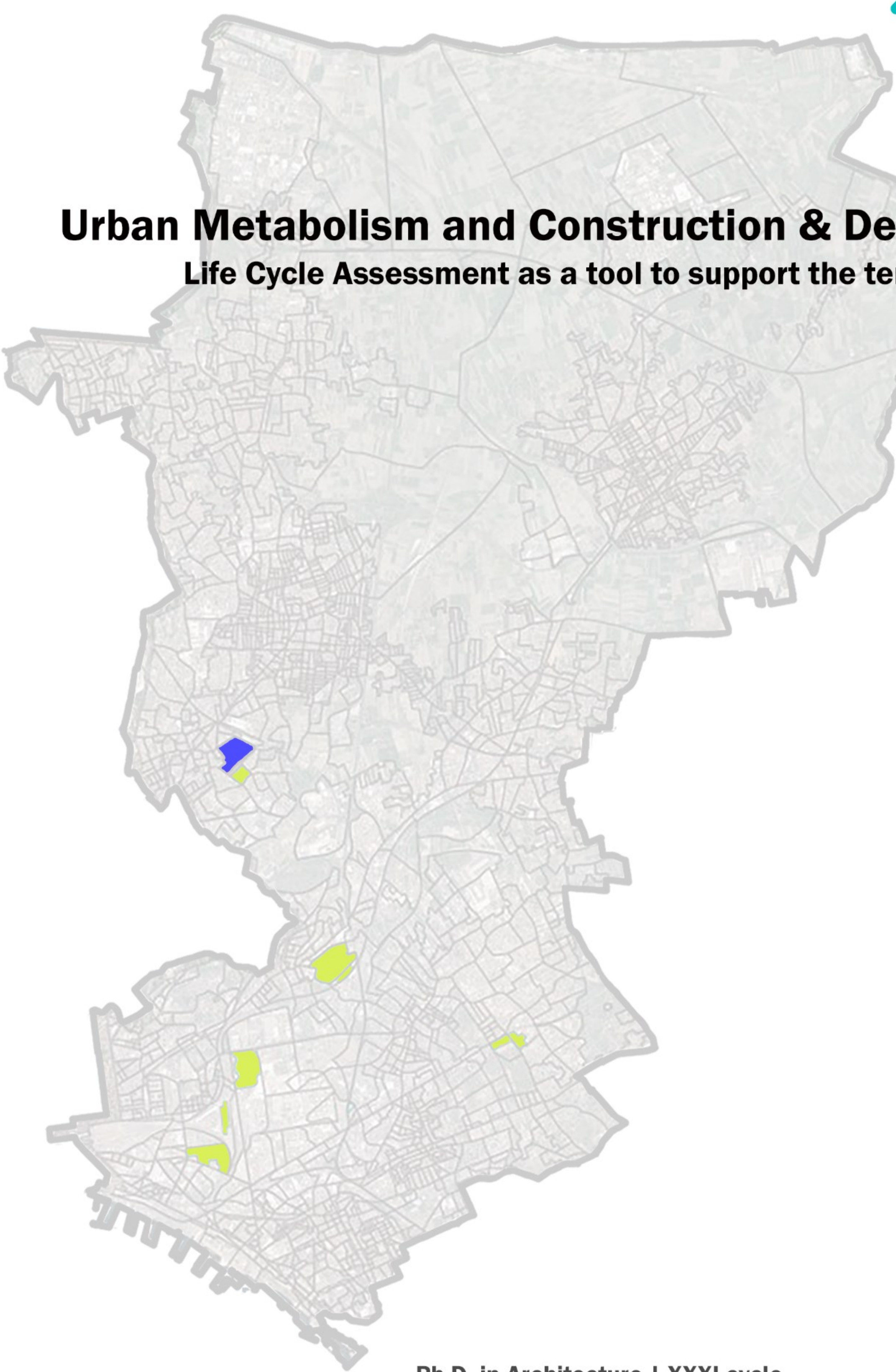
Urban Metabolism and Construction & Demolition Waste

Life Cycle Assessment as a tool to support the territorial regeneration

Silvia Iodice



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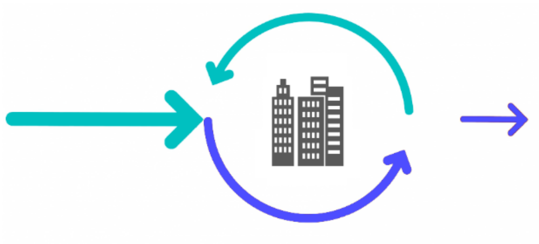

Urban Metabolism and Construction & Demolition Waste

Life Cycle Assessment as a tool to support the territorial regeneration

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I read
I travel
I become

D. Walcott

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Acronyms and Abbreviations

CAM: Criteri Ambientali Minimi
CDW: Construction and Demolition Waste
CLC: Corine Land Cover
CE: Circular Economy
CVM: Contingent Valuation Method
DSS: Decision Support System
EF: Ecological Footprint
EIS: Eco-Innovative Solutions
EMS: Environmental Management Systems
ENA: Ecological Network Analysis
EWC: End of Waste Criteria
FA: Focus Area
GDSE: Geodesign Decision Support Environment
GIS: Geographic Information System
GPP: Green Public Procurement
HPM: Hedonic Price Method
IA: Integrated Assessment
LCA: Life Cycle Assessment
LCC: Life Cycle Costing
LL: Living Lab
MAN: Metropolitan Area of Naples
MCDA: Multi-Criteria Decision Analysis
MFA: Material Flow Analysis
MPS: Materia Prima Seconda
MUD: Modello Unico di Dichiarazione ambientale
OW: Organic Waste
PCA: Principal Component Analysis
PULL: Peri-Urban Living Lab
RA: Recycled Aggregates
SDSS: Spatial Decision Support System
SEA: Strategic Environmental Assessment
SW: Special Waste
UM: Urban Metabolism
WM: Waste Management
WTP: Willingness To Pay

Premise

The main prerogative of the present work is the awareness of the unlimited growth that has produced negative effects on urban ecosystems, in the form of resulting urban spaces, abandoned areas, landscapes of waste, favouring as well the concealing of waste or its stocking in open spaces. It is necessary to add also the difficulty of managing a cycle of production-consumption increasingly linked to the unsustainable generation of waste, causing intensified risks that weaken the relations between natural and built features.

The present research thesis is divided into several phases contained in the general and unitary objective of providing support to environmental assessment linked to spatial and territorial planning.

The first part, which corresponds to the first year of Ph.D., investigates from a literary point of view the general field of research, or rather the field of application of the proposed experimentations. This is represented by urban ecosystems understood as socio-ecological systems.

A deepening is then linked to the concept of ecosystem health and to the possibility of applying it to urban ecosystems as a tool for assessing their environmental, economic and social functioning.

Describing urban ecosystems as living organisms, the concept of Urban Metabolism is introduced as well as that of life cycle of the territory. These issues are deepened in the second chapter together with the assessment tools that are generally used for this purpose, with an in-depth analysis of the Life Cycle Assessment tool and on the possibilities of applying this instrument at the territorial level.

The third chapter consists in presenting the Horizon 2020 project "REPAiR - Resource Management in Peri-Urban Areas: Going Beyond Urban Metabolism" to which this thesis relates in its experimental component, introducing the case study as well. The latter is made up of the Focus Area selected within the REPAiR project, which is investigated in the general framework of the Metropolitan Area of Naples, through a first experimentation that consists in assessing the degree of ecosystem health of the territory under study.

The fourth chapter regards the experimental core of the thesis, developed during an internship abroad at the Joint Research Centre of the European Commission located in Seville. This methodological part traces the lines for the construction of a baseline scenario for the application of Life Cycle Assessment and Life Cycle Costing in relation to the Construction and Demolition Waste flow that crosses both Campania Region and the Focus Area.

The fifth chapter instead, examining more in depth the concept of territorial Life Cycle Assessment investigated in the second chapter, proposes a further application to the scale of a disused industrial building that form some portions of wasted landscapes investigated in REPAiR.

The sixth and final chapter traces the conclusions of the experimental and theoretical path addressed and presents the main learnings that it is possible to deduce from the carried out applications.

The concept of continuous and unlimited growth has produced negative effects on the city, which materialize themselves in the production of resulting urban spaces, abandoned areas, landscapes of waste, together with the difficulty of managing a cycle of production-consumption increasingly linked to the unsustainable generation of waste. A condition of always greater widespread and intensified risks that weaken the relations between cities, living spaces and the environment (Russo, 2018)

Abstract

The present research thesis aims to lay the foundations for the development of a model capable of supporting environmental assessment linked to the regeneration of the territory, through the union of two components: Life Cycle Assessment (LCA) and wasted landscapes.

After a first definition of the field of research investigated, which has as its object urban ecosystems in relation to the metabolic flows that cross them, the instrument of LCA is introduced.

LCA is born in the industrial field as a tool for assessing the environmental impacts related to the life cycle of products and services and can also focus on individual phases of this cycle, such as that of Waste Management (WM). This tool is linked to individual products, but in recent times, some research topics have investigated the possibility of extending it to one or more activities that characterize the functioning of the territory, in order to give life to a LCA of territorial nature.

A first analysis of the territory is conducted through the concept of ecosystem health, that is translated from the ecological to the urban field in order to qualify the urban health from an economic, environmental and social perspective. Through a combination between Multi-Criteria Decision Analysis (MCDA) and Geographic Information System (GIS), the territory can be classified according to its level of urban health. Three different perspectives have been considered: “vigour”, “organisation” and “resilience” and according to this framework, a system of indicators has been developed, identifying their territorial distribution. The application provides a subdivision of the Metropolitan Area of Naples (MAN) and the Focus Area (FA) contained in it in different zones with various degrees of resistance to risks and vulnerabilities.

The main experimental application of the present research is the use of the LCA tool to evaluate the impacts related to the management of Construction and Demolition Waste (CDW) flow, integrated by a Life Cycle Costing (LCC) model.

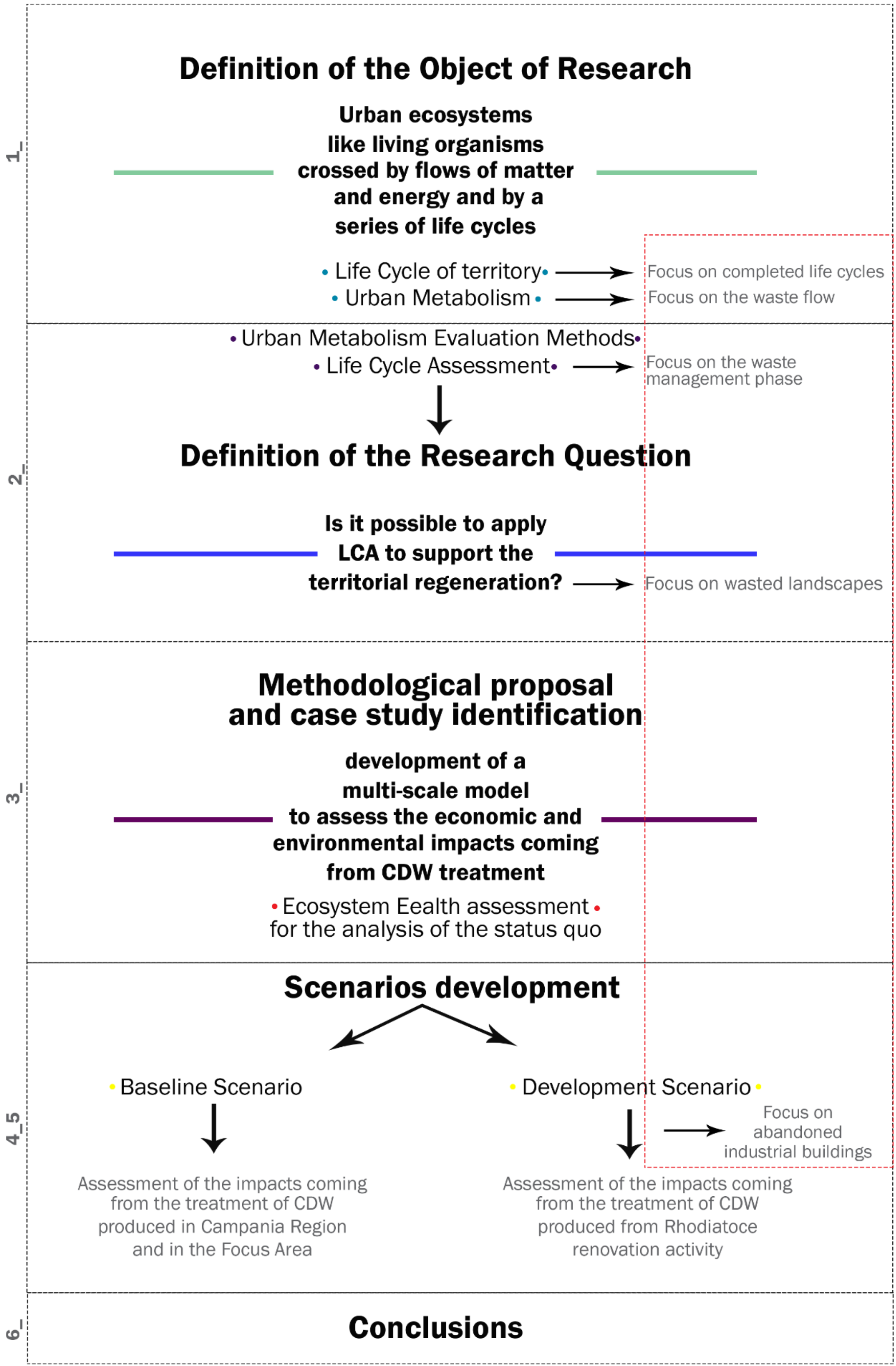
CDW crosses both Campania Region and the Focus Area (FA) selected within the Horizon 2020 project called “REPAiR - Resource Management in Peri-Urban Areas: Going Beyond Urban Metabolism”, to which this thesis is linked.

Subsequently, it is introduced a second vision of territorial nature that concerns the territorial outcomes of Urban Metabolism (UM) linked to urban and peri-urban life cycles, which, by exhausting the available resources, generate not only waste, but also wasted landscapes (*wastescapes*).

Wasted landscapes can be, as it will be seen in the following chapters, of various kinds and the attention is focused on the portion of territory characterized by the presence of abandoned industrial buildings.

By identifying the abandoned buildings of the FA, a second experimental application examines the case study of the former Rhodiatoce factory, for which, through a calculation model, CDW deriving from a building renewal process is assumed. The same LCA model that was used to assess the impacts of the total flows produced in the Region and in the FA, is used to verify the environmental impacts related to this scenario at the construction scale.
This approach represents an exemplification that could be repeated in relation to all the other abandoned industrial buildings, in order to assess the environmental and economic impacts linked to their regeneration.
Definitely, the idea is to present a new utility attributable to LCA and to lay the foundations for the creation of an evaluation model which allows to make the decision making phase linked to the regeneration of wasted territories more aware.

Graphical abstract



CHAPTER ONE

Object of Research

1.1 Urban ecosystems and territory: main definitions

1.1.1 Premise: adoption of the “ecology of cities” approach

The object of the present research is based on urban and peri-urban areas and more precisely on ecosystems formed by the hybrid combination of both natural and manufactured components, i.e. systems formed by the combination of people and nature, where biophysical and social factors regularly interact in a resilient and sustained manner and where different spatial, temporal and organisational scales exist (Redman et al., 2004).
The co-evolution of human and natural systems results in the interpretation of cities like hybrid ecosystems, that are unstable and unpredictable, but also capable of innovating (Alberti, 2015). A city, if treated as an ecosystem, can be better evaluated (Collins et al., 2000) and this represents the main prerogative of the present research thesis.
Urban ecosystems (meant also as socio-ecological systems) face many challenges due to fast and huge urbanization phenomena, leading to dramatic environmental changes at different scales: from local to global (Buhaug and Urdal, 2013; Pataki et al., 2006) and as any form of ecosystem, also an urban ecosystem is dynamic and changing (Chen et al., 2014).
Therefore, it is proposed to move from the “ecology in cities” approach to the “ecology of cities” one. The first approach links ecological approaches in urban areas (Grimm et al., 2000; Sukopp, 2008), while the second incorporates the first and expands the concept considering the city itself as an ecosystem (McPhearson et al., 2016). This approach explicitly assumes humans as drivers of and responders to the dynamics that characterize urban ecosystems along with plants and animals and in general non-human species and other system components (Cadenasso et al., 2006; Grimm et al., 2000; Niemelä, 2011; Pickett et al., 2001).
From this perspective, natural habitats and anthropic environment do not constitute anymore two separate realities, and the culture of natural heritage protection and compatibility of settlement models with the environment and nature projects itself in a different “ecosystem-based” vision (Torricelli, 2015b).

1.1.2 What is an urban ecosystem?

An ecosystem in general «is defined as an area, place or environment where organisms interact with the physical and chemical environment» (Chatzinikolaou et al., 2018, p. 43).
As far as the urban ecosystem is concerned, there is a variety of definitions of this concept. For example Tansley (1935) defines it as a combination of physical factors forming what we call the "environment", while Pickett et al. (2011) provide a definition of urban ecosystems as those areas where people live at high densities and where much of the land surface is covered by built structures and infrastructures.

What primarily characterizes ecosystems is the search for consistency and coordination between the components. In this perspective, cities meant as ecosystems are assimilated to living organisms characterized by a high level of complexity and in continuous transformation, produced by the union of cultural and natural events and composed of places endowed with identity, history, character and long-term structures (Magnaghi, 2010). Furthermore, a spatial unit organized within a hierarchy of spatial scales composes them (Brown, 2017). Definitely, urban ecosystems are:

«dynamic, three-dimensional combinations of natural, social and built features, and their functions, associated with an urban area» (Brown, 2017, p.10).

It can be added that urban ecosystems are mostly influenced by human processes, but not totally dependent on them (Hobbs et al., 2006) and that they are the result of human and ecological processes occurring simultaneously in time and space (Alberti, 2008).
Threlfall and Kendal (2018, p. 248) express the concept according to which «urban ecosystems contain a myriad of natural, constructed and hybrid spaces, where the combination of each is unique in every city and town». Similar concepts are again underlined by Dover (2018), expressing the interaction of biotic and abiotic components and their being modified by anthropogenic activities. Likewise, the interaction of the human-social system (comprising culture, behaviour and economics) and built elements with other ecosystem processes like energy flows, informative flows and material cycling define an urban ecosystem.

Seen as a concentration of people and human activities, urban ecosystems are also energy-intensive, determining their being more unbalanced than most others and of heterotrophic nature, because of their strong dependence on external sources of energy (Collins et al., 2000). Consequently, they are energy-intensive and characterized by extensive human activities (Odum and Odum 1980; Pickett et al., 1997). They are also dynamic and complex and the greater vulnerability to climate change that interacts with the existing urban problems and at the same time determines new perturbations is concentrated in urban ecosystems (Sharifi and Yamagata, 2014).

Anyway, urban ecosystems are also part of the wider territory, meant as a complex and open system that interacts with other territories, with the ecosphere and biosphere and that is transformed, used and managed by a system of actors who relate to each other in socially organized forms.

Moine (2006) considers the territory as a complex and evolving system in which a group of stakeholders is associated to a geographical space. The territory can be considered as an open system, in relation with other territories, but also with the natural and anthropic environment and therefore as a complex, open, adaptive, active system (Torricelli, 2015_a).

In general, in this context, the definition of territory is still widely debated (Nitschelm et al., 2016), however, the existence of three main connotations is now accepted (Etienne, 2014):

– the geographical space;
– the existence of decision-making processes linked to local stakeholders;
– a regional identity.

Loiseau et al. (2018) propose the identification of three main territorial dimensions:

– a material dimension defined by the physical components;
– an organisational dimension due to the presence of social and institutional actors;
– an identity dimension difened by the way social and institutional stakeholders interact with the territorial system.

These complex systems are crossed by economic, ecological and social flows whose quality and quantity is strongly influenced by human activities (Rotmans et al., 2000).

Another important distinction has to be made between urban and peri-urban areas or better between urban and peri-urban ecosystems; the latter are portion of territory in transition, characterized by a juxtaposition of activities and by the possibility of alterations and modifications of their features, induced by human activities (Douglas, 2012). Urbanized areas, as well as open spaces, agricultural lands and high density residential areas mixed with a discontinuous countryside form peri-urban ecosystems (REPAiR, 2015). The peri-urban component is the result of a critical crossing between infrastructural, ecological and environmental networks, but also a largely inhabited city, often a place of urban and social marginality (Russo, 2018).

Furthermore, «like other ecosystems, cities are not the sum of their constituents; they are key examples of emergent phenomena, in which each component contributes to but does not control the form and behaviour of the whole. Traffic congestion, air pollution, and urban sprawl emerge from local-scale interactions among variables such as topography, transportation infrastructure, individual mobility patterns, real estate markets, and social preferences» (Alberti et al., 2008, p.1169).
The main difference between this form of ecosystems and the other kinds is the prevalence of the human component. The evolution of urban and peri-urban ecosystems is due to a huge number of interactions between individuals, but also human agents as well as biophysical agents, thus determining different patterns of development, together with land conversion, use of resources and generation of emissions and waste (Alberti et al., 2003).
According to Machlis et al., (1997), what distinguishes these ecosystems is the presence of a spatio-temporal heterogeneity, characterized by a mosaic of biological and physical patches immersed in a matrix formed by infrastructures, human organizations and social institutions able to affect land cover, but also microclimates and air quality.
Cities as ecosystems are also nodes of consumption of energy and material as well as production of residuals (Rees and Wackernagel, 1994). The complicated interaction between artificial and natural ecological systems determines the formation of a complex structure, where people built their settlements on the remnants of natural ecosystems (Guidotti, 2010).

