously unknown.
From October 1943, the Collegio Costanzo Ciano hosted Anglo-American forces, making Naples a crucial base for troops, with its port playing a vital role in the continuation of World War II. On December 3, 2012, after 59 years, the Allied Joint Force Command vacated the premises of the Collegio Costanzo Ciano.
The Working-Class District and the Myth of the Factory
"It is not appropriate, I believe, to refer to a steel center like the one in Bagnoli as a 'factory.' Yet, I, along with others, continue to use this term, indulging in a kind of lexical pleasure and an ideological afterthought that is hard to abandon. Indeed, 'factory' evokes a particular political era, a kind of 'our land' where, perhaps naively, we dreamed and hoped" (Del Vecchio, 2014).
Bagnoli holds a unique and delicate place in Neapolitan imagination. In the early 20th century, the factory "embodied not only industrial aspirations but also the civic hopes of industrialist Naples; it was a site that the Neapolitan left defended against all proposals for dismantlement" (Lepore, 2007).
The area had already hosted a chemical products factory established by Ernesto Lefèvre in 1853 and, further north, the Melchiorre Bournique glassworks.
In 1904, the Nitti Law for Naples—also known as the "Special Law for the Economic Rehabilitation of the City of Naples"—paved the way for industrialization. In 1905, Ilva was built, facilitated by the construction of the Rome-Formia-Naples railway, also known as the "Rome-Naples Direttissima"[7].
By 1908, additional factories were established in the area, including Montecatini, Società Cementiere Litoranee, and a Cementir facility. Construction of the Ilva steel plant began in 1909. Covering 12 hectares with three blast furnaces capable of producing 150 tons each, it became one of Southern Italy's most significant industrial hubs for 30 years. By 1919, it employed over 4,000 workers, and by 1973, nearly 8,000.
In 1962, Ilva became Italsider, joining three other Italian plants in Genoa Cornigliano, Terni, and the newly built facility in Taranto. Finsider's four-year investment plan included expanding the Bagnoli plant to increase production capacity by about 1 million tons per year, requiring additional space gained through coastal infill. The project cost 70 billion lire and created 800 new jobs in addition to the 4,600 existing positions. However, between 1964 and 1966, the lack of deindustrialization efforts forced Italsider to scale back production.
In 1993, Italsider permanently closed. The overall loss of jobs in the area was significant: in 1973, Italsider employed 7,698 workers, Cementir 327, Eternit 604, and Federconsorzi 165, totaling 8,794 employees, not including related industries.

[7] The train line was finally opened in 1927, also due to WWI, although theproject was made in 1871 (Cottrau 1183)

The Recent Past: From Technopole to a Grand Park

By the early 1990s, with Ilva recently restructured but already in crisis, plans emerged to transform the former industrial areas into a science and technology park.

The establishment of the Science Center in Bagnoli marked the first step toward the future "City of Science." This was Italy's first interactive science museum, initiated by the Idis Foundation in 1989. It built upon the success of the "Futuro Remoto" annual event, organized since 1987 by Vittorio Silvestrini and Mariano D'Antonio, which immediately garnered significant acclaim.

The 1997 Western Variant of Naples' General Regulatory Plan (PRG) marked a definitive shift from the "iron cure" to the "green cure" (Mazzetti, 2009). This included plans for a large, compact public park with cycling paths and pedestrian walkways to meet recreational needs. The park would integrate industrial archaeology structures emblematic of Bagnoli's industrial history, preserving them as landmarks (Fig. 20).

New residential and hotel buildings would be surrounded by appropriate landscaping, and vertical connections to the Posillipo hill would be restored. The Cumana railway would be rerouted toward Coroglio, the coastline reserved for bathing, and a small tourist port constructed. Notable industrial relics, such as the mineral unloading pier (*Pontile Nord*), would be repurposed as a long seaside promenade.

The book *"Vivevamo con le sirene"* (*We Lived with the Sirens*) by Albrizio Selvaggio (2001) provides an initial community investigation into the transformation process.

Figure 20 - Bird's-eye view of Coroglio beach before and after the requalification

The Bagnoli Lab and Jane's Walk.

Since 2018, the Bagnoli Laboratory at the University of Naples Federico II has been organizing heritage and identity walks, known as Jane's Walks, among other initiatives. Through storytelling, these walks aim to foster a renewed cognitive connection with these fenced-off and partially inaccessible areas. The Laboratory's mission is to revive and initiate a dialogue—currently still partly interrupted—to critically discuss the future of a territory that has been in perpetual planning for nearly thirty years. A key element of this initiative has been the active involvement of local schools and identity-based organizations in the neighborhood, such as Circolo Ilva Bagnoli, Invitalia, the Bagnoli SIN Sub-Commissioner, and the Campania Welfare Foundation.

The heritage-identity walks, organized since 2018, primarily addressed the need to shine a spotlight on and reopen a dialogue about a neighborhood that had not been a subject of

discussion for over two decades. This bottom-up approach has sparked a process of raising awareness about the collective and identity-based knowledge of the area.
Attempting to narrate the urban history of this neighborhood means bringing to light the diverse facets that have characterized it, helping to rediscover the *"spirit of place"* (Geddes), and contemplating a realistic yet complex urban transformation process. This process has immobilized this westernmost extension of Naples for the past thirty years.
It took four walks inspired by Jane Jacobs and numerous informal strolls with students from local schools and international institutions (Escola Tècnica Superior d'Arquitectura de Barcelona ETSAB, Aix-Marseille Université, École d'Architecture de Strasbourg, and the Geography Department of Universitat Autònoma de Barcelona) to begin bridging the physical barriers within Bagnoli.
The first walk deliberately avoided the former Italsider area, as gaining authorization for access in 2018 was still unthinkable. Instead, the walk aimed to connect the former NATO area—which opened to the neighborhood for the first time in spring 2013—with the Rione Giusso and the Bagnoli seafront.
On the same day, May 5th, the opening celebration of Parco San Laise (the new name for the former NATO area) took place, marking its transformation into a public space. The goal of the walk was to lead over 100 participants from the Pontile Nord—the most iconic and beloved spot in Bagnoli, a linear terrace over the sea stretching approximately 850 meters—to the once-restricted former NATO area. The route passed through Viale Campi Flegrei, the heart of the neighborhood, and the Masseria Starza, the last remnant of Bagnoli's agricultural past.
Meanwhile, Bagnoli remains in waiting, as writer Valeria Parrella reminds us in Almarina (2019): "In this neighborhood, all orthogonal, streets intersect at right angles as if it were Manhattan. From east to west, they lead to the sea; from south to north, they take you from the smokestacks to the Sibyl's cave. Short streets, a compact neighborhood that serves as the city's toll, its perspective, its shame, its nightmare, its hope."

4.2.2 Treating social risks as crucial to win circularity gaps of urban metabolism. Community resilience and public history of places as compensation

The changing relations between capital and labor, as we transition from established systems of production to uncertain scenarios of consumption, raise blurred questions about the demand for justice in environmental conflicts and ways in which the related social risks should be compensated when multi-hazard approaches are involved.
This situation calls upon decision-makers and urban planners to address the social inequities produced by the shift from the "right to the city" to the "right to urban environments" (Kaika & Swyngedouw, 2011). However, public policies in this regard remain still too sectoral and often more symbolic than substantive, as evidenced by the 42 Italian Sites of National Interest (in Italian, Siti di Interesse Nazionale - SIN), whose restoration is the responsibility of the Ministry of Environment and Energy Security (in Italian, Ministero dell'Ambiente e della Sicurezza Energetica). Consequently, unmet demands for public health and safety continue to influence the perceptions, behaviors, and lifestyles of stakeholders living near these threatened areas. Furthermore, we are witnessing a phenomenon known as "environmentalism of the poor" (Martinez Alier, 2002), which arises from increasing popular awareness of the

connections between nature and human beings — connections that emerge at the intersection of everyday work, health issues, denied or contested rights, and more recently, climate vulnerabilities.

Unfortunately, due to the length and complexity of the administrative procedures involved, little has been accomplished to date in restoring Italian Sites of National Interest (SINs).

The Bagnoli post-industrial settlement, one of the two SINs located in the city of Naples, is no exception. In fact, it is an industrial area of about two million square meters awaiting a long-lasting reclamation process that not only affects human and non-human health but also reverberates on the quality of life for its inhabitants and entails a range of social risks. In this regard Urban Political Ecology (UPE) studies are crucial for providing what several scholars have defined as "toxic narratives".

UPE challenges traditional understandings of cities as entities separate from nature and focuses on how the regeneration of post-industrial settlements — such as Bagnoli — is metabolically linked with flows of capital and more-than-human socio-ecological processes.

According to Tzannis, Mandler, Kaika, and Keil (2021), four waves of UPE must be recognized. This paper will focus on the first two waves: the first includes foundational texts such as the seminal volume *In the Nature of Cities* (Heynen et al., 2006); the second maintains a commitment to a metabolic circulation framework while also situating case studies and their specificities.

During the first wave of Urban Political Ecology (UPE) studies, scholars from various disciplines recognized that natural or ecological processes do not operate separately from social processes. They argued that existing socio-natural conditions must be interpreted as the result of intricate transformations of pre-existing natural and social configurations.

The editors of *In the Nature of Cities* therefore emphasized the act of politicizing the production and consumption of urban natures as a challenge that must be urgently addressed.

Calls from the second wave appear to be more effective in reframing the kind of narratives and relationships at play, not only to analyze and interpret physical rehabilitative processes but also to metabolize community feelings of abandonment to a fate marked by illness, toxicity, and degradation.

Consequently, these calls take into account not only the volcanic risk affecting Bagnoli as part of the Phlegraean Fields – specifically, the phenomenon known as bradyseism – but also the complex entanglement of sanitary and socio-cultural risks impacting the area, which is one of the most vulnerable SINs in Italy.

We are referring to the coastline of the Pozzuoli Gulf – from Coroglio beach, to Nisida island and the wet plain at the back (Andriello et. al. 1991) – which, after hosting a steel plant for more than 80 years, has been awaiting reconversion and reclamation by local and National institutions since the mid-1990s.

Circular urban metabolism for whom?

When we compare socio-economic indicators that describe the profiles of those living near the 42 Italian Sites of National Interest (SINs) in order to measure educational levels, labor market positions, family sizes, existing disadvantages, and dwelling overcrowding, we discover that the highest average index of social and material vulnerability in Italy is found precisely in "Napoli orientale" and "Bagnoli-Coroglio" SINs.

Even though indicators from other southern SINs in Italy are slightly lower than those of Bagnoli, it should not be underestimated that the priority in economic deprivation and social fragility of residents is concentrated in the two Neapolitan SINs (Gemmiti et al., 2022).
Due to its prominence in economic deprivation and social vulnerability, Bagnoli can be considered a pilot case-study. According to the second wave of UPE, this prominence allows us to focus increasing attention on southern and subaltern urbanisms to encourage the production of more just urban environments. Furthermore, by problematizing the application of Northern theories not only to Southern contexts, but also to the poorest regions of the Global North, a key emerges for advocating a more situated UPE – one that "creates the possibility for a broader range of urban experiences to inform theory on how urban environments are shaped, politicized and contested" (Lawhon et al., 2014, 498).
In this framework, Ilva steelworkers and the sedentary inhabitants of Bagnoli, who have been waiting for reconversion since the 1990s, must be treated as vulnerable social risk categories. Meanwhile, the broken promises by politicians and public institutions to transform a once peripheral industrial district into a contemporary site for the advanced tertiary sector can be viewed as a manifestation of subaltern urbanism. If we want to halt this phenomenon wherever it emerges and attempt participatory approaches to address social risks in the context of denied urban natures, socio-ecological rehabilitation for Italian SINs must be collaboratively pursued by citizens, residents, public administrators, and stakeholders. The aim, similarly to what happens in communities that fight the malignant effects of climate change, could be to recover health damages and restore the lost natural environment as an opportunity for shared transformation (Roberts & Pelling, 2000).
More specifically, achieving the circularity of urban metabolism in extreme cases such as the Bagnoli reconversion entails building shared strategies to advocate for contested rights and to remove the obstacles that have been preventing recovery thus far.
What we can learn from Bagnoli is that in such extreme situations, turning urban metabolism into circular also means contrasting the shift of long-term territorial impasses into social conflicts. In fact, if the medium term that separates one generation from the next is about 25 years, it is easy to understand how a wait of more than 30 years can profoundly affect a population and jeopardize its social resilience.
Industrial decommissioning and stalled decontamination as social risks.
Today a complex entanglement of social damages and environmental threats emerges, resulting in growing feelings of abandonment by residents and local stakeholders who feel betrayed by the institutions and politics. In order to achieve the circularity of urban metabolism, losses and the denied rights related to the suspended transformation in Bagnoli must, therefore, be taken into serious account.
What needs to be demanded now is: what does happen in industrial districts when, after hosting a highly polluting plant for a long time[3] the plant becomes neglected?
If we answer this question through the lens of environmental justice (Schlosberg 2007), we can argue that the most difficult social shock to address is not merely overcoming the end of the industrial work or the dismantling of plants, but rather the long-term period of their abandonment without reclamation. This means acknowledging the effects of broken transformation promises and prolonged expectations on urban metabolism and quality of life,

among the risks that decision-makers must face when dealing with multi-hazard approaches to planning. In fact, considering how people living in Bagnoli feel even now marginalized from institutions and the rest of the city, a multiplicity of social risks emerges.
This is why applying a circular urban metabolism approach to the Bagnoli transformation means taking into serious consideration the invisible phenomenon of slow violence: "a violence that occurs gradually and out of sight, a violence of delayed destruction that is dispersed across time and space, an attritional violence that is typically not viewed as violence at all (…) a violence that is neither spectacular nor instantaneous, but rather incremental and accretive, its calamitous repercussions playing out across a range of temporal scales" (Nixon, 2011, 2).
The point is that over time, such violence can heap heavy loads of injustice and sorrow on ordinary people, deeply undermining the lifestyles and beliefs of the affected communities, along with their relationship to the natural environment. This sorrow may resonate even more strongly in younger generations who are born into a post-industrial scenario and lack both the memory of the industrial era and the pride of having been part of the working class, as their grandfathers were.
What must be taken into consideration to avoid further crippling conflicts and claims is, on one hand, the vulnerability of ordinary people and their related feelings of distrust in public administration and politicians; on the other hand, the fragility of decision-makers and public officials who are acutely aware of their failures to address the reclamation process.
In situations as such, in which a multiplicity of environmental risks exists, planners do have to daily ask themselves how to enhance community resilience in order to mitigate social conflicts and misunderstandings in the regard of still ongoing reclamation processes.
In generalizing the lessons learned from the Bagnoli reconversion, we can conclude that an efficient and sustainable urban metabolism that minimizes environmental impacts wouldn't be enough if resilience to social risks is not considered with a dynamic equilibrium among past memories, present needs, and future aspirations of ordinary people and local stakeholders.
That is why the long-lasting waits for SINs reclamation must be urgently compensated as part of a multi-hazard approach in which not only environmental and ecological but also social risks matter.
After describing the Bagnoli district as resulting from a process of "urbanization of nature", the following paragraphs will situate the area in the recent public history and analyze spatial and environmental injustices by means of photographic documents taken between the late 1990s and the early 2000s, i.e. during the first dismantling phase.
What remains particularly striking about the image survey *Bagnoli. Cronaca di una trasformazione*, published five years after the final closure of Ilva, is the many expressions of civic passion and vitality stemming from a regenerative process that was perceived at that time as mere compensation for the significant environmental damage suffered for a long time by workers and their families.
As for the methodology adopted, several pictures will be scrutinized to emphasize the importance of public narratives in describing deindustrialization and supporting participative forms of reclamation as a way to facilitate community resilience.

4.2.3 The SIN Area as the Result of an Urbanization Process of the Coroglio Plain and Coastline

Adhering to the thesis that "the environment of the city (both social and physical) is the result of a historical-geographical process of urbanization of nature" (Swyngedouw and Kaika 2000, 569), the establishment of the Ilva steel plant on the sandy coastline of Coroglio should finally be passed down, 119 years after its founding, as the outcome of a complex urbanization process of the plain's site, which over time crystallized Bagnoli's public history into the current SIN (Site of National Interest) area.

Studies to which reference can be made (Andriello et al., 1991; Andriello & Palestino, 1993) have analyzed in depth all the urbanization phases that succeeded one another between 1906, the year of Ilva's establishment, and 1993, the date of its final closure. This was followed by the dismantling of the plant structures between 1993 and 1998 and the demolition of the smokestacks. In parallel, the long sequence of intermittent reclamation efforts began, initiated by Bagnoli S.p.A. in 1997, followed by Bagnoli Futura between 2002 and 2014, and later continued by the extraordinary commissioner, with an implementing body still in service (Lepore, 2007; 2017).

It is worth noting that up to the 1930s, Ilva's urbanization allowed for the maintenance of a delicate balance between nature and the factory. This balance, in safeguarding the workers' right to employment, also respected residents' needs, offering forms of coexistence and social spaces for all: from post-work vegetable gardens to the seaside colony and the Ferropolis cinema. The factory expanded while preserving, as much as possible, the right to inhabit.

This equilibrium, gradually waning after World War II, culminated in the unsustainable expansion of the 1960s-80s (Andriello et al., cit.), when the steel plant and its related industries, having consumed every remaining space, encroached on the sea with landfills, occupying 2 million square meters and marking the end of those rights.

Yet, the progressive downsizing of the steel plant should have corresponded, according to promises made in the 1990s and 2000s, with the gradual return of nature and the consequent reclaiming of the natural landscape over the factory spaces. This was not only what workers and residents envisioned but also what the urban plan variant for the western area, adopted in 1996, had promised to all Neapolitans. Even the first major concert in 1997 symbolized and staged this vision on the landfill through the temporary uses associated with the Neapolis Rock Live Festival (Lepore, 2007).

Meanwhile, the Bagnoli Laboratory, curated by the Department of Urban Planning at the Faculty of Architecture of the University of Naples Federico II (Laboratorio Bagnoli, 1998), organized, together with Ilva workers and the City's Housing Service, a guided tour of the factory as part of the 1997 May of the Monuments events. On the same occasion, a Bagnoli Room was set up with an exhibition showcasing the dialogue between the City Housing Service and local schools, associations, and active stakeholders.

Going beyond the challenge of eliminating environmental pollution, the public process of constructing new post-Fordist imaginaries for Bagnoli has worked—and could still work—on highly intangible dimensions and values. Despite the collective aspiration to actively safeguard the factory's memory and build a shared, site-specific post-industrial future, the dismantling followed decontextualized decisions driven by other logics.

Moreover, while public health is at risk for all communities living near SIN areas—and thus constantly subjected to epidemiological studies—the social risk linked to the prolonged wait for a failed transformation promise has its own unique character.

The steel plant's dismantling should have been followed by the transformation celebrated by the urban planning variant and promised by the mayor at the time, balancing the sacrifice of workers with the return of nature and the sea, and the beginning of new economies of culture and leisure.

The early years of the dismantling also testify to the neighborhood's strong willingness to defend housing and health rights and, as much as possible, reclaim the sea and imagine new development opportunities for the area. Facing the demolition of smokestacks and sheds, the colorful dream of a reinvented Bagnoli, led by its natural landscape, began to emerge.

In an environmental justice perspective, the issue was never the dismantling of the industrial plant per se, nor the reclamation itself, but rather the unutterable wait. The effects of this waiting period have prevented the restoration of life quality and new employment, denying the social and ecological compensation due for the damage and loss suffered.

4.2.4 Community Resilience as an Attempt to Metabolize the Postponed Reclamation

This section analyzes photographic documents from an image survey conducted between the late 1990s and early 2000s, during the dismantling phase. The photographs were scrutinized to demonstrate that there are still strong reasons to narrate industrialization and support reclamation through public narratives.

What remains striking in the photographic reportage *Bagnoli. Cronaca di una trasformazione*, published five years after Ilva's final closure (Fiorito, cit.), is the many expressions of civic passion and vitality linked to a regeneration process that, at the time, was felt as fair compensation for the severe environmental damages endured by workers and their families.

The pictures show how, for some years, Ilva workers accompanied the technical dismantling efforts with creative forms of socio-cultural participation. In 1998, at the heart of the so-called "Bassolino renaissance" (Bassolino et al., 1996), and shortly after the launch of the area's reclamation plan, workers led factory tours. In February 1998, when the first of the seven towers, the piezometric tower, was demolished, musician Daniele Sepe played *The Internationale* on his saxophone during the event.

Simultaneously, workers collaborated with artist Giancarlo Neri in creating public art installations using leftover materials from the Italsider plant. In July of the same year, a massive totem made of steel and cast iron was inaugurated near the north pier and the Infobox structure, built in the renovated former electrical cabin A to document the factory's history. The artwork, *Pasquale's Island*, 10 meters tall and weighing 35 tons, was created with workers, officials, and technicians from Bagnoli S.p.A. The workers also constructed the metal dragon that paraded through Bagnoli during the 1999 Carnival.

These were years when the University of Naples Federico II, through researchers from the Urban Planning Department (DUN), initiated moments of dialogue with the neighborhood to communicate the scenarios outlined in the urban planning variant, engaging actively with local communities. Fiorito's photographs depict schools participating in the local Carnival, with children dressed as workers in imagined future professions related to leisure and culture. This

brief account reflects the community's desire to move forward and give shape and solutions to the promised transformation. It testifies to the determination to reclaim the sea, to revive the neighborhood through new life forms and economies, and to create spaces of entertainment for the entire city, overcoming the legacy of the factory town.
The aspiration to be compensated for the loss of housing rights was particularly strong until the early 2000s. Looking back at the photographs, once-relevant issues resurface: each tower and chimney had been catalogued for rigorous preservation of the factory site. Yet, far beyond the demolished chimneys, the dismantling caused a massive proliferation of materials—batteries, carcasses, skeletal remains, bricks and slags, pipes, cables, chains, gears—much of it left unused, with only a small portion transformed into sculptural works by artist Giancarlo Neri and the workers.
There were also the vast networks of tracks and paths that could have been enhanced in the transformation process: the alignments along which sheds stood and roads and railways had been laid traced a layered design of the ground, offering a potential foundation for future developments.
As Ilva workers met their Asian counterparts, who came to dismantle and acquire the steel structures, thus sealing the end of the local working-class culture, the symbolic reconquest of the north pier, the landfill, and the sea confirmed the residents' desire to reclaim the natural site that the factory had taken from them.
These historical documents challenge the sense of "tabula rasa" that the area conveys today, confronting the abandonment and suspension endured by its inhabitants.
The excursus leads to the conclusion that beyond the toxicity of the soil, the landfill, the beach, and the sea, one must recognize that Bagnoli is a place where residents have been painfully denied the right to re-inhabit their land.
Capturing the intensity of those needs and aspirations for the future as shown in the photographs from 1997 to 2001 only deepens the feeling of loss, which, though latent and silent, feeds great distrust and potential conflict toward absent institutions and a city that remained passive.
From an environmental justice standpoint, it is not the industrial dismantling itself that constitutes the issue, nor the reclamation per se, but the unspoken, drawn-out time of waiting. The consequences of this wait have prevented the restoration of quality of life and employment, denying the rightful social and ecological reparation.
Where environmental health risks and denied housing rights overlap and become indistinguishable, what does urban metabolic circularity mean? There are places like the Ilva Workers' Club where, in the meantime, people have fought to reclaim fragments of the sea and open spaces for leisure, socializing the long wait for the promised transformation.
In places like Bagnoli, the commitment of all actors involved in the transformation must reignite aspirations for the future and community resilience, ensuring the circularity of urban metabolism in tandem with the slow advancement of the ongoing reclamation.

4.2.5 Seismic risk and governance of urban regeneration in Campi Flegrei e Bagnoli

Nearly a year after the intensification of the bradyseismic emergency affecting the Phlegraean Fields, the new Decree-Law N. 91 of July 2, 2024, was approved. Entitled "Urgent Measures for the Prevention of Seismic Risk Related to the Bradyseismic Phenomenon in the Campi Flegrei Area and for Civil Protection and Cohesion Interventions," it introduces two significant aspects influencing the urban development of the SIN (Site of National Interest) area of Bagnoli-Coroglio: a) no volumetric increases for residential use; and b) the introduction of a special commissioner with the role of overseeing and coordinating the activities of the involved administrations. This introduces both a new governmental figure, adding to an already complex system of public and private entities overseeing the transformation, protection, and enhancement of the area, and a reduction in the attractiveness of financial investments from economic actors who see residential construction as the most profitable sector. This emergency measure also conflicts with the regulations introduced in the urban planning section of the PRARU, which envisions the construction of approximately 900,000 cubic meters to be distributed across the land parcels of thematic areas 1f, 2, 3, and 4, designated for residential, commercial, and production of goods and services purposes. Specifically, the plan includes the construction of about 300,000 cubic meters of residential buildings. The inability to build new residences in an area already classified as a red zone currently makes the implementation of the PRARU unfeasible, necessitating its revision to ensure an organic and comprehensive development of the area.

The relationship between remediation and urban planning presents an additional challenge for the transformation of the former ILVA site in Bagnoli. To date, there is a reclamation plan for the area, which divides the area into different lots, some of which have been reclaimed while for others definitive reclamation projects are planned no remediation plan has been realized, but the proposed remediation efforts are disconnected from the planning forecasts and the project's masterplan. Remediation is being carried out in areas that will later undergo significant transformation, such as soil removal, or in areas designated for activities that do not involve constant human presence and will primarily be waterproof.

To an already complex framework of ongoing activities and planned transformations in the Bagnoli area, a new critical element is added: the construction, scheduled for 2026, of the infrastructure required to host the America's World Cup along the coastal edge of Bagnoli. This initiative introduces an additional layer of complexity to an urban redevelopment process already marked by overlapping regulations, shifting project parameters, and emergency-driven interventions.

In particular, the original PRARU plans for the waterfront have undergone significant alteration following Decree-Law No. 60/2024, which removed the requirement for the complete removal of the offshore landfill in the Coroglio plain. The decision to preserve approximately 18 hectares of this landfill necessitates a comprehensive reconfiguration of the urban plan, particularly in relation to the structure of the urban park and the coastline.

This transformation entails an expansion of Thematic Area 1, especially the waterfront zone, with the resulting need to recalibrate territorial and functional parameters. However, the preserved landfill area makes it unfeasible to implement the building volumes originally designated in the elevation gap between the beach and Via Coroglio, as outlined in the urban planning regulations (NTA) of the PRARU. While these changes do not alter land use designations, surface area, or total permitted volumes, they highlight a fundamental misalignment between regulatory planning frameworks and the site's evolving physical conditions.

The introduction of the America's Cup as a catalytic event exacerbates the risk of reactive and fragmented governance – one driven more by short-term deadlines than by a coherent long-term vision. Without an integrated planning approach that harmonizes permanent transformations with those required for temporary events, there is a tangible danger that the post-event legacy will be unmanageable, unsustainable, and ultimately detrimental.

In this context, the absence of a unified and scientifically grounded model of urban governance threatens to undermine the structural goals of regeneration, sustainability, and resilience. It risks producing a disconnect between strategic planning and actual implementation - a gap that could compromise the viability and functionality of the area for decades to come.

4.3 Critical lens on the territory: Atlas approach and objectives

The Urban Metabolic Risk Atlas, developed within the Task.5.4.4, offers a critical lens through which to examine the complex dynamics governing urban areas in profound transition. This is not merely a geographical catalogue, but an analytical and interpretive framework that challenges conventional narratives, particularly that of an "urban void" in Bagnoli. The atlas aims to reveal a layered landscape, interwoven with industrial history, geological processes, and a surprising ecological vitality. Through the **multi-scalar exploration of Bagnoli** – an emblematic area due to its history of decommissioning and its intrinsic urban metabolism, understood as the territory's capacity to sustain and manage resources effectively amidst processes of production, consumption, and disposal – this work seeks to redefine the understanding of risk and its latent opportunities for regeneration.