Another main feature of urban ecosystems is the presence of dynamic boundaries and a high dependence on their fringe environments. It is possible to identify three main components (Chen et al., 2014):

- structures, that are based on the distribution of organisms, including humans, as well as landscape patches, soil, atmospheric and hydrologic pattern;
- processes, based on various forms of communications as well as political and cultural activities, together with economic and ecological processes in the built environment;
- functions, such as resource consumptions and ecosystem services.

Definitely, urban ecosystems are characterized by the interaction of environmental, economic and social dynamics and are areas in which a high rate of production of negative externalities is concentrated. In other words, cities are definitely less balanced than human-free ecosystems and «the feedback control of ecological consequences to social policy is relatively weak» (Collins et al., 2000, p.140).

Furthermore, they are dynamic, hybrid of both natural and manufactured components, whose interactions are affected not only by the natural environment, but also by culture, politics, economy, social organizations. According to Rees (1997), in order to understand the functioning of urban ecosystems, it is necessary to focus on the material, energy and information flows that sustain the human population.

Cities meant as ecosystems have to face many challenges such as population growth, pollution, changes in climate and water systems as well as many other stressors (McPhearson et al., 2016). As a consequence, the amount of built infrastructures is increasing (Ahern et al., 2014) with negative consequences on natural resources at different scales.

Ultimately, McPhearson et al., (2016, p.206) identify some key elements aimed at conceptualizing cities as ecosystems, that are the following:

- «the structure of urban systems includes human and non-human organisms; abiotic components such as soil, water, land, climate, buildings, roads, and technological infrastructure; social institutions; politics and governance; and economic drivers, all of which interact to produce the observable functions of urban systems;
- humans interact dynamically within social–ecological–technical/built system (SETS) components;
- delineating boundaries and defining response units are crucial for empirical research, as is understanding the influences, material, and energy that cross boundaries;
- urban ecosystem function emerges from the interactions, relationships, and feedbacks of system components;
- urban systems are spatially heterogeneous and temporally dynamic;
- linking urban system patterns with processes at multiple scales is a primary focus;
- conceptual frameworks must work across multiple spatial and temporal scales;
- conceptual frameworks must incorporate key, well-described drivers of urban system dynamics, including social, ecological, political, economic, and technical processes;
- the relationship among urban form, heterogeneous spatial structure, and system functions must be known to theorize and measure ecosystem services;
- conceptual frameworks must be designed to enable comparative studies across cities».

Despite the strong need, urban ecosystems have not yet been appropriately incorporated into the various forms of urban governance and planning approaches aimed at increasing resilience (McPhearson et al., 2015).
Newman and Jennings (2008, p. 108) describe sustainable urban ecosystems as those «which are ethical, effective (healthy and equitable), zero-waste, self-regulating, resilient, self-renewing, flexible, psychologically-fulfilling and cooperative». Although the zero-waste condition is like an utopia, it is important to try to reach better conditions and this can happen through the application of sustainable development principles (Dizdaroglu, 2015).

1.2 Urban ecosystem health

The state of an ecosystem has been defined by the term "ecosystem health" (Costanza, 1992, 2012). According to this concept, ecosystem health is formed by three components:

– the "vigour" of a system is a measure of its activity, metabolism or primary productivity;
– the "organisation" of a system refers to the number and diversity of interactions between its components;
– the "resilience" of a system refers to its ability to maintain its structure and pattern of behaviour in the presence of stress.

Definitely:

«a healthy ecosystem is one that provides the ecosystem services supportive of the human community, such as food, fibre, the capacity for assimilating and recycling waste, potable water, clean air, and so on» (Costanza, 2012, p. 2).

As stated by Brown (2017), this concept has been used both in urban and rural contexts for two purposes: as a metaphor representing the state of an ecosystem and as an operational tool for the definition of indices able to measure ecosystem conditions and outcomes of management measures.
Translating this concept from the ecological to the urban sphere, «a healthy urban ecosystem is the basic requirement of a strong economy, healthy environment and harmonious sustainable development for human society» (Li and Li, 2014, p. 155). It is possible to measure the state of the health by the use of three components, directly adapted from the ones identified to measure ecological ecosystem health:

– "vigour", which means a city's vitality and metabolic activity, reflecting also the productivity;

- "structure", which means the diversity of configuration and the channels, reflecting the economic, social and natural structure of relationship;
- "resilience", which means the function of an urban ecosystem; keeping the structure usability and making a long-term and sustainable development, reflecting a kind of systematic self-regulation. The concept of resilience applied to urban ecosystems can be formed by: 1) metabolic flows, such as production, supply and consumption chains; 2) governance networks; for example, institutional structures; 3) social dynamics; i.e. human capital; 4) built environment, such as ecosystem services in urban landscape.

  Producing territorial and urban resilience means considering environmental balance as a primary (quali-quantitative) reference for planning, to be preserved by acting directly on metabolism through a project capable of managing waste flows, to minimize its production, support its reduction and recycling, regenerating the territory according to the concept of Circular Economy (CE) (Russo, 2017).

Definitely, a healthy ecosystem can balance the three components of "vigour", "organisation" and "resilience" (Costanza, 2012).

Therefore, resilience together with the components of vigour and organisation, can qualify the health of an ecosystem in a comprehensive and exhaustive manner. Furthermore, a system is healthy and free from danger when it is stable and sustainable: this happens when it is active and maintains its organisation and autonomy over time, proving to be resilient despite perturbations. The concepts of ecosystem health and sustainability are closely interdependent, because the term sustainability is also an indication that a system is able to maintain its structure (organisation), its function (vigour) and its ability to recover (resilience) in the presence of external perturbations, while the lack of these factors indicates an ecosystem in crisis (Costanza, 1992).
Translating these parameters from an ecological to an urban sphere, a healthy urban ecosystem is the fundamental prerequisite for a consolidated economy, a well-functioning environment and a fair sustainable development for human society (Li and Li, 2014; Peng et al., 2015).
Decision makers are an important prerogative in shaping urban ecosystem health because they play a fundamental role in the development of healthy objectives and management strategies (Muñoz-Erickson et al., 2007).
From this point of view, healthy ecosystems have to provide ecosystem services and consequent benefits (Lu et al., 2015).

There are only some applications of the concept of ecosystem health at the urban level, for example one refers to the cities of Beijing and Shangai (Li and Li, 2014) and the choice of these two cities is linked to the growing environmental pressure that distinguishes them. The authors identify an indicators system in order to define the two cities' ecosystem health index and the contribution value of each component to the overall index.

A second important application is that developed by Peng et al. (2015) who use Shenzen city as a case study area and aim to assess the ecosystem health of urban landscapes based on ecosystem services, considering a subdivision of the territory in areas according to the level of ecosystem health in different periods of time.

1.3 Environmental assessment in land management policies

About 72% of the European population lives in urban ecosystems; therefore, in order to support their functioning, vast amounts of energy, food, water and other kind of goods are used, generating as well huge quantities of waste (Phillis et al., 2017).
Urban ecosystems are complex and open systems closely linked with their surroundings through exchanges of energy and material flows and information circulation (Su et al., 2012).

In this perspective, urban sustainability depends on complex and multi-scale interactions between the environmental ecosystem, the technical ecosystem and the individuals and institutions, i.e. the social ecosystem, establishing a strong interdependence with the surrounding peri-urban territories (Ramaswami et al., 2012) (Fig. 1).
Actually, urban and peri-urban ecosystems, characterized by the interaction of environmental, economic and social dynamics, are areas in which the production of negative externalities is strongly concentrated, but in the meantime, they can become a fertile context in which to experiment useful and innovative practices of mitigation, adaptation and territorial regeneration.
More than half of the world population lives in urban ecosystems and if the current patterns of consumptions and management remain unaltered, environmental degradation will be destined to increase not only at the local scale but also at the regional and global one (Kennedy et al., 2012). Therefore, these areas are increasingly subject to the attention of the various Agendas for sustainable development (Albertí et al, 2017), with the aim of improving their management in

relation to the economic growth, without leading to social instability and environmental degradation (Rotmans et al., 2000).

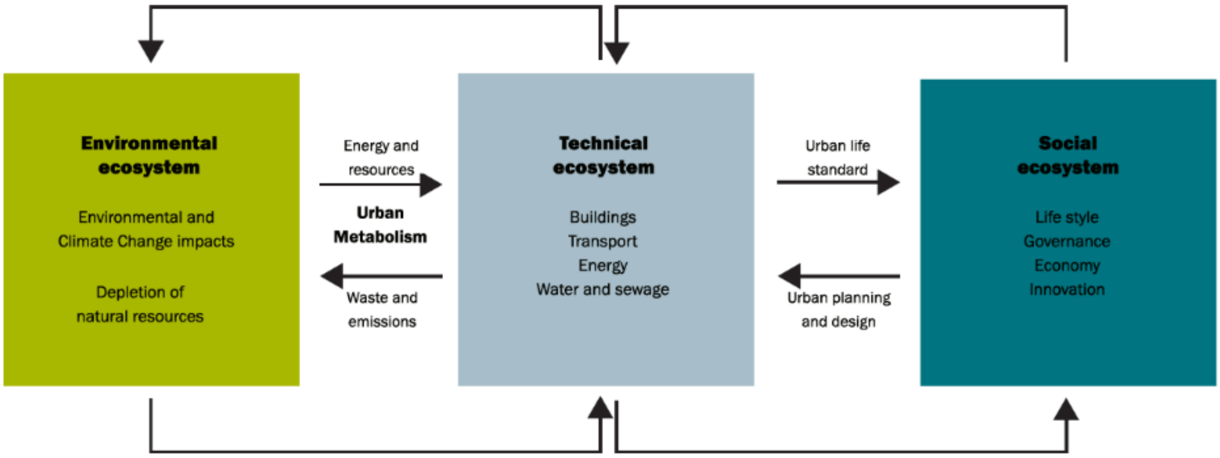


Fig. 1*:* the urban ecosystem, adapted from Bai and Schandl, 2011

Among the most significant environmental assessment tools, there is the Strategic Environmental Assessment (SEA), introduced in the European Community by the Directive 2001/42/EC[1], which integrates the environmental dimension in the strategies of decision making at the territorial scale.

The general concept of environmental assessment was introduced in 1970s with the aim of integrating the environmental component in decision making processes, as well as analysing the state of the environment and increasing the awareness of citizens on environmental issues (Lerond et al., 2003).
Anyway, there is a lack of a standardized methodology for the territorial environmental assessment, despite the existence of a wide number of tools and methods with this purpose (Loiseau et al., 2012).

Starting from this perspective, environmental assessment becomes an instrument of considerable importance, since che high concentration of people in urban ecosystems causes huge environmental pressures not only on ecosystems and natural resources, but also on the well-being and quality of life of the inhabitants.
It is, therefore, fundamental to give life to a territorial government that reflects a sustainable environmental protection, because only starting from a detailed cognitive

[1] https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32001L0042&from=EN

action of the urban environment and of its most important matrices, it is really possible to offer support to the decision makers involved in the environmental planning of the territorial development. The protection of the environment and of its ecological and natural resources, together with the sustainable valorisation of urban and peri-urban spaces, represent an indisputable ethical paradigm as well as an unavoidable reality with which to confront (Scarmellini, 2015).

1.3.1 Strategies and Agendas

The current resource consumption patterns lead to a general ecosystem degradation, thus determining the need to establish new paradigms to create cities that can be defined as "resource efficient" (EEA, 2015), in line with the "Europe 2020 Strategy". The latter proposes three main priorities (European Commission, 2012):
- smart growth;
- sustainable growth;
- inclusive growth.

Urban ecosystems become the cornerstone of the European Agenda for Sustainable Development and the Cohesion Policy for the period 2014-2020, which is focused on the application of the European 2020 Strategy[2], contributing to the achievement of a low carbon economy, adaptation to climate change, environmental protection, as well as an efficient use of resources (ISPRA, 2016).

The Local Agenda 21, developed after the United Nation Conference on Environment and Development in 1992, is another important initiative to promote a sustainable territorial development. It represents, indeed, a program of intentions for the 21st century which is still current and that is today supported by the 2030 Agenda for Sustainable development[3].

The latter is made up of 17 objectives (Fig. 2), known as Sustainable Development Goals (SDGs) and 169 targets aimed at integrating the Millennium Development Goals, balancing the three dimensions of sustainable development.

Significant for the purpose of this study is the goal n.11, that is to *make cities and human settlements inclusive, safe, resilient and sustainable*. Among the targets of this goal, it is worth to mention that of reducing the negative impact per capita in urban ecosystems, in particular with regard to air quality and the management of

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[2] https://ec.europa.eu/info/business-economy-euro/economic-and-fiscal-policy-coordination/eu-economic-governance-monitoring-prevention-correction/european-semester/framework/europe-2020-strategy_it

[3] http://www.2030agenda.undp.org/content/2030agenda/en/home.html

urban and non-urban waste (11.6). Another important factor is the access to safe, inclusive and accessible green and public spaces (11.7) or the adoption by 2020 of integrated policies and plans for inclusion, resource efficiency and mitigation, adaptation to climate change and disaster management (11B). The goal n. 12 is to *ensure sustainable production and consumption patterns*, achieving a sustainable waste management through the entire life cycle of products and minimizing the release of harmful substances to air, water and soil (12.4), promoting as well recycling and reuse (12.5). Ultimately, not less importance is given in this context to goal n.13, aimed at taking *urgent actions to combat climate change and its impacts* and goal n. 15. The latter regards the protection, restoration and promotion of *sustainable use of terrestrial ecosystems*, *sustainable management of forests* as well as the aim to *combat desertification and halt and reverse land degradation and biodiversity loss.*

Fig. 2: SDGs Framework

Other important references are Paris Agreement (COP 21) and the New Urban Agenda. The latter, adopted during the United Nations Conference on Housing and Sustainable Urban Development (Habitat III)[4], promotes an urban development respectful of the environment, providing guidance for the achievement of SDGs.

In particular the "call for action" focus, among many others, also on the "environmentally sustainable and resilient urban development".

[4] http://habitat3.org/the-new-urban-agenda/

It is possible to read that *cities and human settlements face unprecedented threats from unsustainable consumption and production patterns, loss of biodiversity, pressure on ecosystems, pollution, natural and human-made disasters, and climate change and its related risks, undermining the efforts to end poverty in all its forms and dimensions and to achieve sustainable development. Given cities' demographic trends and their central role in the global economy, in the mitigation and adaptation efforts related to climate change, and in the use of resources and ecosystems, the way they are planned, financed, developed, built, governed and managed has a direct impact on sustainability and resilience well beyond urban boundaries* (point n. 63).

Another important point is n. 71; the latter is about the commitment *to strengthening the sustainable management of resources, including land, water (oceans, seas and freshwater), energy, materials, forests and food, with particular attention to the environmentally sound management and minimization of all waste, [...], greenhouse gases and noise, and in a way that considers urban-rural linkages, functional supply and value chains vis-à-vis environmental impact and sustainability and that strives to transition to a circular economy while facilitating ecosystem conservation, regeneration, restoration and resilience in the face of new and emerging challenges*.
In addition, point n. 74 proposes to promote *environmentally sound waste management and to* substantially reduce *waste generation by reducing, reusing and recycling waste, minimizing landfills and converting waste to energy when waste cannot be recycled or when this choice delivers the best environmental outcome.*
Very relevant with the present research is also point n. 76 about the *sustainable use of natural resources and focusing on the resource efficiency of raw and construction materials such as concrete, metals, wood, minerals and land.* It underlines also the necessity *of establishing safe material recovery and recycling facilities, promoting the development of sustainable and resilient buildings and prioritizing the use of local, non-toxic and recycled materials and lead-additive-free paints and coating.*
Among the "planning and managing urban spatial development" chapter, it is worth mentioning point n. 122. about supporting *decentralized decision-making on waste disposal to promote universal access to sustainable waste management systems.* To this, it is added *the promotion of extended producer responsibility schemes that include waste generators and producers in the financing of urban waste management systems,* the reduction of *the hazards and socioeconomic impacts of waste streams and* the *increase* of *recycling rates through better product design.*
These are only some examples of programmed actions in the New Urban Agenda, that is perfectly in line with what is proposed in the following chapters.

Finally, as regards the use of energy resources in the Italian context, about 2000 local Italian administrations have joined the Covenant of Mayors (in Italian “Patto dei Sindaci”)[5]. This is an initiative proposed by European Commission which leads to the adoption of a Sustainable Energy Action Plan (in Italian “Piano d’Azione per l’Energia Sostenibile” – PAES), containing a series of measures aimed at reducing emissions, putting cities in the forefront, in which there are more than 60% of total emissions. The Plan establishes also a monitoring mechanism aimed at assessing the achievement of the defined objectives through two categories of indicators, i.e. performance and impact indicators and indicators of physical and financial implementation.

Still in the Italian context, there are some initiatives concerning environmental assessment in relation to various issues, such as impacts, vulnerability and adaptation together with research projects, in which, however, an explicit reference to the environmental assessment tool in its various forms is still not explicitly mentioned, while it could become an essential element of support.
Therefore, over time, the awareness of the pressure on ecosystems and natural resources has increased progressively, because of the ever-increasing human concentration in urban areas, stimulating the development of new territorial management policies.
With the Law 28 June 2016, n.132, for example, the “National network system for environmental protection” (in Italian “Sistema Nazionale a rete per la Protezione dell’Ambiente” – SNPA)[6] was established.
In this perspective, the government of the territory represents indeed a complex activity, but at the same time it is a guarantee for the territory itself (ISPRA, 2016b).

1.3.2 Environmental Assessment methods and tools

As soon as the concept of sustainable development was introduced (Brundtland, 1987), a variety of methods for environmental assessment has been proposed and developed in relation to territorial sustainability.
Environmental assessment can be defined as an instrument with the aim to support decision-making processes of land planning and management, providing environmental information on the basis of a global approach (Torricelli and Gargari, 2015).
Ness, et al., (2007) subdivide these methods into three categories:

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[5] https://www.pattodeisindaci.eu/it/
[6] http://www.isprambiente.gov.it/it/sistema-nazionale-protezione-ambiente

- methods based on the use of indices and indicators; whereas an indicator, using observed or estimated data, describes one characteristic of the state of the environment (Dizdaroglu, 2015), while an index represents a quantitative aggregation of many indicators, providing a simplified view (Mayer, 2008). Many indices of sustainability at the urban scale have been developed by different organizations and from different perspectives (Albertí et al., 2017). For example the "City Sustainability Index" (Mori and Christodoulou, 2012) and the "Environmental Performance Index" (EPI) (Esty et al., 2005);
- integrated assessment methods, that are used with the aim of investigating policy changes or project implementation using scenarios of development.
  Among this category, some examples are represented by Multi-Criteria Decision Analysis (MCDA), Cost Benefit Analysis (CBA), Impact Assessment (such as Environmental Impact Assessment and SEA) (Dizdaroglu, 2015);
- methods that asses sustainability at the scale of a single product, that focus on the material and energy flows of a product or service adopting a Life Cycle perspective (Dizdaroglu, 2015). Among them, the "Ecological Footprint" (EF) (Wackernage and Rees, 1997), sometimes based on the concept of "carrying capacity" (Rees, 1992), Material Flow Analysis (MFA), Substance Flow Analysis (SFA), Physical Input Output Tables (PIOT), Ecological Network Analysis (ENA), Emergy, Exergy, Life Cycle Assessment (LCA).

  These methods represent other approaches for the territorial environmental assessment and they will be discussed in the following chapters.

Dizdaroglu (2015) proposes to add to this list also the so-called "indicator-based sustainability assessment", using urban ecosystem indicators in order to achieve urban sustainability.
Moreover, Albertí et al. (2017) propose a detailed description and classification of sustainability indices developed for cities.

1.4 Life Cycle of territory

Urban ecosystems are crossed by metabolic processes that define a series of life cycles: the end of life cycles represents the phase in which the transformation and use chains produce flows of materials no longer usable: waste, transformable materials, sometimes even no more usable, destined for disposal (Russo, 2016).
Life cycle in general refers to all the phases that distinguish the life of an element, which can be not only a single product, as this concept can also be extended to other elements, such as the wider territorial system.

The concept of life cycle referred to urban ecosystems is related to the evolution of the territory as heritage and as a system of environmental, social and economic resources and services, whose transformation is linked to the governance to which that particular territory is subjected. The territorial life cycle is formed by interconnected phases referred by the sub-systems of resources and performances of that territory, according to a predefined plan scenario (Torricelli, 2015_b).
This concept can be referred to a particular temporal scenario in which, according to Torricelli, (2015_b), it is possible to find three different processes:
- settlement processes;
- processes of use and consumption of resources, equipment and services;
- processes of production and consumption of goods destined more or less to the territory.

These processes generate various kind of environmental flows and social relations linked to the territorial activities.
In general, the evolution and consequent exhaustion of the territorial life cycles and of its matrixes formed by soil and water, are due in turn to the exhaustion of the industrial, agricultural, commercial, real estate, extraction and metabolic cycles; the latter are related to the relational and social dimensions (Terracciano and De Marco, 2016).

According to Zucchetti (2008), in a systemic conception, a determined portion of the territory does not have the possibility to grow indefinitely but will be subjected to an involution phase, that manifests itself with an increasing degree of entropy and a reduction of the value of the ecosystem. The process will continue until the creation of a new system with a different structure and a new life cycle is started. More in depth, in the phase of depression, the area is only characterized by the presence of basic factors, such as the presence of raw materials and, from an economic point of view, companies can be motivated to localize themselves in those areas only if encouraged by a reduction of costs. The development phase is characterized by the presence of qualified services and research laboratories. During the maturity phase, all the areas offer the same conditions and in the decline phase, the territorial features become obsolete and are no longer able to attract business processes, determining a process of de-industrialization and creating an involution.