The construction of this Atlas is founded on a robust and innovative **methodological approach**, intended to build an integrated and insightful knowledge system. The process has required in-depth reconnaissance and the systematization of heterogeneous sources: from robust institutional databases that allow for the tracking of trends and dynamics over time (such as demographic changes), to the qualitative elements emerged from the Living Labs, reflecting residents' perceptions. Each map is the result of rigorous cartographic elaboration within a GIS environment, transforming a vast informational heritage into a powerful visual narrative. Critical analysis of these spatial representations enables the deciphering of interconnections among the physical, functional, environmental, and socio-economic components of the territory, highlighting criticalities and illuminating transformative potentials. This approach forms the basis for delineating adaptation and regeneration strategies, with particular attention to circular strategies.

The Urban Metabolic Risk Atlas is not an endpoint, but a catalyst for the future. By feeding a digital information system and supporting collaborative decision-making processes, it aims to transform the perception of risk from a threat into an opportunity for regeneration. Its maps act as a **bridge between scientific research and on-the-ground action**, inviting a new reading of the territory that recognizes its intrinsic dynamism, its complex history, and its surprising potential for adaptation and mitigation.

Thematic maps in the Atlas translate acquired knowledge into impactful visual and analytical tools. This research strategy utilizes each map as a core instrument, designed to:

i. **Build a knowledge framework**: By creating a robust territorial database for modeling future scenarios.
ii. **Identify and map risks:** By detailing hydraulic hazards, multi-risk interactions, seismic and volcanic vulnerabilities, and pollution factors, with a specific focus on urban metabolic risk.

iii. **Analyse Urban Metabolism and Life Cycles**: By investigating processes of disuse, material and energy flows, and urban life cycles, demonstrating how the research strategy emerges from overlaying risk issues with a comprehensive understanding of the territory's metabolism.

iv. **Foster Regeneration and Circular strategies**: By classifying the network of open and public spaces, highlighting their fragilities and transformative potential (also informed by their ownership regimes), and supporting adaptive strategies for measurable scenarios.

4.3.1 Horizons and Details: The Scales of Territorial Reading

The Atlas is structured to provide a layered reading of the territory, traversing three distinct scales of analysis, each with its specific objectives, yet all converging toward a holistic understanding of urban risk and potential.

Focus Scale: regional flows. Understanding the broader risks (Inter-municipal Scale). This broader scale frames the Gulf of Pozzuoli and the municipalities of Naples, Bacoli, Pozzuoli, and Monte di Procida, a landscape where territorial dynamics, geological vulnerabilities like bradyseism, and hydraulic risks manifest on an inter-municipal dimension. It allows to read the complex interactions between natural and anthropogenic factors that shape the destiny of this peculiar context.

Test Scale: the urban lens (Sub-municipal Test Scale). Focusing on key districts within the City of Naples, including Bagnoli, Coroglio, Fuorigrotta, and Posillipo, this intermediate scale offers a more detailed and critical investigation. Here, the analysis goes beyond settlement systems, service networks, and demographic dynamics to decipher the complex relationship between the territory and its planning history. It is at this scale that the "planning cycle" is explored, revealing the often-unrealized projects that have stratified over time and the legacy of expectations and mistrust they have left. This urban lens allows us to grasp the emerging local fragilities and potentials, putting them in dialogue with processes of decommissioning and transformation.

SIN Scale: the core revealed (SIN Scale). As the most proximate scale, this section is the result of a meticulous on-site survey within the Bagnoli Site of National Interest (SIN). It deconstructs the perception of an "urban void," instead revealing a surprising ecosystem: resilient spontaneous vegetation, remains and imprints of an industrial past that narrate a living memory, and natural formations with unexpected depurative properties. It is a direct immersion into the ecological resilience and heritage of a place in perennial transformation.

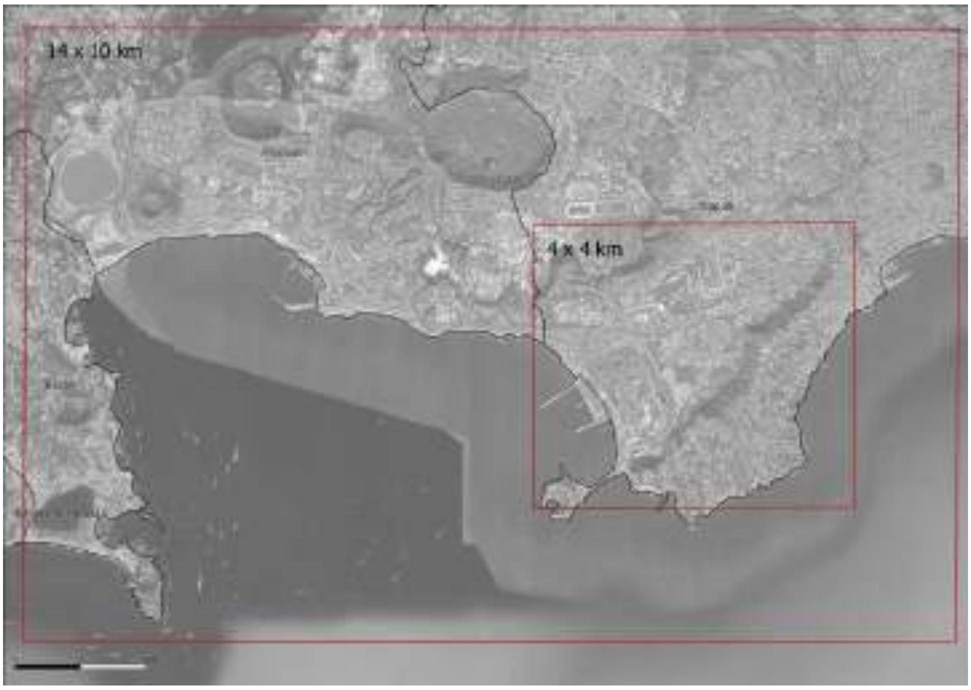


Figure 21 - The focus area and the test area analyzed in the Atlas of metabolic risk and in the Test case.

4.4 The construction process: data, maps, and interpretation

The construction of the RETURN Atlas is based on a theoretical and methodological framework that integrates the collection and re-elaboration of data for a complex representation of the Bagnoli territory. The methodology, founded on a precise selection of sources, is articulated in a dual phase (cognitive and interpretive) to decipher the urban metabolic risk of the territory. The entire process was structured into three main phases:

Data Reconnaissance and Organization: This initial phase was essential for building a territorial information system to support the analysis of the Bagnoli context. It involved the research and acquisition of primary and secondary data, their harmonization and georeferencing, and their subsequent systematization in a structured geospatial archive. The activity was developed according to a multi-level logic, aimed at integrating heterogeneous sources and updating the territorial knowledge framework. The sources were selected based on criteria of reliability, thematic relevance, spatial coverage, and historical significance, allowing for the tracking of trends and dynamics over time (such as demographic changes).

Sources Used: These include information from digital and open-access databases, Open Data from the City of Naples, ISTAT data, sector studies on volcanology and bradyseism, planning documents, and administrative acts that recount the history of projects in the Bagnoli area, as well as the results of the Living Labs, the outcomes of co-mapping exercises with local stakeholders, and risk management plans. These are supplemented by complementary sources such as press reviews, reconnaissance on Google Earth, and direct on-site observations accompanied by thematic photographic documentation.

Data modelling and visualization: This phase involved structuring a final territorial information system (GIS), where the collected data were entered into a queryable relational database. The process was articulated through the modelling of thematic, regulatory, environmental, and socio-territorial data, with a particular emphasis on urban metabolism and

risk. The entire data infrastructure, developed in a GIS environment, allowed for thematic querying, multi-level analysis, and the dynamic representation of relationships between the different components of risk and urban life cycles. The result is the graphical re-elaboration of the data into a series of thematic cartographic works, with an approach that favors an analytical-interpretive visualization.
Types of Data Elaborated: These include basic territorial data (administrative boundaries, hydrography, built fabric, toponymy), environmental heritage, facilities and infrastructure (public heritage, mobility services), the mobility network, territorial risks and vulnerabilities (hydraulic, seismic and volcanic risk, pollution risk), demographic and socio-economic data, and data related to planning history and industrial decommissioning processes.
Critical analysis and interpretation: This phase represents the moment of reflective synthesis in the knowledge-building process, the objective of which was to transcend the simple representation of data to construct synthesis maps. The approach is aimed at reconstructing the systemic interrelations among the physical, functional, environmental, and socio-economic components of the territory. Through the integrated analysis of the various thematic maps, we have identified the latent transformative potentials and emerging spatial criticalities, with particular attention to the dynamics of urban metabolic risk.

The Maps developed are:
At the Focus scale:

1. Living on the Edge: Volcanic Pulse & Ground Motion
2. Unstable Slopes: The Gravity of Landslide Risk
3. Currents of Risk: Navigating Water Dynamic
4. The Invisible Threat: Environmental Contamination & Hazard Landscapes
5. Mobility network and flows
6. Governing the Gulf: Administrative Frameworks & Planning Challenges
7. Human Presence: Distribution and Numbers (2021)
8. Human Footprints: density in the Gulf landscape
9. Population change and dynamics:1991/2021
10. Multi-risk Territorial Profile

At the test area scale:

11. Mobility network and flows
12. Who Owns Bagnoli? A Deeper Look at Land Tenure
13. Urban Settlement and Cycle
14. Voices from the Living Lab: mapping community' perceptions
15. The Planning Cycle: visions, revisions, and legacies

At the SIN scale:

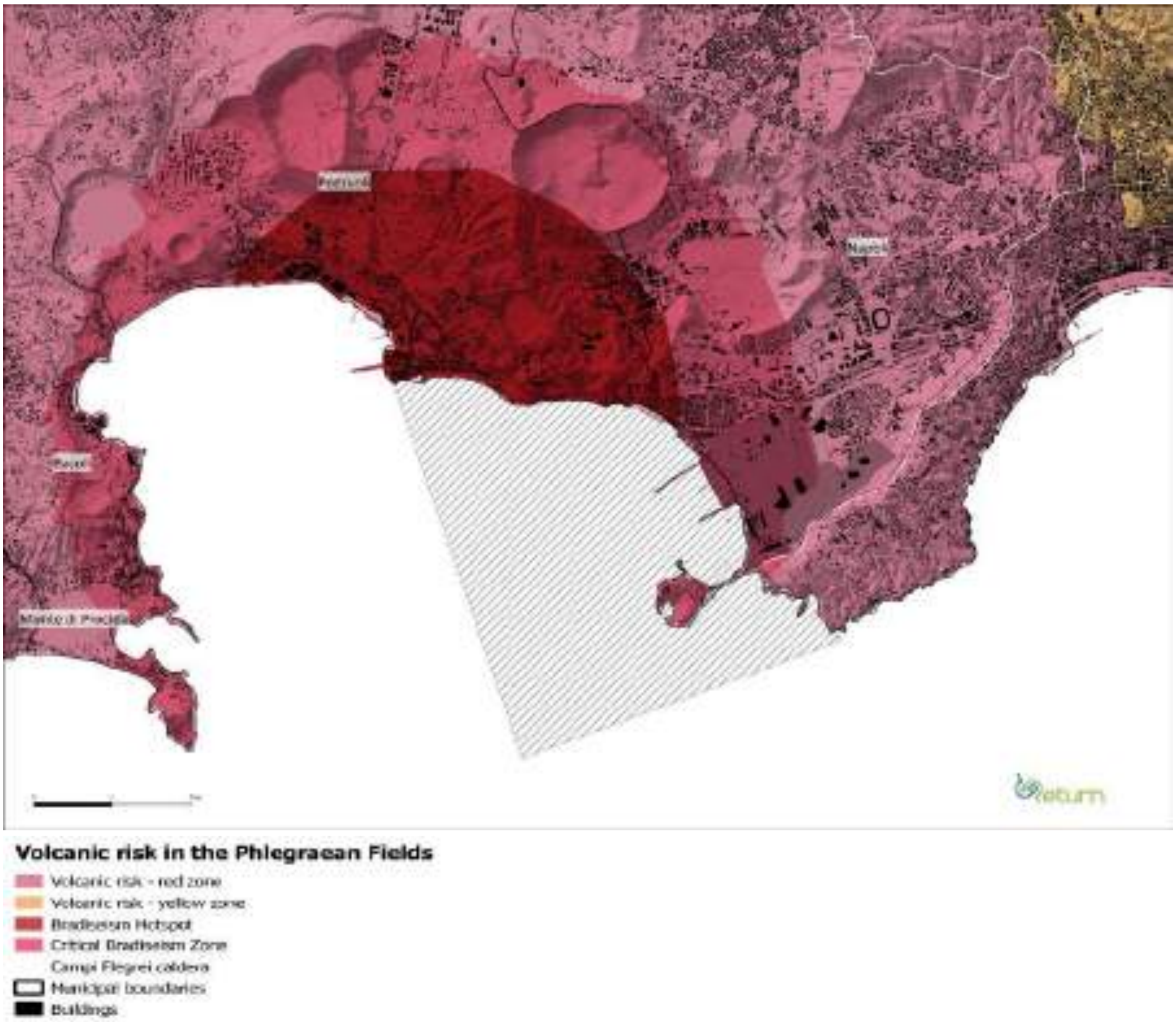
16. Anthropization index
17. Naturalness index
18. Structure index: vegetation
19. Land Cover & Ecological Characterization

4.4.1 Atlas of Urban Metabolic Risk in Bagnoli

1. **Living on the edge: volcanic pulse & ground motion**

Scale: focus

This map illustrates the high volcanic risk in the Focus Area, which lies entirely within the "red zones" of the Campi Flegrei volcanic complex, as defined by Civil Protection. The territory is characterized by intense geothermal activity and a complex volcanic-hydrothermal system, requiring constant monitoring. Beyond the eruption hazard, the map highlights the bradyseismic phenomenon (ground motion), a key dynamic that poses a unique challenge to a densely populated area.



2. **Currents of Risk: Navigating Water Dynamic**

Scale: focus

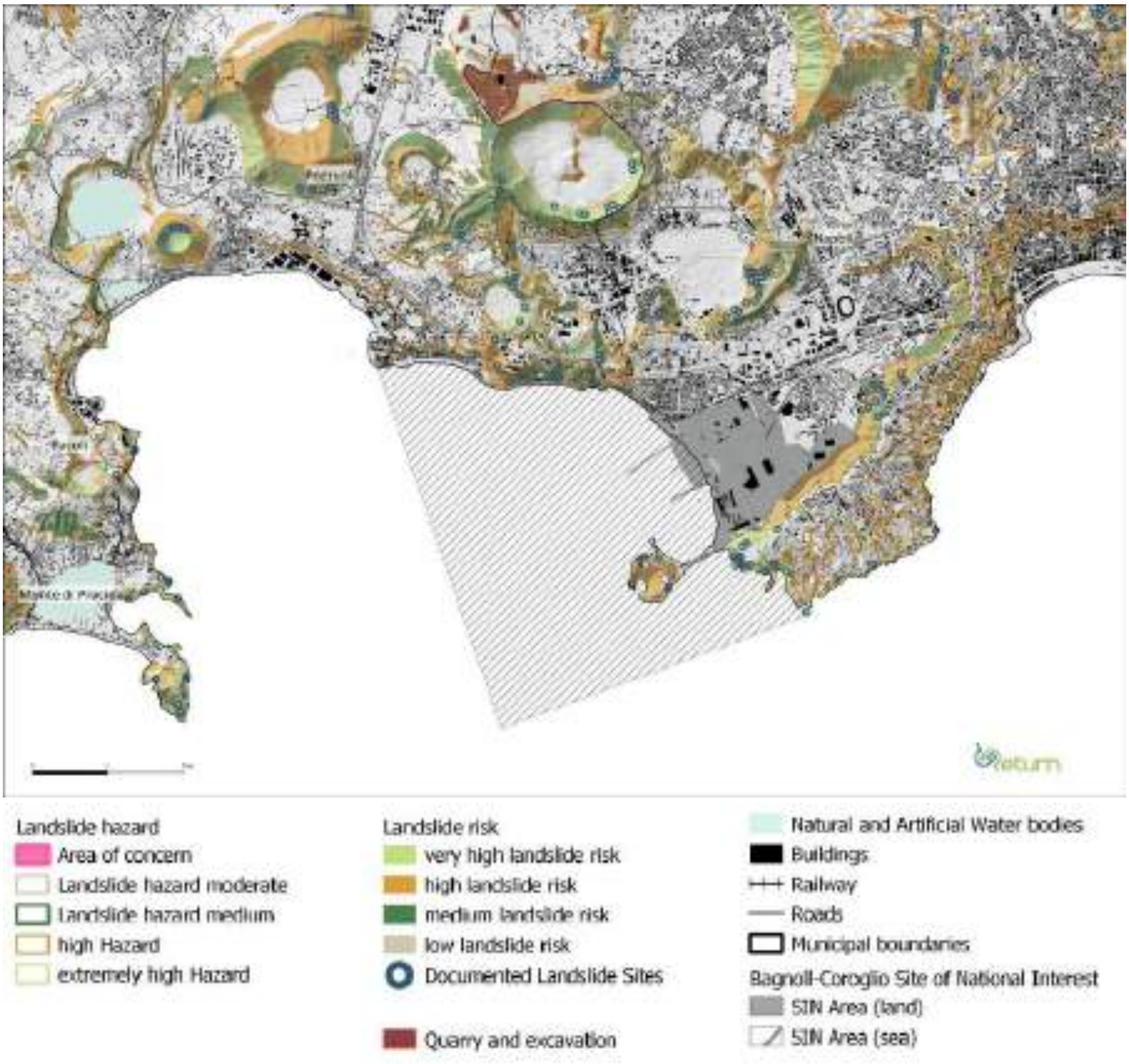
This map provides an interpretive analysis of the local water system, highlighting areas of hydraulic hazard (moderate to high) and the corresponding hydraulic risk (moderate, medium, high, very high). It visualizes the hydrographic network and bodies, including those in a state of crisis, such as the drainage system of Lake Agnano and rivers converted into roads. The analysis reveals the intricate correlation between water dynamics and the territory's

environmental vulnerabilities, offering a framework for understanding the complex interplay between the water system and urban metabolic risk.
(To view the map, consult the attached Atlas)

3. Unstable Slopes: the gravity of landslide risk

Scale: focus

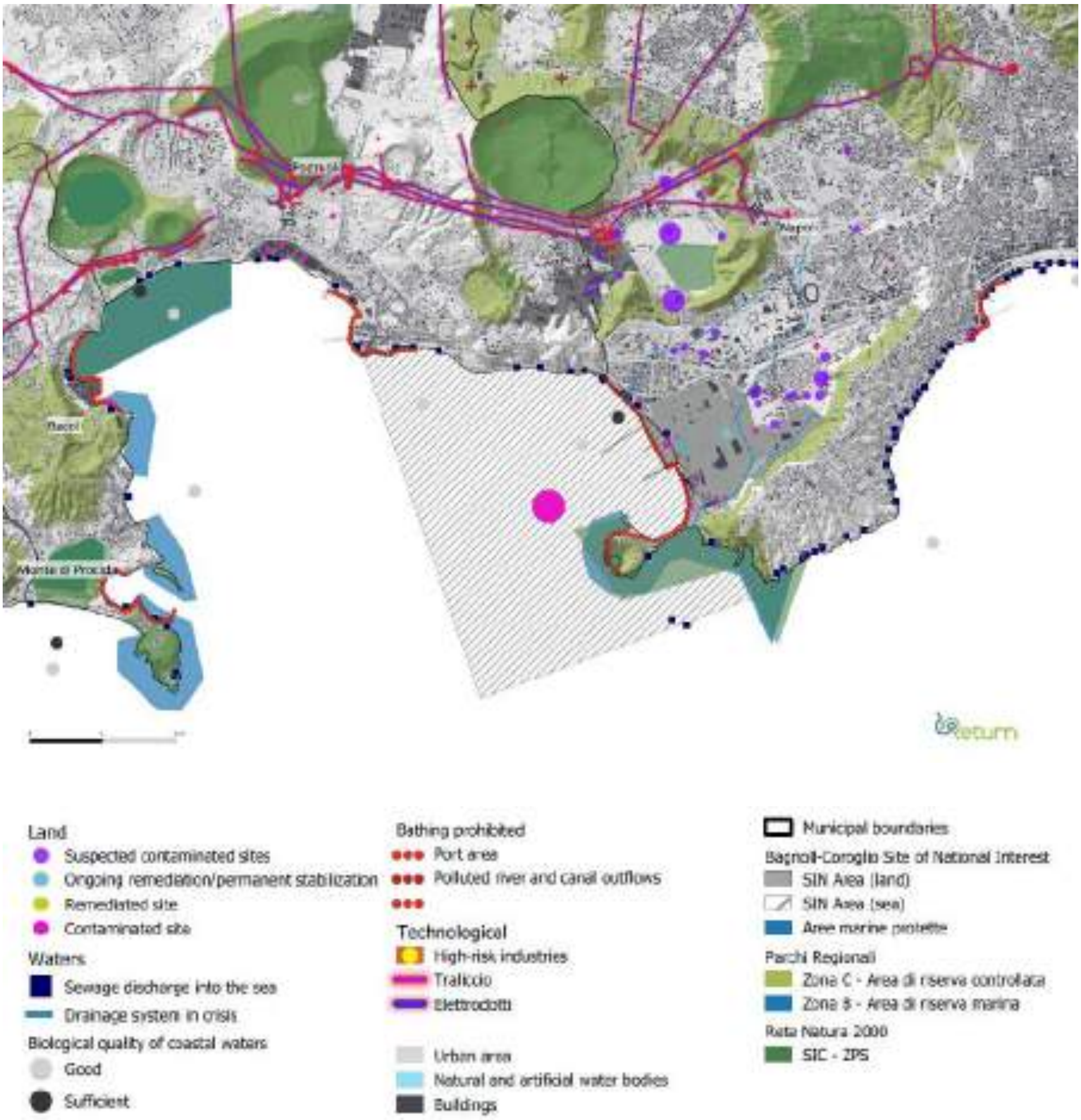
This map focuses on the fragility of the territory, identifying areas susceptible to landslides and soil movements. It highlights critical zones where the terrain is prone to erosion, sliding, or collapse, which can pose a significant threat to infrastructure and residents. It shows how factors such as steep slopes and urban development on unstable ground contribute to increasing this risk, underscoring the need for careful land-use planning and effective mitigation measures within the urban metabolic cycle.



4. **The Invisible threat: environmental contamination & hazard landscapes**

Scale: focus

The map highlights the effects of human activity on the environment, interpreting the territory's vulnerability through the lens of urban metabolic risk. By emphasizing spatial relationships, it identifies how factors such as degraded soils, deteriorating water bodies, and technological hazards from infrastructure networks interact. The analysis underscores how these dynamic processes contribute to systemic environmental and public health risks, revealing a landscape shaped by both visible and invisible threats.



5. **Mobility network and flows**

Scale: focus

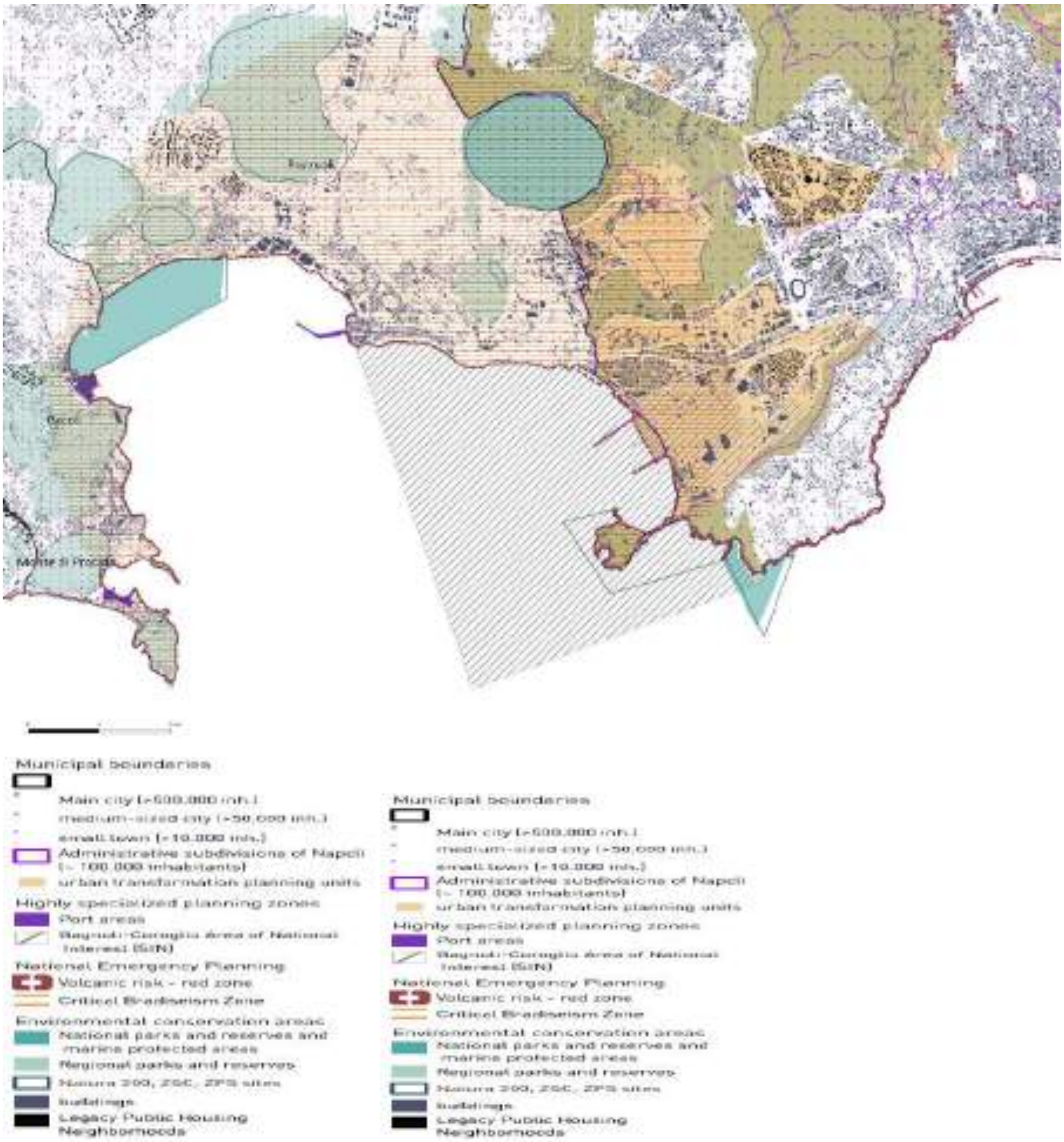
This map illustrates the complex network of infrastructure that underpins urban mobility and flows within the Focus Area. It provides a comprehensive picture of the road, rail, and maritime transport systems, and their interconnections. The analysis focuses on how these networks support accessibility

and influence the territory's flows, highlighting the critical relationship between mobility infrastructure and the spatial organization of the city.
(To view the map, consult the attached Atlas)

6. Governing the Gulf: administrative frameworks & planning challenges

Scale: focus

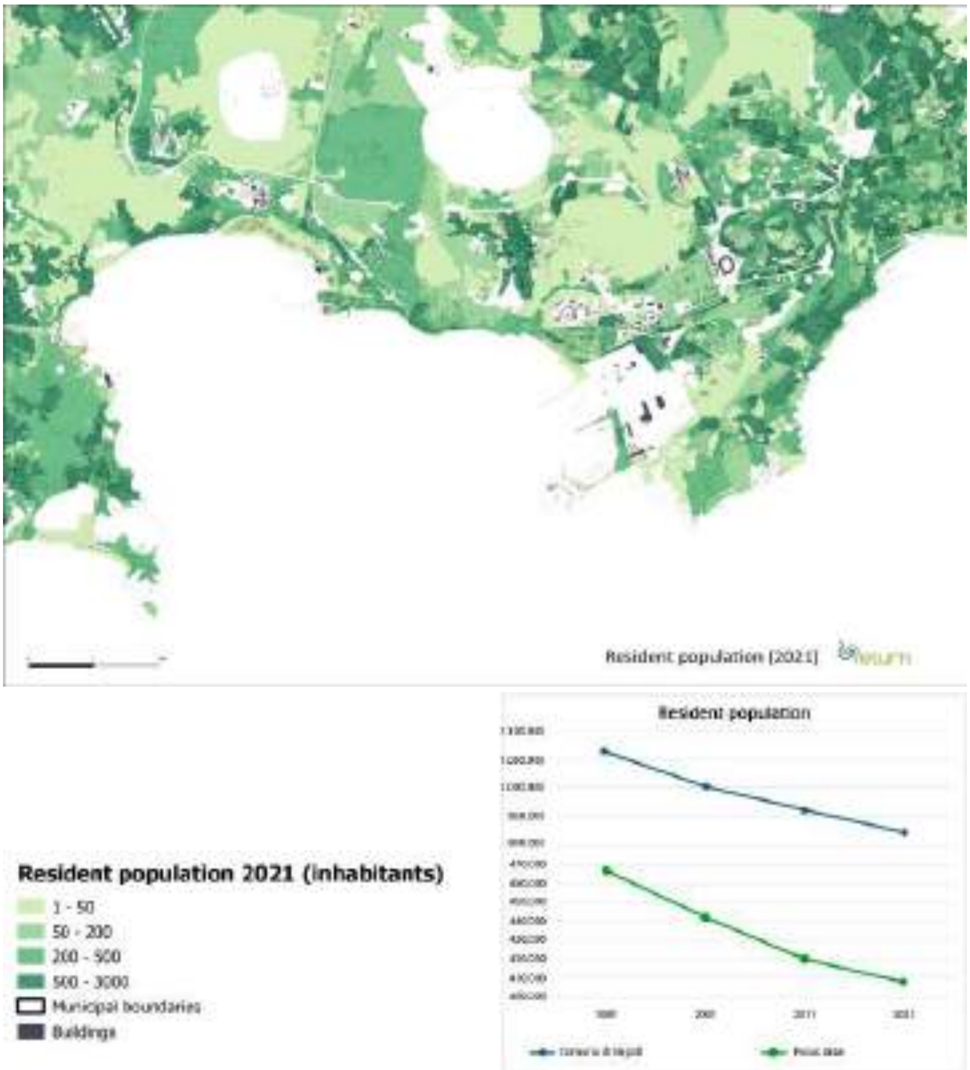
This map explores the complexities of governance and planning in the Focus Area by highlighting a fragmented decision-making process. In multi-risk contexts, urban planning and risk management are often complicated by a mosaic of overlapping jurisdictions and competing agendas. The map visualizes how these layers of planning, each with distinct aims and governed by different entities, can hinder effective urban transformation and perpetuate a legacy of unrealized projects. It reveals a key component of urban metabolic risk, where institutional fragmentation directly impacts the territory's capacity for adaptive and coordinated change.