In general, there are many different drivers that could determine the evolution of the territorial life cycle, not only economic factors, but also social and environmental ones and each case has its own specificity.
For example, Narcisi (2014) proposes an analysis of the life cycle of a tourist place, introducing seven different phases (Fig.3):

1. exploration phase, characterized by the presence of few tourists who want to know the place for its cultural or natural characteristics and live in contact with the local population; this flow does not involve changes;
2. start-up phase, in which a regular flow of tourist arrival takes place and at this moment the relationship with the residents is considerable and the first accommodation facilities are born;
3. development phase, characterized by huge progresses determining significant changes and physical, economic and social transformations;
4. consolidation phase, when the growth rate of tourists begins to slow down, giving rise to discontent;
5. stagnation phase, with a peak in attendance and use of resources; nevertheless, the organizations are committed to keeping the number of tourists who tend to decline and supporting the image of the area constant;
6. decline phase, when the area is no longer up to competitors;
7. regeneration phase, in which it is possible to apply the concept of re-cycle, realizing new structures and enhancing neglected natural and cultural resources.

This concept, however, is not new. For example, it is possible to think about the slogan developed by the American architect William MC Donough “Cradle to Cradle”, which is based on the application of biological criteria to industrial processes, that, passing from one state to another, can generate new life cycles.
In the present research, this concept is based on the possibility to generate new life cycles to abandoned portion of the territory, giving rise to recycling strategies of building, urban and environmental resources (Aymonino and Bocchi, 2013), determining to the so-called “hyper–cycle, i.e. a reactivation of a certain life cycle.

Carta (2013) identifies three categories of life cycle:
- completed or never born life cycles: these are spaces of abandonment and waste or closed work spaces, unfinished or no longer used structures. In these areas it is possible to adopt an up-cycle process, activating transformations capable of giving life to multiple functions, with a view to hyper-cycle;
- seasonal life cycles: linked to the system of second homes and tourism in crisis because they are on sale or subject to a real estate crisis. Also in this case, the hyper cycle, acting on the causes of decline, allows activating new life cycles at the same time, promoting the regeneration of new connection networks;
- productive life cycles in “border landscapes”: these are production areas that generate wasted landscapes, in which a linear production cycle requires the transformation into a circular production cycle. Here it is possible to apply the

concept of sub-cycle and the "from cradle to cradle" approach, creating new resilient and adaptive processes.

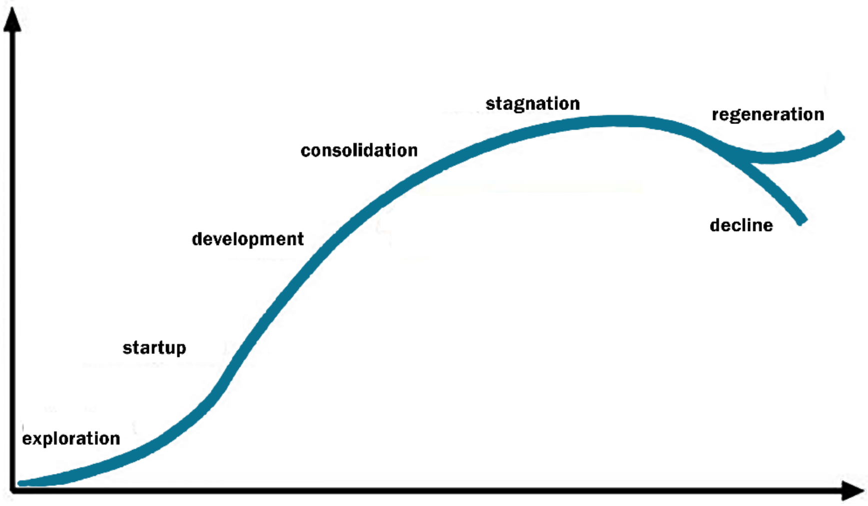


Fig. 3: the life cycle of a tourist area, adapted from Narcisi, 2014

Furthermore, Carta (2016) proposes the so called Cityforming©, that is a design protocol capable of reactivating the metabolism of an area starting from its latent regenerative components, activating multiple cycles of increasing intensity to create a new sustainable urban ecosystem over time. The application of this protocol is able to reactivate the inactive cycles, but also to reconnect the interrupted ones or to activate new ones, more suited to the new identity of the places.
The author identifies three main life cycle phases:

– the colonization phase, in which some new functions are identified or some buildings are recovered; the latter are like stamina cells. This phase can also comprise the removal of some infrastructural or environmental detractors, facilitating the reconstitution of some ecological networks;
– the consolidation phase, that acts on the new ecosystem through the grafting of some more valuable functions, able to generate profits, increasing the attractiveness of the area;
– the development phase, in which the new metabolism of the area is able to generate new urban value.

Therefore, the life cycle phases of the territory can be generated by different causes, spontaneous or induced. The latter generally intervene on those portions of the

territory whose life cycles, almost completely exhausted, require the initiation of strategic regeneration actions capable of giving new life to the territory.
Moreover, still Carta (2013) proposes an interesting comparison of the city to a living organism, stating that the start of a new life cycle, proliferating and hybridizing the surrounding tissues, can transform a group of cells that at the beginning are undifferentiated, giving rise to new organs. The areas subject to recycling actions are like sprouts that generate new connective tissues.

The concept of life cycle can be compared to that of change and is closely linked to the analogy between ecosystems and the urban environment, which is the basis of an idea of a city in constant transformation (McDonough and Braungart, 2002). In this sense, cities in their making and discarding themselves, are seen as renewable resources and recycling the city stands as a fundamental strategy that touches different scales and themes of the contemporary urban question (Ciavatta, 2016).

1.5 Urban Metabolism

Comparing the urban ecosystem to an organism crossed by metabolic flows, determines the absolute necessity of introducing the concept of Urban Metabolism (UM).
Metabolism in general refers to the biochemical reactions of synthesis and degradation that happen in every living organism in order to sustain its growth, renewal and maintenance.
UM represents a scientific phenomenon comprising individual processes that take place in all cities at different spatial and temporal scales (Kennedy et al., 2014) and that is based on the principle of conservation of mass and energy. One of the first who introduced this phenomenon was Marx (1909), followed by Wolman (1965), who formally proposes the concept of UM.
Analysing the metabolism of a city makes it possible to understand the impacts of the urban development (Mostafavi et al., 2014), taking into account the flows of energy, water, nutrients and waste and the materials in general that circulate within a city, allowing a multidimensional assessment of sustainability (Beloin-Saint-Pierre et al., 2017). Furthermore, the inputs and outputs are quantified as well as the components of the flows that remain stored in the cities (Chrysoulakis et al., 2013).

UM can be defined as:

«the sum 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, p.44).

In this context, the analysed area is considered as an interaction of subsystems in continuous adaptation to the economic, natural and political conditions, and UM becomes a framework for modelling the flows of matter and energy within complex urban systems, considering the city as an ecosystem (REPAiR, 2015). The territory as an organism is characterized by an alternation of its vital cycles, which determine continuous variations of its metabolism and a mutation of the functioning and the shape of the city and of its networks (Russo, 2013).
Therefore the metabolism deploys processes that on the one hand interact with the space, influencing the urban form, the density, the morphology, the biodiversity, the ecological integrity and on the other are influenced by economic and social immaterial factors (Russo, 2018).

Urban metabolism can be analysed according to four fundamental flows/cycles: water, materials, energy and nutrients (in input and output of the system) and it is currently characterized by a linear development model, in contrast to natural systems, which are cyclical and are characterized by an efficient use of resources. This causes an intensification of environmental impacts such as climate change and biodiversity loss (EEA, 2015) (Fig. 4).
The analysis of UM not only affects the flows, but also the anthropogenic stocks that transform the input flows into the so-called "grey infrastructures", which shape the physical environment of urban areas and determine their development models.
The phase of radicalization of economic, ecological and social processes is at the basis of environmental risks also due to climate change, determining the need to rely no longer on a linear metabolism. The latter considers the city as an urban machine, consuming unlimited resources and producing waste to dispose of (Gasparrini, 2013).

Three main typologies of metabolic flows can be identified within a city (Minx et al., 2010):
- direct extractions and releases, that are resources directly extracted and waste and emissions released;
- imports and exports, that are different products that can be imported or exported in and out of the urban ecosystem;
- indirect flows associated with imports and exports, such as resources indirectly extracted and emissions and waste products indirectly released.

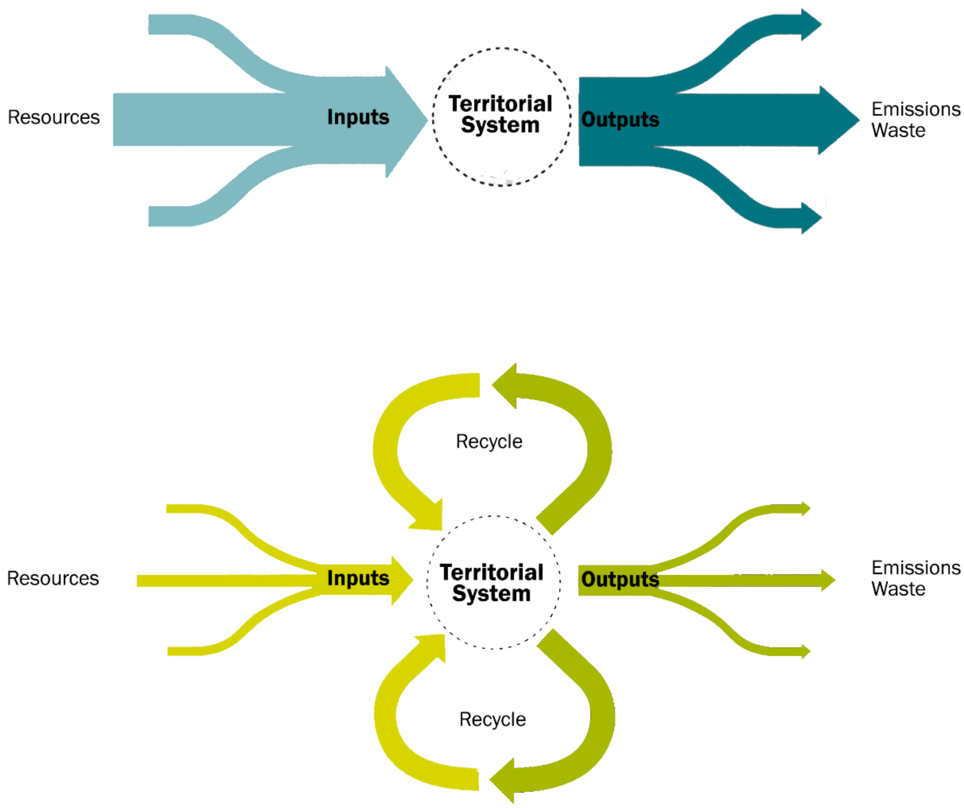


Fig. 4: linear and circular UM, adapted from Rogers, 1996

In general, with the growing interest in environmental issues such as climate change, UM has become a key concept in determining and maintaining the level of urban sustainability and consumption of resources (Qi et al., 2016), as well as in the assessment of environmental impacts, opening the way to innovative systemic approaches.
There are many studies focusing on the analysis of UM in individual cities, but there are also many others focusing on the comparison of resource use across cities (Kennedy et al., 2009; Sovacool and Brown, 2010).
In general, lots of approaches and applications are used to compare from a quantitative point of view the environmental sustainability of different scenarios of urban consumption/production (Beloin-Saint-Pierre et al., 2017). Furthermore, as stated by Li and Kwan (2017), UM can be examined at different scales: global UM studies analyse the global antroposphere, while there are studies at the national or regional scale as well as at the urban and local dimension.

As stated by Minx et al. (2010), MFA is considered a suitable evaluation tool to quantify UM, being able to capture a great variety of metabolic flow types. Despite

this, there are also experimentations focusing on the quantification of a single flow, such as energy or CO_2 emissions on specific cities, especially because of a limited availability of data (Druckman et al., 2008; Hillman and Ramaswami, 2010).
Furthermore, still Minx et al., (2010) underline the necessity to associate metabolic flows to some characterizing aspects that usually occur in cities, such as land use-intensity, the urban form and size, the population density, together with other kind of phenomena, such as land use planning and the life styles of citizens, summarized in the following three components (Fig.5):
–urban drivers;
–urban patterns;
–urban lifestyles.

According to Broto et al. (2012), UM enables the consideration of the city as an ecosystem, linking material flow with social and ecological processes and the possibility to modify the actual patterns of consumption and production, towards more sustainable schemes.
UM determines the necessity to adopt a flow perspective on urban ecosystems (Dijst et al., 2018).

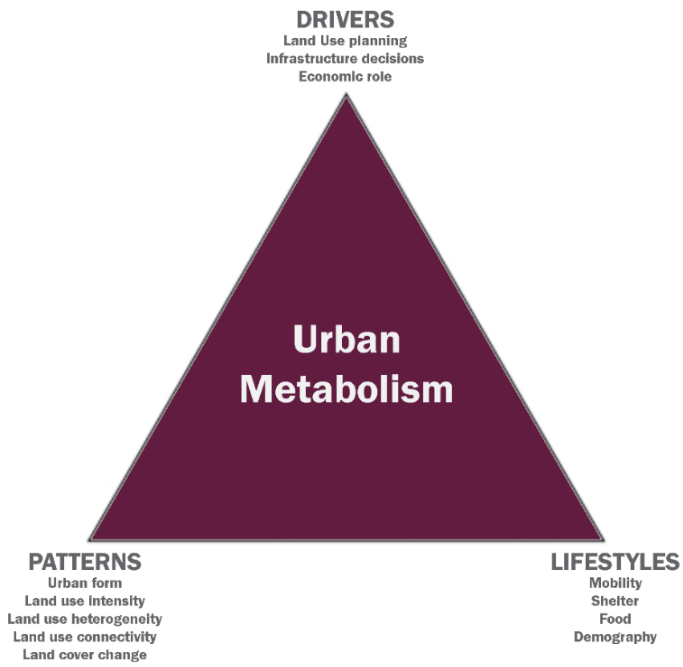


Fig. 5: UM drivers, patterns and lifestyles, adapted from Minx et al., 2010

According to Dijst (2013) and Wegener (2004) it is possible to identify different typologies of urban processes (Fig. 6).

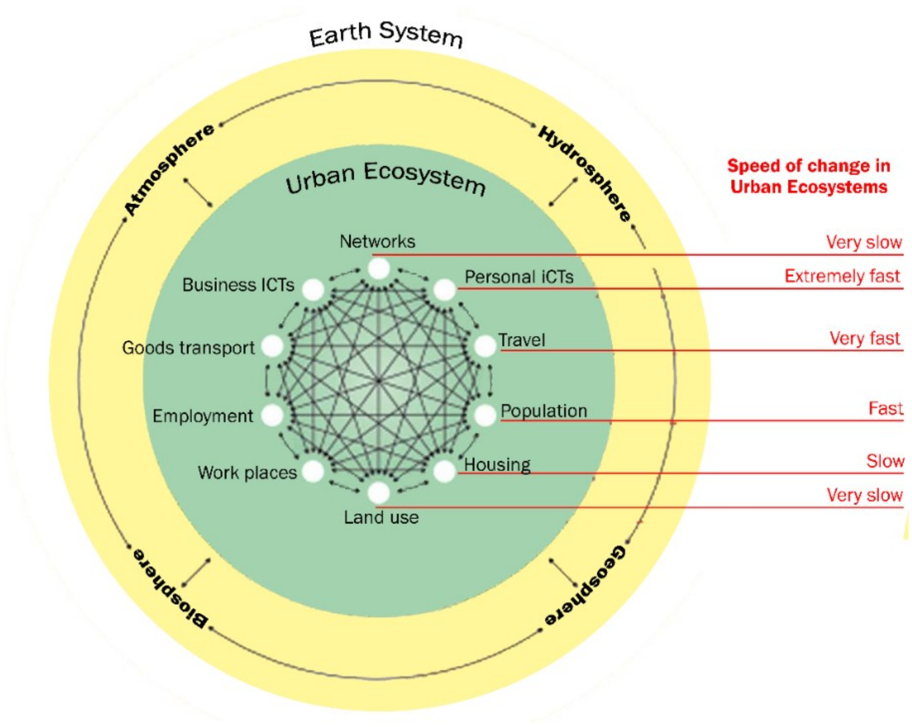


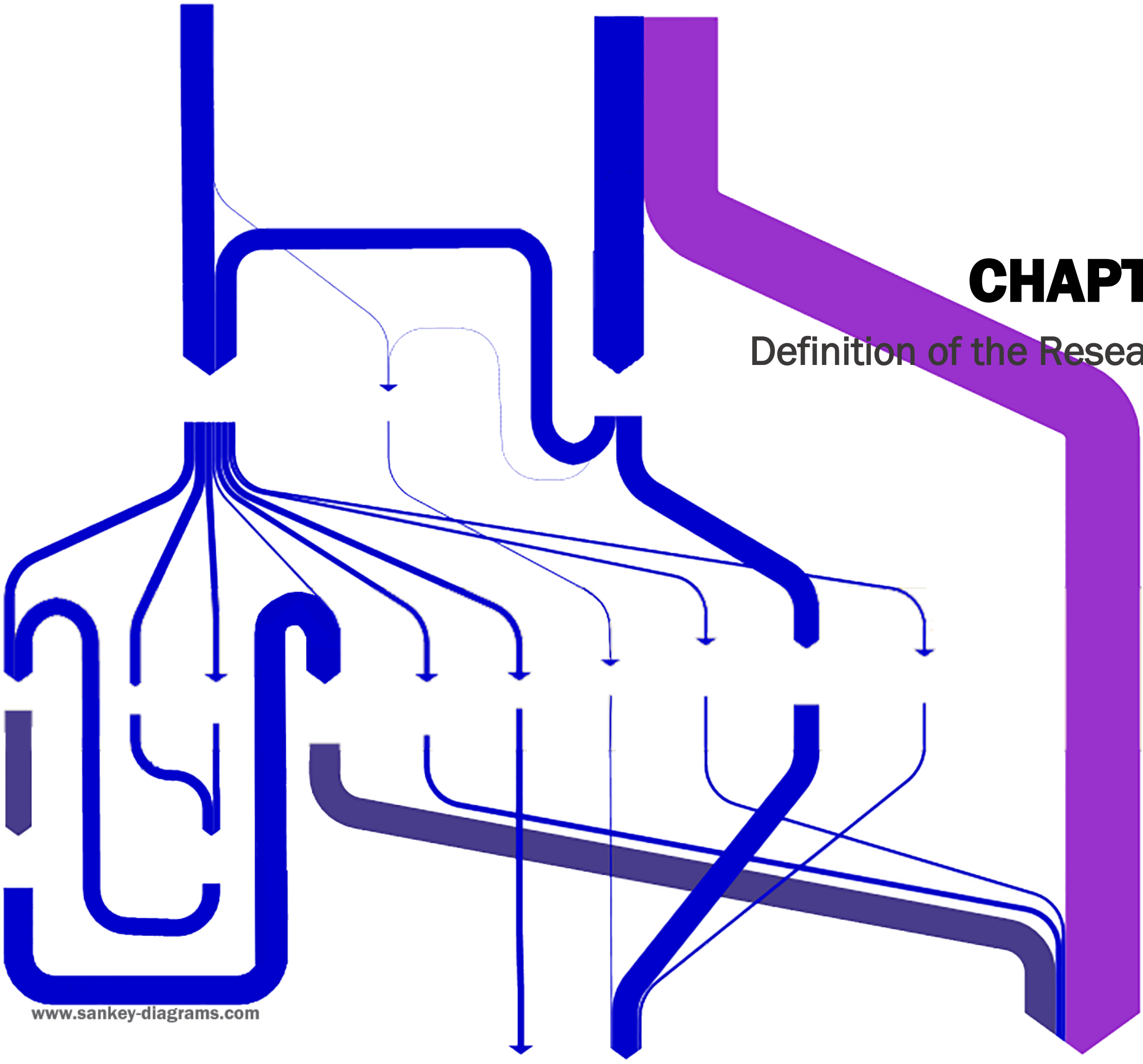
Fig. 6: processes and flows in urban ecosystems, adapted from Dijst et al., 2018

The latter can be divided in two main categories: social and economic spatio-temporal processes and natural spatio-temporal processes in the earth system.

The first category comprises:
– slow processes, linked to changes in transport, infrastructures and land uses;
– the lifecycle of housing, workplaces and non-residential buildings;
– the fast change in employment and household composition;
– the fast daily flows of people and goods;
– information in all its forms, such as flows of data, knowledge and money.

The second category comprises:
– climate change;
– water, energy and nutrient flows;
– erosion;
– human induced natural processes.

The above flows are affected by different kind of drivers, such as: consumption patterns, residential choices, built environment features as well as socio-cultural drivers (Dijst et al., 2018).



CHAPTER TWO

Definition of the Research Question

2.1 Urban Metabolism evaluation methods: literary review

Many authors have explored the phenomenon of UM, experimenting with indices and evaluation methods, but it does not exist a consensus about the assessment methods to use; there are, indeed, many different experimental approaches.

For example, Kennedy et al. (2014) propose a complex indicator to evaluate the UM of some large cities (megacities), with the aim of collecting information related to multiple aspects:
- the biophysical characteristics, such as climate and population;
- metabolic flows, represented by water, waste, materials and energy;
- urban definition, linked to spatial boundaries and constituent urban elements.

In their study, Kennedy et al. (2015) subsequently demonstrate that megacities are responsible for 9% of global electricity consumption, generating in the meantime 13% of solid waste and housing 7% of global population.
Conke and Ferreira (2015) evaluate the changes in matter and energy that take place in a city in Brazil in the period between 2000 and 2010, to monitor urban transformations and the contribution of cities to sustainable development.
Mostafavi et al. (2014) propose an integrated analysis framework called IUMAT (Integrated Urban Metabolism Analysis Tool), based on the quantification and aggregation of human, social and environmental capital linked to urban activity.
Giampietro et al., (2009) propose the “multi-scale integrated analysis of societal and ecosystem metabolism (MuSIASEM)” approach, that is based on the analysis of the patterns of metabolism of socio-economic systems at different levels and scales:
- socio-economic activities;
- ecological constraints.

Despite the development of many evaluation tools, there is still a lack of consensus about the methods and techniques of evaluation of this phenomenon.

At the European level, remarkable significance is covered by two projects:
- SUME project (Sustainable Urban Metabolism for Europe[7]), that links the evaluation of UM to the spatial component and in particular to urban planning, assessing development scenarios for six different cities (Athens, Oporto, Monaco, Newcastle, Stockholm and Vienna) up to 2050 in relation to three layers: soil consumption, energy consumption and materials consumption;

[7] www.sume.at

– BRIDGE project (SustainaBle uRban planning Decision support accounting[8]), that presents a bottom up approach to quantitatively asses UM at the local scale, connecting biophysical sciences to urban planning.

In general, according to Beloin-Saint-Pierre et al. (2017) who make a review of the main urban metabolism studies, more than 150 studies presenting different assessment methodologies of urban metabolism have been performed, analysing more than 60 cities.
Actually, it is possible to propose three main typologies of system modelling approaches (Beloin-Saint-Pierre et al., 2017) (Fig. 7):

– black-box (BB) approach, that is based on the description of flows in input and output of the system;
– gray-box (GB) approach, that disaggregates the flows in input and output according to the different components (for example: buildings, roads, etc.);
– network (NE) approach, that is similar to the GB approach, but in addition describes the environmental impacts of specific components of the assessed life cycle.

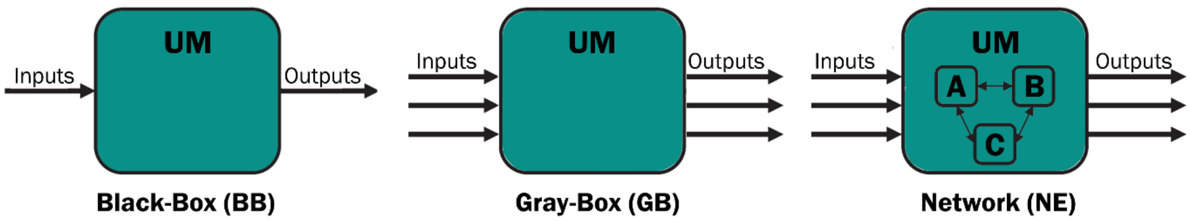


Fig. 7: UM modelling approaches, adapted from Beloin-Saint-Pierre et al., 2017

Furthermore, Li and Kwan, (2017) state that UM assessment methods can be divided in two main approaches:

– material-based analysis, that includes for example Material Flow Analysis (MFA), Life Cycle Assessment (LCA), Ecological Footprint Assessment (EFA), Substance Flow Analysis (SFA), Input-Output Tables, Ecological Network Analysis (ENA), etc.
– energy-based analysis, that studies the energy flows within an urban ecosystem.

[8] www.bridge-fp7.eu

MFA is a method able to establish the material (and energy) balances of a system, while the EFA represents the theoretical area used by men to consume bio resources and to assimilate waste (Loiseau et al., 2012).
MFA introduces a distinction between “stocks”, that are materials accumulating in the system, and “flows”, that are elements in and out of the system (Dijst et al., 2018). For example: «the number of cars that belong to the inhabitants of a city is a stock, but if we want to measure congestion or traffic, we need to know some spatial decomposition of the stock and the details of the flows between these stock subsets, i.e. given the road capacity the number of cars per hour flowing from area A to area B» (Dijst et al., 2018, pp. 192-193). Flows and stocks are influenced by the activities happening inside the urban ecosystem and depending on the necessities of individuals and communities (Dijst, 2013). Flows can be material (such as energy, water, materials, etc.) or immaterial (such as social capital, culture, etc.) (Dijst et al., 2018).
Furthermore Chen et al. (2014) subdivide flows in two types: flows of small volume but characterized by a high environmental impact (for example heavy metals) and flows of large volume with low environmental impact (such as water), presenting also many references of applications of MFA in global cities. In these applications MFA is used to model the metabolic intensity in relation to urbanization processes (Douglas, 2012; Hendriks et al., 2000).

SFA instead is used to evaluate the flows of substance on a given area over a given time. Input-Output Tables is a method more focused on monetary flows, while Physical Input-Output Table (PIOT) deals with physical flows. ENA bases the evaluation on system modelling, linking material flows to an ecosystem structure. In the end, it is worthwhile to mention Exergy analysis and Emergy analysis; the first identifies «technical improvements or protection measures which should be implemented in order to improve energy performance and to maintain resource availability» (Loiseau et al., 2012, p.218). The second provides information on territorial functioning thanks to the use of four indicators that «reveal the degree of independence of anthrophized territories in terms of resource use and of their interaction with their surrounding environments» (Loiseau et al., 2012, p. 218).

Furthermore, as specified by Dijst et al. (2018), there are also other typologies of urban metabolism assessment methods and indicators. Some examples are: urban ecology models (Chen et al., 2014; Zhang et al., 2006); ecosystem services and land use models (Haase et al., 2014; Kroll et al., 2012); urban transport and accessibility models (Wegener, 2011) and finally urban energy models (Keirstead et al., 2012).
Chen et al. (2014) divide urban ecosystem models in three categories:

- top-down models: that focus on materials/energy flows or system structure, including in this category MFA;
- bottom-up models: that focus on land use and infrastructure;
- hybrid models and integrated models.

Environmental analysis of UM can also be carried out using another kind of modelling approach, that of “life cycle perspective”, that takes in consideration the entire supply chain, from the raw materials extraction to the waste treatment (Beloin-Saint-Pierre et al., 2017). Indeed, many authors (Beloin-Saint-Pierre et al., 2017; Loiseau et al., 2013; Mat et al., 2013) suggest adopting a life cycle and multi-criteria approach, highlighting at the same time the difficulties in the practical application of this methodology at the territorial level due to the absence of a standardized methodology.
An important study in this regard is that elaborated by Goldstein et al. (2013), who proposes a hybrid approach based on the integration between UM and LCA (UM-LCA) to quantify environmental impacts by modelling both upstream, i.e. incoming flows, and downstream, i.e. outgoing flows, introducing a set of appropriate indicators.
It is therefore necessary to evaluate the environmental loads connected to the upstream and downstream processes in relation to the metabolic flows of a city.

2.2 Life Cycle Assessment: from the single product to the entire territory

Territorial environmental assessment methods should provide stakeholders with useful information to encourage the development of public decision-making policies aimed primarily at spatial planning and it is required for this purpose an approach that consents a holistic, site-specific, multi-criteria evaluation, in accordance as well with life cycle thinking (Loiseau et al., 2012).

2.2.1 Life Cycle Assessment: main characteristics description

Life Cycle Aassessment (LCA) represents the canonical environmental assessment tool of the life cycle (generally of products).
This evaluation method was born in order to evaluate the environmental impacts related to the life cycle of products and services and the first examples appear around the 70s, in conjunction with the evolution of the concept of sustainable development and with the ever-increasing attention towards the identification of strategies aimed at reducing environmental impacts.

However, in 1990 an official and formal procedure was created to evaluate the life cycle of a product, known as LCA, a term coined during the SETAC congress (Society of Environmental Toxicology and Chemistry). This process was subsequently standardized through the enactment of the ISO 14040, 14041, 14042 and 14043 standards, characterized by the development of guidelines that are subsequently incorporated into two unique standards: ISO 14040: 2006 and ISO 14044: 2006. The International Reference Life Cycle Data System (ILCD)[9] developed by the European Commission together with the Joint Research Center (JRC) and the UNEP-SETAC Life Cycle Initiatives are the two major initiatives in terms of LCA and they are also a guarantee for future developments.
LCA is an objective procedure for evaluating energy and environmental loads related to a process or activity, performed by identifying the energy and materials used and the waste products and emissions released into the environment. The assessment includes the whole life cycle of the process or activity, comprising the extraction and processing of raw materials, transportation, manufacturing, distribution, use, reuse, recycling and final disposal (Consoli et al., 1993) (Fig.8).
By describing the potential complex and multidimensional impacts related to human activities, LCA provides quantitative information aimed at facilitating sustainable choices (Helling, 2017). As already previously specified, the LCA approach can be adapted and integrated to the analysis of UM, providing the latter with standardized scientific bases that can quantify the urban environmental loads (Torricelli and Gargari, 2015b).

The procedure for performing a proper LCA consists of four phases:

- goal and scope definition, during which the so-called “Functional Unit” (FU) is established, that becomes the reference point of the study and is defined by the ISO 14040 standard as the measure of the performance of the functional output flow of the product system. The whole analysis and the consequent comparison with the different alternatives will be based on the FU. During this phase, the purpose for which the LCA is conducted and the consequent level of detail that is to be maintained are defined too;
- inventory analysis, during which the flows of materials and energy that cross the system (in and out) and its boundaries are described. This step also involves the collection of all the data necessary to conduct the evaluation;
- impact evaluation, in which the effects of substances on the environment and on humans are analysed. The data identified during the previous phase are classified and divided into categories of environmental impacts;

[9] http://eplca.jrc.ec.europa.eu/uploads/JRC-Reference-Report-ILCD-Handbook-Towards-more-sustainable-production-and-consumption-for-a-resource-efficient-Europe.pdf

– results interpretation, that consists in verifying the completeness and reliability of the results, as well as the variability of the same, through the application of appropriate sensitivity analyses that will lead to the formulation of a series of reflections.

During an LCA application, impact indicators are divided into two categories (Fig.9):
– midpoint, expressed in the form of impact categories and subject to a characterization process;
– endpoint, representing damage categories obtainable by submitting midpoint indicators to normalization.

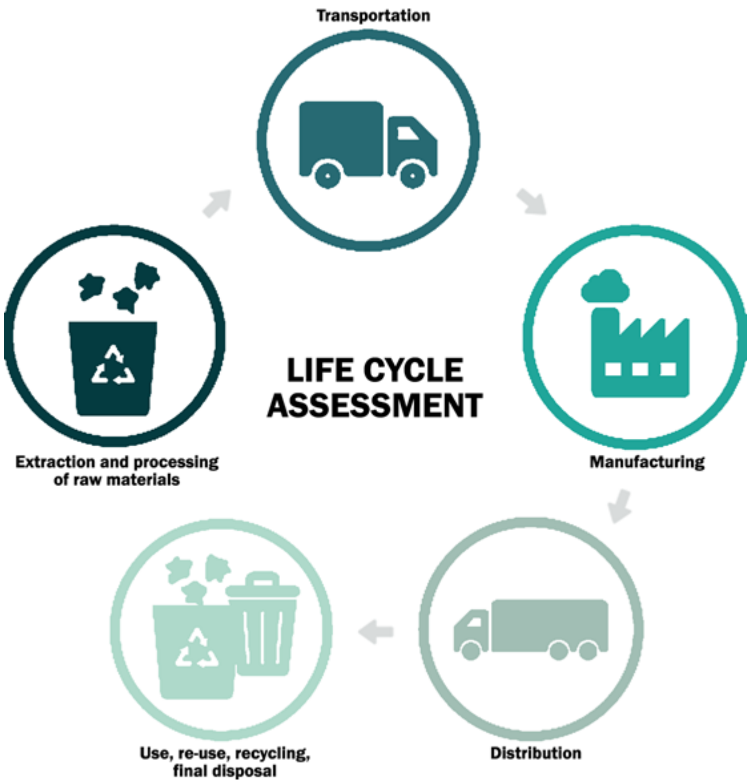


Fig. 8: LCA phases

This kind of analysis, having to take into consideration the entire life cycle of a product or service, starts from the production of raw materials, until their disposal; the whole of these macro phases is called “from cradle to grave”, in a life cycle thinking perspective. The latter consists of going beyond the narrow focus on the production site and the production process, to include the environmental, social and economic impacts associated with a product in the whole life cycle (Udo de Haes et al., 2002), in line with what established by the CE approach.

Furthermore, there are also many examples of LCA applications focusing on some particular phases of the product life cycle. In particular, many studies focus on the Waste Management (WM) phase, that comprises everything that happens when the product becomes waste, in order to evaluate the impacts of its disposal (Boldrin et al., 2011; Brogaard and Christensen, 2016; Damgaard et al., 2010; Hauschild et al., 2013) (Fig.10).

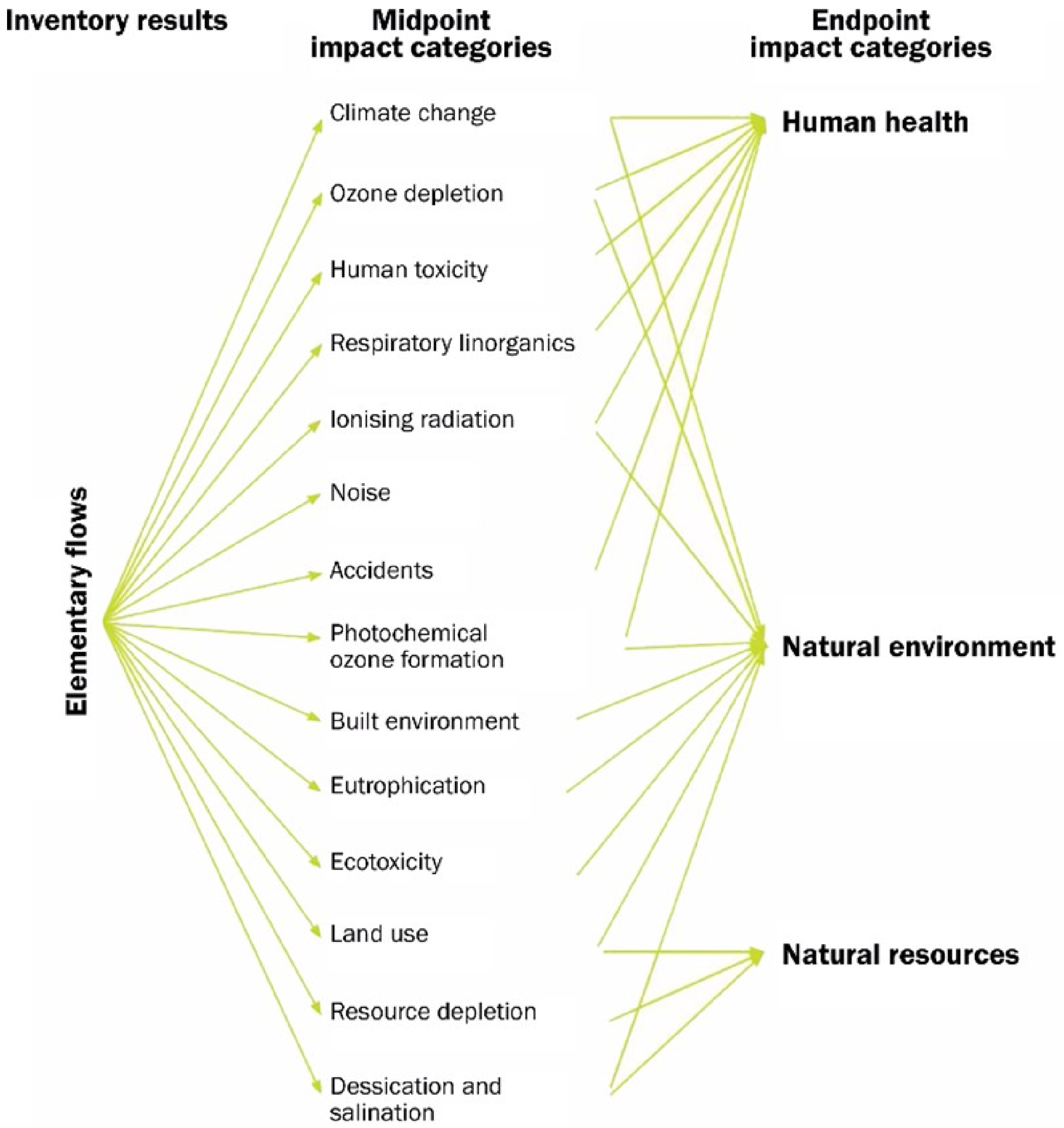


Fig. 9: impact categories, adapted from Garcia Gusano, 2015

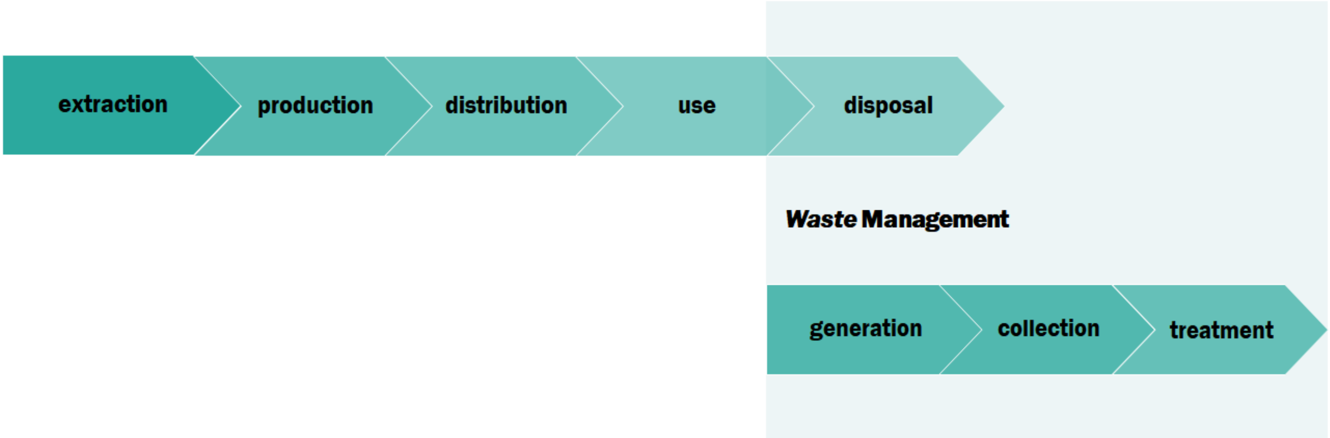


Fig. 10: LCA phases with focus on WM

2.2.2 Scale variations in LCA applications

Over the years there has been an increase in the LCA application field, with the introduction of variations of scale and therefore a distinction between LCA at the level of the single product and LCA at the meso level (for example municipal) and macro level (European Commission et al., 2010). In this regard, Guinée et al. (2011) propose to extend the LCA application from a single product perspective to a meso perspective on a municipal scale or individual urban districts.
Indeed, Albertí et al., (2017) represent the built environment in the form of a hierarchical pyramid formed by elements of ever increasing complexity and the functioning of the layers of this pyramid requires the existence of five types of flow (water, materials, energy, mobility and information) (Fig.11). In red, the figure shows that at the scale of city and urban region, LCA is a field of application that has not yet been properly explored.

Actually, the LCA approach could prove to be a valid tool for assessing the sustainability of a territory, adopting appropriate methodological modifications and hybridizations (Torricelli and Gargari, 2015a).
For example Zamagni et al. (2009) propose the concept of Life Cycle Sustainability Analysis (LCSA) within CALCAS project (Co-ordination Action for Innovation in Life-Cycle Analysis), investigating in this way the possibility of assessing the socio-economic sustainability of complex systems, adopting a life cycle approach that embraces an entire territory, exceeding the limits of the traditional LCA.
Loiseau et al. (2012) propose an approach called “Territorial LCA” (Fig.12), establishing a comparison between different methods for implementing the European Directive (2001/42/EC) on SEA. An example is represented by techniques

such as MFA or ENA, arriving to the conclusion that only the LCA approach can provide a complete framework for the assessment of territorial sustainability.
In subsequent experimentations, they demonstrate that this approach allows the integration of resources, emissions and their potential environmental impacts within the same model.