Resident population (2021)

Scale: focus area

This map illustrates the distribution of the resident population in 2021, based on ISTAT data. It provides a visual representation of population density at the census unit scale, highlighting areas with high and low concentrations. This analysis is crucial for understanding the social dimension of risk, as it identifies which populations are most exposed to potential hazards within the territory.



Human Footprints: density in the Gulf landscape

Scale: focus area

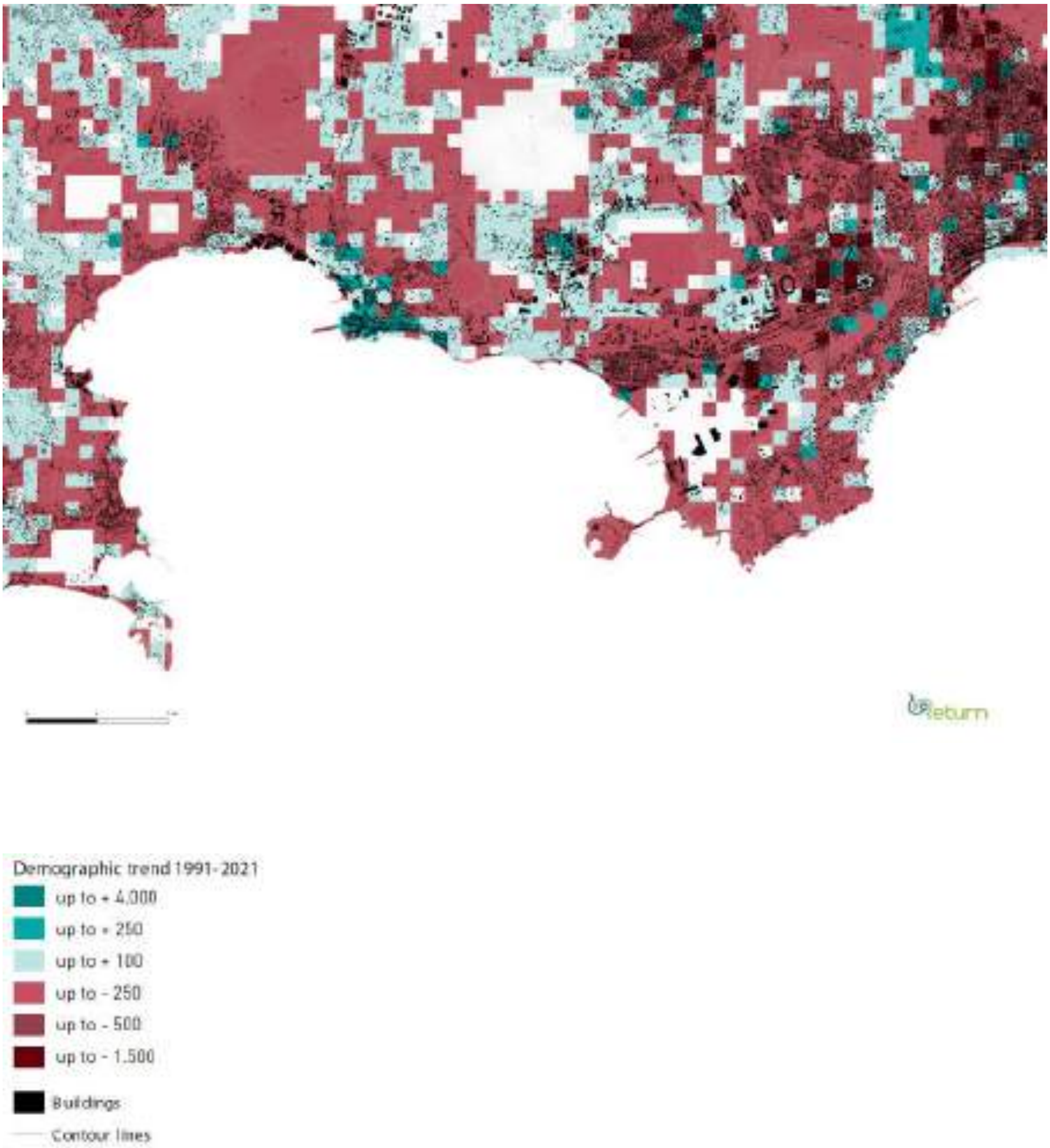
This map focuses on population density, a key factor in assessing territorial vulnerability. To achieve this, a uniform analytical grid of 200 meters per side was created to overcome the limitations of traditional census units. The resulting layer is a fundamental synthesis tool, which can be overlaid with risk maps to identify densely populated areas most exposed to potential hazards.

(To view the map, consult the attached Atlas)

Population changes and dynamics: 1991/2021

Scale: focus area

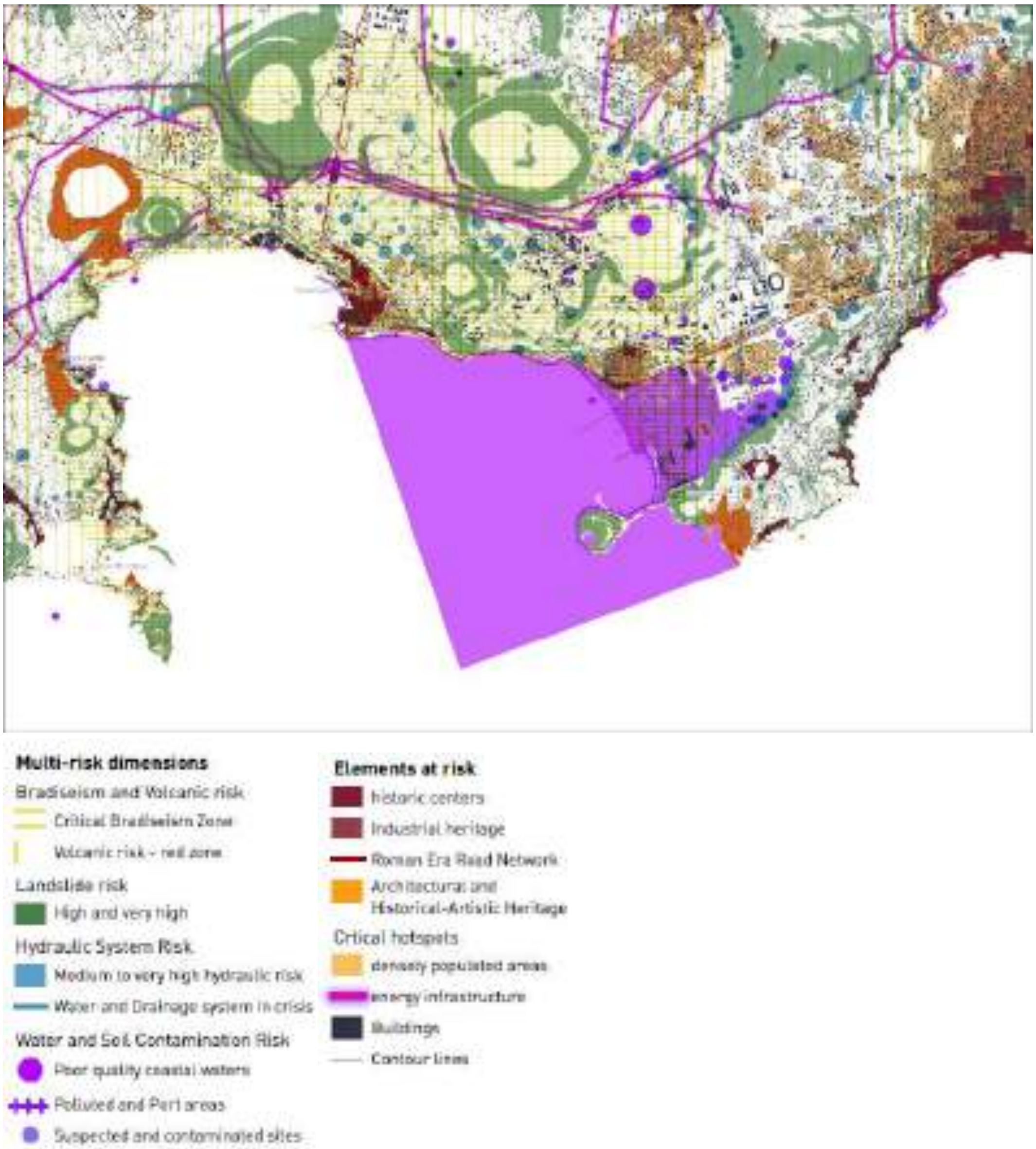
This map provides a historical perspective on the demographic transformations of the territory by analysing population dynamics and trends from 1991 to 2021. By comparing data over a 30-year period, it highlights areas of population growth and decline, revealing long-term socio-economic shifts. A particularly interesting fact is the repopulation of the municipality of Pozzuoli after the bradyseismic crises of the 1980s, which suggestes the resilience and complex relationship between the population and geological risk. The analysis of these demographic changes is crucial for understanding the evolution of the urban system's vulnerability and resilience.



Multi-risk territorial profile

Scale: focus area

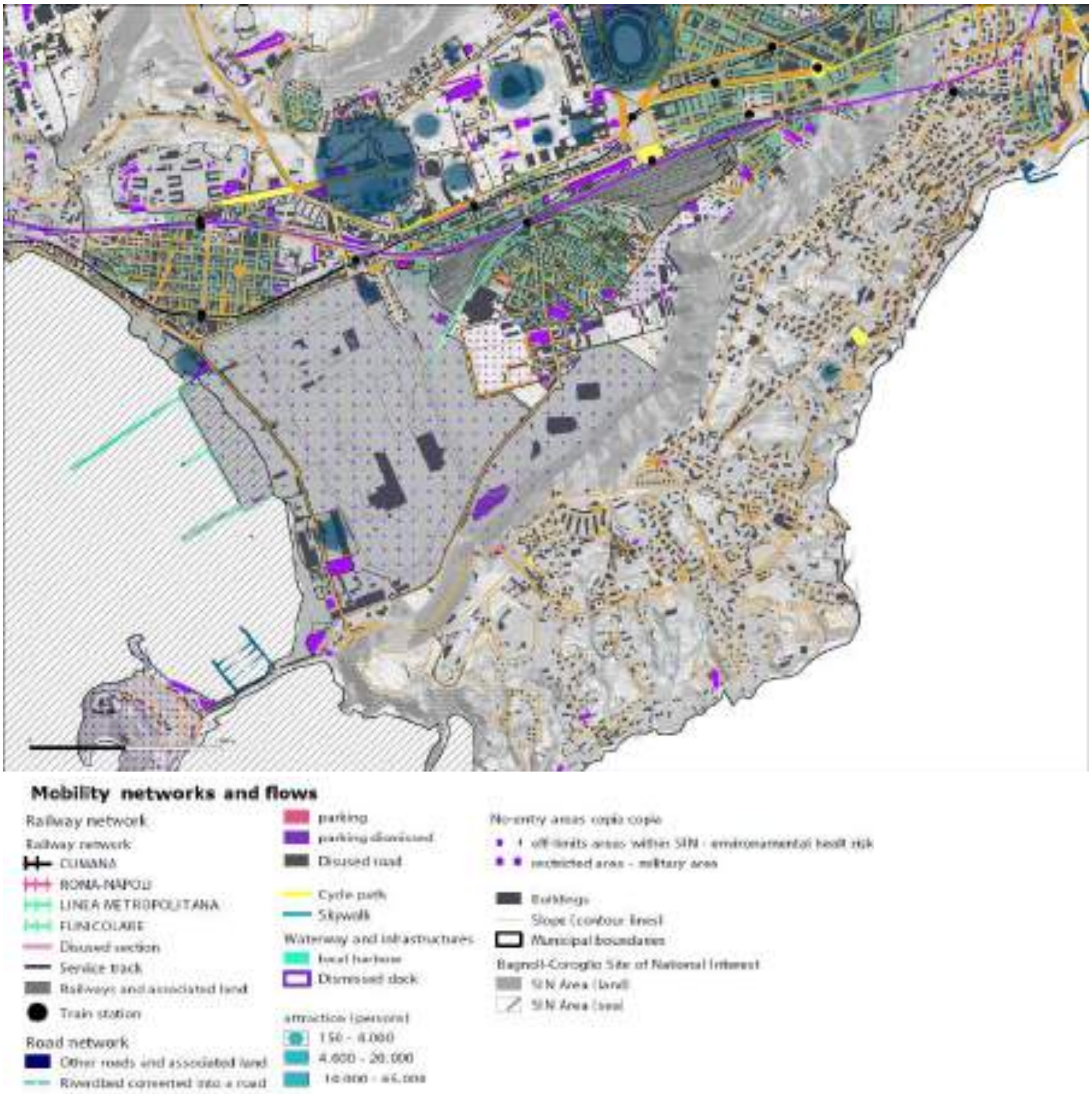
The synthesis map provides a comprehensive overview of the territorial vulnerabilities by overlaying the various risks analyzed at the Focus scale. It integrates data on bradyseism and volcanic risk, landslide risk, hydraulic system risk, and water and soil contamination risk into a single, cohesive representation. The map is designed to identify "critical hotspots" where these multi-risk interactions converge, revealing the complex systemic pressures on the territory. By also considering "elements at risk" such as historic centers, industrial heritage, densely populated areas, and critical energy infrastructure, it highlights which components of the urban system are most exposed. It serves as a crucial interpretive tool for developing integrated and adaptive strategies.



Mobility networks and flows

Scale: test area

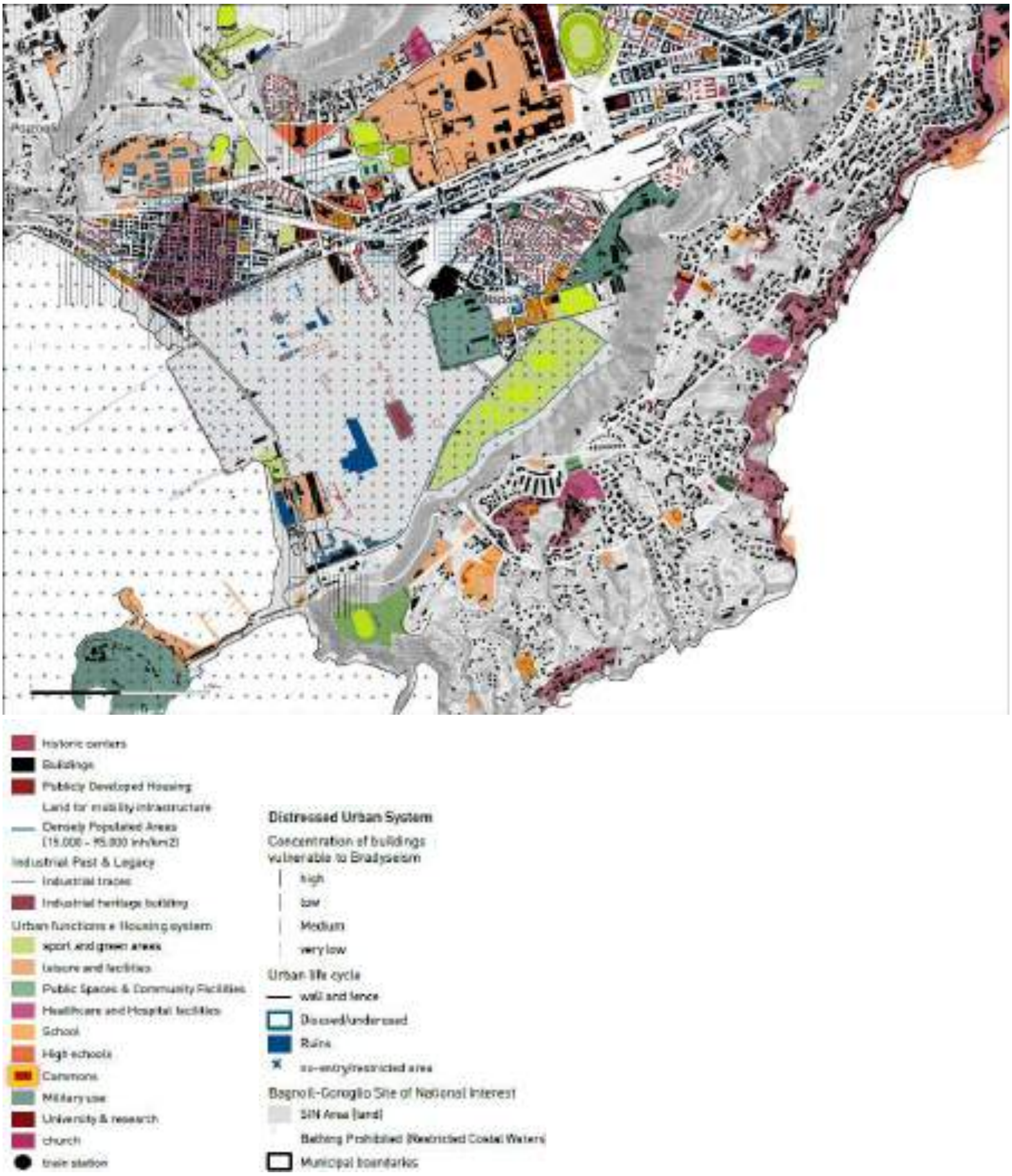
This map provides a detailed analysis of the mobility network at the Test scale, interpreting it as a critical component of the urban metabolic system. It includes both active and disused infrastructures sections, as well as critical points of access control such as fences and walls. Beyond simply mapping the transport infrastructure, this analysis overlays elements of stress and vulnerability, such as volcanic risk departure areas and densely populated zones. By highlighting the relationship between mobility flows, access constraints, and areas of high human presence, the map reveals the system's capacity for resilience—or its potential for crisis—in the face of a risk event.



Urban Settlement and Cycle

Scale: test area

This map provides a multi-layered analysis of Bagnoli's urban fabric and its metabolic cycle. It visualizes not only the current urban functions and housing systems, but also the "Distressed urban system," such as the concentration of buildings vulnerable to bradyseism. Strategically, the map also deciphers the urban life cycle by highlighting the industrial past and legacy, along with elements of disuse, such as ruins and underused areas. By integrating these layers, the map reveals the complex, ongoing processes of transformation and decay that define the territory's metabolic rhythm.



Who owns Bagnoli? A deeper look at land tenure

Scale: test area

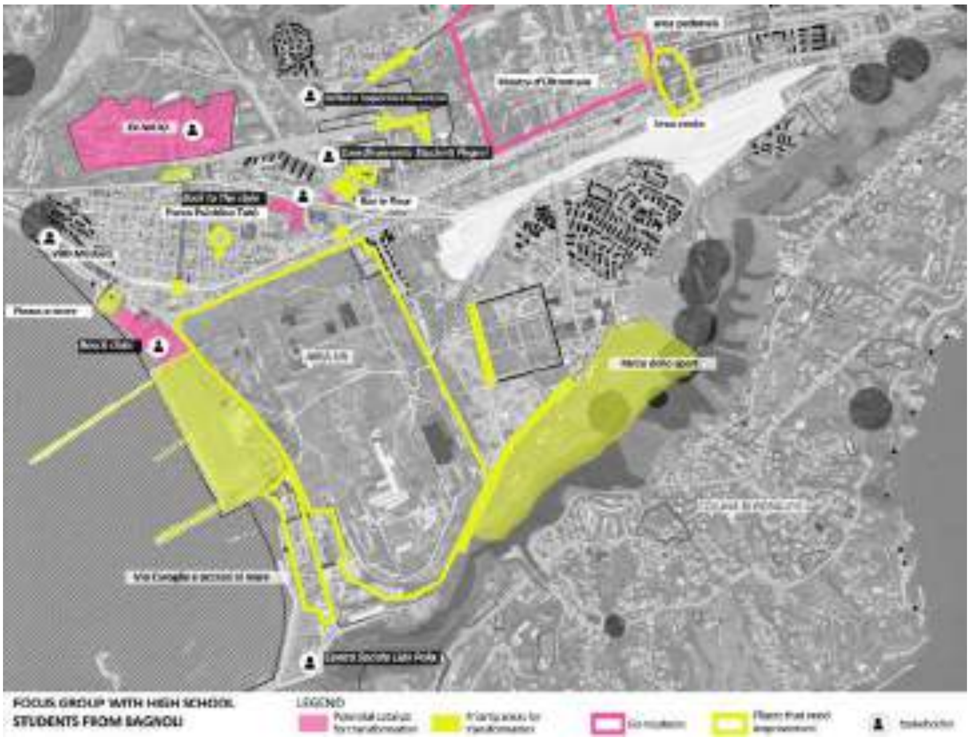
This map provides a detailed analysis of the complex mosaic of land tenure and ownership within the Test area. By classifying the territory according to its ownership—including publicly-controlled companies, state and municipal properties, and national public entities—it reveals the intricate web of actors involved. This fragmentation of ownership is a critical factor in urban metabolic risk, often complicating planning and hindering coordinated regeneration efforts. The map serves as a fundamental tool for understanding the institutional challenges and the potential pathways for transformation.

(To view the map, consult the attached Atlas)

Voices from the Living Lab: mapping community' perceptions

Scale: test area

This map visualizes the qualitative data gathered from the community through focus groups and co-mapping exercises. It georeferences the community's perceptions, needs, and concerns regarding the urban environment, public services, and mobility, highlighting where residents perceive both opportunities and safety issues. The findings are a critical input for urban development strategies, as they provide a vital counterpoint to purely quantitative data, ensuring that regeneration efforts are grounded in the lived experience of the territory.



The planning cycle: visions, revisions, and legacies

Scale: test area

This map provides a historical analysis of the territory by revealing the "palimpsest" of urban plans, design competitions, and architectural interventions that have shaped (or not) the transformation of the former industrial area of Bagnoli from the 1990s to the present day. By visualizing the different "layers of changes", the map clarifies the envisioned futures for the site and the types of transformations planned over time. The analysis uncovers a key component of urban metabolic risk: the legacy of unrealized projects and fragmented visions. This creates

a legacy of expectations and mistrust, a crucial factor in understanding the challenges to regeneration and the urban life cycle.
(To view the map, consult the attached Atlas).

Urban Metabolism at risk

Scale: test area

This interpretive and synthesis map of Bagnoli visualizes the complex and multi-layered relationships between the city built environment, its natural processes, and human activities. It moves beyond a conventional risk assessment by introducing the concept of "urban metabolism," which represents the city as a living organism with its own flows of materials, people, and energy. The map is structured around two main themes: risk and vulnerability and urban metabolism and regeneration.

Risk and Vulnerability: This section highlights the territorial fragilities, including hydrogeological risks, areas of environmental compromise (such as un-swimmable coastal waters), and the location of sensitive urban elements like schools and hospitals. It also identifies specific "health risk hotspots" where the concentration of pollutants exceeds safety thresholds, revealing the localized nature of some of the most critical environmental challenges.

Urban Metabolism and Regeneration: This section maps the city's regenerative forces, which act as drivers of resilience. These include the "urban life cycle," which visualizes the constant flux of construction, ruins, and disused areas. The map also showcases "heritage and memory" by including archaeological and industrial heritage, and highlights "urban ecological anchors" and "spontaneous renaturalization" areas within the SIN, where nature is reclaiming spaces and generating new ecological value. This dual approach reveals a territory marked by a unique coexistence of risk and resource, of degradation and resilience.
(To view the map, consult the attached Atlas).

Land cover & ecological characterization

Scale: SIN area

This map is the result of a meticulous on-site survey that ventures beyond the perimeter wall of the SIN area to challenge the perception of an "urban void." By analyzing the land cover, the map reveals a surprisingly resilient ecosystem that has developed over the remnants of an industrial past. It visualizes a complex mosaic of land uses, including meadows of continuous and discontinuous recolonization, various types of reeds, and mixed vegetation. The map also identifies the legacy of industrial activity through the footprints of demolished buildings and ruins. It is a foundational tool for understanding the territory's metabolic reality, showing how natural processes have adapted to the industrial heritage of the site.
(To view the map, consult the attached Atlas).