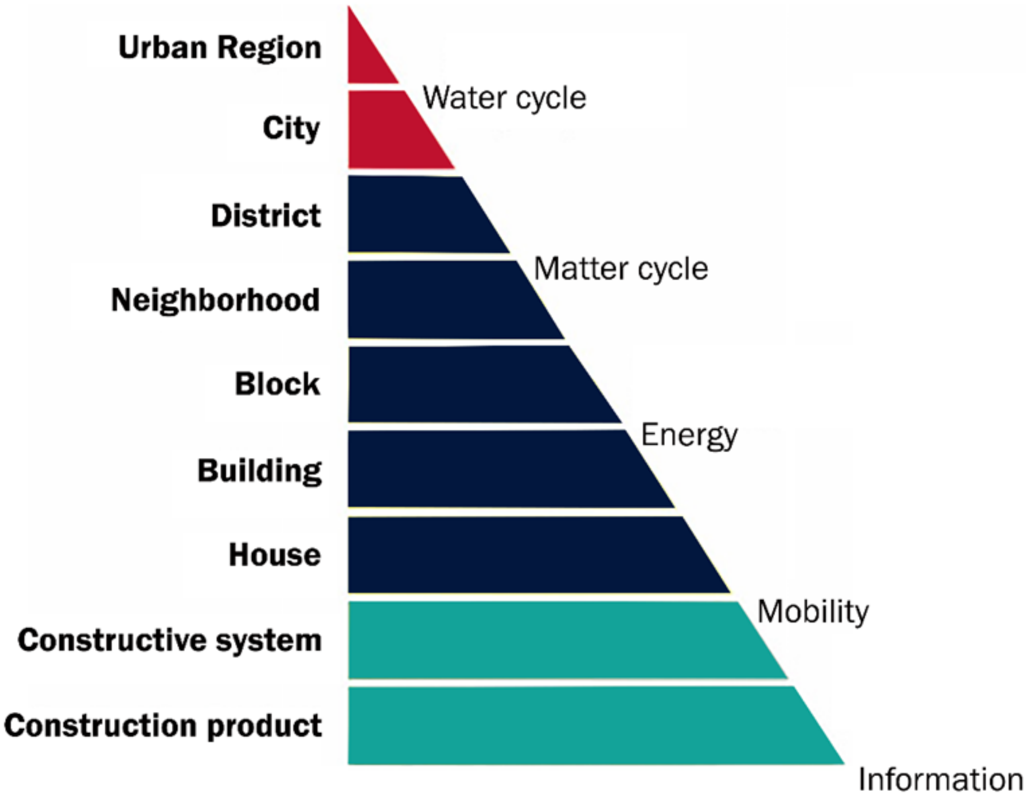


Fig. 11: hierarchy of the built environment, adapted from Albertí et al., 2017

Nitschelm et al. (2016) propose a spatialized territorial LCA (STLCA) applied to an agricultural territory and other authors as well, such as Bidstrup et al. (2015) and Björklund (2012), in the wake of Owens (1997) and Tukker (2000).
Many other studies adapt the LCA method to the analysis of the territory at the regional scale (IRSTEA, AgroParis Tech, Ecole des Mines d'Alès, ELSA).

A first aspect to consider concerns the definition of the aims of an LCA applied to a territorial system, since, in the case of a territory, the environmental impact assessment must provide in support of the decision-making process also relevant information on the potential local environmental impacts deriving from the different planning scenarios. Furthermore, it is necessary to consider local stakeholders and those with whom the territorial system interacts at different scales (Torricelli and Gargari, 2015b). Adopting such a type of approach for the analysis of a territory implies a dynamic interpretation of the same and of the transformations that distinguish it.

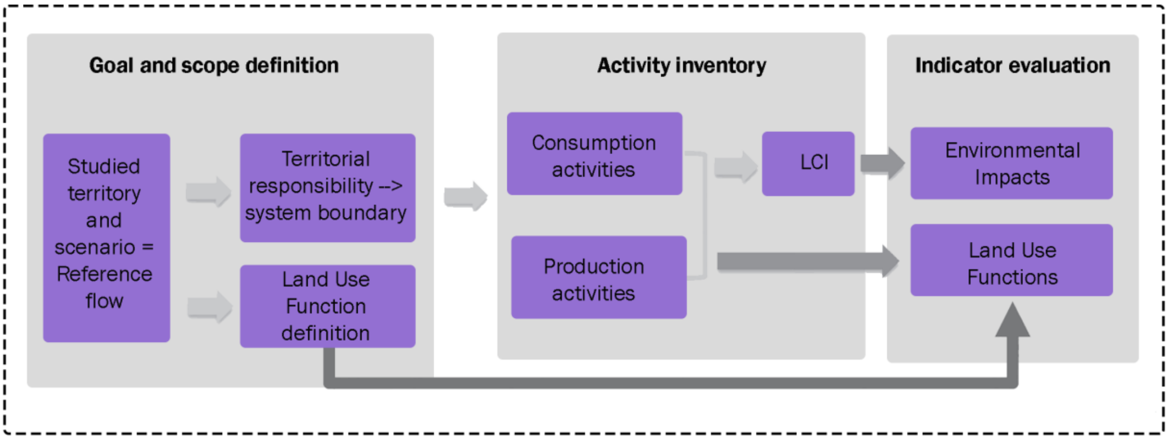


Fig. 12: territorial LCA framework, adapted from Loiseau et al., 2014

As far as the practical application of LCA to the territory is concerned, one of the first obstacle to face is the definition of the FU.

As an example, in the study proposed by Torricelli (2015a), where LCA becomes a tool adopted in order to evaluate the sustainability of a protected natural area, it is proposed the concept of "Functional Equivalent". This concept has been adapted from the building sector and refers to the territory as a complex of territorial resources and services that are both economic, social as well as environmental. In these terms, the Functional Equivalent of a territory is defined as a system of territorial resources and performances, quantified or qualified as adequate to meet the requirements of a given plan scenario, for a given territory, taken as a basis for the comparison of different case studies or scenarios of development (Torricelli, 2015b). An alternative to the Functional Equivalent is represented by Land Use Functions (LUF) (Pérez-Soba et al., 2008), representable as the economic, ecological and social goods and services that derive from the use of the territory by human society and starting from them it is possible to identify a set of territorially valid indicators.

2.3 Territorial LCA: possible developments and applications

As specified above, LCA approach is evolving and from the scale of the single product, the first few and rare applications and hypotheses of applications at scales different from the micro one are spreading (Hellweg and Milà i Canals, 2014; Saner et al., 2013), with the aim of identifying hotspots, thus supporting decision making in land management.
Loiseau et al. (2012) demonstrate the supremacy of the LCA approach for evaluating the sustainability of a territorial system, testing the applicability of the "territorial LCA" through the experimentation on a French Mediterranean case study (Loiseau et al., 2014). The method consists of defining system boundaries and LUF and of preparing an inventory related to the production and consumption activities, assessing their impact on the territory, in line with the necessities of SEA.

Later on, Loiseau et al. (2018) propose a further clarification, dividing territorial LCA in two main approaches (p.474):

- «type A, which focuses on the assessment of a specific activity or supply chain anchored in a given territory»;
- «type B, which attempt to assess all production and consumption activities located in a territory, including all environmental pressures embodied in trade flows with other territories».

An example related to the first type is that developed by Bidstrup et al. (2015), who propose an approach aimed at operationalizing LCA in SEA, evaluating systemic impacts and supporting urban planning through the introduction of sustainability processes (Fig. 13).

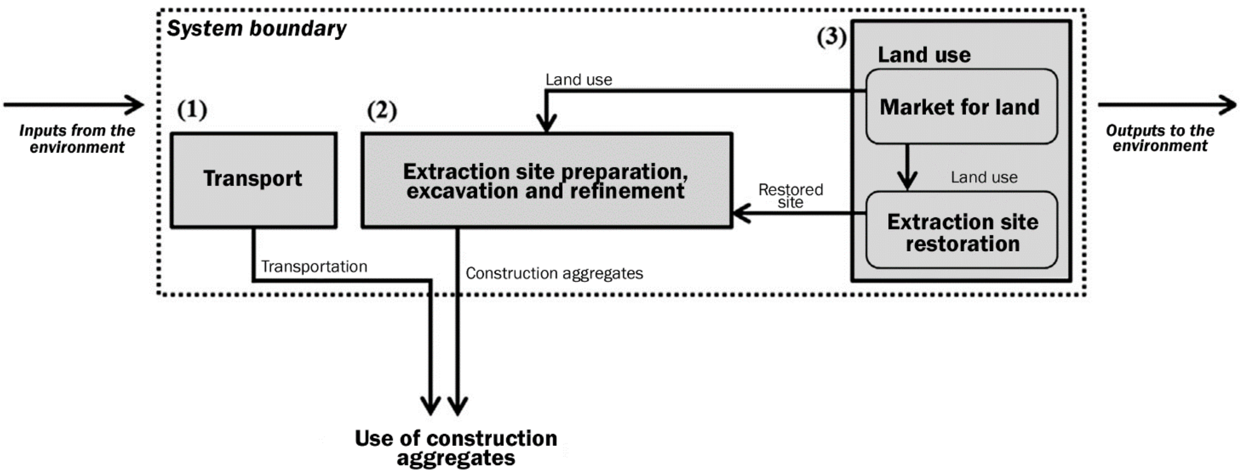


Fig. 13: LCA system boundary, adapted from Bidstrup et al., 2015

The proposed case study is a Danish extraction planning and the starting point is the awareness that SEA, and therefore planning processes, can influence the flow of products and services, and the latter can be modelled through the LCA approach. The first step of the procedure consists in the definition of the so-called "planning variables", and the identified ones are the following:

– transport;
– extraction intensity;
– resource thickness;
– site restoration.

The second step comprises the development of the LCA model, considering as FU 1 m^3 of construction aggregates from an average Danish gravel quarry. The third step is based on the formulation of the planning scenarios, while the fourth and last step is based on the analysis of LCA impacts; finally, the fifth step is that of formulating some planning recommendations. An important focus of this study is related to land use, as it can be changed both during the extraction phase and in the future by site restoration plans.

Another example of LCA of type A is that developed by Laurent (2015), based on the assessment of collective biogas plants in relation to the territorial interest in implementing this kind of plant and considering biogas facilities as multifunctional systems.

LCA of type B is that developed by Loiseau et al. (2014). The starting point of this approach is represented by the presence of a geographical area associated with a territorial planning scenario and the objective is to evaluate the eco-efficiency of this territory, identifiable as a system of flows. The inventory phase considers all the production and consumption activities, including as well upstream processes linked to these activities during 2010 and determining as outputs a vector of environmental impacts and a vector of LUF. Production activities comprise for example agriculture, aquaculture, fisheries, quarrying, manufacturing, shops and service; consumption activities regard inhabitants and tourists. More in depth, societal, economic and environmental LUF are considered and are assessed through performance indicators. As far as the activities are concerned, precise data about them are collected, comprising types and amounts of goods and services consumed or produced. The results of the study shows that human health and ecosystem quality suffer higher impacts from production activities than for consumption ones. The study performs also a distinction between in-site impacts, that are caused by environmental flows that occur in the territory and off-site impacts, that are caused by environmental flows happening outside the territorial border, developing a baseline scenario useful for future comparisons and supporting SEA.

Fig. 14 shows an example of the results obtained by this first application in relation to human health.

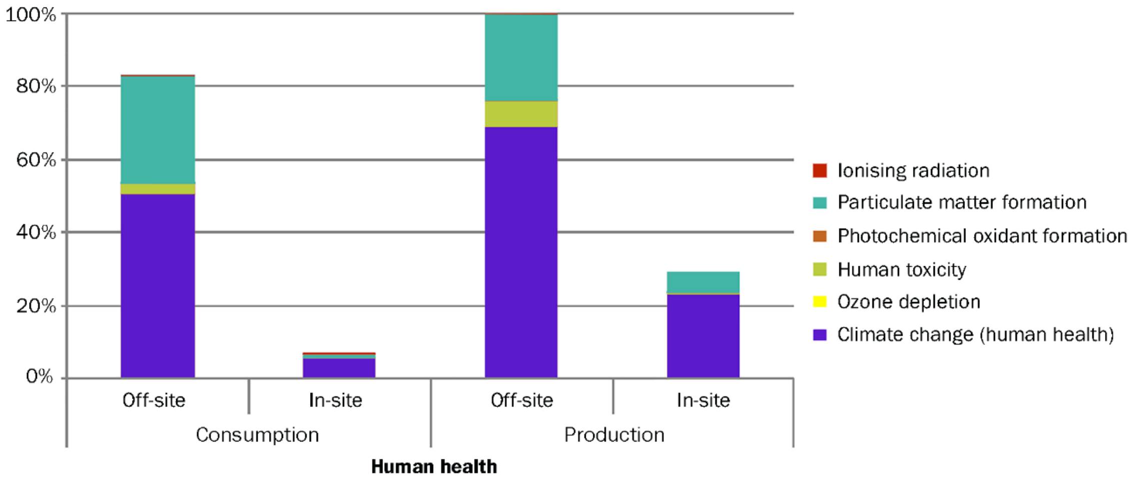


Fig. 14: territorial LCA results, adapted from Loiseau et al., 2014

Gargari (2015) conducts an environmental impact assessment according to the life cycle methodology in relation to the LUF "river boat service" in a natural protected area. The application refers to the Functional Equivalent, to which the environmental loads are to be compared, represented by the Km/passenger parameter. The Functional Equivalent refers to a round trip route calculated on an annual basis in relation to the number of journeys made by the boat along the canal and considering the phases of the life cycle related to the use processes and management of the boat navigation service. The experimentation includes a comparison between the environmental impacts caused by the current transport system and those deriving from the use of the boat (Fig.15).

Another application that takes inspiration from the "territorial LCA" approach is that developed by Mazzi et al., (2017), who propose to combine at the territorial level Environmental Management System (EMS) and LCA in a systemic way.

Furthermore, some policy initiatives aim to generalize the LCA approach in consumption sectors as well as many applications have been carried out in the building sector or assessing the building system taking into account all the life cycle phases. In addition LCA is a required tool in the sector of WM because the European Waste Framework Directive[10] requires the use of LCA to analyse the impacts related to the classical waste hierarchy (Hellweg and Milà i Canals, 2014).

[10]http://ec.europa.eu/environment/waste/framework/

Fig. 15: territorial LCA results for a protected natural area, adapted from Gargari, 2015

Another important approach is that of "regionalized LCA" that is based on the application of regionalized impact assessment methods in order to compare the environmental impacts between different locations of resource extraction or emission through the GIS support (Hellweg and Milà i Canals, 2014).
Therefore this emerging approaches aim at identifying environmental hotspots and to support decision-making in the improvement of environmental performances of future policies (Loiseau et al., 2018).

Nitschelm et al. (2016) underline the necessity to expand the potentiality of territorial LCA by using spatially explicit data considering the territorial nature of decisions, taking into account the locations of activities in a spatially explicit manner. Therefore, they propose a Spatialized LCA (STLCA) with reference to agricultural territories that considers the location of the emissions using spatially explicit databases and GIS to geolocalize the various processes. According to this approach, FU depends on the main territorial function and differently from the territorial LCA approach, they decide to focus the attention not on all the human activities occurring within a territory but on agricultural activity typologies, performing an LCA of type A. The main feature of this method is the spatial differentiation within territorial assessment in relation to a complex system rather than a product or service.
Finally, as already previously specified, many authors propose to integrate LCA and SEA in order to adopt a life cycle and multi-criteria approach in the field of urban planning (Beloin-Saint-Pierre et al., 2017; Bidstrup et al., 2015; Björklund, 2012; Loiseau et al., 2012, 2013).

2.4 Definition of the Research question: LCA as a tool to support the territorial regeneration

Despite the first applications of LCA at different scales, this approach is still at the initial stages of development and therefore little debated. This lays the groundwork for future developments, making it a fertile research context, as there is still not a standardized approach that systematizes the application of this method at the territorial scale and there are still numerous compatibility problems.

Starting from this assumption and from the studies that have already been carried out in this area, it is possible to define a research question focused on the field of environmental assessment from a territorial life cycle perspective, defining a new evaluation framework.

The starting point is the assumption according to which urban and peri-urban ecosystems are considered at the same time cause and solution of today's economic, environmental and social difficulties.
Choosing to apply the LCA of type A approach, therefore LCA application that focuses on a single activity that takes place in the territory and depends on the geographical context (Loiseau et al., 2018), the objective of this Ph.D. thesis is to demonstrate how LCA can represent an instrument to support the regeneration of the territory.

A territorial LCA can have two main goals (European Commission and Joint Research Centre, 2010):

- accounting, that is only based on the description of the system under study for a territorial diagnosis;
- meso-macro-level decision support, that is based on the environmental impacts of spatial planning scenarios and their consequences.

For the present aim, the second goal is adopted, applying a consequential approach that is based on the implementation of future comparison scenarios.
As it will be seen, a multi-scalar model for the assessment of impacts related to the treatment of Construction and Demolition Waste (CDW) is developed, applying an LCA focused on the WM phase. The multi-scalability becomes an important element, as from an assessment of the CDW flows crossing the entire Campania Region, the application moves to the Focus Area, which will be described in the following paragraphs, and finally a single exemplifying case study at the construction scale will be chosen.

Therefore, based on the aspects analysed so far, the aim of the present thesis is to apply a territorial LCA of type A to some municipalities of the Metropolitan Area of Naples (MAN), in relation to a baseline scenario and to a possible scenario of development.

Urban Metabolism is, therefore, investigated according to the waste flow, adopting a network approach (see paragraph 2.1) (Fig. 16).

Following the canonical phases of an LCA, the first step will consist in defining the reasons for which the assessment is carried out in relation to the objectives to be pursued (goal and scope). It is of considerable importance to create an information base that can support decision makers, increasing the level of knowledge and awareness of the territory and consequently stimulating balanced and sustainable planning choices, safeguarding natural and man-made capital and assessing environmental burdens and the resulting impacts. This is due to the fact that in many cases, decision makers do not have enough spatially defined information available (Kumar et al., 2016).

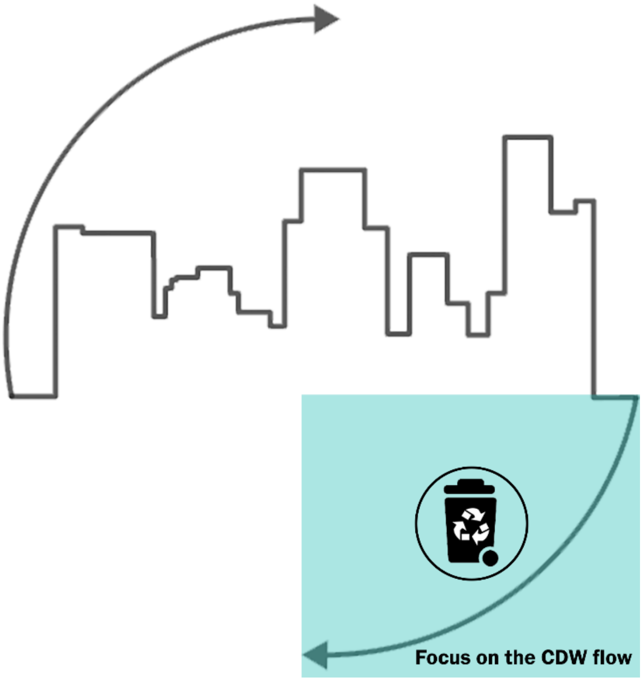


Fig. 16: Focus on the waste metabolic flow

The next step will be the definition of the so-called FU, which will become a reference point in the analysis of environmental impacts and loads. Subsequently, the boundaries of the system under analysis will be established, which according to UNI EN ISO 14044 define which parts of the life cycle and which processes belong to the analysed system and are necessary to provide for its function, as defined by its FU. The boundaries therefore separate the system under analysis from the rest of the technosphere. At the same time, the boundaries also define the limits between the analysed system and the ecosphere, to establish through which borders the exchanges of elementary flows with nature take place (European Commission et al., 2010). Then, an inventory analysis of resources and emissions will be carried out in relation to the input and output flows that will be examined.

Finally, the last phase will consist in the interpretation of the results of the evaluation and in the identification of conclusions and useful recommendations for the decision makers who operate in the territory under investigation.

The territory is commonly considered a geographical space managed by local stakeholders and characterized by a regional identity. The inclusion of this concept in the application of LCA is still an open field (Mazzi et al., 2017) which requires new definitions and experimental applications. The use of spatially explicit data is necessary to evaluate the environmental impacts of a territory and although LCA was born as an approach independent from spatial characteristics, it is necessary to consider that decisions (for example of an environmental and administrative nature) take place locally. Therefore, it is important to evaluate the environmental impacts of the activities that take place on the territory, considering their location in a spatially explicit way and starting from the assumption that emissions and impacts take place in different locations (Nitschelm et al., 2016).

Urban ecosystems are endowed with high potential to reduce the input and output flows of resources through more efficient territorial management, based on a better spatial organization and a governance based on a participatory construction of choices.
In order to obtain an urban management that can be defined as *resource-efficient*, it is advisable to have a detailed knowledge of the territory and the urban metabolic flows (EEA, 2015), to guide decision makers in defining sustainable planning choices. The current linear models of UM are configured as sources of vulnerability that determine the need to close the cycles in line with the principles of CE. In fact, the concept of UM, thanks to its interdisciplinary character, makes it possible to compare alternative urban structures, configuring itself as an effective evaluation tool. In the present approach, UM is analysed from the waste perspective, evaluating the impacts of output waste flows.

Definitely, the present research thesis aims to lay the foundations for the development of a model capable of supporting environmental assessment linked to the regeneration of the territory, through the union of two components: LCA and wasted landscapes, the latter representing the territorial component of the proposed approach. Consequently, the idea is to present a new utility attributable to LCA and to lay the foundations for the creation of an evaluation model which allows to make the decision making phase linked to the regeneration of wasted territories more aware, thus supporting the regeneration of the territory itself.

As it will be shown in the following chapters, from the evaluation of a single product or service, this tool proves to be valid in supporting the environmental assessment in relation to the treatment of CDW coming from the regeneration of the territories occupied by disused industrial buildings.

Therefore, the metabolic flow under investigation is in output compared to the urban ecosystem analysed and is represented by the waste component in relation to the WM phase of the supply chain (Fig.17).

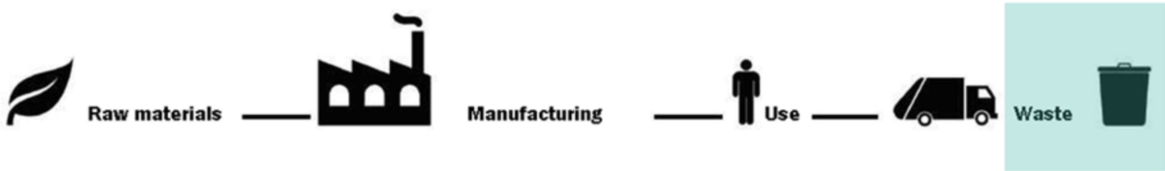


Fig. 17: focus on the waste component flow, adapted from Kalatha, 2015

Starting from the awareness of the environmental pressures that are generated in the cities, understood as urban-territorial ecosystems, the research objective is to propose a framework that allows to methodologically define a process of environmental assessment in a life cycle perspective.
In order to stem the negative externalities, it is necessary to create a territorial government that reflects a sustainable environmental protection, considering the territory as a complex dynamic system. To this purpose, it is proposed to reshape the instrument of LCA, introducing some methodological changes to adapt it to the analysis of the territorial metabolic flows, with focus on the CDW waste flows.