Land cover & ecological characterization

Scale: SIN area

This map analyses the degree of "naturalness" within the Bagnoli Site of National Interest (SIN), a concept that takes on an unexpected meaning in post-industrial contexts. The index measures the presence and vitality of spontaneous ecosystems, demonstrating a surprising resilience of nature which, despite the site's high contamination and soil compromise, has colonized large areas. The reading of

this map challenges the perception of an "urban void," revealing that the territory offers an ecological richness and potential ecosystem services that can provide valuable guidance for future regeneration projects.
(To view the map, consult the attached Atlas).

Naturalness index
Scale: SIN area
This map analyses the degree of "naturalness" within the Bagnoli Site of National Interest (SIN), a concept that takes on an unexpected meaning in post-industrial contexts. The index measures the presence and vitality of spontaneous ecosystems, demonstrating a surprising resilience of nature which, despite the site's high contamination and soil compromise, has colonized large areas. The reading of this map challenges the perception of an "urban void," revealing that the territory offers an ecological richness and potential ecosystem services that can provide valuable guidance for future regeneration projects.
(To view the map, consult the attached Atlas).

Structure index
Scale: SIN area
This map analyzes the ecological complexity of the territory through a vegetation "structure index". The index goes beyond simply measuring the presence of green space by evaluating the stratification, species diversity, and structural complexity of the spontaneous vegetation ecosystems that have developed. Applied to a post-industrial context like the Bagnoli SIN, this map reveals an unexpected richness and organization of natural spaces, showing how nature has created new, resilient ecological structures. This analysis is fundamental for understanding the territory's potential in terms of biodiversity and ecosystem services, providing a basis for future nature-based regeneration strategies.
(To view the map, consult the attached Atlas).

Anthropization index
Scale: SIN area
This map measures the anthropization index, which is the impact and pressure of human activities on the territory. Unlike a traditional reading, in this context, the index not only maps what is present but also captures the legacy of the industrial era, including the traces left by demolished infrastructure, industrial footprints, and soil alterations. The overlay of this map with the naturalness index reveals the conflict and coexistence between human imprints and the resilience of nature. It provides a direct visualization of the "urban metabolic risk," showing how the industrial past continues to influence the current dynamics of the territory and the challenges for its regeneration.
(To view the map, consult the attached Atlas).

4.4.2 Urban Metabolic Risk through interrelations, life cycles, and temporal (A)synchronies

Although the multiscale spatial analysis provides a structured and measurable framework for understanding the physical, ecological, and socio-economic conditions of the Bagnoli area, it also reveals something deeper: the presence of latent dynamics that influence territorial transformation in ways that often escape purely quantitative and qualitative readings, as also illustrated in paragraph 4.2. What emerges is not just a map of overlapping risks—environmental, infrastructural, and social—but a complex and living scenario shaped by chronic misalignments between heterogeneous life cycles, fragmented decision-making processes, and structural inefficiencies. Urban Metabolic Risk, in this sense, is not the mere sum of isolated hazards. It takes shape over time, through the ways in which different factors interact, reinforce each other, and fall out of sync. The risk intensifies when institutional, ecological, economic, and spatial rhythms drift apart. These temporal mismatches don't simply delay transformation—they create long-term blockages, often deeply rooted and resistant to change.

In Bagnoli, what has hindered urban transformation is not a lack of projects or interventions, but a persistent misalignment between the timing of decisions and the temporalities of the systems that make up the territory—natural, institutional, social. Observing how different layers of urban metabolism evolve over time allows these disconnections to surface. And these fractures—though often invisible at first glance—accumulate slowly, fed by institutional fragmentation, economic inefficiency, infrastructural inertia, and ecological degradation. In this case, shifting the analytical lens from where risk is located to how risk is generated has revealed the deeper mechanisms behind stagnation. This layered and asynchronous reading brings into focus not only the structural barriers that slow down change, but also, crucially, the latent spaces where transformation might still be possible. What makes Bagnoli such a compelling case study is precisely its stratified complexity. Over the course of more than a century, the area has undergone profound transitions—from agricultural land and thermal destination to industrial hub, and later to a space suspended in post-industrial limbo. Each phase reshaped its form, its function, and its identity, leaving traces that still weigh on its metabolism today. The legacy of heavy industry, environmental degradation, and the unresolved tension between planned regeneration and institutional paralysis has turned Bagnoli into a microcosm of urban metabolic contradictions. A turning point in our research was the development of a methodological framework aimed at going beyond descriptive cartography. The goal was not just to map what exists, but to read how different urban processes intertwine—across time, across sectors, and across institutions. The maps produced were not illustrations, but analytical tools in their own right. They made visible the accumulation of dysfunctions and delays, the discontinuities between plans and outcomes, and the points of tension where cycles broke down or failed to synchronize. This interpretive effort drew from a wide range of data and sources: not only planning documents, legislation, and environmental monitoring, but also indicators such as real estate values (OMI zones), public investment flows and funding programs, biodiversity patterns in marginal and neglected areas, and the temporal and spatial distribution of civic action—from street protests and legal battles to summer festivals and grassroots activism. Each of these aspects was mapped and analyzed not as a stand-alone topic, but as part of a complex and interconnected system of signals. Together, they form a narrative capable of explaining how and why certain urban processes fail to activate—despite political attention or financial input—and where unexpected forms of resilience or reactivation might still emerge.

The methodology adopted privileged a systemic and diachronic approach, one capable of reconstructing the shifting relationships among governance structures, ecological pressures, economic dynamics, and spatial practices. From this perspective, the maps allowed us to identify contradictions that are not always evident in policy documents: the gap between strategic visions and actual implementation, the paradox of ecological resurgence amidst land devaluation, or the coexistence of institutional neglect with spontaneous civic mobilization.

More than a catalogue of findings, the result is an interpretive framework that views urban metabolism in its full, relational complexity. It's a framework that resists simplified cause-effect logics and instead exposes the entangled conditions that produce fragility—while still leaving space to imagine trajectories of change. In this light, the methodological framework—and the maps that embody it—do not just describe the present. They offer a way to think strategically about the conditions under which transformation becomes possible again: not as a single event, but as the slow reweaving of fragmented cycles, and the reactivation of latent potential within the urban fabric of Bagnoli. In this research, the analysis of the Bagnoli area was never limited to a technical reconstruction of space. What we attempted was something more complex and layered: a critical reading that could bring together different dimensions — political, spatial, ecological, economic, and social — and, above all, restore their multiple and often conflicting temporalities. The territory was approached as a metabolic organism, traversed by life cycles that rarely proceed in linear or synchronized ways. The challenge, then, was to construct a diachronic and systemic reading, one that could interweave heterogeneous materials and reconstruct the relationships, frictions, and interruptions that have shaped the area over time.

We began with an exploration of governance and political action, both at the national and local levels, examining the strategies, legislative tools, and missed opportunities that have marked Bagnoli's development trajectory. We then looked into the economic dimension, conducting a detailed reconstruction of the public funds and investments allocated to the area over the years — tracing their amounts, timing, and actual implementation. At the same time, we focused on the spatial evolution of the site, redrawing the phases of construction, deconstruction, and reconfiguration. This allowed us to interpret how the physical form of Bagnoli responded to or resisted broader urban dynamics.

Data were considered both for the city of Naples and the district of Bagnoli, when available we have considered data for the district X which include the area of Bagnoli. It is worth to notice that data are not always available on the same perimeter.

Within this broader framework, we also included an analysis of real estate selling values, using data from the OMI (Osservatorio del Mercato Immobiliare)[8] zones (Fig. 22). The data show that while since 2016 the value for the city of Naples increase, value on the area of Bagnoli decrease even more severely since 2021.

[8] Data are available at: https://www.agenziaentrate.gov.it/portale/schede/fabbricatiterreni/omi/banche-dati/quotazioni-immobiliari

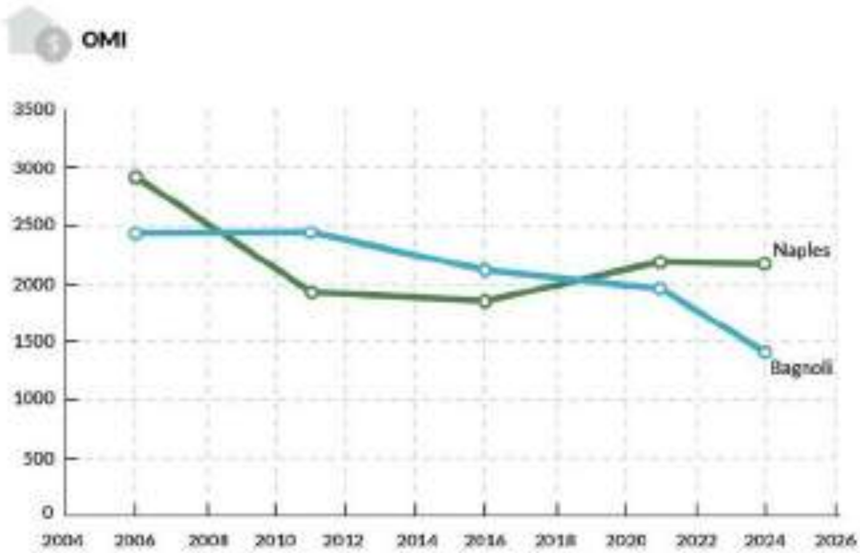


Figure 22 - Temporal evolution of OMI real estate values in Bagnoli and Naples (2004–2024).

These values were not treated as central, but as one among several interpretive indicators — revealing economic perceptions, speculative pressures, or, conversely, patterns of disinvestment and marginalization. All of these elements were then connected with dimensions often considered marginal, such as the trajectory of biodiversity (expressed as Biodiversity Units), tracking ecological shifts across decades and interpreting spontaneous ecological returns as silent indicators of abandonment or resilience (Fig. 23).

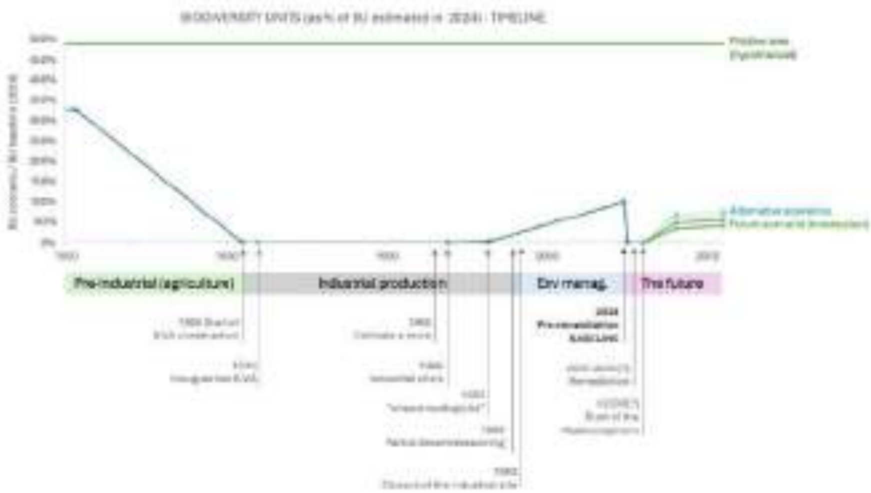


Figure 23 - Evolution of Biodiversity Units (BU) over time at the Bagnoli site highlighting historical transformations and projected future scenarios

Population data, both at the neighborhood level and across the city of Naples, is analyzed observing how demographic trends reflect or diverge from territorial dynamics (Fig. 24).

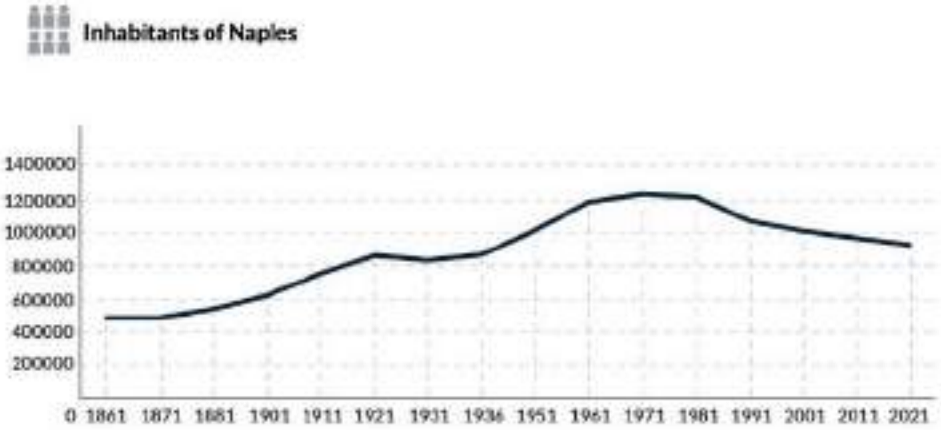


Figura 24 - Historical demographic evolution of Naples (1861–2021)

Data on employment and unemployment were considered both for the municipality of Naples ad the district X (Fig. 25). Seismic activity related to bradyseism is also considered incorporated to understand whether geological disruptions had ripple effects on the political or urban agenda (Fig. 26).

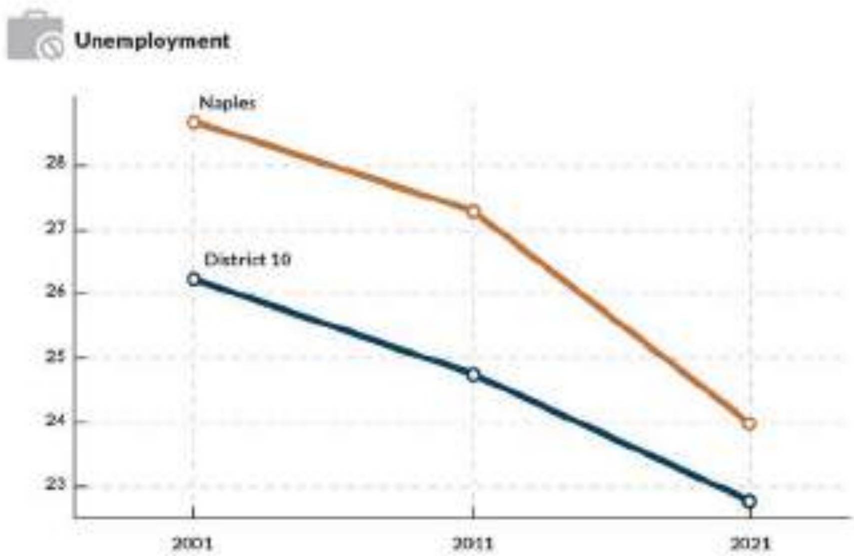


Figure 25 - Unemployment trends in Naples and District 10 from 2001 to 2021

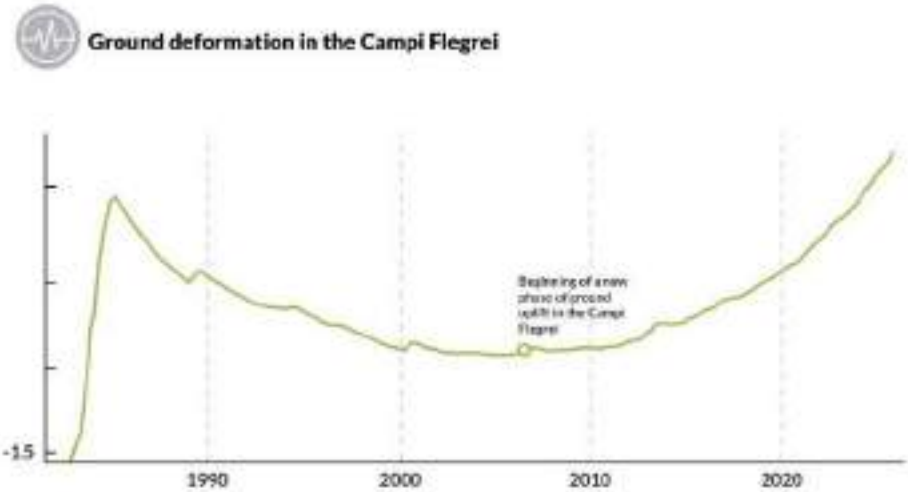


Figure 26 - Ground deformation in the Campi Flegrei between the 1980s and 2020s, showing the onset of a new uplift phase around 2006.

A particularly meaningful part of the work involved the reconstruction of civic struggles and grassroots activation. We mapped and interpreted a wide array of events: from cultural initiatives like the Bagnoli Rock Festival, to public protests, the formation of neighborhood committees, and the emergence of civic observatories. These practices were not treated as peripheral episodes, but rather as core signals of a living urban metabolism — capable of producing agency, care, and collective meaning even in contexts marked by institutional inertia. The result was not a linear narrative, but a constellation of intersecting readings — capable of revealing the deep asynchronies between political intention and implementation, between economic investment and social response, between ecological time and bureaucratic schedules. In this light, the maps produced throughout the research were never merely descriptive tools. They became critical devices for making sense of complexity — visualizing delay, tension, accumulation, disconnection, and resurgence. Mapping, in this case, was not only about representing space, but about reading time through space — to reveal not only what has happened, but what has been deferred, disrupted, or forgotten.

An ecological assessment of the SIN Bagnoli-Coroglio was performed with the aim to collect site-specific information on the ecological status as well as level of naturalness and biodiversity (with focus on vegetation structure, patterns and habitats), thus document the ecological baseline of the SIN area (before the remediation activities), evaluating the “unexpected” re-naturalization occurred in the industrial area, after a long period of abandonment.

Photo interpretation and vegetation surveys carried out directly in the field allowed the identification of around thirty land use types in SIN area (and in the adjacent area belonging to the Regional Park “Parco Regionale dei Campi Flegrei”), groupable into nine macrotypes (areas without vegetation, areas with sparse vegetation, gardens and cultivated areas, grasslands, high-herbs vegetation, shrubs, arboreal-shrubby vegetations, plantings, water bodies).

Considering the SIN area covered with vegetation (around 50% of the area), most of the territory is characterized by secondary grasslands. The most common ones (23% of the area – about 60ha) are secondary subnitrophilous perennial grasslands, dense secondary grassland that develops on surface soil, dominated by grasses and hemicryptophytes (Piptatherum miliaceum, Avena fatua, Bromus hordeaceus, Bromus madritensis, Dactilys glomerata, Calamintha nepeta, Anethum foeniculum, Daucus carota, Verbascum sinuatum, as well as scattered shrubs, mainly Inula viscosa, Artemisia arborescens ed Helichrysum litoreum). These grasslands appear to be the least disturbed soils, except when existing structures are removed, resulting in the passage of vehicles and compaction of the soil.

A different type of grassland that characterizes the northernmost portion of the SIN coincides with the secondary mesohygrophilous perennial grasslands, dense and continuous grassland dominated by post-crop mesohygrophilous species (Reichardia picroides, Bituminaria bituminosa, Mercurialis perennis, Galactites tomentosa,Verbena officinalis, Chenopodium album, Rumex crispus, Malva sylvestris). The northern part of the SIN was recently affected by land works that could have provided more structured and humus-rich soil material. Overall, they occupy about 10 ha of the surface of the SIN (5%).

With special regard to biodiversity, we estimated a quantitative estimate of the Biodiversity Units (BU) along time, considering the habitat type and size, their quality and relevance in terms of conservation priority and strategic significance. This approach was used to evaluate the pre-remediation baseline biodiversity value (2024) and to estimate its changes over time; the same approach was also used to support preliminary alternatives analyses for future scenarios, with the final aim to support the decision-making process for land use planning/design/management, operating in a framework for managing risks and potential impacts related to biodiversity and ecosystem services (Fig. 27). As can be observed in the timeline, the long period of abandonment and the absence of human use in the last 30 years allowed the recolonization of the industrial area by vegetation, with the creation of several habitats that, although not in the optimal condition, are likely to host and support a certain degree of biodiversity. The BU currently provided by the area (in the pre-remediation scenario, 2024) will likely not be totally replaced/recreated in the near future, being the remediation and redevelopment of the SIN area aimed to remove contamination and to allow a direct use of the area from the population (and not specifically on the preservation/increase of the ecological values of the area).

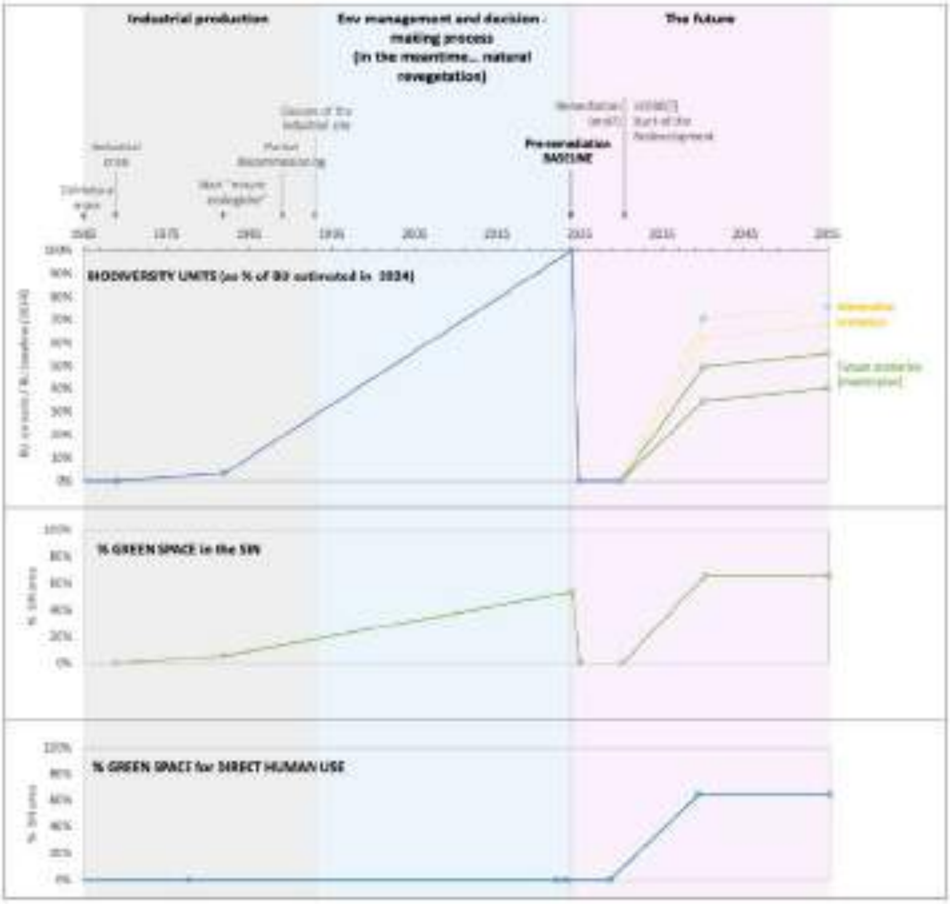


Figure 27 - Trends over time in biodiversity, total green space, and human-accessible green areas in the Bagnoli SIN, from industrial decline to future redevelopment scenarios.

5 Experiment on the test case of Bagnoli: co-created scenarios and circular remediation solutions.

Chapter 5 introduces two different experiments on the test case of Bagnoli. Paragraph 5.1 shows design actions and scenarios co-created and co-tested thanks to several workshops held on the project RETURN, through site visits, a serious game expressly designed for the project, and a learning walk. Paragraph 5.2 shows the results on the area of Bagnoli of a simplified tool that combines different indicators for circular remediation solutions.

5.1 Co-creating regeneration and mitigation scenarios for the test case of Bagnoli

The following paragraph introduces the outcomes of the co-design and co-testing activities developed during the RETURN project timeframe about the test case of the Bagnoli-Coroglio Site of National Interest (SIN), Naples, Italy. All activities have been carried out during open encounters involving experts, citizens, and stakeholders and took place in the city of Naples between November 2023 and July 2025. The meetings follow a threefold objective: advancing research status, producing research results, and transferring knowledge to participants and organizations involved, moving back and forth between desk research and real-life engagement in the territory. Territorial experimentation on the test case has been conducted following the Urban Living Lab (ULL) logic in direct correlation with the work of Task 5.5.2, entitled "City scale exercise for risk evaluation scenarios." Thus, its structure corresponds to the three phases of the ULL methodology built into the Deliverable DV 5.5.2 "City-scale exercise preparation and setup report", corresponding to:

i. The Co-exploring Phase: construction of a shared territorial knowledge among different actors;
ii. The Co-design Phase: definition of a shared vision through concepts, ideas, policies, and strategies, resulting from the joint effort of different actors involved in the process;
iii. The Co-testing Phase: shared implementation and testing of solutions proposed by different actors, assessing the effectiveness, appropriateness, and impact of the strategies and solutions that emerged in the previous stakeholder consultation phases (in the local context) according to a multidimensional evaluation approach.

In this section, the focus is primarily on the elaboration of co-created scenarios for Urban Metabolic Risk mitigation and urban regeneration developed during the last two phases through various participatory tools, both analogical and digital (cfr. Deliverable 5.5.2). Among the chosen tools, the **serious game** plays a pivotal role as an inclusive instrument to co-explore risk perception and co-create risk-resilient scenarios, encouraging stakeholder engagement.

5.1.1 Co-exploring risk perception and co-designing risk-resilient scenarios through gamification

The research team developed a specific serious game to transfer risk awareness — both in general and about the test case — and a basic introduction to the concept of Urban Metabolism for participants to develop their risk-resilient metabolic scenarios with a systemic logic and transcending a sectoral one-risk-oriented view. In line with this theoretical approach, the group of gamers can play simultaneously with four territorial risks: Climate Risk, Seismic-volcanic Risk, Health and environmental Risk, and Social Risk

The **serious game "Non correre rischi. Attiva il metabolismo della tua città!" - *Take no risks. Activate your city's metabolism!*** [9] has been designed for the 38th edition of Futuro Remoto Science Festival, which took place at Città della Scienza (Bagnoli, Naples, Italy) from 18th to 20th of October 2024. Founded in Naples in 1987, *Futuro Remoto* aims to make science accessible to all, especially to new generations; its 38th edition, entitled "Co-sciences," focuses on the ability to discern, evaluate, and act through all sciences, both natural and human[10]. According to both Futuro Remoto and RETURN philosophies, the proposed game promotes co-production of knowledge, territorial awareness, and shared scenarios while strengthening public engagement.

The *Take no risks. Activate your city's metabolism!* game simulates a regeneration process of a multi-risk peripheral urban area by implementing actions useful to reduce the chances of one or more risks occurring and to limit their impact, while activating a virtuous Circular Urban

[9] The serious game was ideated and realized by Libera Amenta, Rosaria Iodice, Benedetta Pastena, Sara Piccirillo, Bruna Vendemmia and Federica Vingelli.

[10] Cfr. Futuro Remoto general program 2024: FR_2024_HOME · Programma Edizione 2024 · NAPOLI – Futuro Remoto, last accessed on 12 December 202

Metabolism in the same area. The implementation of these actions on a test case, the district of Bagnoli, taking into account not only the environmental reclamation and urban redevelopment of the Bagnoli-Coroglio SIN, but also the regeneration of the surrounding residential areas and Sports Park, simulates possible regeneration scenarios for a real urban critical multi-risk context.

Interaction with participants is managed by the researcher, guiding the players through the process, and by five typologies of physical objects: the Gameboard, the Maps, the 'Risk Boxes', the 'Actions' Stickers, and the 'Unforeseen Cards'. The structure, the rules, and the methodology of the game are deeply explained in the RETURN Deliverable DV 5.5.2 - City-scale exercise preparation and setup report, inside the "4.2.1 Citizen-led co-design activities" paragraph, and detailed instructions are illustrated in the gameboard too (Fig. 28).

Figure 28 - Gameboard of the RETURN serious game "Non correre rischi. Attiva il metabolismo della tua città!" - Take no risks. Activate your city's metabolism! Source: L. Amenta, R. Iodice, B. Pastena, S. Piccirillo, B. Vendemmia, and F. Vingelli

Starting from Futuro Remoto, *Take no risks. Activate your city's metabolism!* has been played various times and in different settings in the last months. The serious game co-design activity was held during the "Università Svelata" - *Unveiled Universities* -, organized by the University of Naples Federico II in the SS. Marcellino and Festo university complex, to boost interactions between citizens and the academy. Moreover, the game has also been used to promote the DiARC OpenDay activities and as an ice-breaker tool during the "Co-design Urban Living Lab Bagnoli-Coroglio" ULL, held in Naples in March 2025 as part of the RETURN Academy. All events were characterized by an audience made up of different backgrounds, with a major concentration of students and researchers. Feedback among the participants has always been positive.

Confronted with the choice between four different kinds of risks portrayed on the game boxes, thirty-two groups chose to play with the following risks (Fig. 29):

- 19 times - Climatic Risk;
- 17 times - Seismic-volcanic Risk;
- 18 times - Health and Environmental Risk;
- 21 times - Social Risk.

Confronted with the choice between four different kinds of risks portrayed on the game boxes, thirty-two groups chose to play with the following risks (Fig. 29):

- 19 times - Climatic Risk;
- 17 times - Seismic-volcanic Risk;
- 18 times - Health and Environmental Risk;
- 21 times - Social Risk.

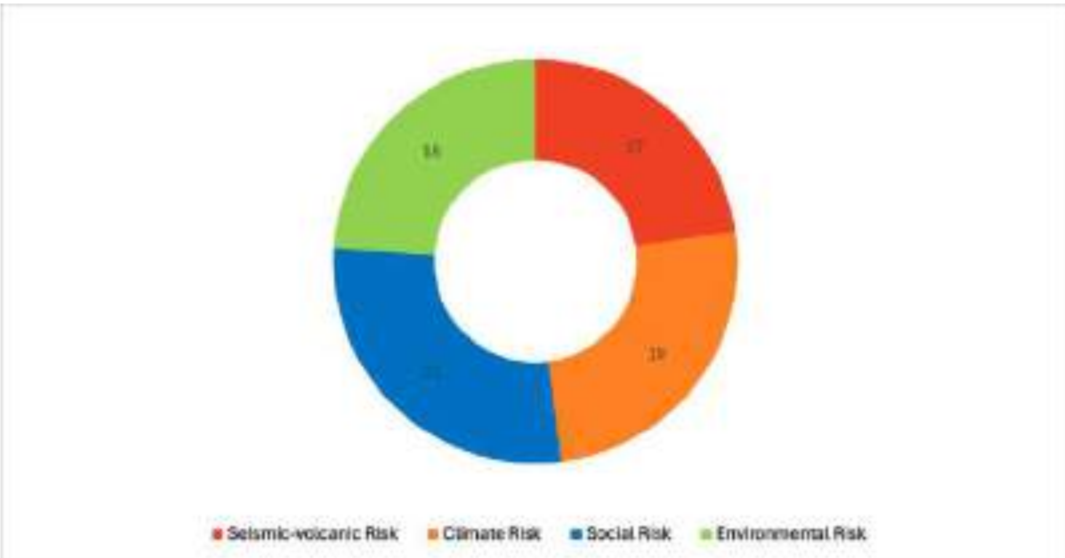


Figure 29 - Risk choices. Wheel graph describing the number of times individual risks have been chosen by players. Source: ..., Maria Di Rosa, Benedetta Pastena

The data collected shows that Social Risk was the risk with which participants interacted most; nonetheless, there is no great discrepancy between the most played risk and the last one, which is the Seismic-volcanic Risk, with a total of 17 game times. It is important to notice that the choice of the risk is linked to the image portrayed on the box: participants do not directly choose the risk they are going to play with, they choose the image, and so the box, they would like to interact with, then they discover the risk the box is linked to. Moreover, another important annotation is that some groups played with one risk, some with two risks and some even with three. In a multi-risk optic, participants were invited to interact with more than one risk: each group responded differently.

Based on the biographical data collected during the gaming sessions, an analysis of the choices of various risks based on the reference age group has been developed (Fig. 30). Teenagers and people over forty seem to select with more frequency the Climate Risk, while the 19-39 age group has preferred the Social Risk.

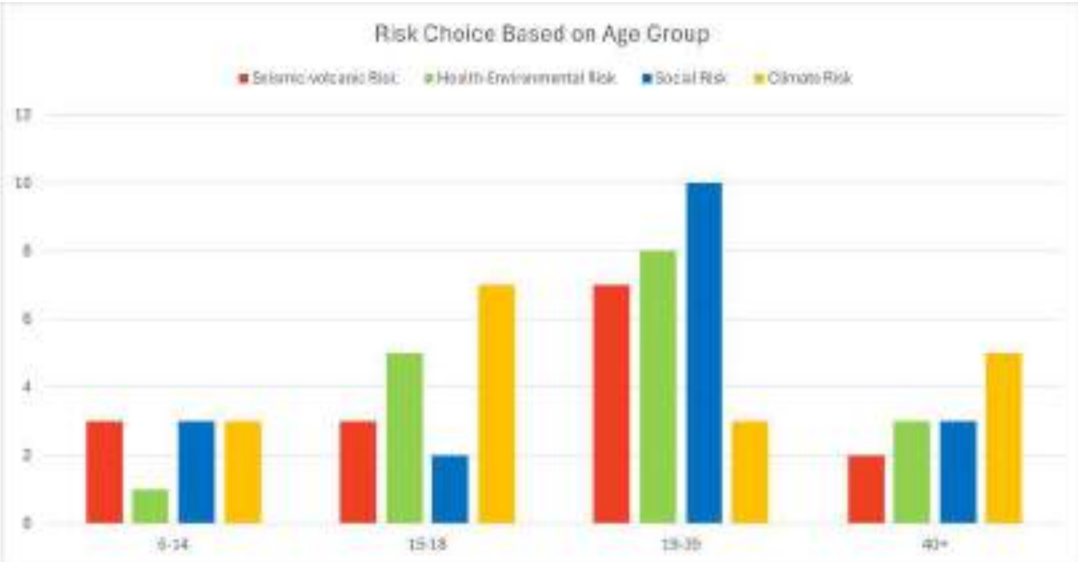


Figure 30 - Risk choices based on age group. Source: A. Annunziata, F.M .De Paola, M. Di Rosa, B. Pastena

After choosing risks, players individuate specific actions to implement in the territory. For the test case of Bagnoli-Coroglio the most chosen action among the ones related to Climatic Risk was ‘Permeable Pavements’, for Health and environmental Risk the ‘Phytoremediation of Water and Soil’ action, for Seismic-volcanic Risk the ‘Improvement of Escape Routes’ action and, finally, for Social Risk the ‘Sustainable Mobility’ action (Fig. 31). In general, the most chosen action were ‘Phytoremediation of Water and Soil’ and ‘Sustainable Mobility’, while the less chosen action – just 1% of choices – corresponds to the ‘Food Self-Production’ action, which probably suffers of the stigma linked to the contaminated nature of the site (Fig. 32).

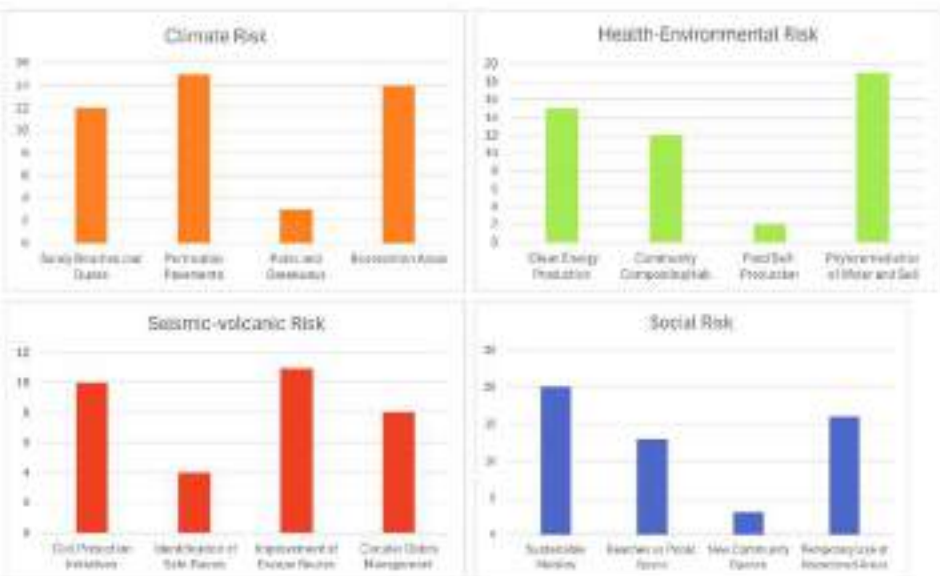


Figure 31 - Actions choice in relation to Risks. Column chart reporting the number of times actions have been chosen by participants. Source: A. Annunziata, F.M .De Paola, M. Di Rosa, B. Pastena

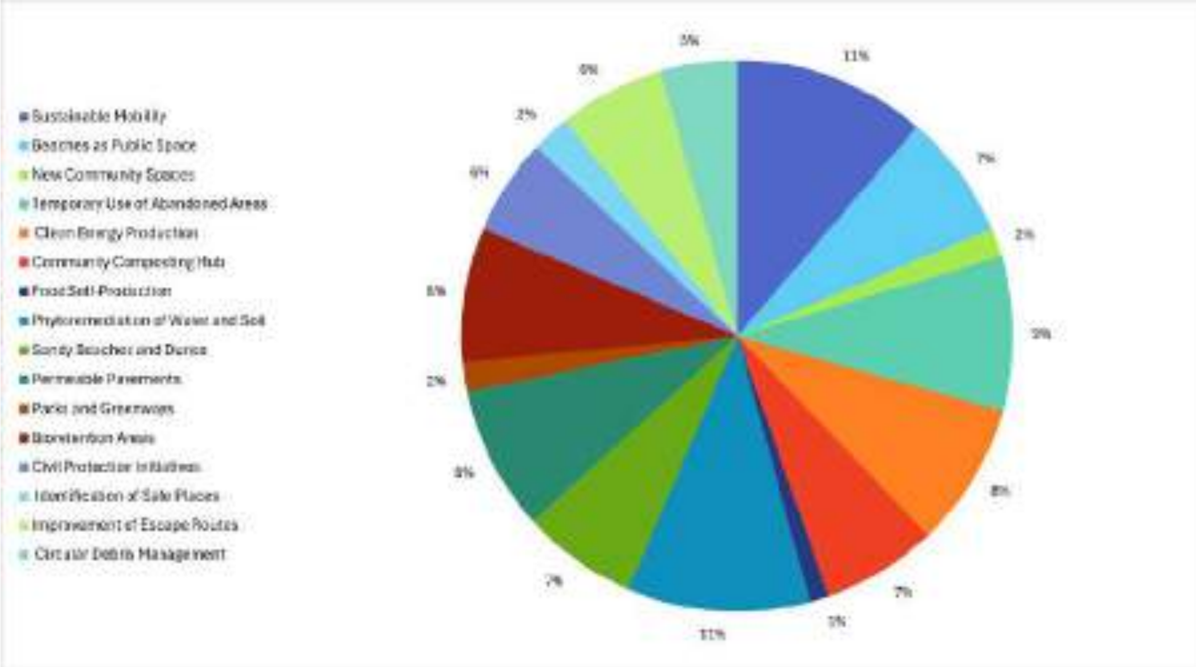


Figure 32 - Actions choice. Source: A. Annunziata, F.M .De Paola, M. Di Rosa, B. Pastena

By overlaying the action choices with their localization, the serious game output reveals alternative possible scenarios for mitigating the Urban Metabolic Risk in a critical urban context, such as the SIN of Bagnoli-Coroglio (Fig. 33). Understanding the composite nature of UMR by working with solutions related to four different Territorial Risks, it is essential to co-design an inclusive and just transitional project which lays its foundation on a collaborative and systemic design approach. Citizens and experts playing with the serious game disruptive scenarios, in which, for example, the landfill at sea becomes an amenable territory for experimentation with 'Sandy Beaches and Dunes', 'New Community Spaces', 'Bioretention Areas', 'Civil Protection Initiatives', 'Food Self-Production', 'Beaches as Public Spaces' and more. Participants showed a preference for acting on the core area of the Site of National Interest, but out-of-the-box thinkers and site connoisseurs applied a broader vision, localizing actions on the borders of the study areas and in unexpected places. Athor prioritized spots, such as the former Steel Plant and the Sports Park, are also linked to the industrial past of the area and its history of abandonment and constitute landmarks in its contemporary landscape. Finally, reading the juxtaposition of so many layers in the summary scheme provides interesting and innovative suggestions for designers and policymakers working on Bagnoli.

v

Figure 33 – Serious game results. Scheme describing the interaction between risks, actions and their localization on the test case. Source: B. Pastena

5.1.2 Co-testing scenarios for risk mitigation in the SIN Bagnoli-Coroglio

A co-test workshop was held on 23th of May during the 6th edition of the Bagnoli Jane's Walk. Analysis of the collected data reveals some relevant trends. Regarding the first objective—"to reconnect the system of human, environmental, value-based, and urban relationships"—the most highly endorsed action was 1.5 (fig. 34), namely the "implementation of soft mobility and green corridors to connect the city with the park." This highlights a clear, collectively felt need for material and symbolic reconnection between Bagnoli and its former industrial area, through sustainable and accessible solutions. The strong support for this action, while rooted in the environmental dimension, also directly impacts social wellbeing and urban quality of life, reinforcing territorial cohesion.

Also noteworthy within this objective is the significant interest in action 1.2, which involves the establishment of a Renewable Energy Community. This indicates a growing awareness and willingness among citizens to engage in active energy citizenship, not merely as beneficiaries of new infrastructure but as co-producers and co-managers of shared resources. This orientation suggests a transformation model where environmental and economic dimensions are intertwined with social engagement.

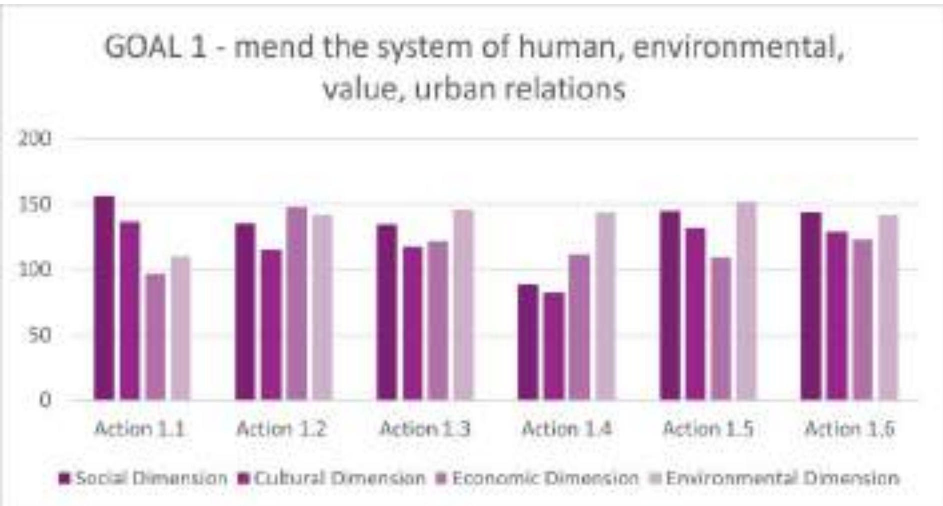


Figure 34 - Preferences expressed by local community during co-test phase – scenario 1. M. Di Rosa, M. Bosone

Under the second objective—"to preserve the cultural, identity-based, and social value of the factory in shaping the community's collective identity"—the most preferred actions were 2.1 (temporary use of abandoned spaces for cultural and social activities) and 2.4 (creation of community spaces for events and gatherings) as shown in fig. 35. These preferences clearly reflect a community desire not to erase the industrial legacy of the area, but rather to re-signify it through collective reappropriation. The factory is thus not viewed as a relic of the past, but as a vital resource for constructing new forms of community identity. Here, social and cultural dimensions converge in the understanding of heritage as a living commons.

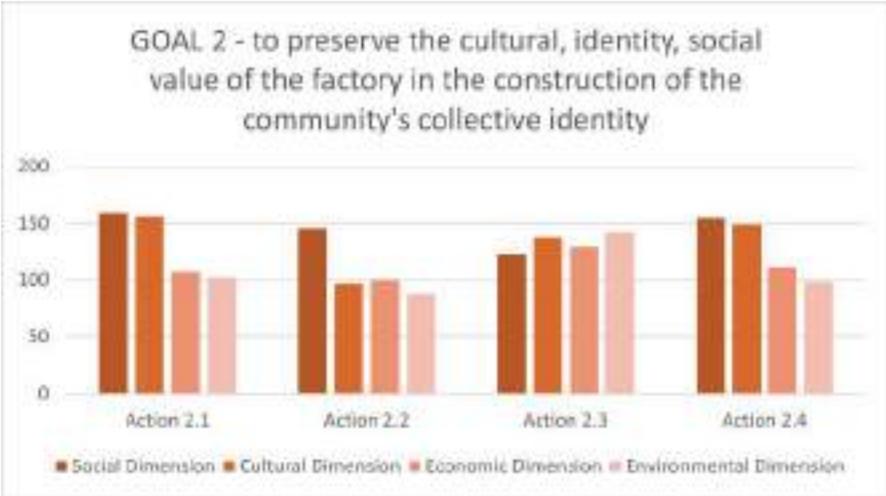


Figure 35 – Preferences expressed by local community during co-test phase – scenario 2. M. Di Rosa, M. Bosone

Of particular interest is the convergence between responses to the second and third objectives. In the third scenario—"protection and enhancement of spontaneous renaturalization and biodiversity"—the most supported action was 3.1, the creation of a local seed market (fig. 36). Although strongly environmental in nature, this action also carries significant cultural weight, as it involves the transmission of local knowledge and agronomic practices, as well as the valorization of native plant species. In this sense, a continuity can be identified between the desire to safeguard the memory of the factory and the will to preserve biodiversity: both stem from the notion of "regeneration through care" and a reconnection to the (human or natural) history of the site.

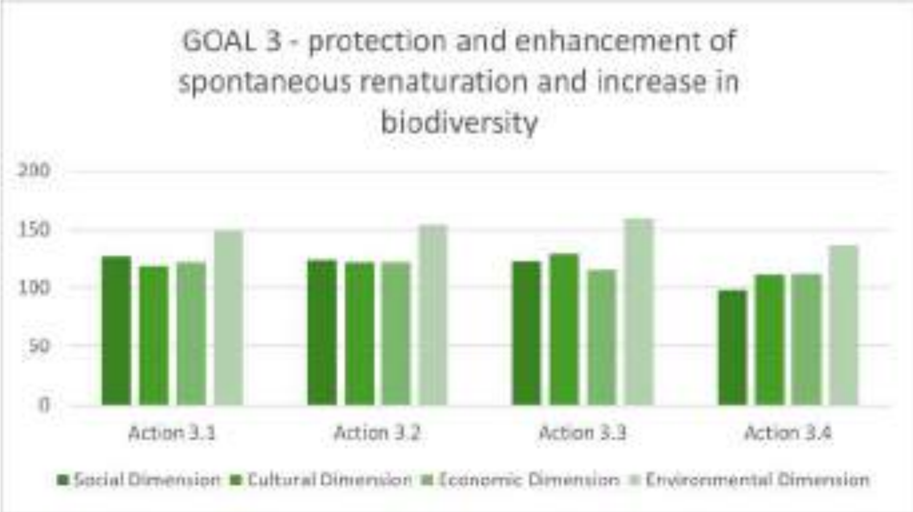


Figure 36 - Preferences expressed by local community during co-test phase – scenario 3. M. Di Rosa, M. Bosone

For the fourth objective—"reconstruction and valorization of the ecotonal land-water ecosystem"—the most favored actions were 4.1 (reconfiguration of the coastline to make it accessible and usable) and 4.3 (introduction of flexible and/or seasonal-independent public functions on the beach) see fig. 37. These responses point to a dual interest: on the one hand, improving access to the sea, and on the other, creating inclusive public spaces that can break the seasonal limitations of tourism. This suggests that the local community is not simply asking for physical access to the coastline, but is envisioning an integrated project that enhances the coastal ecosystem while maintaining social inclusiveness. This, in turn, implies a delicate balancing act between environmental protection and the right to the city.

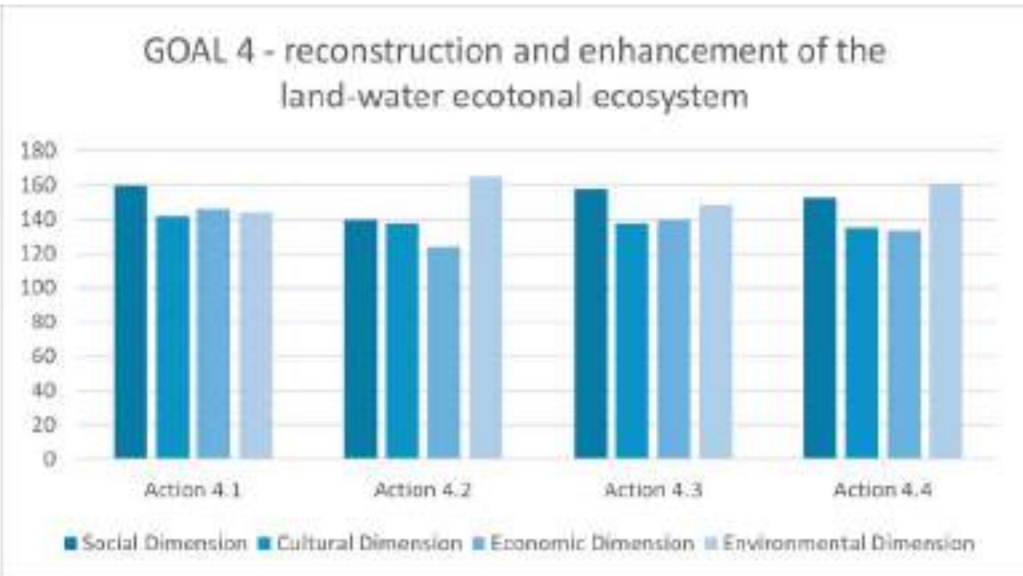


Figure 37 - Preferences expressed by local community during co-test phase – scenario 4. M. Di Rosa, M. Bosone

A cross-cutting reading of the results allows for the identification of both tensions and potentialities. The most highly endorsed actions share a strong inclusive component: they involve not only physical transformation, but also the activation of civic agency, whether through participation in processes (mobility, energy, urban agriculture) or the active use of reconverted spaces (industrial heritage, coastline). This trend confirms the value of the co-test's participatory approach, which succeeded in capturing both tangible needs (accessibility, mobility, environmental quality) and intangible desires (belonging, memory, environmental justice).

Nonetheless, some critical issues emerge. Actions involving greater technical complexity or perceived as less directly relevant to everyday life—such as those concerning regenerative remediation (3.4) or marine habitat reconstruction using eco-compatible materials (4.2)—received lower levels of engagement. This may reflect an information gap or a difficulty in recognizing the strategic importance of medium- to long-term interventions that are not immediately visible. Consequently, it becomes essential to enhance the communicative and educational dimension of participatory processes, to prevent preference from being skewed toward only the most immediate or familiar aspects.

Lastly, it is worth emphasizing how the combination of actions across different dimensions—for instance, linking soft mobility (1.5) with cultural uses of industrial spaces (2.1)—points to a multi-layered and integrated vision held by the community. Residents do not seem to be seeking "one thing at a time," but rather demonstrate an ability to articulate a multi-dimensional reading of urban transformation: they want to move sustainably, but also have spaces for social interaction; they wish for access to the sea, without abandoning the memory of the factory; they aspire to a healthier environment alongside a more equitable economy. This integrated outlook offers a valuable foundation for future planning and underscores the need for truly cross-sectoral urban policies, grounded in ongoing dialogue between expert.

5.2 Application of the circularity and sustainability framework to a remediation case study

As indicated in paragraph 2.6, contaminated sites generate an environmental and health risk associated to concentration of contaminants in different matrix, such as surface soil, deep soil, backfill and groundwater. Consequently, interventions are needed with the aim to remove the contaminated matrix or to contain the contamination and therefore to eliminate the risk to human health and environment. Also, in order to avoid generations of further environmental, economic and social impacts, it is necessary to guide the choice of intervention strategy toward remediation solutions that are not only sustainable but also attentive to the application of circular economy principles.

Based on the complexity of data retrieval at the preliminary project level (i.e., when the assessment is made for the selection of the best intervention to be developed at the final level), it is necessary an application to a case study in order to evaluate the applicability of the selected indicators (Table 4, paragraph 2.6.2 of this deliverable) in order to obtain a simplified tool that could be useful in defining a framework applicable in a national context.

The framework for sustainability and circularity assessment in the screening phase of different technological remediation solutions, developed through the implementation of the indicators identified above (Table 4, paragraph 2.6.2 of this deliverable), was applied to Bagnoli -

Coroglio (NA) case study, one of the Site of National Interest (SIN), determined by Law Decree no. 133/2014, converted into Law no. 164/2014.
Selected indicators belonging to the 3 sustainability areas (environmental, economic and social) and circularity regulated by the UNI/TS 11820 standard "Circularity measurement - Methods and indicators for measuring circular processes" have been evaluated. The decision-making framework developed is shown in Table 4, where the sustainability and circularity indicators contribute to the calculation of the sustainability and circularity index respectively.
The redevelopment project of the area defined in a specific PRARU, provided for the subdivision of the area into lots to be treated separately. In particular, within Lot. 1 Fondiarie, the sub-area 1f represented in the figure below was taken into consideration for this study (Fig. 38).

Figure 38 - Image of sub-lot 1f within Lot 1 Fondiarie (taken from 2020E028INV-01_DEF_AMB_BF. 2.01)

According to design data, this area has a total surface area of 3ha with contamination located at depths ranging from -1.0m ÷ -4.0m.
Two different non-real scenarios were compared by evaluating the application of an on-site bioremediation technology (Alternative 1) on the one hand and Dig&Dump on the other hand to the entire sub-lot 1f.
Biopiles are considered the most widespread bioremediation treatment for the remediation of contaminated soils (Jørgensen et al., 2000). The process consists of taking contaminated soils and subsequently treating them in structures called "piles", within which conditions such as oxygen concentration, soil moisture, nutrient concentration and pH are controlled to optimize the growth and activity of the indigenous microbial community (Fig. 39).

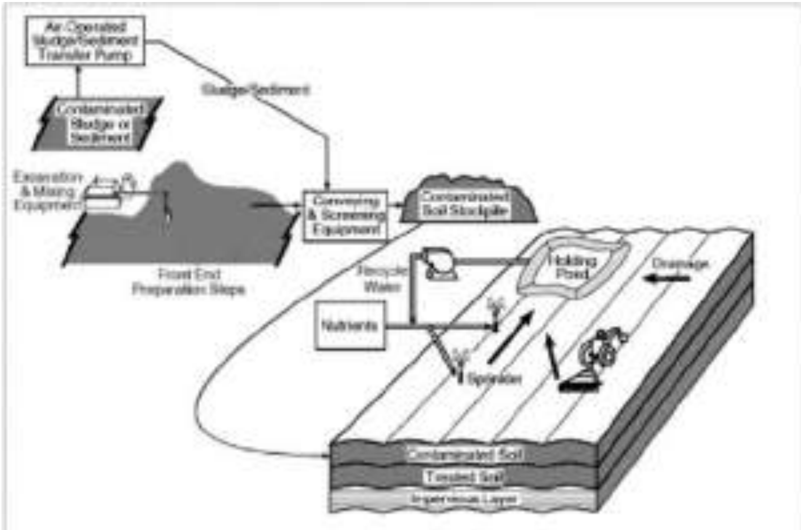


Figure 39 - Biopila scheme (source: FRTR, EPA)

In particular, in the application to the case study of Bagnoli, Alternative 1 envisages the preliminary excavation of the soil to be treated on site, the setting up of treatment bays in which the treatment of the soil will be carried out in successive steps through its humidification and the addition of nutrients and structuring agents. The “dynamic” mode was selected for the biopile, which provides for the introduction into the soil of the oxygen necessary for the survival of the bacteria through periodic turning with a shovel, which generally occurs once/week. In addition, it is considered to reuse the previously treated soil in the excavation itself to restore the area.
Alternative 2, on the other hand, involves the excavation and disposal of the soil in a landfill for non-hazardous waste. Also in this case, the setting up of soil storage bays necessary for their characterisation prior to their removal from the site is considered, while the restoration of the area will be carried out using virgin soil supplied from outside.