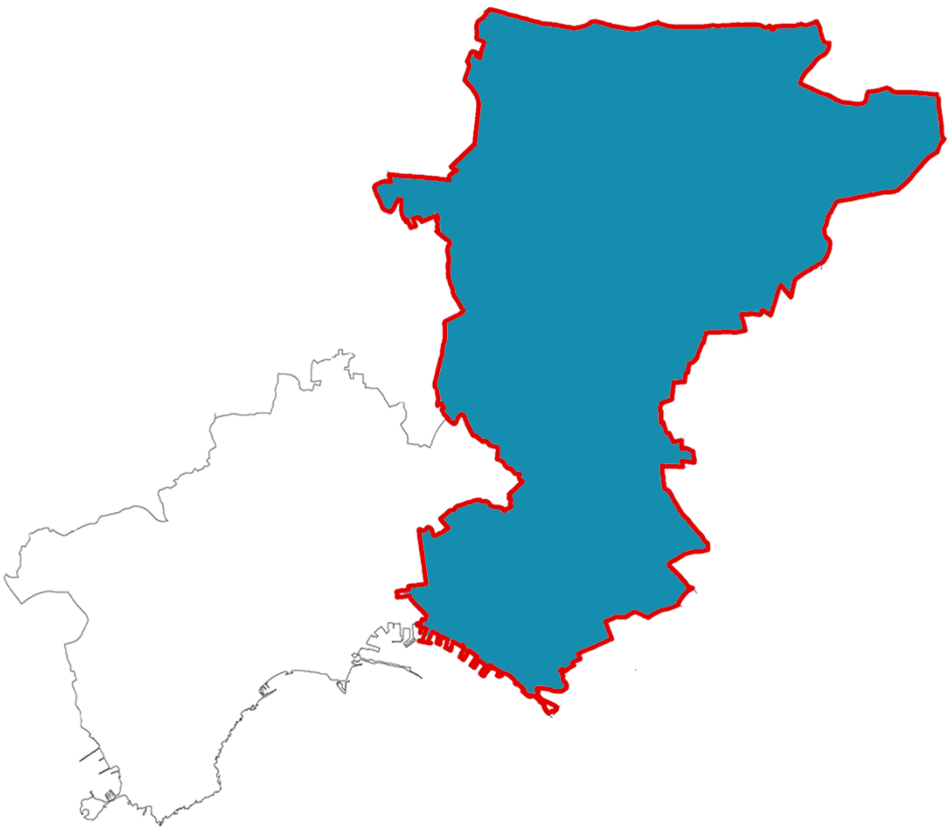
As a matter of fact, urban and peri-urban areas are sources of environmental pressures that go even beyond their own territorial borders, making clear the need to quantify the metabolic flows in and out of urban ecosystems, i.e. the metabolism of the same and the physical exchange processes. From this perspective, a multi-scale approach is adopted. This is because «planning, designing, and managing urban spaces across multiple scales require understanding how the many interacting components and subsystems together create patterns and processes that influence system dynamics» (McPhearson et al., 2016, p. 200).
Moreover the "ecology of cities" approach proposed by McPhearson et al., (2016) is adopted, according to which built infrastructure is incorporated in the way social and ecological components interact in urban ecosystems (Cadenasso et al., 2006). In this way, urban ecosystems can become models for the analysis of the interactions of social and biophysical patterns and processes (Collins et al., 2011), adopting a systems focused perspective. According to this, the relationships among social, ecological and technical infrastructures and subsystems of a defined urban ecosystem are analysed (McPhearson et al., 2016).

Definitely, it is proposed to adopt a life cycle based perspective in the evaluation of urban metabolism with focus on the outgoing waste flows, defining a functional framework for the environmental assessment of the territory, with a multi-scale application, establishing a methodological approach that can represent a Spatial Decision Support System (SDSS), that, as it will be seen in the next chapters, is due to the use of both LCA and GIS with reference to wasted landscapes. The latter are investigated according to abandoned industrial buildings, focusing on the category of territorial life cycle defined by Carta (2013) as “completed or never born life cycles”, in which to adopt regenerative solutions.

In this way, multiple spatial scales are investigated as well as cross-scale interactions, adopting new methods, models and tools to deal with human complexity and integrating knowledge on urban ecosystems processes and dynamics (McPhearson et al., 2016).

CHAPTER THREE

Methodological proposal and case study identification



3.1 REPAiR – Resource Management in Peri-Urban Areas: Going Beyond Urban Metabolism[11]

The present thesis originates and develops from the Horizon 2020 project REPAiR, that is the starting point from which the research question has been identified and constructed.

REPAiR investigates the possible methodologies to analyse and operationalize the UM concept and to understand the relationships between the flows that cross urban ecosystems with regard to peri-urban areas and the consequent territorial impacts. The principal aim of the project is that of developing integrated, place-based, eco-innovative spatial development strategies, through the creation of a Geodesign Decision Support Environment (GDSE) that will be provided to regional authorities.

GDSE is integrated with the LCA approach and this two tools will coordinate the dialogue among stakeholders, that happens through Living Labs focused on peri-urban territories and called Peri-Urban Living Lab (PULL) (Fig. 18).

All these tools will be briefly introduced in the next paragraphs.

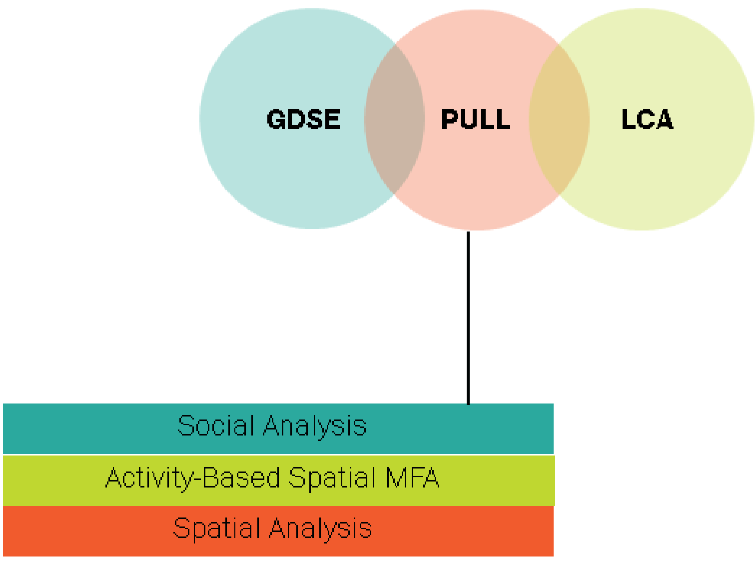


Fig. 18: REPAiR methodology

[11] All the information about REPAiR derive from the Project proposals and from the cited Deliverables. More news and information can be found by visiting the Project website: http://h2020repair.eu/

3.1.1 Geodesign Decision Support Environment

GDSE is based on the concept of Geodesign (Steinitz, 2012), that means *changing geography by design.* It represents *a* dynamic and collaborative process that integrates the creation of bottom-up proposals with the simulation of their impacts, through the support of the geographical context, the systemic thinking and the digital technology (Fig. 19).
The importance of this tool is represented by the fact that while the traditional planning and design processes are used to separate the analysis, design and evaluation phases, determining three distinct steps, Geodesign brings together the three phases, allowing to formulate an advanced design solution.

In REPAiR, this tool allows developing and simultaneously evaluating alternative strategies in the field of matter and WM and it is integrated to the concept of "life cycle thinking". The latter is based on the consideration of all the phases that a product crosses in the course of its life cycle, starting from that of extraction of raw materials up to that of waste disposal (Zamagni and Reale, 2015), all enclosed in the "supply chain" concept.

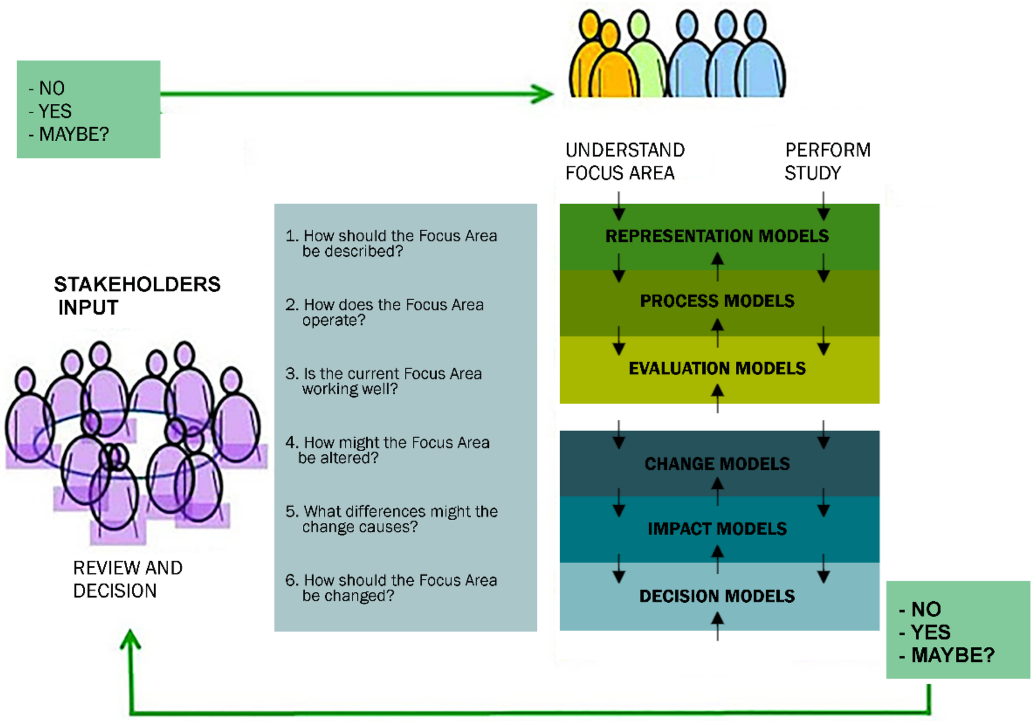


Fig. 19: Geodesign model, adapted from Steinitz, 2012

3.1.2 Peri Urban Living Lab

As far as the PULL concept is concerned, the PULL of REPAiR are the instrument of dialogue among stakeholders and they allow promoting inclusiveness and participation, representing one of the main innovations.

Living Labs (LL) in general can be defined as:

«user-centered, open innovation ecosystems based on a systematic user co-creation approach in public–private–people partnerships, integrating research and innovation processes in real life communities and settings» (Garcìa Robles et al., 2015, p.12).

Furthermore, it is important that stakeholders are involved in a creative space in which they can be able to develop design ideas that can bring to societal changes, integrating common knowledge and expert knowledge, as well as linking public and private stakeholders. The key actors involved in REPAiR and whose attention is focused on the peri-urban areas of the territory are heterogeneous and mainly represented by the main regional and local authorities, but also by national governments, as well as by representatives of industrial reality, non-governmental organizations, universities and even ordinary citizens.
The main objective of each LL is to develop products and services in close cooperation between the involved stakeholders, in order to base the choices on the real needs of users, thus rewarding a less technology-driven approach and promoting the needs and desires of the users at each stage of development (Ståhlbröst, 2008).
Specifically, the purpose of each PULL is to identify Eco-Innovative Solutions (EIS) that can give new value to waste products, which transforming themselves into a new resource, in line with the principles of CE, can also mitigate territorial impacts and reduce metabolic flows crossing peri-urban areas (REPAiR, 2015).
The dialogue among stakeholders during the REPAiR PULL for the identification of EIS is guided by two DSS (Simon, 1960) represented by GDSE and LCA. These two tools, together with PULL workshops, structure the methodological component of REPAiR, operating autonomously and at the same time dialoguing with each other through a succession of mutually interconnected phases.

3.1.3 REPAiR purposes

The REPAiR project creates the possibility of identifying new governance approaches and management practices, involving multiple actors at different levels. REPAiR

indeed is based on the concept of "quadruple helix" (Arnkil et al., 2010) which is focused on the collaboration between universities, public administrations, companies and citizens. This model represents a possibility of interaction between WM and urban regeneration practices as well as the functionality of urban metabolic processes, considering CE as a basic framework.
By integrating the two key principles of CE and UM, REPAiR intends to demonstrate, through the assessment tools previously described, that by the implementation of EIS based on the principles of CE, it is possible to reduce waste in terms of outgoing metabolic flows. In this way, it is also possible to create opportunities for the spatial regeneration, reconnecting the waste spaces of the peri-urban territories to the remaining urban fabric. In this context, EIS do not necessarily represent project actions, but are also configured as new services, addresses and strategies or small-localized actions able to improve the functioning mechanisms of the territorial system.
Ultimately, REPAiR wants to achieve a model of land management that intertwines with WM and with the redevelopment of peri-urban areas, laying the foundations for reactivating waste areas from an environmental, economic and social point of view. It is shown that waste can be understood as a potential resource, assuming a positive meaning from the point of view of circularity and recycling.

3.1.4 Activity-Based Spatial Material Flow Analysis

Definitely, starting from the support of technical evaluation tools, it is necessary to guarantee a trend reversal, which allows translating technological innovations into actions and solutions that are effective but compatible with the urban and environmental heritage, to allow conservation and recovery together with the conferment of new qualities. In this perspective, UM becomes a model that allows to combine the anthropic activities that take place in urban and territorial ecosystems and that characterize the various phases of the supply chain with the related urban and territorial infrastructures that host these activities (Beloin-Saint-Pierre et al., 2017).
In addition, «REPAiR examines the processes that drive the transformation of resources into products, services and waste, as well as their impacts», integrating MFA and LCA «into spatial models and planning policies» (REPAIR, 2015, p.3).
Furthermore, REPAiR adopts a systemic perspective, and this means that looking at materials when they have already become waste is not sufficient; it is necessary to analyse why, how, where and by whom the same materials were generated. For this purpose, it is not adopted a simple MFA, but an Activity-Based Spatial Material Flow

Analysis (AS-MFA) that investigates the links between activities, the production and consumption systems and the actors involved, revealing where responsibilities lie and analysing the links between spatial characteristics and material flows (Geldermans et al., 2017).

3.1.5 Spatial and Social Analyses

Spatial and Social Analyses are performed as well. On the one hand, the first associates the investigation of the flows that cross and are processed within the territory under analysis and the spatial effects of UM on the territory, identifying «the boundaries, the geographies, the *wastescapes*, and the policies and planning instruments [...]» (Geldermans et al., 2017, p.14). Social Analysis on the other hand investigates the sociocultural features and social sensitiveness with reference to waste and resource management.

3.2 Waste and "*wastescapes*" flows

REPAiR parallels waste products and wasted landscapes, called "*wastescapes*" (Amenta and Attademo, 2016).

According to Lynch (1990, p.146), waste «is worthless or unused for human purpose. It is a lessening of something without useful result; it is loss and abandonment, decline, separation and death. It is the spent and valueless material left after some act of production or consumption, but can also refer to any used thing: garbage, trash, litter, junk, impurity and dirt. There are waste things, waste lands, waste time and wasted lives».

Similarly, Berger (2006a, p. 203) states that «contemporary modes of industrial production driven by economical and consumerist influences contribute to urbanization and the formation of waste landscapes – meaning actual *waste* (such as municipal solid waste, sewage, scrap metal, etc.), *wasted* places (such as abandoned and/or contaminated sites) or *wasteful* places (such as oversized parking lots or duplicate big-box retail venues)».

From this perspective, «cities are not static objects, but active arenas marked by continuous energy flows and transformations of which landscapes and buildings and other hard parts are not permanent structures but transitional manifestations». (Berger, 2006b, p. 203).

Waste in its spatial connotation is the outcome of urban processes that characterize the activities of the supply chain, i.e. the set of activities that feed the life cycle of a product from the phase of extraction of raw materials up to the disposal of waste materials.
The supply chain, in other words, represents the distribution chain of a product or service from the supplier to the customer, starting from the raw materials necessary for its realization, then moving on to the realization of the product, and subsequently to the phases of management and distribution to the customer, which carries out the consumption phase. Each single phase determines the production of waste products, and tracing the waste streams starting from the production phase of the products, allows to analyse the consumption patterns and to identify better paths to be taken, facilitating the transition from the linear economy model to the circular one. For this purpose, as already specified, REPAiR uses an AS-MFA methodology that «provides a systematic way of analysing material flows within regions using three main system components:

1. (economic) activities;
2. activity-associated materials;
3. the actors involved and their interrelations.

This methodology enables the identification of key activities and actors, which reveals where responsibilities lie and therefore lays open distinct points for policy or business (case) interventions. Knowledge of the actors discloses their spatial location, thereby providing spatial understanding of the regional actor network and its geographical position related to material flows» (Geldermans et al., 2017, p. 40) (Fig. 20).

In the same time, *wastescapes* are an inevitable result of the processes of economic growth. Therefore, the flows of matter and energy and those of waste that feed or come from the activities of the supply chain are also able to shape the territory in its physicality. This generates the development of portions of territory that are no longer able to provide goods and services and, finding themselves at the end of their life cycle, they connote themselves as “waiting spaces” or *terrain vague*. This is because resources, i.e. everything that is found in nature and that can be used for production or economic consumption, feed these activities (OECD, 2010). The latter produce waste and emissions that damage land, water, fields, but also buildings and infrastructures. The activation of new urban regeneration processes, as a result of PULL workshops, may be able to give new functions to these portions of territory and to reconnect them to the surrounding urban fabric. This means that the real challenge is to integrate these portions of land into the functioning of urban ecosystems (Berger, 2006b), turning useless matter into useful matter, as it happens in the waste recycling system (Erz, 1992; Strasser, 1992).

The starting point of this process is the assumption that the city does not follow an unmodifiable biological path, but has the ability to regenerate itself, overcoming a life cycle and decline phase, reinterpreting its components (Gabbianelli, 2013).

In particular, the Neapolitan case study has selected as key waste flows to analyse two categories that collect interest on the territory:
- Organic Waste (OW);
- Construction and Demolition Waste (CDW).

Anyway, as already underlined, «going beyond the material dimension of waste flows, REPAiR includes in its experimentations the category of *wastescapes* that embrace the spatial effects of waste flows on the landscape as well as all the residual spaces scattered in the peri-urban areas object of the study» (Geldermans, et al., 2017, p. 25).

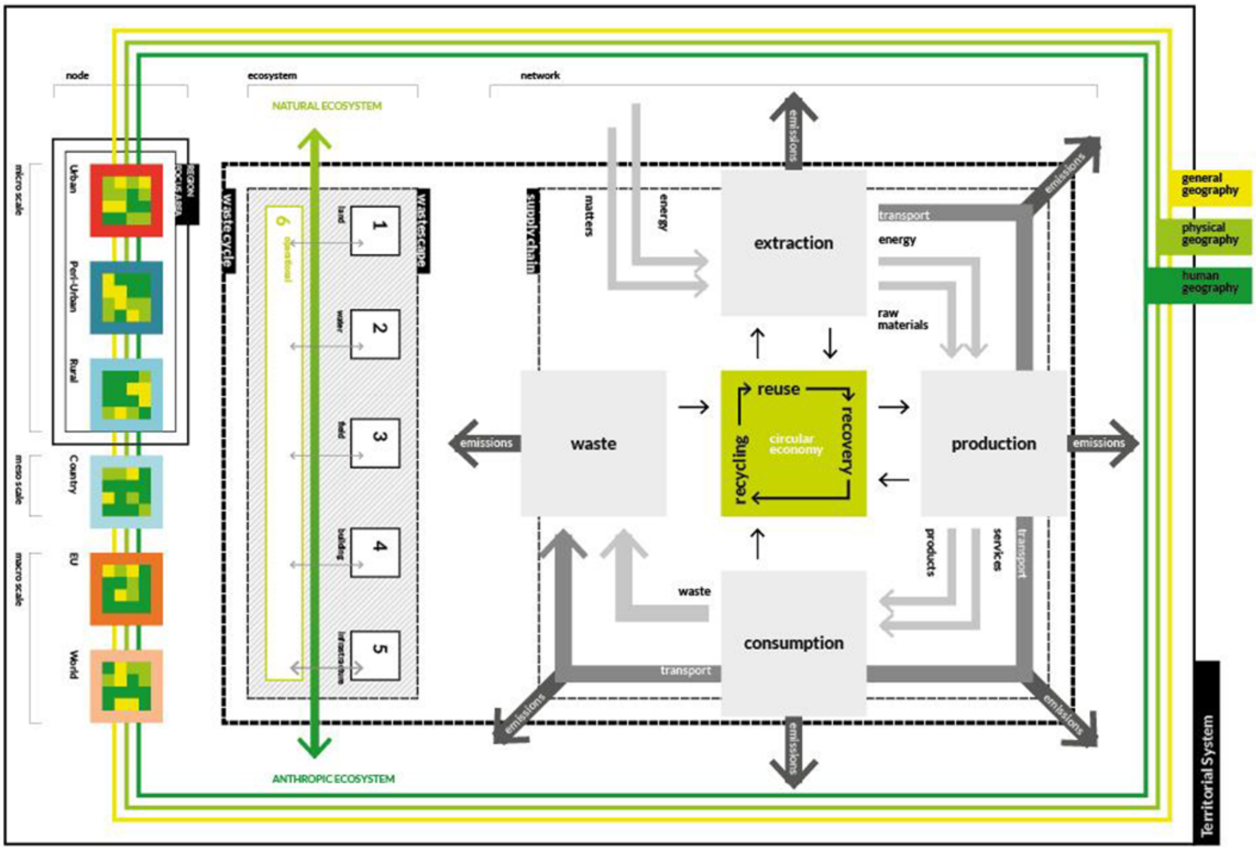


Fig. 20: the waste supply chain, Geldermans et al., 2017[12]

[12] The present figure has been presented at the poster session of the Conference "Valutare la Rigenerazione Urbana", organized by Associazione Analisti Ambientali and held in Naples (October 27-28, 2017). Authors: Cerreta M., De Rosa F., De Toro P., Inglese P., Iodice S.