5.2.1 Method and Results

The table below shows the input data for the developed sustainability and circularity indicators (Table 10).

	Sustainability Indicators	U.M.	Alternative 1 BIOREMEDIATION	Alternative 2 DIG&DUMP
ENVIRONMENTAL INDICATORS	Mineral resource scarcity (LCA midpoint)	kg Cu eq	46.732,86	779.708,24
	Solid waste production	ton	0	130.275,25
	Global warming (LCA midpoint)	kg CO_2 eq	15.941.851,51	64.918.629,15
	Cumulative Energy Demand (LCA midpoint)	MJ	395.337.465,59	1.060.147.609
ECONOMIC INDICATORS	Expected duration of intervention	months/ha	78,00	8,00
	Construction costs physical capital used in the intervention	€/ha	2.250.987	6.239.462
	Intervention operating costs	€/ha	13.804	3.609.196
	Increase in land value following reclamation	adim	2	2
SOCIAL INDICATORS	Health impacts on workers and residents in communities adjacent to the remediated site	adim	3	3
	Equity across generations and populations	adim	3	1
	Negative externalities for residents and stakeholders	adim	2	4
	Human capital (i.e., investment in training, experimentation, research and development)	adim	4	1
	Circularity Indicators	**U.M.**	**Alternative 1 BIOREMEDIATION**	**Alternative 2 DIG&DUMP**
	(UNI 1) Self-produced secondary material resources reused in the process, compared with total used secondary material resources	adim	1	0
	(UNI 18a-18b) Disposed urban and/or special waste compared to total generated waste	adim	1	0
	(UNI 24a-24b) Urban and/or special waste treated at local valorization facilities compared to total treated waste	adim	1	0
	(UNI 32) Generated by-products compared to total generated production waste	adim	0,108	0,108

Table 10 - Sustainability and circularity indicators.

The exhaustive explanation of the input value assigned to each indicator is provided in Annex 2 of this Deliverable.

The framework proposed here follows a decision-making logic in which the comparison between project alternatives is based on identifying suitable sustainability objectives that the analyzed remediation interventions must achieve. These objectives are classified according to the three areas of sustainability (environmental, economic, and social), that are the economic viability of the interventions, their social sustainability and the reduction of their environmental footprint. The degree to which these objectives have been achieved is evaluated by measuring appropriate indicators, which are grouped according to the objective they relate to. For the purpose of evaluating sustainability, the indicators are valued, normalized, and then integrated to give a score for the different areas and, finally, an overall sustainability score for each remediation alternative.

For the purpose of evaluating circularity, the indicators are valued and integrated to give an overall circularity score. The sustainability and circularity indices are calculated by integrating all the relevant indicators using the Weighted Ordered Weighted Average (WOWA). WOWA is a parametric function that generalizes all aggregation functions between minimum and maximum. By configuring its weights, it is possible to obtain the minimum, maximum, average, median, and everything in between. WOWA includes two sets of weights: the first is for the parameterization of the aggregation function, and the second is useful for establishing priorities among the aggregated criteria. For the application to this case study, a default set of weights equal to 1 was used for each indicator.

Calculation of the sustainability index for each alternative

The sustainability results are as follows:

$LS_{ALT1} = 0{,}602$ (60%)

$LS_{ALT2} = 0{,}347$ (35%)

The alternative that scores highest is the first one, which involves using bioremediation technology through the application of an on-site biopile. In contrast, Alternative 2, related to D&D, is less sustainable (see Fig. 40).

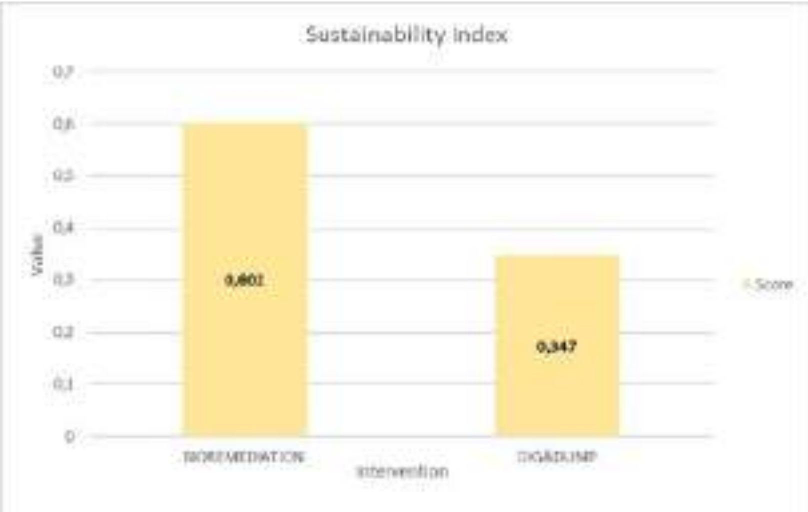


Figure 40 - Overall sustainability score achieved by the two alternatives; the one with the higher score corresponds to the most sustainable alternative

As shown in the following Fig. 41, alternative 1 is the most sustainable, both in terms of environmental sustainability and economic and social sustainability.

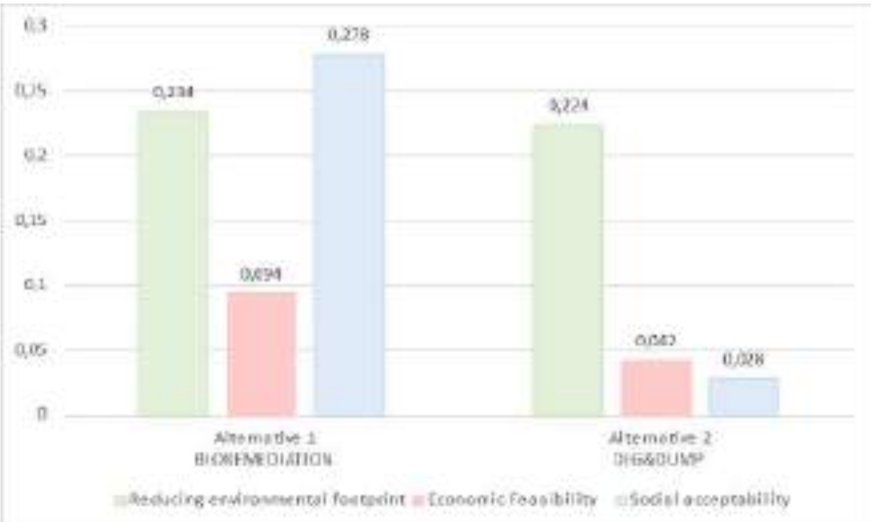


Figure 41 - Scores obtained for each objective

The chart shows that the biggest gap is in the social acceptability of the two alternatives. This is because, while the on-site biopile application involves decontaminating excavated soil on-site for reuse, Alternative 2 (D&D) results in both resource loss and the transfer of the environmental problem from the waste-generating site to a disposal site.
From an economic perspective, D&D also entails a higher cost for the remediation company, primarily due to the transportation and disposal of soil at an external landfill. However, the gap in economic sustainability is smaller because the on-site biopile alternative takes much longer to implement than D&D.
Finally, from an environmental perspective, the impacts are not very different. This is because the biopile approach involves a significant use of materials like water, nutrients, and bulking agents, which leads to a non-negligible environmental impact.
As seen in Table 11, the objectives evaluated in this process include reducing the consumption of mineral resources, minimizing the production of gaseous emissions, and reducing waste for environmental impact. For economic impact, the objective is cost-benefit optimization, and for the social sphere, it is equity, with effects on local communities and human capital.

Purposes	Objectives	Alternative 1 BIOREMEDIATION	Alternative 2 DIG&DUMP
Reducing environmental footprint	Reducing the consumption of natural resources	0,118	0,106
	Minimization of solid waste generation	0,167	0,164
	Reducing greenhouse gas emissions	0,048	0,038
	Reduction of impacts from energy consumption	0,036	0,029
Economic Feasibility	Reducing the duration of intervention	0,000	0,000
	Optimizing direct costs and benefits	0,354	0,183
Social acceptability	Human health and safety	0,125	0,125
	Equity	0,250	0,000
	Effects on local communities	0,188	0,065
	Employment and human capital	0,188	0,000

Table 11 - Objectives of the Evaluation Process

The following figure shows these results (Fig.42)

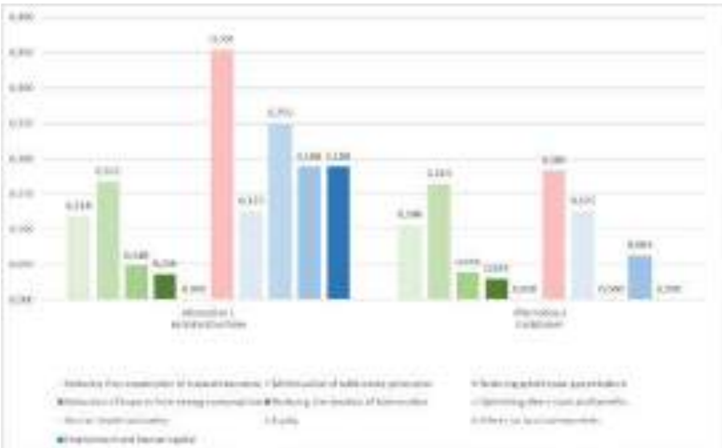


Figure 42 - Scores obtained for each objective.

The circularity results obtained by applying the tool described above are as follows:

LC_{ALT1}=0,527 (53 %)
LC_{ALT2}=0,369 (37%)
Based on the results, we can conclude that the most circular intervention scenario is Alternative 1, which involves treating the soil with bioremediation.
A bar chart visualization of the circularity results is provided below (Fig. 43).

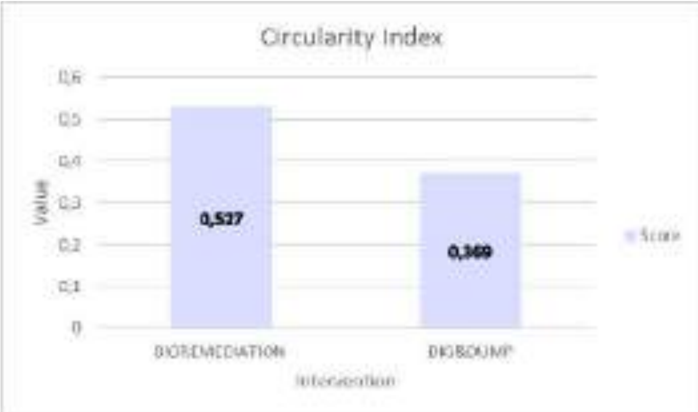


Figure 43 - Bar chart showing the results

The sustainability and circularity assessment framework applied to the two identified remediation alternatives identified a substantial difference that determines bioremediation as the more sustainable and more circular technology compared to Dig&Dump. The bioremediation technology is therefore more sustainable from an environmental, social and economic point of view, but also more cyclical, thus evaluating the Dig&Dump as an obsolete solution in order to minimizing waste production and valorizing available resources.

6 Proof of concept: developing principles for CUM regeneration approach to metabolic risk mitigation

Building upon the insights gained from co-testing activities within a real-world case study, the research activities culminated in the development of a Proof of Concept (PoC). This PoC aims to demonstrate the validity and transferability of a regenerative approach grounded in the principles of Circular Urban Metabolism (CUM), with particular focus on Urban Metabolic Risk (UMR) mitigation. This concept, explored in depth in part one of this deliverable, refers to a set of systemic vulnerabilities—environmental, social, infrastructural, and energetic—arising from imbalances or disruptions in the flows that structure urban life: matter, energy, information, and both social and cultural capital.
In this framework, risk is no longer understood merely as a sudden event or extraordinary emergency, but rather as the manifestation of a structural fragility that emerges and accumulates over time through metabolic dysfunctions. The city, conceived as a complex and living organism, reveals its criticalities where flows are interrupted, overloaded, or dispersed inefficiently. This may result in the breakdown of urban life cycles, the prolonged stagnation of specific areas, and the exclusion of territories and communities from broader development

processes. These conditions often produce liminal or suspended urban spaces—neither entirely abandoned nor fully reactivated—where urban metabolism remains stalled.
In contrast, the CUM approach envisions a regenerative model based on closed-loop systems, life cycle continuity, resource efficiency, and the integration of both the material and immaterial dimensions of urban transformation. It promotes a circular understanding of urban dynamics, aimed at restoring flow connectivity and enabling adaptive, sustainable regeneration.
The PoC thus serves as a first testing ground for the operational translation of these principles, through the formulation of recommendations intended to support public decision-makers, urban planners, and local stakeholders involved in the transformation of complex territories. The goal is not to generate a rigid or universally replicable model, but to outline a flexible and context-sensitive methodological framework, capable of interpreting the specificity of place and activating underused or latent resources through systemic regenerative strategies.
The selection of Bagnoli as a pilot area is anything but arbitrary. The convergence of severe environmental degradation (e.g., soil and groundwater contamination), the proximity to an active volcanic system, and a long, layered industrial legacy make this territory a complex yet paradigmatic urban laboratory. Here, risk is not only geological or sanitary, but also deeply social and symbolic: the repeated failures of past regeneration initiatives, the interruption of economic and productive cycles, and the long-term absence of functional urban roles have generated a discontinuous and fragmented metabolism. Bagnoli today exemplifies those urban areas where life cycles have been suspended, and entire parts of the city have remained excluded or stagnant for decades, awaiting coherent and transformative action. This PoC is therefore an attempt to recompose those fragments, reactivating flows and functions within a broader regenerative vision.

6.1 Spatial, process and governance circular design principles

This chapter presents an integrated multidimensional approach to the circular and sustainable regeneration of degraded decommissioned areas, with a particular focus on industrial brownfields and Sites of National Interest (SINs). The overarching goal is to foster sustainable site regeneration through a robust operational framework that supports public and private decision-makers in defining valorization strategies that are designed to be sustainable across environmental, economic, and social dimensions, with a strong focus on risk mitigation and adaptation.
The principles contribute to strengthening the understanding and awareness of environmental, natural, and anthropogenic risks as they interpret the complexity of these interactions in response to contemporary spatial, environmental, and socioeconomic challenges, aiming to define and implement intervention strategies aligned with European and global strategic agendas (SDGs, European Green Deal, Sendai Framework)
At the core of this approach lies the recognition of the multi-level and cross-sectoral nature of urban transformation processes, in which the environmental dimension cannot be separated from cultural, social, and economic factors. The principles indeed embody a holistic perspective, acknowledging that effective regeneration extends beyond the immediate site to

encompass its surrounding context, recognizing its broader impacts on the urban metabolism. In this frame, these recommendations contribute to mitigating Urban Metabolic Risk by not considering risk as a singular event, but rather as an integral part of complex urban processes and their multi-risk interdependencies.
The method of visioning trough scenario building is also emphasized, involving the anticipation of potential transformations to explore high level social, economic, and environmental benefits.
The prefigurative nature of scenario building lies in its capacity to imagine and structure multiple futures, thereby enhancing flexibility and adaptability in long-term transformation processes and envisioning different phases for the project implementation that can involve also temporary uses particularly for underused and inaccessible areas and brownfields. By anticipating different possible futures and embedding them within the project design, stakeholders can better navigate uncertainty, adjust their strategies over time, and build resilience into evolving systems.
As demonstrated in the co-creation workshops held during the project in the area of the test-case (see paragraph 5.1.1 of this deliverable and deliverable 5.5.2), this forward-looking approach supports decision-making under complexity by encouraging iterative reflection and scenario revision as conditions change (see fig. 44, 45, 46, 47)
.

Figure 44 - "Building community between the park and the city" Jane's Walk Scenarios. Source: B. Pastena

Figure 45 - “Accessible archeologies" Jane’s Walk Scenarios. Source: B. Pastena

Figure 46 - “The park that already exists" Jane’s Walk Scenarios. Source: B. Pastena, F. Vozzella

Figure 47 - "Rediscovering the sea" Jane's Walk Scenarios. Source: B. Pastena, F. Vozzella

The use of scenario helps to define the design principles as illustrated in table 12. The principles are structured to facilitate the definition of strategies adaptable to local contexts, particularly those grappling with complex multi-risk scenarios and undergoing metabolic transitions as post-industrial transformation. They promote an integrated approach focused on the circularity of both material and immaterial flows, life cycles, and on the valorization of territorial capital, fostering regenerative and resilient development visions/scenarios. In this perspective, regeneration is not understood merely as the physical recovery of contaminated or abandoned areas and soil, but as a cultural and design-driven process capable of generating new meanings, new centralities, and new forms of citizenship.

A distinctive element of these circular design principles is the integration between remediation strategies and land-use planning tools, ensuring consistency between regeneration actions and public policies. This includes the strategic selection of sustainable remediation technologies, such as Nature-Based Solutions (NBS), phytoremediation, bioremediation, tailored to the specific characteristics of the site and the valorization objectives.

To navigate complex analytical frameworks, the principles outline advanced territorial assessment tools, such as Geographic Information Systems (GIS) and Multi-Criteria Decision Analysis (MCDA), as a key element of a new grammar of regeneration. These tools are crucial for understanding and mapping Urban Metabolic Risk (UMR), identifying hotspots of vulnerability, and providing data-driven insights into demographic dynamics, socio-economic challenges (e.g., population change, density, unemployment), and environmental hazards. This spatial understanding is critical for tailoring remediation technologies and requirements to align with the overall regeneration process.

To ensure their effectiveness and widespread adoption, the principles are designed to be:

- Simple: Easy to navigate, offering a balance between being comprehensive and concise
- User-friendly: Easy to use, with practical information that can be used directly
- Practical: Content should be useful, accurate, and responding to the user's needs.
- Appealing: Graphics and visual aids should be attractive and contribute to explain the content.
- Inclusive: Consider different type of users and avoid jargon that might exclude non-experts.

The circular design principles are based on an iterative methodological process, structured to accompany the entire regeneration process of decommissioned sites. Specifically, this chapter is structured into distinct sections addressing spatial planning and governance, site assessment and site remediation as different aspects of regeneration.

PRINCIPLE 1 – COASTAL MANAGEMENT AND REGENERATION THROUGH NBS AND COMMUNITY GOVERNANCE

This priciple proposes an integrated approach to coastal management and regeneration, combining Nature-Based Solutions (NBS) with a shared governance model. The objective is twofold: on the one hand, to enhance the ecosystem services provided by beaches and dunes to prevent erosion and block storm surges. On the other hand, it aims to mitigate social risk by designating beaches as accessible and inclusive public spaces for the local community, ensuring free access to the sea. The approach therefore combines ecological with social regeneration, promoting management that is sustainable, participatory, and multi-risk

1

Beaches and dunes: Sandy beaches and dunes prevent coastal erosion caused by strong winds, waves, and tides. They can also block storm surges from reaching inland areas. The natural services provided by these Nature-Based Solutions (NBS) can be enhanced through artificial sand nourishment;

MAIN RISK
Climate

✓ Reduce
✓ Regenerate ✗ Reuse
✓ Recover
✗ Rethink

2

Beaches as public spaces: Designate beaches as public areas for the local community, ensuring free access to the sea;

MAIN RISK
Social

✗ Reduce
✓ Regenerate ✓ Reuse
✓ Recover
✗ Rethink

PRINCIPLE 2 – THE DIFFUSED PARK

This principle redefines the concept of an urban park, no longer as an isolated area, but as a network of green infrastructure that "infiltrates" the fabric of the city. The goal is to move beyond the idea of a "green patch" to create a multifunctional ecological system that integrates paths, shaded areas, and spaces for biodiversity. The actions it encompasses are aimed at ecologically and socially connecting the city, using parks and green spaces as tools for urban regeneration and mitigation of environmental and climate risks.

4

Parks and greenways: The benefits can be substantial: A study on green spaces in Beijing, China,

demonstrated that these areas stored 154 million cubic meters of rainwater, roughly equivalent to the annual water needs of the city's urban ecological landscape. They also absorb CO_2;

MAIN RISK
Climate

✓ Reduce
✓ Regenerate ✗ Reuse
✓ Recover
✗ Rethink

5

Increase in biodiversity: the aim is to increase the variety of plant and animal species within the urban environment. This strengthens local ecosystems, making them more resilient to environmental and climate stresses and contributing to the overall ecological quality of the area.

MAIN RISK
Climate

✗ Reduce
✓ Regenerate ✗ Reuse
✓ Recover
✓ Rethink

PRINCIPLE 3 – RESILIENT COMMUNITY SPACES: SOCIAL AND EMERGENCY HUBS.

This principle combines the creation of community spaces with their designation as safe havens for emergencies. The objective is to transform public areas into multifunctional centers of resilience. By promoting social cohesion in daily life and providing a familiar refuge in times of crisis, this approach mitigates social and psychological risks. These spaces serve as a vital resource for both community well-being and effective emergency management.

6

Creation of community spaces: This action involves establishing accessible and safe public spaces that are designed to foster social cohesion. By creating areas for recreation and community gathering, this action aims to mitigate social risks and strengthen the resilience of the local population, ensuring that residents have safe havens and a strong social support network.

MAIN RISK
Social

✗ Reduce
✓ Regenerate ✗ Reuse
✗ Recover
✓ Rethink

7

Availability of accessible and **safe public spaces for local communities in emergency situations.** Ensuring that public spaces are not only accessible but also safe havens for local communities during emergency situations. It involves planning and designating specific areas, such as squares, or other communal facilities, that can serve as assembly points or shelters during a crisis. The objective is to mitigate the volcanic risk by providing clear, safe, and readily available spaces for the population, thereby strengthening the community's overall resilience and preparedness.

MAIN RISK
Seismic

✗ Reduce
✓ Regenerate ✓ Reuse
✗ Recover

✓ Rethink

16 

Urban Living lab in multi-risk contexts is a dynamic physical and virtual environment for co-designing solutions with stakeholders, including public bodies, private entities, citizens, and other identified subjects. It frames risk not as isolated events but as integral to complex urban processes and multi-risk interdependencies.

MAIN RISK
Social

✓Reduce
✗Regenerate ✗Reuse
✗Recover
✓Rethink

PRINCIPLE 4 – ECOREMEDIATION AND RESILIENT LANDSCAPE

This principle combines phytoremediation with the creation of bioretention areas to jointly address environmental and hydraulic risks. Phytoremediation aims to treat water and soil pollution using natural processes. In parallel, bioretention areas, such as rain gardens and bioswales, are designed to effectively manage stormwater. The added value of this approach lies in integrating these solutions not only as protective tools but as elements of a new urban landscape. Strategically designed, these areas can transform derelict spaces into functional and aesthetically pleasing places, combining site remediation with urban regeneration and the improvement of landscape quality.

8 

Bioretention areas: Bioretention areas, including rain gardens and bioswales, are vegetated trenches designed to capture stormwater runoff at specific locations, helping to manage rainwater effectively.

MAIN RISK
Climate

✓ Reduce
✓ Regenerate ✗ Reuse
✗ Recover
✓ Rethink

9 

Phytoremediation: This action consists of treating water and soil pollution using natural processes. Phytoremediation leverages plants to absorb, stabilize, or degrade contaminants present in the environment. It is a "gentle" and ecological solution that aims to remediate the site, reducing the impact of environmental risks.

MAIN RISK
Environmental

✓Reduce
✓Regenerate ✓Reuse
✗Recover
✓Rethink

PRINCIPLE 5 – SMART AND RESILIENT NETWORKS: MOBILITY, ENERGY, AND GREEN INFRASTRUCTURE.

This principle proposes a holistic approach to mobility, combining sustainable and "slow" transport networks with innovative technologies and green infrastructure management. The objective is to transform roads into multifunctional systems that generate energy (SolaRoad), enhance climate resilience (tree protection), an improve escape routes for emergencies. Improving active and slow mobility networks helps to reduce car traffic, giving more space to people and at the same time reduce pollution. This approach ensures that vegetation along roads is not only a crucial resource but is also managed to mitigate its potential risk during extreme events.

10

Improvement of connections and escape routes: This action focuses on enhancing accessibility to and from the site by improving connections and creating clear, visible, and accessible pathways. The goal is to improve the territory's resilience by ensuring that, in the event of an emergency, the population has safe and efficient escape routes. This is particularly crucial in a multi-risk context, where effective mobility networks are vital for both disaster response and urban vitality.

MAIN RISK
Seismic

✓Reduce
✗Regenerate ✗Reuse
✗Recover
✓Rethink

11

Development of sustainable and slow mobility networks: Promote safe and environmentally friendly transportation options.

MAIN RISK
Social

✓Reduce
✓Regenerate ✗Reuse
✗Recover
✓Rethink

12

SolaRoad: An infrastructure project aimed at transforming public roads into a source of clean and renewable energy

MAIN RISK
Environmental

✓Reduce
✓Regenerate ✗Reuse
✗Recover
✓Rethink

13

Protection of trees and vegetation from extreme events

This action focuses on strengthening the resilience of urban green infrastructure, protecting trees and vegetation from extreme weather events. The goal is to reduce the impact of climate risks, ensuring that the city's ecological heritage remains a vital resource capable of providing essential ecosystem services, even under conditions of environmental stress.

MAIN RISK
Climate

✓Reduce
✓Regenerate ✗Reuse
✗Recover
✗Rethink

PRINCIPLE 6 – CIRCULAR USES: FROM URBAN METABOLISM TO SOCIAL ACTIVATION.

This principle proposes to rethink spaces undergoing transformation as opportunities for urban regeneration and social activation through circular and temporary solutions. The approach combines the "Rebrick" action, which promotes the automated recycling of demolition waste, with the creation of a "Traveling Museum".

The objective is to transform areas, typically inaccessible and inert, into places that host temporary cultural and creative activities. In this way, the use of recycled materials and the circular management of demolition waste are combined with social activation, offering the community a point of interest and gathering even during the long phases of transformation.

14 

Rebrick 'Market uptake of an automated technology for reusing old bricks': Project for the recycling of used bricks through the automated sorting of demolition waste, followed by separation and cleaning.

MAIN RISK
Environmental

✓Reduce
✓Regenerate ✗Reuse
✗Recover
✗Rethink

15 

Traveling museum: created using recycled and recyclable materials, specifically containers arranged in a checkerboard pattern stacked on top of each other

MAIN RISK
Environmental
Social

✓Reduce
✓Regenerate ✓Reuse
✓Recover
✓Rethink

16 

Temporary uses of existing infrastructure: Temporary use of abandoned structures plays a key role in building community. Those processes, by activating, also temporary, underused areas, foster social interaction, local participation, and collective ownership.

MAIN RISK
Environmental
Social

✓ Reduce
✓ Regenerate
✓Reuse
✓ Recover
✓ Rethink

PRINCIPLE 7 – INTEGRATED URBAN WATER MANAGEMENT: THE "SPONGE" APPROACH.

This principle is a strategic tool that combines risk management and urban regeneration by transforming spaces into multifunctional assets. It links the use of permeable pavements, Water Squares, and Rain Gardens, with the objective of creating a resilient urban fabric capable of absorbing, draining, and storing rainwater. The "sponge" approach leverages the capacity of soil and vegetation to mitigate hydraulic risk while simultaneously regenerating the environment, turning a problem into a resource and an opportunity for urban transformation.

17 

Rain Gardens: "Sponge Garden"
A public garden with vegetable plots, flowers, and compost, designed to test solutions for water absorption, drainage, and storage.

MAIN RISK
Environmental
Climate

✓Reduce
✓Regenerate ✗Reuse
✗Recover
✗Rethink

18 **Water squares:** Spaces designed to be publicly accessible, such as recreational areas intended for

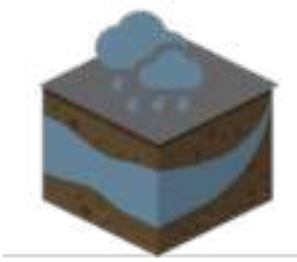
		families or sports activities, which, in the event of rain, become reservoirs for rainwater. MAIN RISK Climate ✓Reduce ✓Regenerate ✗Reuse ✗Recover ✗Rethink
19		**Permeable pavements**: Permeable pavements made of porous concrete, asphalt, or pavers allow rainwater to infiltrate where it falls, reducing stormwater runoff; MAIN RISK Climate ✓ Reduce ✗ Regenerate ✗ Reuse ✗ Recover ✓ Rethink

Table 11 – Circular design principles

6.1.1 Recommendations for the evaluation of biodiversity in contaminated/degraded area

For the case-study of Bagnoli, site specific evaluations were conducted to assess and document the existing ecological values (in terms of vegetation patterns and habitats) and the ecological pre-remediation baseline of the SIN area, evaluating the "unexpected" re-naturalization occurred in the industrial area, after a long period of abandonment. The presence of the existing wild vegetation and related habitats was quantified in terms of Biodiversity Units (BU) and assessed in terms of Ecosystem Services (ES); the adopted approach and methods could also be useful to support environmental management for other contaminated or degraded sites characterized by the presence of recolonizing vegetation and related habitats.

As general rules for site remediation and redevelopment, the following recommendations can be derived from the present study:

Ecological assessment: although not specifically required by the Italian Legislation related to contaminated sites, the evaluation of ecological values and related services can represent an important information for a full knowledge of the site and an informed decision-making. As example, colonization of spontaneous vegetation (also in case of ephemeral/ruderal/stress tolerant species or even invasive species) can introduce several ecological functions (e.g., supporting the pedogenesis process, enhancing soil stabilization, supporting contaminant sequestration and degradation, reducing erosion and increasing water retention and energy capture process, etc); a proper knowledge of this benefits could be useful to support the decision making process and strategies for site management. That is, existing vegetation/habitats should represent a resource and not a waste or an extemporaneous factor to be erased during the remediation activities. The assessment of the ecological features of the site may be supported by field survey and remote sensing analysis, with evaluation of biodiversity (also using pre-defined tools, e.g. with estimate of the BU) and related ecosystem services.

Risk assessment: the remediation community traditionally relies upon human health risk assessment (HHRA) to derive cleanup standards that are suitable for future use, while an evaluation of ecological values and ecological risks is not always required or admitted by legislation (as in the case of the Italian legislation). Moreover, despite the progress made in successful green alternatives in the remediation practice area, many regulators are still hesitant towards their application as current policies set remediation targets based on total contaminant removal or destruction, rather than risk reduction to acceptable levels. As a consequence, site remediation is often based on conservative target-based risk assessments, leading to over-designed, invasive, and unnecessary risk management solutions that entail large costs to society (Drenning et al. 2022). Under this context, a change in the approach to risk assessment and remediation strategies would be required and desirable to increase the sustainability of remediation and regeneration activities. In this context, information deriving from Ecological Risk Assessment (when useful and informative, depending by the case-study) can be useful to support different strategies for the management of sites with presence of ecological receptors and habitats of interest; specifically, this information could also be used to better explore alternative scenarios (e.g., green alternative) in the remediation and redevelopment of the area.
Decision making and site management strategies: proper management of contaminated or degraded sites should facilitate the creation of a self-repairing landscape, enhancing the delivery of functions and services necessary for ecologic and socioeconomic sustainability. Depending on the overall context, this may include also an enhancement and valorisation of existing ecological values; this approach should also be supported by the legislative framework. Ecosystems in degraded/contaminated areas encounter several challenges, such as pollution, habitat fragmentation, and invasive species, but they also present opportunities for innovation in ecological practices; in this sense, also citizen involvement is key factor to foster awareness and support for local ecology.

6.1.2 Sustainable and circular remediation principles

The vulnerability of the national context, characterized by areas potentially affected by risks to the environment and the population due to the widespread presence of contaminated sites, highlights the need to explore aspects related to the sustainable management of contaminated sites and the increasingly urgent need to apply less impactful methodologies and technologies that are attentive to aspects related to the circularity of the resources and sustainable costs (B.A.T.N.E.E.C. – Best Available Technology Not Entailing Excessive Costs).
Among the various soil remediation and safety technologies, one of the most common in Italy is still Dig&Dump (D&D), i.e. excavation and disposal (SuRF-ITaly&Reconnet, 2015), an approach that involves the generation of waste, its transport by vehicle and the use of raw materials (Dixon, 2006), which identify this method as the least sustainable from an environmental, economic and social point of view and completely inappropriate in terms of the principles of the circular economy. Similarly, many other existing remediation technologies also have an impact in these areas.
With reference to current European and non-European legislation, it has been highlighted that Italy is one of the few countries analyzed that is completely lacking in regulations and tools for a standardized assessment of the sustainability of remediation. This research also identified the

absence of specific studies on the integration of circular economy principles into the management of contaminated sites, which currently represents a significant gap in the scientific literature.
The research work led to the definition and testing of a useful framework as a decision-making support tool which, through the use of specific indicators, aims to guide design choices in favor of identifying the best solution that maximizes environmental, social and economic benefits through a decision-making process shared with stakeholders. This tool also identifies indicators related to the assessment of circular economy performance, which currently represent one of the major contributions to sustainable development policies.
On this basis, guidelines can be identified in which the framework and selected indicators can be used to define a clear, operational and comprehensive measurement process capable of objectively supporting the development of the strategic model of sustainability and circular remediation choices over time, even though Italian regulations currently do not reward the application of innovative technologies over dig&dump.
This research highlights the need for greater ex-ante dialogue between the administration managing the remediation procedures, the stakeholders involved and the designers appointed, in order to give greater consideration to more innovative and sustainable choices that comply with the Italian regulations.

6.2 Circular Remediation principles

In line with the principles of circular urban metabolism, and addressing the weaknesses of the current framework for implementing remediation in critical urban areas as described in Part 1 of this deliverable, Task 5.4.4. RETURN proposes a guidance tool for designing remediation and regeneration processes. The entire process is designed to minimize environmental impacts, maximize social benefits, and ensure the economic sustainability of interventions, thus providing an effective operational tool for the regeneration of complex and strategic areas.

- Key Economic Factors: What are the primary economic considerations—such as market demand, potential revenue streams, and local economic impacts—that can influence the feasibility of different options?
- Cost-Benefit Analysis: How can we preliminarily evaluate both direct and indirect costs and benefits to compare options effectively?
- Funding and Financial Resources: What funding mechanisms are available, and how do they shape the scope and potential of each regeneration approach?

These initial evaluations provide a strategic foundation, ensuring that subsequent, more detailed assessments are both focused and aligned with overarching project goals.

Figure 48 - Site valorization process.

VALORIZATION RANKING SYSTEM

A high-level, simplified scoring system has been developed to support both the navigation of this document and the evaluation process outlined in the guidelines.

Figure 49 - Ranking System example

This system introduces a structured scoring matrix at each stage, allowing for a concise recap of key considerations discussed within each section. By summarizing the performance of a specific site against the outlined criteria at every step, the scoring matrix offers a clear and consistent overview, helping users to easily assess and compare sites based on their alignment with each aspect of the evaluation process. At the end of each section, a Ranking Evaluation Indicator will be identified.

At the end of the document, all these elements are integrated within an evaluation matrix – the Valorization a ranking Matrix – which allows for the objective, transparent, and replicable comparison of alternative reuse scenarios. The indicators used are evaluated both qualitatively and quantitatively, enabling a comparative reading of the potentials and critical issues of each site.

Figure 50 - Ranking System example

PRINCIPLES DEFINITION

The process begins with principles' definition - broad and overarching ideas that act as the guiding compass for decision-making. These principles encapsulate the vision and objectives of the stakeholders involved in site regeneration, whether driven by a corporate mission in the case of private enterprises or a political agenda in the case of public bodies. By establishing clear principles, the transformation process can align with broader societal goals, specific business plans, or a political mandate. Principles must be deeply rooted in the social, environmental, and economic realities of the place and time. They should inspire and articulate a future-oriented path, addressing critical challenges like climate change, social inequalities, and economic resilience. By doing so, principles help shape places that are sustainable, inclusive, and equipped for the future. While existing guidelines offer a valuable starting point to frame these principles, tailoring them to the specific context of a site is essential.

Figure 51 - The three pillars of sustainability

With an in-depth preliminary analysis of the site, which includes the collection and systematization of environmental, historical, infrastructural, and regulatory information. Based on this, guiding principles are defined, representing the strategic orientation of the intervention and reflecting the environmental, economic, and social priorities of the reference context. The subsequent phase involves a multidimensional assessment of the site, articulated along three main axes: environmental, economic, and social. Environmental aspects include, among others, soil and groundwater quality, the presence of contaminants, biodiversity, and hydrogeological risk. The economic dimension considers parameters such as remediation costs, development potential, accessibility, and attractiveness for public and private investors. Finally, the social component analyzes the impact on the local community, employment opportunities, quality of life, and the level of social acceptability of the project.

REMEDIATION STRATEGIES

Developing an effective remediation strategy requires careful evaluation of several key aspects, including the specific contaminants present, the extent of pollution, and the site's intended future use.

In fact, starting from a clear and in-depth understanding of contamination levels, it is recommended that the most suitable technical and administrative remediation strategy be defined based on the site's intrinsic characteristics, the surrounding context and the potential future reuse scenarios in the context of the area's general urban regeneration.

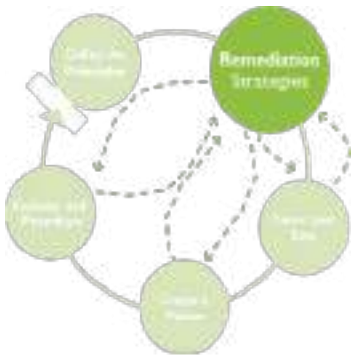


Figure 52 - Site valorization processes, remediation strategy

Guided by a clear vision of the site's redevelopment scenario, it will be possible to strategically direct remediation technologies: the use of less sustainable but highly rapid remediation technologies, such as dig & disposal, can be limited to areas requiring urgent restoration, while prioritizing more sustainable technologies such as Nature- Based Solutions (NBS), bio-remediation/phytoremediation/ phytocapping, or pathway interruption measures, if compatible with the reuse of other sections of the area.

A key point to take into account is also the presence of underground or above-ground infrastructures to be demolished, as the inability to carry out environmental investigations beneath their footprint poses the risk of underestimating the actual extent of contamination. Even the presence of buildings protected by the Heritage Authorities should not be underestimated, as it could constrain future redevelopment options for the site or, at the same time, an opportunity.

Various remediation options, such as excavation, bio- remediation, or in-situ treatment, must be assessed for feasibility, cost, and environmental impact. Comprehensive assessments - including soil and groundwater analysis, risk evaluations, and regulatory compliance reviews - are also essential to give the right information to the strategy owner. A thorough remediation approach not only mitigates risks but also lays the foundation for successful site transformation.

Site specific variables

As part of the decision-making process aimed at selecting the most suitable remediation technologies applicable to a contaminated site, not only is it essential to carry out an in-depth assessment/comparison of the different applicable technologies, remediation times and costs

associated, but also a strict and thorough analysis of the environmental administrative status of a site (e.g. characterization completed? Remediation plan already approved, etc.). The strategic view of the opportunities for the site redevelopment should be considered indispensable.
Have the opportunity to choose the most suitable technique between the possible remediation technologies cannot disregard an in-depth assessment and balancing of the different technical-strategic interests at play, and the analysis of the different general and, first and foremost, site-specific variables, such as:

- The status of the sites (abandoned or active)
- Possible redevelopment projects already defined for the site;
- The desirable environmental protection level to be achieved;
- The existence of reliable techniques to obtain and achieve such protection level over time;
- The environmental sustainability of the remediation techniques selected;
- The design, implementation, management, monitoring costs, etc. to be borne in the different intervention phases
- The opportunity to proceed with different remediation technologies in function of the redevelopment strategy (e.g. apply short term technology (dig&disposal) where is needed a quick reclaim of the sub-area vs. longer technologies (phytoremediation/ phytocapping, traditional capping) in other sub-areas).

It is important to underline that any remediation technology associated with the site-specific characteristics of the contamination and of the site subsoil can have a wide range of remediation times, from months to decades and, of course, different costs.
Environmental Investigations
Environmental investigations are aimed to deliver the key basis for the development of cost- and environmentally friendly strategies to remediate brownfields, to identify approaches to avoid and minimize dump materials and methods to save consumption of raw materials.
To better understand the environmental remediation process, it is therefore considered appropriate to investigate some knowledge elements relating to the soil - subsoil - aquifer system and its main characteristics.
The right definition and subsequent implementation of the remediation activities must be also preceded by an accurate characterization of the polluted site and the area subject to the effects of pollution.
Also is crucial to understand the conceptual model of how the contamination spread out and the contaminants characteristics and to perform an in-depth Risk Analysis.
Remediation technologies
To identify the most suitable type of intervention is mandatory to have a deep knowledge on the contaminated matrix treatment technologies available to be applied:

- On-site interventions: carried out without handling or removing the soil;
- On-site ex-situ interventions: with handling and removal of polluted material and soil, which are treated on site, and possible reuse of the soil treated;
- Off-site ex-situ interventions: with handling and removal of polluted material and soil off-site, by sending the material and soil to authorize treatment plants or to the landfill.

Among the different in-situ interventions there is also contamination containment, generally as MISE action, consisting in the implementation of operations aimed at limiting the pollutant's migration potential.
Remediation treatments can be classified based on the process or mechanism nature:

- Biological
- Chemical
- Physical

Aspects to consider
Among the factors related to the applicable remediation technologies, the following aspects should be taken into account:

- Technical feasibility, development level, limits and confidence level;
- Presence of adverse effects and accident risk;
- Treatment costs and remediation times;
- Level of environmental sustainability.

Often Screening Matrices were used to select the most suitable remediation techniques applicable to soil and underground water (e.g. The screening matrix created by ISPRA)
The matrix considers 25 in situ and ex situ technologies for soil remediation and 16 in situ and ex situ technologies for groundwater remediation. Variables used include timing, need for long-term monitoring, limitations and applicability and, where available, case studies.

Figure 53 - Remediation techology screening matrix. Source: ISPRA

SITE ASSESSMENT

The second step in the valorization process is centered on acquiring a holistic understanding of the site. This involves gathering, analysing, and integrating information across all aspects of the site to create a robust foundation for future decision-making.

Figure 54 - Site valorization process, site assessment

A wide range of sources will be utilized to ensure this step is thorough and accurate, including:

- Existing Datasets: Pre-collected data or records about the site, such as historical maps, land use records, or demographic statistics. These serve as a starting point to understand what is already known about the site.
- Applicable Norms and Regulations: Legal and regulatory frameworks that apply to the site, including zoning laws, environmental regulations, and cultural heritage protections.
- Desktop Assessments: Preliminary analyses conducted using tools like GIS software, satellite imagery, and online databases to gather insights without direct fieldwork.

Site Surveys: On-the-ground evaluations of the site to validate desktop assessments, collect additional data, and gain a deeper contextual understanding of its conditions.
The integration of data involves collecting and synthesizing information across multiple spheres to ensure a comprehensive understanding of the site's conditions, such as:

- General Information: These details serve as the foundation upon which all subsequent specialized evaluations are built, ensuring consistency and clarity throughout the appraisal process. The general information to be gathered includes:
- Name and any relevant reference code: The official designation of the site, along with any associated identification codes that may be relevant for administrative or technical purposes.
- Location: A precise description of the site's geographic placement, including address and coordinates where applicable.
- Administrative Context: Identification of the governing administrative bodies and jurisdictions, such as the local municipality, province, or region, which may influence regulatory compliance or redevelopment plans.
- Site Area: The total size of the site, typically measured in square meters or hectares, which provides critical context for planning and evaluation.
- Asset Typology: A classification of the site's historical or current use, such as refinery, warehouse, or power plant, to better understand its characteristics and potential challenges.

This guide applies to all types of sites; however, particular emphasis is placed on brownfield locations - decommissioned industrial sites - due to their pivotal role in redevelopment and valorization projects. Such sites, often presenting unique complexities and opportunities, demand a careful and informed approach to unlock their potential while addressing legacy issues associated with prior activities

Asset, Site and Context: A thorough assessment of a site should adopt a holistic perspective, considering not only the asset itself - the specific activity or facility that previously defined the site - but also the broader context in which the site exists. This approach recognizes that a site does not operate in isolation; rather, its condition, challenges, and potential are influenced by the characteristics of the immediate area and the larger environment in which it is embedded. In addition to analyzing the physical state of the asset and its infrastructure, an assessment must examine the surrounding area where the asset's activities were located. This includes understanding how past operations may have influenced the surrounding land, water, air quality, and ecosystems. For example, contamination from industrial processes may extend beyond the site boundary, affecting neighboring properties or natural features. Furthermore, the assessment should consider the broader environmental, social, and economic context. The extent of this evaluation depends on the specific site and the interconnections that are most relevant. Key factors might include nearby communities and their needs, regional infrastructure, zoning regulations, and natural features such as watercourses or habitats. The interplay between these elements can reveal critical constraints and opportunities, shaping redevelopment plans that are not only viable but also sustainable and beneficial to the wider area. By addressing both the site-specific and contextual aspects, a holistic assessment ensures that potential risks are identified and mitigated, while redevelopment strategies can be designed to integrate seamlessly with and enhance their surroundings.

- Site History: When beginning an assessment activity to inform a valorization strategy for a specific site, examining its history is critical. Several key aspects should be considered, starting with the type of operations, the timescale of these operations, and the current state of activity at the site. This historical and operational insight enables a tailored valorization strategy, ensuring that decisions are informed by the site's legacy, current state, and future potential.
- Site Inventory: A crucial first step in understanding a site is creating a comprehensive "site inventory." This process involves cataloguing the physical elements present on the site, such as buildings, plants, machinery, and other structures.
- Site Control: When defining a regeneration strategy for a site, it is essential to consider various factors related to the control of the site. Ownership, legal arrangements, and the dynamics of the surrounding area can significantly influence the feasibility and scope of the strategy.
- Site Hazards: Understanding the hazards associated with a site is a foundational step in evaluating its redevelopment potential. Hazards can arise from a variety of sources, including past uses, current conditions, or environmental factors, and their identification is crucial to ensure both safety and compliance with regulations.

By thoroughly assessing these risks, stakeholders can make informed decisions about the feasibility, scope, and limitations of redevelopment projects. This process not only protects future users and the surrounding community but also helps to mitigate financial and legal risks for developers, ensuring a smoother path to revitalization. This assessment is particularly significant when dealing with decommissioned industrial sites, which are often associated with a heightened likelihood of environmental and structural hazards. The legacy of industrial activities, including the storage and use of hazardous materials, improper waste disposal, or subsurface contamination, presents unique challenges. Understanding these site- specific conditions is essential to determine remediation needs, outline redevelopment possibilities, and identify constraints. Without a clear understanding of the hazards, redevelopment efforts may face unexpected costs, delays, or even failure, underscoring the importance of comprehensive site evaluation for any redevelopment effort.

ENVIRONMENTAL ASPECTS

Understanding the environmental aspects of a site is a pivotal step in assessing its development potential and crafting an effective valorization strategy. This chapter focuses on the process of gathering and analysing information about the site's environmental characteristics, which form the foundation for informed decision-making. The analysis is structured to encompass a comprehensive view of the site, considering various dimensions of its environmental context:

- Site-Specific Physical Conditions: These include inherent physical characteristics of the site that directly influence its viability and resilience, such as geologic risks, air quality, hydrology, and other.
- Environmental Systems: This dimension addresses broader ecological and landscape elements, such as biodiversity, ecosystems, and the integration of the site into its surrounding natural environment.
- Man-made Physical Elements: This category considers elements like heritage and infrastructure, that are physical in nature, and extend beyond environmental concerns to encompass economic and social implications.

The disciplines considered are illustrated in table 13.

- Geologic Risk	- Noise
- Seismic Risk	- Infrastructure
- Air Quality	- Landscape and Ecology
- Climate Change	Ecosystem services
- Flood Risk	- Heritage and Archaeology
- Natural protected areas	

Table 13 – discipline involved for environmental analysis

ECONOMIC ASPECTS

When exploring regeneration options for a site, assessing the economic implications is a critical first step. At this early stage, evaluations are high-level, designed to steer initial decision-making and guide the selection of viable options. As the process progresses, more detailed and comprehensive assessments will refine and validate these initial insights, ensuring a robust and well-informed approach. Key questions shaping this early-stage analysis include:

- Market Analysis: An economic assessment for site regeneration begins with a thorough analysis of the local market. The economic conditions of the area play a pivotal role in shaping the viability of different regeneration scenarios.

- Land Uses: Land uses are a key determinant of the types of activities that can be proposed for a site. A land use analysis begins by identifying the uses permitted by the site's regulatory framework and examining the land uses of surrounding areas. Together, these factors help clarify the scope and compatibility of potential regeneration activities.
- Land Values: Land values are a critical factor in the economic assessment of site regeneration, as they provide immediate insights into the site's current worth and its potential for future income. Evaluating land values helps shape decisions regarding remediation feasibility, regeneration strategies, and long- term economic planning.
- Funding: Access to financial resources is a critical factor in shaping early-stage decision-making for site regeneration. Ensuring that funding and investment strategies are aligned with project goals lays the foundation for successful implementation. Several key aspects should be considered when evaluating the financial resources available:
- Circular Economy: The principles of a circular economy prioritize minimizing waste, reusing resources, and designing processes that regenerate and sustain natural systems. Unlike the traditional linear economy model of "take, make, dispose," a circular economy emphasizes keeping materials in use for as long as possible, extracting maximum value before recovery and regeneration. This approach fosters sustainability while presenting significant opportunities for economic and environmental benefits, particularly in the context of site regeneration.
- Circular Economy as a Development Strategy Framework: Adopting circular economy principles can guide the development strategy for a site by fostering innovation and promoting efficient resource use.
- Jobs: The value of a regeneration project extends beyond economic returns and includes its impact on local job creation and retention.
- Remediation cost: Finally, an essential element in the evaluation of the economic aspects characteristic of a brownfield is the cost of site remediation activities. A frequently applied statistical approach for estimating the environmental costs of remediation at complex and multi-faceted sites, where different remediation technologies are applicable, is Monte Carlo Analysis.

SOCIAL ASPECTS

The social value of site valorization is a critical measure of success. By addressing the social dimensions of regeneration - from community engagement to health and well-being - site valorization can transform underutilized or deteriorating areas into vibrant, inclusive, and sustainable communities. Ensuring that regeneration efforts maximize social value not only benefits the people who live and work in the area but also contributes to broader goals of equity, resilience, and social justice. Through a comprehensive approach to planning and collaboration, the social value of regeneration can be harnessed to create lasting, positive change.

This chapter outlines the social factors that must be considered in these projects, provides strategies for maximizing the social value created, and a valuation matrix based on a system of indicators that helps measure different aspects of the "social value". A focus on social value ensures that regeneration efforts contribute to the well-being of communities, promote inclusion, and build long-term resilience, all of which are essential for achieving sustainable outcomes. Key social factors to consider in site valorization are:

- Community Engagement and Stakeholder Participation: At the heart of maximizing social value is the active engagement of local communities and key stakeholders. Meaningful participation is essential in the early stages of the valorization process to identify local needs, challenges, and aspirations. Through continuous collaboration, residents, businesses, and organizations can help shape redevelopment efforts in ways that reflect their values and contribute to lasting social benefits.
- Social Inclusion and Equity: Ensuring that regeneration benefits all members of the community, especially the most vulnerable groups, is a key pillar of social value. Inclusion involves designing interventions that offer equal access to housing, services, job opportunities, and public amenities. This approach also includes addressing potential risks such as displacement and gentrification to maintain socio-economic diversity and social harmony within the community.
- Cultural Heritage and Identity: A successful valorization project recognizes and integrates the cultural and historical significance of a site. By preserving or incorporating elements of cultural heritage, regeneration efforts foster a sense of pride and belonging among local populations. This not only strengthens the community's connection to the past but also enhances the unique identity of the site, creating a meaningful place for current and future generations.
- Access to Services, Amenities, and Infrastructure: Regeneration should improve access to essential services and infrastructure, such as healthcare, education, transportation, and recreational spaces. Social value is created when these improvements are designed with a focus on equity, ensuring that all residents—especially marginalized groups—benefit from better access to resources that enhance their quality of life.
- Economic Opportunity and Employment: A core element of maximizing social value is creating sustainable economic opportunities through site valorization. Regeneration efforts should prioritize local job creation, skills development, and support for local businesses. By ensuring that community members have access to meaningful employment and economic empowerment, the project can help reduce poverty, promote social mobility, and build a stronger local economy.
- Health, Well-being, and Resilience: Regeneration projects should enhance the overall health and well-being of the community by improving environmental quality, increasing green spaces, and promoting active lifestyles. Prioritizing mental and physical health within the design of public spaces and infrastructure fosters a resilient community, prepared to face both social and environmental challenges in the future.

PERMITTING ASPECTS

Permitting represents the set of activities aimed at obtaining all the necessary authorizations, however denominated (e.g. understandings, concessions, licenses, opinions, consents, etc.) pursuant to the relevant environmental and sectoral regulations.

The authorization process is carried out in very different ways depending on the characteristics of the site and of the surrounding environment and of the type of project and activities envisaged in the different valorization scenarios; it is therefore impossible to trace a possible permitting path in the absence of such detailed elements.
Despite the efforts made in recent years to speed up and streamline administrative procedures, permitting in Italy still represents a challenge that requires technical and legal expertise to correctly implement the complex legislation, both at state and local level, and its rapid evolution over time.
Without prejudice to the above, at a general level, two macro-categories of permitting can be identified:
Single authorization procedure: Procedural scheme focused on the final goal of the developer, in which the relevant permits are all those that the developer needs in order to implement his own initiative.
Separate authorization procedure: Procedural scheme based on individual authorizations and the sectoral competence of the administration responsible for issuing them): involves the activation of different sectoral authorization procedures often conducted by different competent authorities and not always being activated in parallel but through sequential steps.
Although the single authorization procedure represents a scheme that maximizes the efficiency of administrative action, with consequent advantages for the developer, complexity, resulting in a lengthening of permitting proceeding, regardless of being single or separate, represents the key factors that can significantly impact the fulfilment of the asset valorization objectives.
The legislation provides specific timeframes for the implementation of the various stages and for the conclusion of permitting proceedings, which may be peremptory or indicative (not mandatory).
Numerous provisions have been introduced in recent legislation to simplify and speed-up procedures, also driven by European requirements (e.g. Environmental Impact Assessment - EIA, energy production from renewable sources, implementation of the National Recovery and Resilience Plan – NRRP and Integrated National Energy and Climate Plan -INECP, etc.).
However, in practical experience, the timeframes, although peremptory, are not always respected by the competent administrations for a wide range of causes (e.g. lack of administrative resources, requests for additional documentation, suspension of proceedings, opposition from local communities, appeals, etc.) leading to substantial delays or, in some cases, decision inertia and consequently undermining planned investments and increasing the related burdens (time and costs) .
As the above-mentioned factors are not reasonably predictable, their impact on a specific development scenario cannot be estimated a priori.
It should be highlighted that, within the permitting process, the EIA procedure represents a crucial prodromic step that can significantly impact both the timing and, more generally, the success of the authorization process.
EIA applies to specific types of projects and modifications of existing works and is carried out at both State and Regional level which have different regulations (separate procedure at State level, single procedure at regional level) and consequently different timeframes.