The concept of *wastescapes* derives from that of *drosscapes* coined by Berger (2006), i.e. wasted landscapes that are an outcome of metabolic processes. *Drosscapes* «accumulate in the wake of the socio – and spatio – economic processes of deindustrialization, post-Fordism and technological innovation» and they «are located in the declining, neglected and deindustrializing areas of cities» (Berger, 2006, p. 239).
Consequently, there are physical components of the urban structure that lose their function and, at the same time, the economic and social recognition of their usefulness: what occurs is the definitive or temporary suspension of a determined use of a certain space, with its consequent abandonment, the subsequent re-use, and more rarely and more distant in time its full replacement.

The categories of *wastescapes* that have been selected in REPAiR comprise some *drosscapes* as well as the facilities dedicated to the management of waste. Therefore, «*wastescapes* are related to the spatial effect of material waste flows on the territories and to the configurations of the infrastructures for their management. From a spatial, environmental, and social point of view, *wastescapes* can represent challenging areas. Therefore, to be spatially connected with the surrounding settlements and become accessible areas as public spaces, they need to be transformed and regenerated» (Geldermans et al., 2017, p. 25).

More precisely, *wastescapes* are defined as: «patches of landscape related to waste-cycles both by functional relations and because they are "wasted-lands": anomalous areas inconsistent with the peri-urban metabolism that become neglected spaces» (Russo et al., 2017, p. 67).
In addition, «the notion of *drosscape* emphasizes the opportunity to reuse the material scraps of the city as in-between areas and abandoned spaces go beyond the mere spatial reference of soils and fields and embrace the wider and multidisciplinary field of landscape. In the REPAiR research focus, *wastescapes* involve also the spaces that enable the urban system to be efficient» (Geldermans et al., 2017, p. 13).

REPAiR identifies 5+1 categories of *wastescapes* (Fig. 21), which are grouped in *drosscapes* and *operational infrastructure of waste*.
The categories are the following:
1. degraded land (W1);
2. degraded water and connected areas (W2);
3. declining fields (W3);
4. settlements and buildings in crisis (W4);

5. “dross” of facilities and infrastructures (W5);
6. operational infrastructure of waste (W6).

Ultimately, REPAiR is composed by two macro phases, the first consists in understanding the spatial processes that characterize the current scenario, analysing the conditions in order to prepare the ground for the future proposal of intervention scenarios and the analysis of the impact of the same, with the support of participatory planning processes. The second macro phase consists in the elaboration of intervention scenarios aimed at promoting waste as a new resource and giving new life to *wastescapes*, identifying possible EIS and possible alternatives of spatial regeneration.

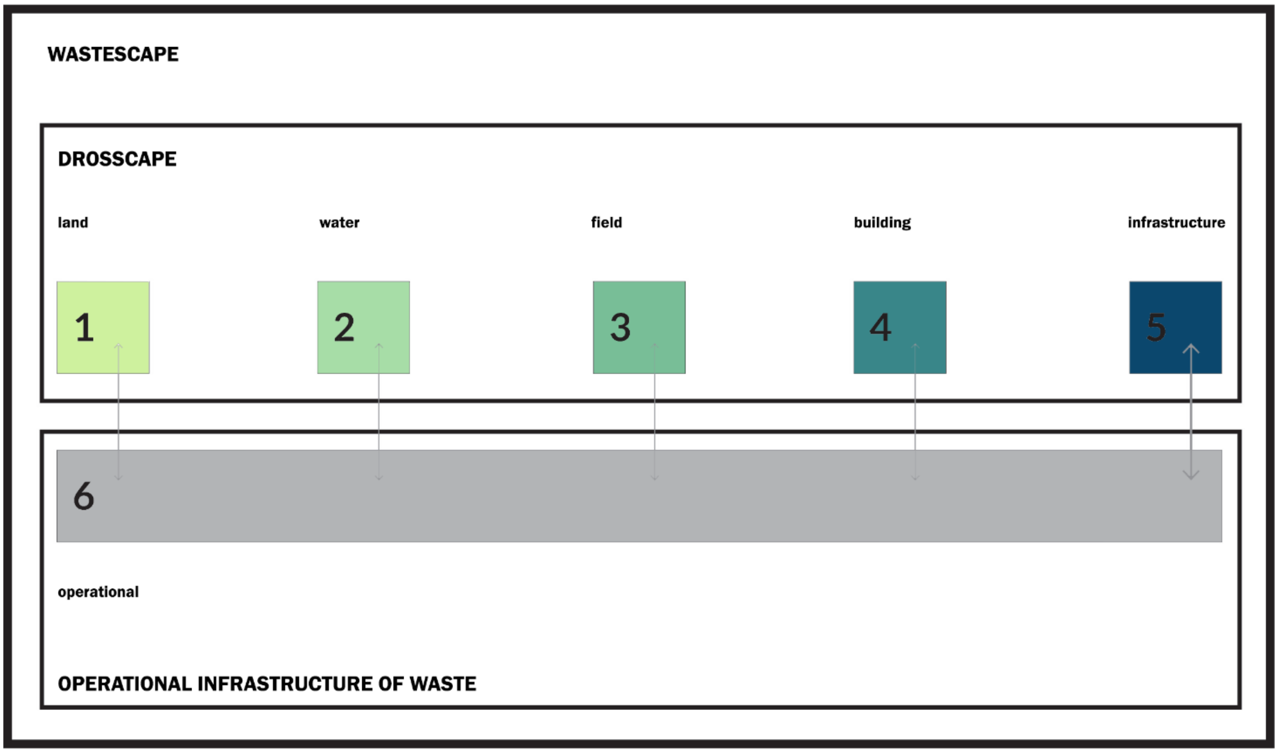


Fig. 21: *wastescapes* categories, adapted from Geldermans et al., 2017

The disuse can be understood as a “natural” phase of the life cycle of the functions and spaces predisposed to welcome them (Baiocco et al., 2018). This vision determines the consideration of urban ecosystems as endowed with a metabolism capable of digesting, assimilate and feed the succession of cycles of production and where space is always small with respect to the quantity of flows (economic and human) that cross it. In the last twenty years, with an acceleration in recent years, also Italy has known the multiplication of situations in which disposal processes and underutilisation of public and private assets have manifested themselves with a certain impact (Baiocco et al., 2018).

Definitely, waste can be interpreted as a natural and unavoidable component of an evolving and dynamic urban ecosystem and represents an indicator of its healthy growth (Berger, 2006b).

3.3 How to identify *wastescapes*? Land Use Functions and indicators definition

As seen below, *wastescapes* are intended as the negative externalities of the environmental, social and economic interactions that happen in urban ecosystems.
For the territorial identification of *wastescapes*, it is necessary to define a precise spatial methodology of analysis that could be systematically replicable in the heterogeneous contexts proposed in REPAiR.

The flows of matters and energy that cross the territory, allowing the carrying out of the activities of the supply chain, cause not only emissions and waste flows, but they also physically shape the territory. There is, indeed, a strict link between territorial processes and *wastescapes* determination, which can be considered the spatial result of UM together with impacts at micro, meso and macro scale.
Therefore, the metabolic activities of extraction, production, distribution and consumption that define the supply chain and the activity of WM, affect resources, but simultaneously are able to generate Land Use Functions (LUF) and to provide environmental, social and economic services as well. In the same time, they alter the territorial performances, generating multidimensional impacts and in addition a particular form of spatial impact known as *wastescape*. As already specified, the latter are portions of territory at the end of their life cycle that need to be regenerated in order to give rise to new functions as well as to new services (Fig. 22).

The general idea for the *wastescapes* characterization methodology is that of aggregating increasingly complex information up to the definition of performance indicators. The spatial organization of a city, as well as its infrastructural system, affect the resources used to support the human activities of urban ecosystems and therefore its level of environmental pressure on the regional and global environment (Alberti and Susskind, 1996).

The starting point is the concept that these metabolic activities are powered by resources (EEA, 2015) that feed the processes that act on the territory and generate in the meantime environmental, social and economic performances.
The European Commission's Thematic Strategy on the Sustainable Use of Natural Resources (European Commission, 2005) states that European Economies depend on natural resources that can be defined as anything that occurs in nature that has the possibility to be used for economic production or consumption (OECD, 2010) or also that can be used for producing something else (UNEP, 2011). According to European Commission (2005), natural resources that feed European economies are composed by:

- raw materials, such as minerals, biomass and biological resources;
- environmental media such as air, water and soil;
- flow resources such as wind, geothermal, tidal and solar energy;
- space (land area)

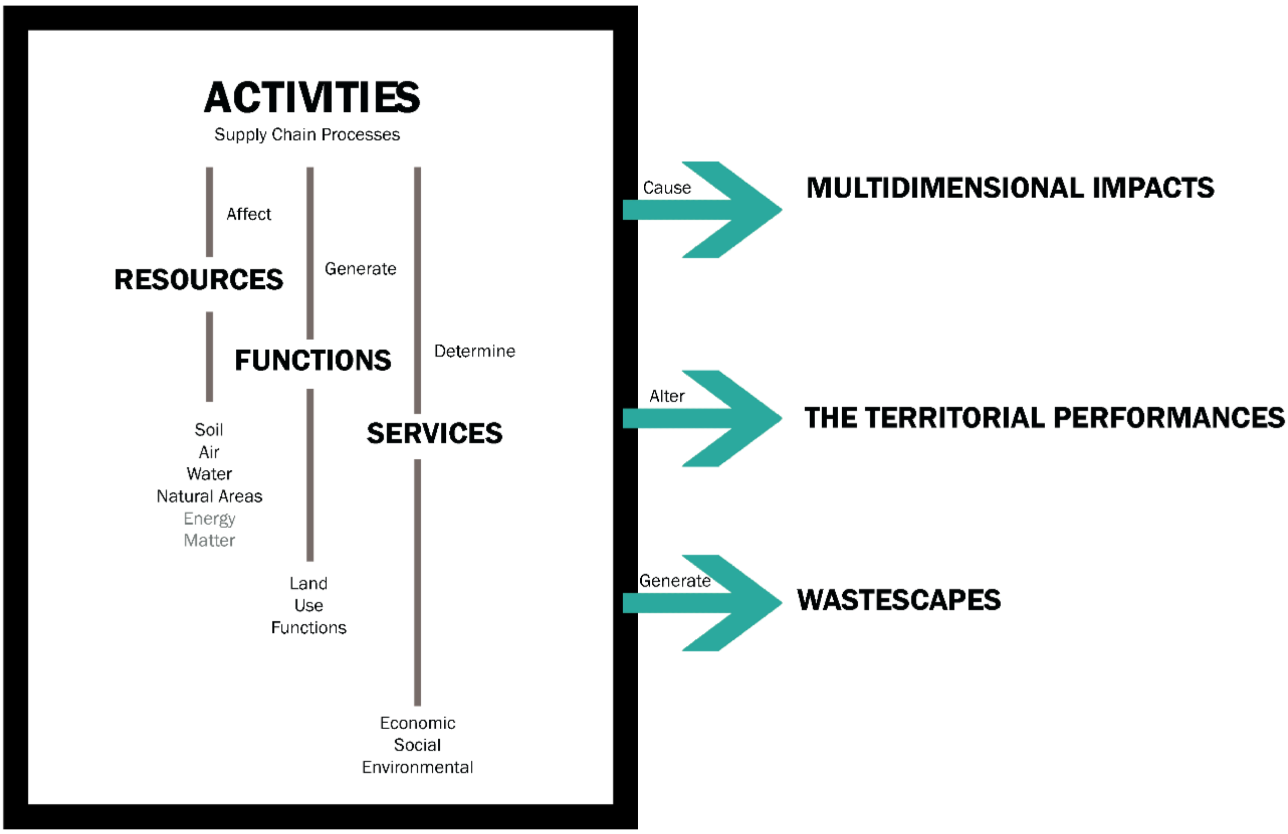


Fig. 22: activities in the supply chain processes and their consequences, Geldermans et al., 2017

The life cycle of the supply chain processes and the available resources allow interpreting the territory as a system of use functions (Loiseau et al., 2014; Torricelli and Gargari, 2015a). Brown (2017) speaks about “Urban ecosystem functions”, described as the ecosystem properties over time, i.e. the result of pattern, structure, and/or processes happening in urban ecosystems over time.

The system of interpretation for the *wastescapes* characterization is formed by four main steps which follow each other cyclically.

- pattern;
- process;
- driver;
- effect.

As far as the pattern is concerned, once selected the *wastescape* to characterize, the first step is the selection of the appropriate geographies that allow defining the main features of the area under analysis from a physical and human perspective (Geldermans et al., 2017). As a matter of fact, «form – the spatial patterns of the built, infrastructural, and embedded biotic components of cities – is a crucial component of urban structure». This link between urban structure and its functioning provides a new way of analysing urban ecosystems patterns and processes (McPhearson et al., 2016, p. 206).
The selection of the *wastescape* to characterize has to be made from the beginning, as this choice will influence the subsequent methodology.

Secondly, *wastescapes* are the results of the territorial processes and therefore they could be analysed according to each single activity of the supply chain, that influences flows and stocks within the urban ecosystem (Dijst et al., 2018). Once chosen the activity to analyse, it is necessary to define the land cover that hosts this activity and the subsequent land use.
On the one hand, the first represents the observed (bio)physical cover of the earth’s surface (Di Gregorio and Jansen, 2005) and it is formed by three main categories: natural vegetation, crops and human structure, each of one generating a certain number of sub-categories. The main reference for the land cover is represented by the Corine Land Cover (CLC) elaborated by Copernicus at its latest version (2012)[13].
On the other hand, land use refers to the human activities carried out on a certain land cover from a functional dimension (Torricelli, 2015a) and the reference can be represented by the categories of land use proposed by European Environment Agency

[13] https://land.copernicus.eu/pan-european/corine-land-cover/clc-2012/view

for the latest version of Urban Atlas (2012)[14]. Land use is a determining factor that influences the ability of ecosystems to provide services (EEA, 2015).

From a combination of the two informative layer, a system of Land Use Functions is developed according to the categories proposed by Pérez-Soba et al. (2008), to which the cycles of the activities of the supply chain and the resources that feed these activities refer. As stated by Verburg et al., (2009), more attention should be given to land use as well as to LUF and to the correlations between the two.
LUF can be defined as the «goods and services that the use of land provides to human society, which are of economical, ecological and socio-cultural value and are likely to be affected by policy changes» (ESPON, 2013, p. 12).

Land Use Functions, representing the social, environmental and economic issues of a territory, are classified by Pérez-Soba et al. (2008) as follows:
- provision of work;
- human health and recreation;
- cultural and aesthetic values;
- residential and non land-based industry and services;
- land-based production;
- infrastructure;
- provision of abiotic resources;
- support and provision of biotic resources;
- maintenance of ecosystem processes.

Each LUF can be analysed from an environmental, social or economic perspective according to the *wastescape* to characterize. LUF consideration allows to complete the pattern definition.

The following step is related to the processes that happen in the territorial system, as the activities of the supply chain that define the territorial processes are contained in the LUF categories. In particular, it is possible to identify two systems (Fig. 23):
- the background system, that is related to the activities of extraction, production, distribution and consumption, each of them generating a certain amount of waste;
- the foreground system refers to the WM activities that happen in the Focus Area or Region (Taelman et al., 2017b). Collection is a transversal activity, followed by storage, transport and treatment of the collected amount. The territorial component of WM activities can be associated to W6 "operational infrastructure of waste". Therefore, WM can be interpreted as a hybrid component, halfway

[14] https://www.eea.europa.eu/data-and-maps/data/copernicus-land-monitoring-service-urban-atlas.

between an activity from a process dimension and a *wastescape* from a pattern dimension, and this will depend on the purposes of the analysis.

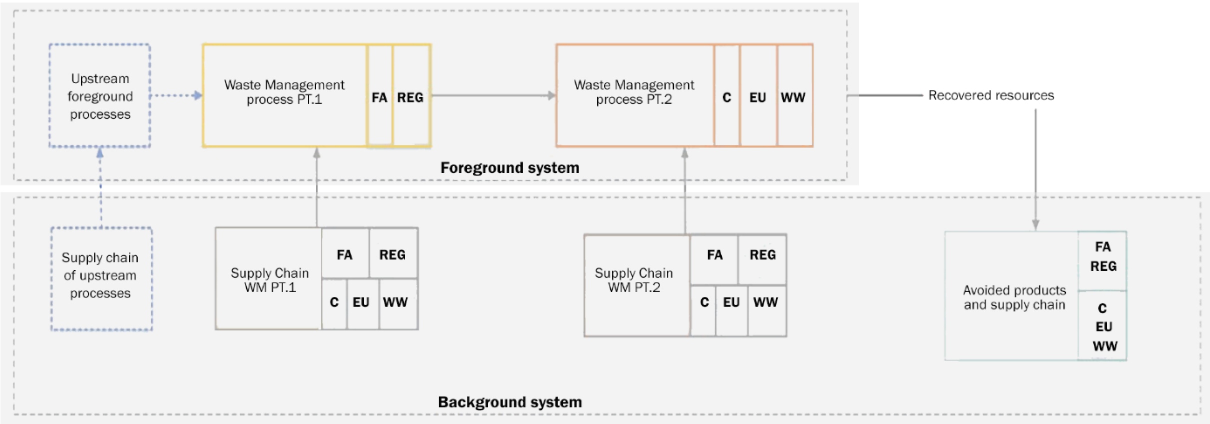


Fig. 23: background and foreground systems, adapted from Taelman et al., 2017b

These territorial processes determine an effect represented in the form of impacts at micro, meso and macro level (Taelman et al., 2017b) as well as the above-mentioned *wastescapes*.

The final step of this chain is the identification of performance indicators (Loiseau et al., 2014), characterized by thresholds for a territorial benchmark. If these thresholds are exceeded, they act on the pattern through degradation processes and they generate the transition from services to disservices (Fig. 24).

While at the initial life cycle the performance is high and the pattern is in a healthy condition, able to provide goods and services through LUF, as the territorial processes take place, they generate drivers of change and the life cycle tends to run out, until it flows into the *wastescapes* at the end of the territorial life cycle.

Drivers refer to causes of alteration of the territorial functioning and represent factors of change with influence on the environment and also on economy and society.
According to Dijst et al. (2018, p. 193), «drivers refer to macro developments which have an impact on needs and constraints experienced at the micro (individual or community) level. We can distinguish various types of drivers: socio-cultural (e.g. values and norms), economic (e.g. growth and decline), political (e.g. power relations and policy aims), demographic (e.g. ageing and population decline), urbanization, climate change and natural resources».

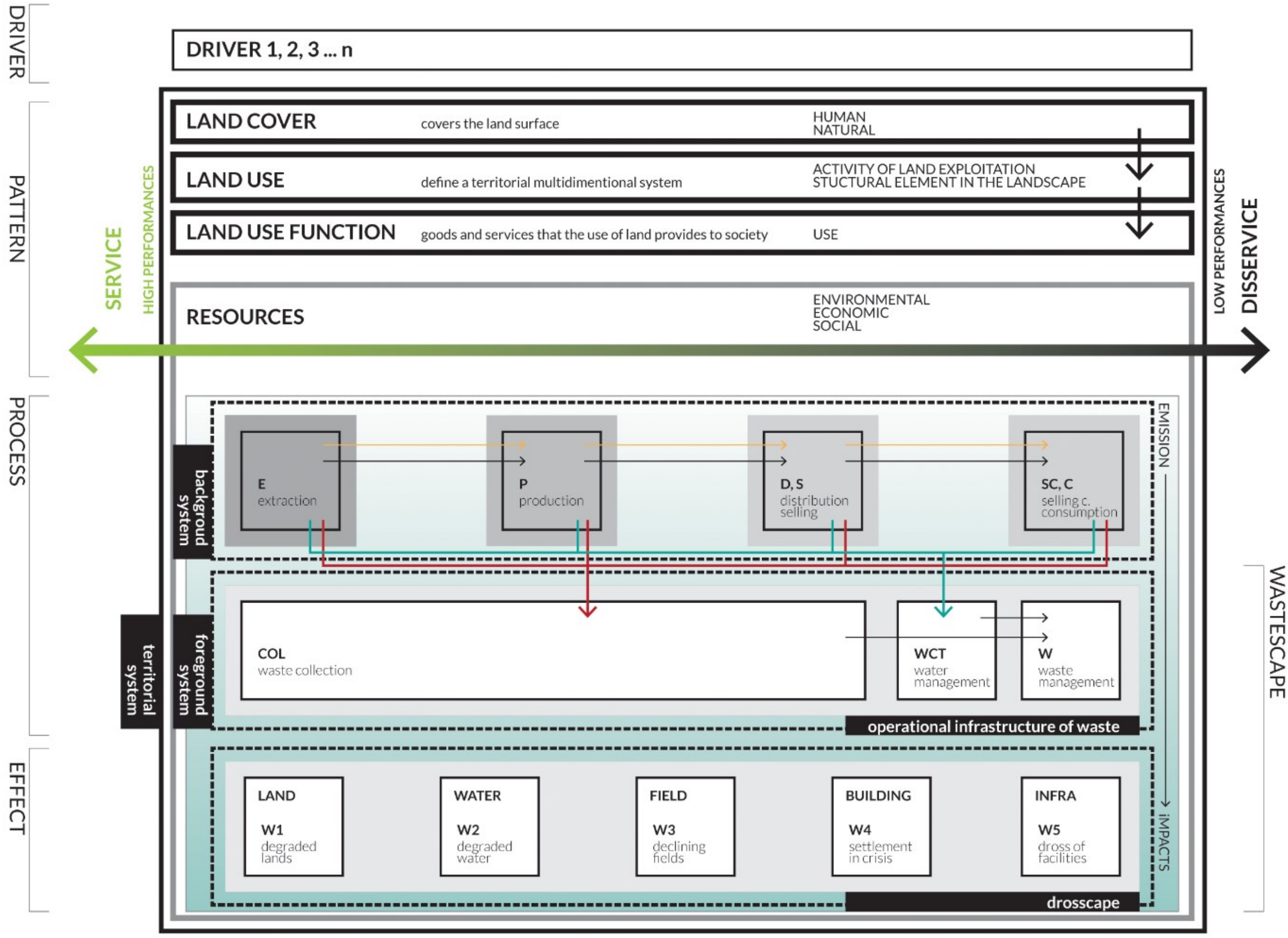


Fig. 24: *wastescapes* mapping and characterization: system of interpretation, Geldermans et al., 2017[15]

Furthermore, spatial planning in general is able to condition the use of resources, influencing as well the consumption pattern of an urban ecosystem, because the spatial form of cities *has a long-standing impact on the daily resources needed* (Dijst, 2013). As a consequence, urban ecosystems are undergoing multiple and often contradictory changes from expansion to de-industrialization and land abandonment (McPhearson et al., 2016).