It is therefore important to understand whether the EIA must be carried out and the competent authority.
Although simplifications and fast-tracks have been introduced for certain project types subject to state EIAs (e.g. NRRP and INECP projects) the single authorization procedure carried out at regional level, which includes the EIA, represents to date a more efficient procedural system.
The variables involved in permitting process can therefore, at general level and consistently with the purpose of the guidelines, be substantially attributed to the key factor indicated above (complexity), whose assessment requires a careful prior analysis based on the relevant regulatory sources to be applied to the different valorization options and related projects.
Moreover, the legislative analysis must consider the characteristics of the site and of the surrounding environment and the specific type of project to be developed for the implementation of the different valorization scenarios; for these reasons it can only be effectively carried out when these elements are sufficiently defined.
VISIONING
The act of coming up with a Vision, commonly known as “Visioning”, is an important, creative step to understand the potential of a site, which requires open interaction with different stakeholders.

Figura 55 - Site valorization process, visioning.

The process of visioning is a pivotal stage in the decision-making process for the valorization of a site. At its core, visioning entails defining a potential future scenario for the site - a forward-looking narrative that captures aspirations, goals, and opportunities.
This step is essential to bridge the gap between site analysis and the development of practical, actionable scenarios that will shape the subsequent stages of planning and evaluation.
Visioning involves synthesizing insights from the site analysis—such as its physical characteristics, market potential, and social or environmental context—and translating them into an inspirational yet tangible concept for the site's future. It allows abstract ideas and diverse aspirations to coalesce into a coherent framework that stakeholders can understand and rally

around. The vision serves as a guiding star, setting a clear direction for the project's development while remaining broad enough to allow for flexibility and refinement during later stages. It establishes a shared sense of purpose, ensuring that all decisions align with a cohesive overarching narrative.

Importance of Visioning in the Decision-Making Process:

Translating Analysis into Action: Visioning naturally follows the site analysis phase. Where analysis provides data and insights, visioning uses this foundation to articulate possibilities and establish pathways toward realizing a site's potential.

Engaging and Inspiring Stakeholders: A well- crafted vision expresses ideas in an engaging manner, inspiring stakeholders by showing the site's potential and demonstrating how their aspirations and goals can be met.

Facilitating Dialogue and Consensus: Visioning serves as a platform to discuss diverse agendas and goals. It brings potential conflicts to the surface early in the process, allowing for proactive identification of areas that require compromise or creative solutions.

Providing a Framework for Evaluation: By defining potential scenarios, the visioning process creates a framework within which options can be evaluated in terms of feasibility, desirability, and alignment with strategic goals.

Key Characteristics of Effective Visioning are:

Visionary and Inspirational: The vision should ignite imagination, presenting an ambitious yet achievable picture of what the site can become. It should inspire stakeholders and galvanize action.

Simple and Accessible: An effective vision is easy to describe and understand, ensuring it resonates with a wide audience, including technical experts, decision- makers, and community members.

Exploratory: Visioning should consider multiple options, including less practical or unconventional ideas. This openness encourages creative thinking and ensures that opportunities are not overlooked prematurely.

EVALUATION AND PRIORITIZATION

At the conclusion of the evaluation process, after reviewing the rankings assigned to each individual aspect and step, all the collected evaluations can be consolidated into a comprehensive summary list, referred to as the "Ranking Matrix."

This matrix serves as an overarching tool, bringing together the various scores to present a clear and cohesive overview of the site's overall value. By compiling the individual assessments into a single framework, the Ranking Matrix allows for an at-a-glance comparison of how a site performs across all evaluation criteria, supporting informed decision- making and facilitating a holistic understanding of the site's strengths and weaknesses **Remediation strategy tailoring** After defining potential scenarios, the remediation strategy must be evaluated again and refined for implementation. Tailoring the remediation technology to the specific scenario will help reduce both time and costs. In the preliminary phase, the site's environmental status— such as present pollutants and affected matrices has already been assessed, along with potential contamination exceeding regulatory limits for its current use. If a site is deemed potentially contaminated, the choice between remediation up to regulatory

limits or conducting a Risk Analysis will depend on the extent of contamination and the affected matrices.
Remediation up to regulatory limits may be suitable for cases of limited soil contamination, where excavation and disposal can be minimized to save time and avoid long-term site constraints. If a Risk Analysis is chosen, it will be conducted based on the characteristics of the identified scenario, considering factors such as intended land use, existing structures, site users, and implementation timelines.

Evaluation

In the testing phase, each option gets evaluated based on its environmental, social, and economic aspects. The evaluation helps to identify the critical aspects, as well as the key "selling points". As part of this initial evaluation, it is helpful to identify whether some of the critical aspects could be mitigated.
In this phase a relevant part of the evaluation is related to the status of the brownfield in terms of remediation options: the remediation activities have been completed, not needed or is still possible to propose/proceed with different remediation technologies in function of the redevelopment strategy and are envisaged short time of remediation and related medium to low costs? Or the remediation activities are already in place with a long time of remediation and high costs expected.
The permitting process must also be considered when evaluating the different options, as it represents a crucial fulfilment to be dealt with within an often-complex regulatory context at both central and local level.
One of the main factors in the competitiveness of production systems is in fact represented by administrative efficiency, the lack of which generates huge costs for enterprises and, more generally, for the community, entailing a series of negative consequences such as long and complex procedures for the acquisition of authorizations and for the start-up of activities, waste of resources, rising costs and competitiveness of production systems is in fact represented by administrative efficiency, the lack of which generates huge costs for enterprises and, more generally, for the community, entailing a series of negative consequences such as long and complex procedures for the acquisition of authorizations and for the start-up of activities, waste of resources, rising costs and competitiveness deficits
Where different visions have been defined for a site, it is useful to compare options to understand which one might offer the greater potential, and which one could be more critical to deliver. The comparison is not always easy, as different options might differ on aspects that are not directly comparable, and therefore requiring the definition of scoring systems where, for instance, different weights are applied to a series of indicators within an agreed matrix to allow for an objective comparison.
As a result, the testing process allows to identify the development scenario that offers the best gain in value for the site, that can be intended as the optimal ratio between the increase in value and the effort required. The testing process might also lead to identify new scenarios that combine the aspects that have proven to be particularly positive for a site and minimize the negative impact of aspects that have emerged as particularly critical.

Prioritization

Setting priorities is the last step in the process described by these guidelines and addresses the overarching questions of what should be prioritized to give value to a specific site. Defining what is a priority can be interpreted in different ways and can lead to a variety of considerations, in relation to the specificities of each site. Some of these prioritization scenarios will be explored on the following pages.

The process that is described by these guidelines can be seen as linear, intended as a sequence of steps one following the other, but more typically will lead to a variety of approaches where emerging new considerations might give the opportunity to review and reconsider initial steps, or where different steps can be addressed simultaneously, or in a different order.

More significantly, site evaluation and project setting are to be intended as iterative processes, where steps can be repeated to allow for increasingly detailed considerations to take place, to consider options or to include in the process aspects that might have emerged in due course.

One of the outcomes of the "initial round" of evaluations, is to identify aspects that might be particularly critical for a specific site, for which more detailed information might be needed, or that might have been overlooked in the first instance.

This is one of the iterative steps that are to be considered when using these guidelines, by revisiting the "Know your Site" step in the process, which might trigger a different type of evaluation and a different approach to the valorization of a specific site.

There might be instances where the outcome of the process allows to look at a site in a different light or suggests different ways of tackling its potential valorization. In such instances, it is worth considering whether a new vision for the site could be defined, to better respond to new considerations that might have emerged.

Guidelines intends to propose an innovative methodological contribution for the sustainable enhancement of abandoned sites. Although not yet applied to real cases, the document provides a solid and replicable operational framework capable of guiding public and private decision-makers in the definition. of intervention strategies consistent with the principles of environmental, economic, and social sustainability. Through the integration of over twenty key variables, the model constructs a multidimensional evaluation matrix (Valorization Ranking Matrix) that supports the comparison of alternative reuse scenarios. This approach allows project choices to be oriented according to the specific characteristics of the site, territorial priorities, and stakeholder expectations.

The remediation strategies, although still in theoretical definition, are designed to be adaptable to the context, with particular attention to technical feasibility, costs, and environmental impacts. The methodological process also encourages the construction of shared development visions, inspired by the Sustainable Development Goals (SDGs) and the European principle 'Do No Significant Harm' (DNSH), promoting resilient, circular, and inclusive solutions. In summary, the RETURN guidelines constitute a strategic tool for systematically and sustainably addressing the challenges related to the regeneration of contaminated sites, providing a useful framework for future operational applications.

6.3 Evaluation principles

6.3.1 Site evaluation guide: supporting tool in defining a strategic and operational approach for the redevelopment of decommissioned industrial assets

Principles for the Valorization of Sites aims to facilitate decision-making process and optimize the potential value of sites. These principles are universally applicable to all types of sites but place particular emphasis on brownfield regeneration, especially for decommissioned industrial areas, due to their strategic importance.

The principles will help defining and implementing a robust regeneration strategy, identifying potential future uses, and tailoring remediation technologies and requirements to align with the timescale and value of the overall regeneration process.

The overarching goal is to promote sustainable site regeneration, with a strong focus on addressing climate change and contributing to the UN Sustainability Goals. The approach is holistic, considering environmental, economic, and social dimensions of sustainability.

The principles draw from national and international best practices, existing frameworks, and exemplary case studies, providing aspirational support for decision-making. They adopt a broad definition of "site," encompassing the asset (e.g., existing structures), the legal area where it is located, and the surrounding context, recognizing that effective regeneration has broader impacts that must be considered.

This tool simplifies navigating complex regulatory and analytical frameworks, outlining critical factors for consideration and introducing assessments necessary to evaluate site conditions and development potential. The concept of "vision" is also emphasized, involving the anticipation of potential development scenarios to explore social, economic, and environmental benefits at a high level.

Different scenarios can be tested based on site conditions to identify the most valuable or least problematic options. This process enables prioritization, helping stakeholders select the most suitable actions and establish a regeneration strategy that can be applied to individual sites or larger portfolios.

6.3.2 Multicriteria GIS-based tools for CUM assessment

Urban metabolism is an approach that requires a vision of cities as a living organism. The flow of matter and energy in cities is a metabolic process very similar to the one that sustains our own life, except for one major difference: it is linear, whereas Mother Nature gave to all her living organisms with very sophisticated mechanisms that regulate our metabolism, which is based on cyclical processes.

Life is based on its relationship with its surroundings and the dense network of local and global resources it feeds on. The faster the metabolism, the higher the consumption, resulting in the loss of agricultural land, forests and biodiversity (often in faraway places) and the consequent increase in vehicle traffic and pollution.

A city (or city-region) is a complex system, made up of overlapping components (people, social systems, buildings, infrastructure, services, etc.) that interact with each other in multiple, non-linear relationships, leading to circular mechanisms of cause and effect, which is why cities exhibit a potentially circular nature. However, they are generally planned and managed in a

linear manner: the individual components are treated as individual compartments, without considering their interactions, but above all without considering that people are the main driver of the mechanisms that occur within and between them.
With the urban metabolism approach, components are instead reintroduced within a kind of 'urban superorganism' that can be analysed and redesigned in terms of innovation and sustainability.
Urban metabolism is a model that helps to describe and analyse flows within cities, through the metaphor of living organisms: such a systemic vision makes it possible to understand all the activities within a city in a single model, with the aim of improving its quality of life.
The urban metabolism framework is used in regional studies to enable the assessment of efficiency in the use of territorial resources, considering the "input" and "output" of materials, wastes and emissions in a specific territorial area. Moreover, the concept of "circular metabolism" introduces the need of reducing the waste of materials, energy, water, soil and other natural resources in the territorial area, promoting the re-generation of resources and the collaboration between diverse actors to "close the loops", using residual wastes and energy of diverse production and consumption processes for new cycles ("cradle-to-cradle") (Ellen MacArthur Foundation, 2015).
However, only environmental resources are currently considered in urban metabolism studies, while cultural resources, tangible and intangible, human and social capital, as well as financial capital are often neglected, reducing the assessment of cities and regions circularity to environmental concerns. While it is clear that the reduction of negative environmental impacts of human activity is key for sustainable regional development and to contribute to address climate change, the broader concept of sustainability is not limited to environmental aspects as it includes the social, economic and also cultural dimension, as well as the governance dimension in the territory.
Over the years, therefore, the theory of urban metabolism has evolved from an analysis of resource flows within the physical urban boundaries, towards the use of environmental and social indicators on a broader scale, to include the infrastructure serving a city located outside its perimeter. This approach can provide a useful key to understanding the complex relationships between cities in order to redesign them in a sustainable manner.
This study proposes a circular urban metabolism assessment framework which includes tangible and intangible resources, considering their interrelationships as integral part of the urban metabolism of cities and regions.
The results will provide decision-makers and stakeholders with better understanding of diverse flows of tangible and intangible resources, supporting more effective decisions towards sustainable, circular and resilient urban settlements.
Feiferytė-Skirienė and Stasiškienė (2021) propose the integration of the concept of urban metabolism and industrial symbiosis, assuming the perspective of the circular economy model in order to propose a model of Circular Urban Metabolism (CUM). The starting point is a literature review based on indicators deduced from European official documents and reports, strategic development plans of circular cities, papers and related to each of the three areas investigated (circular economy, urban metabolism and industrial symbiosis), at the end of which the authors state that physical flows, involving matter and energy, are most closely

examined by scientists because of the ease with which they can be monitored and evaluated by collecting local data (Paiho et al., 2020; Tanguy et al., 2020; Wang et al., 2020).

The Metabolism of Cities[11] project identifies three main steps to conduct an urban metabolism analysis: 1) Data collection, 2) Data processing, 3) Data analysis.

On the other hand, the approach of some European projects, such as REPAiR[12], UrBAN-WASTE[13], SmartCultour[14] and CityLoops[15], is different. They confirm the growing ferment and interest of the scientific world towards the definition and experimentation of data collection and management models, for the monitoring and evaluation of the urban metabolism to support the switch to a circular model. In particular, the UrBAN-WASTE project proposes an interesting approach for the evaluation of social flows, based on the research of Jørgensen et al. (2008). In this research, the LCA approach is used in terms of Social Life Cycle Assessment, thus reserving an evolutionary and dynamic dimension to the interpretation of social flows affecting the overall balance of urban ecosystems.

However, despite the fact that recent research is increasingly oriented towards considering cities as complex ecosystems (Bahers et al., 2020; Fusco Girard, 2020; Fusco Girard et al., 2014) , there is still little research that broadens the interpretation of the concept of flow beyond that exclusively related to matter and energy, also including the social dynamics that determine these flows (Bahers et al., 2020) and that in turn are conditioned by them (Bai, 2016) .

Feiferytė-Skirienė and Stasiškienė (2021) note that the concept of circular urban metabolism, interpreted according to this 'expanded' perspective, is scarcely analyzed in the literature (Céspedes Restrepo & Morales-Pinzón, 2018; Kennedy et al., 2007; Novotny, 2011; van Broekhoven & Vernay, 2018). Although it is evident that cities represent a dissipative system mainly because of the material and energy flows they consume and produce (Bai, 2016; Girardet, 2008), nevertheless, a complex analysis cannot fail to take into account the 'hidden flows' that elude economic or statistical readings but have a weight in terms of their impact on the urban ecosystem.

Bai, in his research, includes among the input capital and information (supporting social activities and urban functions) and among the output knowledge and services.

The research results of Iacovidou et al. (2017) showed that current waste resource recovery valuation strategies to improve ecology fail to express the level of value conservation of waste resources, highlighting the need to simultaneously consider the environmental, economic, social and technical components involved in a system.

Brandt et al. (2022) propose a review of indicators of circular cities as a basis for the proposal of "Smart urban metabolism", defined as "a hybrid approach to developing smart and sustainable cities that takes into account technological, economic, environmental, and social perspectives", thus able to "become a strategic tool for decision makers, urban managers, and planners". However, the same authors point out that the problem of a lack of integration of social and economic components in the assessment of urban metabolism is also present in the

[11] Please see: https://metabolismofcities.org/
[12] Please see: https://h2020repair.eu/
[13] Please see: http://www.urban-waste.eu/project/
[14] Please see: http://www.smartcultour.eu/
[15] Please see: https://cityloops.metabolismofcities.org/

many different definitions of circular economy, which mostly refer to the environmental dimension, does not include the economic and social components.
The lack of a systemic vision is also reflected in the predominance of research in which the analysis of metabolism focuses on the flows occurring within the urban perimeter (Agudelo-Vera et al., 2012; Lucertini & Musco, 2020), without considering that what happens in an urban ecosystem inevitably conditions (and is in turn conditioned by) the surrounding urban ecosystems (Ulgiati & Zucaro, 2019).
In short, talking about metabolism implies the adoption of a perspective that interprets circularity as a system of material and immaterial relationships (Fusco Girard, 2020), inspired by the autopoietic models of natural ecosystems (Bai, 2016; Fusco Girard, 2021), capable of maximizing co-benefits from recognizing the interconnection between different types of flow. In this perspective, achieving the objectives of self-sufficiency and reduction of consumption and waste (which characterize the circular economy model) requires rethinking urban activities, re-projecting social and urban infrastructure, reduction and recovery of resources (Lucertini & Musco, 2020). Clearly, climate change is impacting on the capacity of human communities to thrive on Earth, thus a huge effort is needed to reduce greenhouse gas emissions and pollution in all sectors, however a "just" transition should consider the achievement of wellbeing in a complex perspective which includes social and cultural needs.
Adopting a systemic vision already at the stage of data collection and, subsequently, data analysis, would allow not only to improve the status quo monitoring system, but also to strengthen the forecasting system for the elaboration of scenarios and development dynamics, enhancing the capacity to predict, adapt and respond to environmental changes.
Multi-risk contexts, where natural and anthropogenic risks intersect, exacerbate the vulnerabilities of urban systems. In this context, CUM represents a sustainable and systemic framework able to support the transition of cities from linear to circular dynamic in terms of resource management, waste reduction, resource efficiency, and system resilience (Kennedy et al., 2007; Ragazou et al., 2024). However, assessing the feasibility and implementation of CUM strategies requires robust analytical tools capable of manage and integrate multidimensional data and diverse stakeholder objectives. Geographic Information Systems (GIS), combined with Multi-Criteria Decision Analysis (MCDA), provide an innovative methodological approach to support these evaluations.
GIS is a powerful tool for spatial data integration, visualization, and analysis, enabling the assessment of urban systems at varying spatial and temporal scales (Malczewski & Rinner, 2015). When integrated with MCDA, GIS becomes a platform for evaluating multiple criteria, incorporating quantitative and qualitative inputs into decision-making frameworks. MCDA methods allow for the prioritization of different objectives, often competing with each other, such as economic efficiency, environmental sustainability, and social equity (Saaty, 1980; Hwang & Yoon, 1981).
In the context of CUM, GIS-MCDA can evaluate the spatial distribution of resources, waste flows, and environmental risks, providing actionable insights for urban planners. For instance, GIS can map the availability of renewable energy sources, while MCDA can rank potential interventions based on cost, feasibility, and environmental impact. This integration ensures that circular strategies are not only theoretically sound but also practically viable.

Multi-risk urban contexts require decision-making frameworks that account for the interdependencies between different hazards, such as floods, earthquakes, and industrial accidents. GIS-MCDA provides a mechanism to evaluate these risks in conjunction with circular strategies. For example, waste-to-energy plants may contribute to circularity but increase fire risks in certain areas. GIS can map these risks, while MCDA can balance their trade-offs.

Case studies in literature highlight the utility of GIS-MCDA in risk assessment. For instance, Kappes et al. (2012) used GIS to analyze multi-hazard risks in urban areas, while Malczewski (2006) demonstrated the use of MCDA for environmental planning. However, few studies explicitly link these tools to circular urban metabolism, indicating a gap in the literature.

The integration of GIS and MCDA in the context of CUM and multi-risk urban environments is underexplored. While GIS is widely used for spatial analysis, its application to circular resource management is an emerging field. Similarly, MCDA has been employed in urban planning but rarely in conjunction with GIS to address circularity. Existing studies, such as those by Mendez et al. (2020) and Petit-Boix et al. (2017), emphasize the potential of CUM but lack the methodological rigor provided by GIS-MCDA.

This study proposes an innovative approach by combining GIS-MCDA to evaluate circular strategies in multi-risk contexts. The novelty lies in its ability to integrate spatially explicit risk data with circularity metrics, enabling a holistic assessment of urban sustainability.

Incorporating GIS and MCDA into the evaluation of CUM strategies offers significant potential to enhance urban resilience in multi-risk environments. By addressing the spatial and multidimensional nature of urban challenges, this approach provides an evaluation framework for decision-making, ensuring that circular strategies are adaptive, inclusive, and risk-informed.

GIS-based Multi-Criteria Decision Analysis (MCDA) methods can be highly effective for evaluating Circular Urban Metabolism (CUM) across the three phases of assessment—ex-ante, in itinere, and ex-post—by integrating spatial data with various indicators related to the social, cultural, environmental, and economic dimensions. These methods allow for a systematic evaluation of different scenarios, taking into account the complexity of urban systems and the interconnectedness of various factors.

In the ex-ante phase, MCDA GIS-based methods are used to predict and evaluate potential future scenarios, focusing on assessing the possible impacts of proposed circular strategies (such as waste management, resource efficiency, or energy systems) on the urban metabolism. GIS tools allow for the creation of spatial models, which help visualize different regeneration or sustainability strategies and their effects on the environment and society.

In this phase, maps can be used to visualize the potential impacts of regeneration scenarios across different urban areas. They can represent areas of high vulnerability to environmental or social issues, helping stakeholders to make informed decisions on where to prioritize interventions. For example, maps can show the spatial distribution of resource flows (e.g., water, energy) or the location of cultural landmarks, providing clear insights into areas that may benefit the most from circular economy interventions.

During the *in itinere* phase, which corresponds to the monitoring and implementation stage, MCDA GIS methods allow for ongoing evaluation of the effectiveness of circular strategies as they are being implemented. Real-time data and updated indicators can be integrated into GIS platforms, enabling dynamic assessment and adjustment of strategies based on observed results.

In this phase, maps can be updated with real-time data to show the actual progress of interventions. For example, maps could display current recycling rates across different neighborhoods, or track improvements in public health and air quality. GIS-based tools also enable scenario testing, allowing stakeholders to visualize alternative strategies and their potential outcomes.

The ex-post phase evaluates the final outcomes and impacts of circular strategies after they have been implemented. In this phase, MCDA GIS methods assess the success of the interventions based on the established indicators, comparing the outcomes to initial goals.

Ex-post maps can show the final impact of interventions, for instance, changes in energy consumption or waste management improvements at the neighborhood level. These maps can compare pre- and post-intervention conditions, illustrating improvements in environmental quality, economic resilience, and social well-being. They also help visualize the success of circular economy projects in fostering a more sustainable and inclusive urban environment.

Throughout these three phases, the core set of indicators remains consistent but may vary slightly depending on the availability and ease of data collection. For example, in the ex-ante phase, predictive models might rely on estimates or proxy data, while in the in itinere phase, real-time data from sensors or monitoring systems could be used for more accurate evaluation. By utilizing GIS tools, data from different sources can be integrated, allowing for flexible approaches to indicator selection, ensuring that the evaluation process can adapt to changing circumstances and available data.

MCDA GIS-based methods offer a powerful framework for assessing circular urban metabolism across all phases of evaluation. By using spatial tools, stakeholders can visualize the impacts of circular strategies on the urban environment, economy, and society. The integration of maps and spatial data is essential not only for assessing the current state of the urban metabolism but also for planning future regeneration scenarios and evaluating their success over time. This approach ensures that urban planning is informed, transparent, and responsive to the needs of the community and the environment.

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8 List of figures

9 List of tables

10 Authors Contribution

Research Glossary
Libera Amenta, Federica Vingelli (eds.)

1. "Brownfield" *Benedetta Pastena*
2. "Circular city" *Bruna Vendemmia*
3. "Circular Economy (CE)" *Libera Amenta, Bruna Vendemmia*
4. "Critical urban context" *Benedetta Pastena*
5. "Circular Urban Metabolism (CUM)" *Libera Amenta*
6. "Co-design" (cfr. DV 5.5.2) *Benedetta Pastena*
7. "Environmental Justice (EJ)" *Federica Vingelli*
8. "Hazard" *Federica Vingelli*
9. "Health and Environmental Risk Analysis" *Giulia Meneghin*
10. "Multi-Risk" *Bruna Vendemmia*
11. "Orphan sites" *Giulia Meneghin*
12. "Remediation" *Giulia Meneghin*
13. "Resilience" *(Glossario RETURN)*
14. "Territorial Metabolism" *Bruna Vendemmia*
15. "Urban and Territorial Risk" *Sara Piccirillo*
16. "Urban Metabolic Risk" *Michelangelo Russo*
17. "Urban Metabolism (UM)" *Libera Amenta*
18. "Urban Political Ecology (UPE)" *Bruna Vendemmia*
19. "Urban Regeneration" *Federica Vingelli*
20. "Wastescape" *Libera Amenta*

1.Introduction. Definition, objectives and structure of Task 5.4.4
Authors: Libera Amenta, Michelangelo Russo, Bruna Vendemmia

2.1. Circular Urban Metabolism. The challenge of applying Circular Economy and Urban Metabolism principles toward circular cities
Authors: Libera Amenta, Benedetta Pastena, Sara Piccirillo, Bruna Vendemmia
2.2. The impact of Urban Political Ecology and Environmental Justice in defining CUM approach in multi-risk contexts
Authors: Libera Amenta, Bruna Vendemmia, Federica Vingelli.
2.3 The emergence of Urban Metabolic Risk
Authors: Sara Piccirillo, Benedetta Pastena, Federica Vingelli.

2.3.1 The Unexplored Concept of "Urban Metabolic Risk"
Authors: Sara Piccirillo, Benedetta Pastena, Federica Vingelli.
2.3.2 Identified limitations
Authors: Sara Piccirillo, Benedetta Pastena, Federica Vingelli.

2.4 Urban Metabolic Risk, a definition
Authors: Libera Amenta, Michelangelo Russo, Bruna Vendemmia, Federica Vingelli
2.5 Circular city Evaluation Framework: Metabolic Risk indicators
Authors: Libera Amenta, Anna Attademo, Martina Bosone

2.5.1 Resilience potential in wastescapes
Authors: Libera Amenta, Anna Attademo, Martina Bosone

2.6 The risk associated with contaminated sites and criteria for circular and sustainable remediation
Authors: Petra Scanferla, Giulia Meneghin, Giorgia Di Carlo, Antonio Sellitri

2.6.1 Criteria and standard for circular remediation and sustainable requalification
Authors: Petra Scanferla, Giulia Meneghin, Giorgia Di Carlo, Antonio Sellitri

Annex