It is provided a first example of this iterative and cyclical process of characterization, taking in consideration W1 category represented by "degraded lands" and more in

[15] The following model for *wastescapes* identification has been carried out in joint cooperation with Dr. Pasquale Inglese, collaborator for REPAiR Project (year 2016-2017) and under supervision of Prof. Maria Cerreta, Department of Architecture, University of Naples Federico II

depth the sub-category “polluted soil” in relation to the activity “waste treatment” and to the resource “soil”.

The geographies[16] that can describe the reference pattern and the reference activity, apart from the General Geography related to the boundaries, are:

– “land” and the topics “soil” and “land cover” as far as Physical Geography is concerned;
– “health” with the topics “pollution” according to the sub-topics “soil contamination”, “production and industrial facilities” as far as Human Geography is concerned;
– “urban” with the topic “land use” as well in the Human Geography category.

In order to complete the pattern description, it is necessary to establish the correspondent land cover and land use, represented respectively by artificial surfaces and industrial use. From the combination of these to patterns, it is selected the examined LUF that falls in the category: “residential and non land-based industry and services” according to the activity “waste treatment” that defines the process to analyse.

At this point, each *wastescape* category is caused by a specific degradation process, that in this case is related to soil. According to European Commission (2002), the soil degradation processes are represented by the following ones:

– soil erosion;
– soil contamination;
– soil salinisation;
– decline in soil organic matter;
– soil sealing;
– floods and landslides;
– soil compaction;
– loss of soil biodiversity.

Soil contamination in relation to a specific activity of WM, such as a landfill, will be in particular a local one, that «above certain levels entails multiple negative

[16] The geographies definition is part of the spatial analysis carried out in REPAiR and is based on the identification of three typologies of geographies:

– General Geography (GG) that is based on the identification of boundaries;
– Physical Geography (PG), related to the components of land, water air and nature;
– Human Geography (HG) that focus on culture, governance, social settlements, infrastructures, health.

The spatial analysis consist in the specification of the above geographies with spatial indicators. A complete description is provided by Geldermans et al. (2017a), Deliverable 3.1.

consequences for the food chain and thus for human health» (European Commission, 2002, p.12).

Combination of these processes define the sub-categories W 1.1 and W 1.2[17].

Apart from the Contaminated Sites and Potentially Contaminated Sites that are already part of this *wastescape* category, it is necessary to identify some performance indicators with a correspondent threshold to be defined, for example the emissions intensity of contaminants in soil due to WM activities, such as heavy metals. Where the intensity exceed the defined threshold, there is a transition from a service provided by the soil to a disservice or also lack of service. Definitely soil «loses its capacity to carry out its functions» (European Commission, 2002, p.9) ending its life cycle until a process of regeneration is started.

At this last step, the initial pattern, completely degraded, closes the chain of the entire methodology, waiting for the start of new conditions that could allow a new life cycle to be performed (Fig. 25).

- [17] W1: degraded lands;
  - W1.1: polluted soils;
  - W1.2 : artificial soils;
- W2: degraded water and connected areas;
  - W2.1: water bodies;
  - W2.2 : banks, shores, tanks, plants and other elements linked to W2.1;
  - W2.3: flooding zones characterized by hydraulic hazard;
- W3: declining fields;
  - W3.1: abandoned agricultural fields;
  - W3.2 : vulnerable lands;
- W4: settlements and building in crisis;
  - W4.1: vacant/underused buildings and settlements;
  - W4.2 : urban settlements suffering from fatigue
  - W4.3: informal settlements
  - W4.4: urban lots in transformation/tampered
  - W4.5: unauthorized building and settlements
  - W4.2: confiscated assets;
- W5: “dross” of public facilities and infrastructures
  - W5.1: in peri-urban areas;
  - W5.2 : dismissed or underused public facilities;
  - W5.3: interstitial zones;
- W6: operational infrastructure of waste;

A complete description of the sub-categories is provided by Geldermans et al, (2017b), Deliverable 3.3.

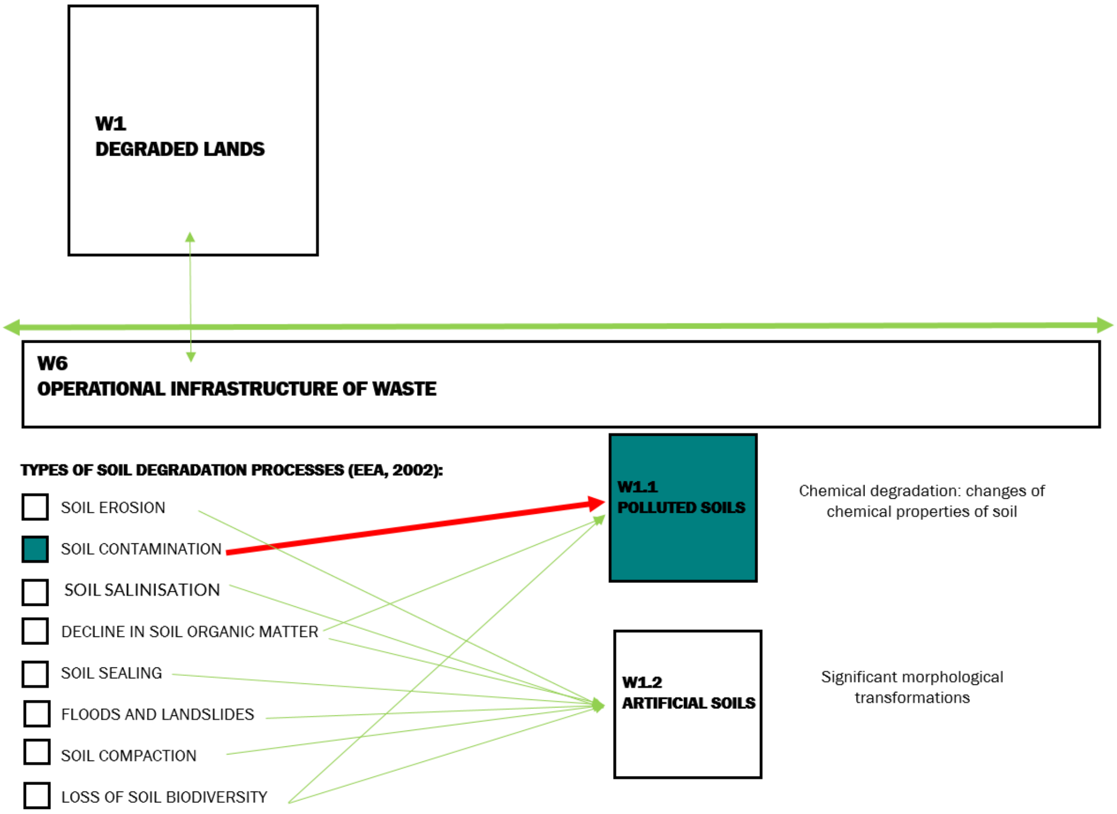


Fig. 25: example of characterization for the *wastescape* “degraded lands” in relation to “polluted soils”

3.4 Evaluation instruments and DSS: MCDA, LCA and GIS

The general tool that will allow the proposed methodological application is that of “evaluation”, that defines the set of activities oriented to the organization of the information necessary for the choice, so that each actor of the decision-making process can be able to take the decision as balanced as possible (Nijkamp et al., 1990).

3.4.1 Evaluation

Territorial governance policies may be indeed characterized by uncertainty, conflicting values, high stakes and urgent decisions (Funtowicz and Ravetz, 1993). Therefore, the evaluation phase, in its different approaches, allows to facilitate the decision-making process in the eventuality in which different solutions are available, but different criteria must be taken into account and, because of this, the involved decision-makers may be strongly conflicting (Mendas and Delali, 2012). Moreover, referring to the decision-making processes for urban planning and design:

«evaluation can be considered a relevant tool to build choices, to recognise values, interests and needs, and to explore the different aspects that can influence decisions» (Cerreta and De Toro, 2012, p. 77).

As a consequence, the evaluation phase assumes an increasingly important role, allowing not only to facilitate the construction of choices, but also to explain the interests and values at stake (Fusco Girard and Nijkamp, 1997).
The environmental assessment proposed for the present research application requires as well a geographical differentiation that takes into account the severity of the impacts in relation to the spatial specificity and load capacities present in a given territorial context.

The first analysis carried out is about urban ecosystem health in relation to the spatial characteristics of the territory under exam.
Moreover, for the core application, it is necessary to localize the *wastescape* that will be selected for the LCA assessment and that is represented by “underused industrial building”, as it will be seen in the next paragraphs.

3.4.2 Spatial Decision Support Systems and Integrated Assessment

As a consequence, GIS proves to be one of the most useful answers for this purpose, as it is composed of a series of software tools to acquire, store, extract, transform, and visualize spatial data from the real world (Burrough, 1986). GIS is especially used when the elements of the decision-making problem have a clear and defined spatial delimitation (Massei, 2015) and the evaluation criteria are associated with geographical entities and are represented through reference thematic maps (Cerreta and De Toro, 2012; Malczewski, 1999).
An important potentiality is represented by the integration of MCDA with GIS because this creates the basis for the development of a Spatial Decision Support System (SDSS), integrating geospatial data with decision makers’ preferences and producing information for decision making (Malczewski, 1999). In this way, «a variety of territorial information (social, economic and environmental) may be easily combined and related to the characteristics of the different options of territorial use, facilitating the construction of appropriate indicators and improving impacts forecasting, leading up to a preference priority list of the various options» (Cerreta and De Toro, 2012, p. 81).
By combining the potentialities of these two instruments, it is possible to create an ideal platform for the analysis, the structuring and the resolution of problems related

to the environmental and territorial management (Geneletti, 2000), developing win-win solutions.

This type of integration has showed to be very useful in the field of urban planning, considering the spatial connotation that characterizes land use choices (Carone et al., 2017; Cerreta and De Toro, 2012; Cerreta and Fusco Girard, 2014; De Toro and Iodice, 2016, 2018). Indeed, urban planning, understood as a process of selection and distribution of resources in relation to certain objectives, can be considered a particular type of decision-making process (Ferretti, 2012).

Thus, in relation to the objectives of this research, decision-making problems are typically characterized by the involvement of a spatial component, requiring more than one evaluation criterion and pursuing more than one objective (environmental protection, but also economic growth and justice) social development, i.e. sustainable development (Ferretti, 2012).
Therefore, the proposal is to create an integrated evaluation approach (IA – Integrated Assessment) that allows planning future activities by linking them to economic, environmental, social aspects, in order to examine the physical impacts on economies and ecosystems and to verify existing relationships between physical impacts and their economic evaluation. The advantage of IA lies also in the possibility of holding together a broader set of components of the same question (Parson, 1994) as it happens in the present application. This represents a model that brings together information and analysis deriving from other disciplines that traditionally are not combined.
An integrated approach in general considers different options and involves impacts on a variety of sectors, including as well many points of view. Therefore, IA can supply decision makers with information on possible consequences, assembling different aspects of the same issue (Weyant et al., 1996).

This kind of combination has been used to address environmental problems, but it is widely recognized that it could become an useful tool for addressing complex problems, such as those related to urban planning (Rotmans et al., 2000). As a matter of fact, «land-use planning can be conceived as the process of dealing with conflicts among different land-use types through resolving the conflicts among stakeholders» with the aim of promoting sustainable development and «the economic, social and environmental processes involved in land-use planning are inherently spatial» (Zhang et al., 2012, pp. 2264-2265). Furthermore, «involving the geographical dimension in the visualization process greatly facilitates the

identification and interpretation of spatial patterns and relationships in complex data in the geographical context of a particular study area» (Dijst et al., 2018, p. 200).
Therefore, the objective of the application is to lay the foundations for the construction of a Decision Support System (DSS) that has also some spatial connotations, given the territorial effects of the proposed study.
A DSS (Simon, 1960) allows to delineate a logical reference structure for decision-making problems, which are organized and systematized on the basis of a model that allows a rational analysis to be carried out (Massei et al., 2014; Rocchi et al., 2014).

More in depth, it is proposed a methodological approach aimed at developing a Spatial Decision Support System (SDSS) through an IA (Cerreta and De Toro, 2012), firstly combining MCDA and GIS for the visualization of urban ecosystem health components and secondly a Life Cycle Based approach with GIS for the visualization of the spatial components of the territorial decision-making process analysed.
SDSS can be described as computerized interactive systems designed to support a user or a group of users to achieve a high level of effectiveness of decision makers in solving a semi-structured spatial problem (Malczewski, 1999). In this sense, SDSS use spatial data, better known as “geographical” or “geo-referenced” data, as they refer to a location on Earth’s surface (Malczewski, 1999). There are, indeed, many examples in which the decision making process has a clear spatial dimension, and that often integrate GIS with MCDA (Coutinho-Rodrigues et al., 2011; Ferretti and Pomarico, 2013; Rikalovic et al., 2014; Sánchez-Lozano et al., 2014; Zhang et al., 2013).

Definitely, this approach creates the possibility to develop a platform for the management of problems related to environmental and in general to territorial management (Geneletti, 2000). Decision-makers can indeed be facilitated by the use of spatial tools to locate the boundary lines and the identification of current and potential land uses (Brabyn, 2005), combining support to public decision-makers with territorial analysis.

3.4.3 Focus on MCDA

MCDA can be defined as a series of multiple criteria comparison procedures aimed at contributing to the development of learning processes that facilitate the decision making phase (Las Casas, 1992). It is a very useful tool in environmental assessments and can be used in several cases, i.e. when:
- there are more alternatives;

- it is necessary to use multiple and often conflicting criteria, as in the case of environmental and economic criteria;
- it is necessary to combine the interests of different and in most cases conflicting subjects (Grafakos, 2015). This type of analysis allows to compare different alternatives or scenarios according to some criteria, often in conflict with each other, in order to guide the decision maker towards a considered choice (Roy, 1996). It also makes it possible to structure a decision problem by defining criteria and alternatives, attributing a weight to the criteria and evaluating the alternatives.

Depending on the type of problem to be analysed, it is possible to identify the most appropriate method (Ishizaka and Nemery, 2013):

– the choice problem (AHP, ANP, MACBETH, PROMETHEE, etc.);
– the sorting problem (AHP, ANP, ELECTRE-Tri, etc.);
– the ranking problem (ELECTRE-Tri, UTADIS, etc.);
– the description problem (GAIA, FS-Gaia).

The decision making process consists of three main phases:

– formulation of alternatives or scenarios;
– evaluation of alternatives through criteria and indicators;
– choice.

This is done through the construction of an evaluation matrix and, to each component of the same, numerical scores are assigned, considering also the possibility of assigning weights that reflect the relative importance of the various evaluation criteria, where the highest value recognized to a criterion represents the greater importance of the criterion itself compared to the others.
Given the spatial nature of the decision problem posed, it is often necessary to integrate MCDA with GIS to give life to a GIS-based Multicriteria Decision Analysis (GIS-MCDA) (Malczewski, 1999, 2006).

The environmental assessment that is proposed forward requires a geographical differentiation that takes into account the intensity of the impacts in relation to the spatial specificity and the load capacities present in urban and peri-urban contexts. This could also be done thanks to the use of models of spatial characterization, introduced at the end of the 1990s in LCA (Torricelli, M. C., Gargari, 2015b).
In the proposed application, as previously specified, the spatial connotation is firstly linked to the clear spatial definition of the selected indicators and the necessity to spatially visualise the distribution of the three components of urban health, especially

taking into account the difference in intensity according to the municipalities of the MAN and the territorial distribution of the values.
Another important spatial connotation is due to the need to localize *wastescapes*, creating the possibility to control the phenomenon of abandoned territories through GIS and to identify the local sources of production of CDW.

3.5 Case study: REPAiR Focus Area

The case study selected for the experimental applications coincides with the Focus Area (FA) chosen for the Italian case study in REPAiR, formed by a portion of the Metropolitan Area of Naples (MAN), that includes the following municipalities (Fig. 26-27):

– Acerra;
– Afragola;
– Caivano;
– Casalnuovo di Napoli;
– Casoria;
– Cardito;
– Cercola;
– Crispano;
– Frattaminore;
– Naples (with the following areas: Poggioreale, Industrial Zone, Ponticelli, San Giovanni a Teduccio, Barra);
– Volla.

The boundaries of the Neapolitan case study have been selected according to the transport system as well as some ecological linkages and the plain area that characterizes it reaches the Regi Lagni, that represent a network of rectilinear channels, mostly artificial, located in the North-East.

Metropolitan cities in general are territorial entities of wide area aimed at the care of the strategic development of the metropolitan territory, the promotion and integrated management of services, infrastructures and communication networks and finally the care of institutional relations, including those with European cities and metropolitan areas (law 56/2014, art.1)[18].

[18] http://www.bosettiegatti.eu/info/norme/statali/2014_0056.htm

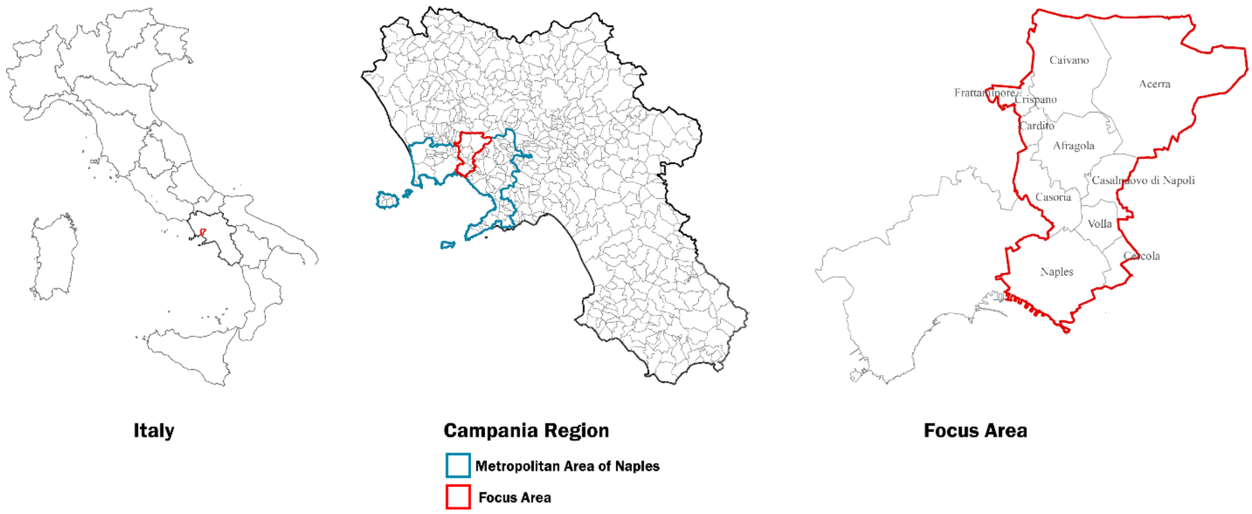


Fig. 26: from country to FA

Furthermore, metropolitan areas are also particularly vulnerable to climatic hazards because of a high agglomeration of population, economic activities and an improper urban development (Kirshen et al., 2008). Additionally, «a wide range of climate change and hazard impacts are particularly acute in metropolitan areas where there is a dynamic and complex interaction of natural and socioeconomic systems under highly heterogeneous contexts [...] however, metropolitan authorities rarely use resilience approach to frame climate adaptation strategies and land use policies» (Hung et al., 2016, p. 49). As a matter of fact, metropolitan areas require as well suitable planning instruments because of the presence of environmental conditions that are more critical due to energy consumption and greenhouse gas emissions, generating many negative impacts.

The MAN as a whole can be considered highly affected by territorial aggressions of human matrix (Mazzeo and Russo, 2016). Is is formed by 92 municipalities, representing the third most populated metropolitan area in Italy, with more than 3.5 million inhabitants. The MAN is characterised by an unregulated urban development and during the last two decades, the different municipalities have welded together, creating undifferentiated suburbs, characterised by socio-economic and environmental disorder. Moreover, it is characterized by an extremely anthropic urban development with a notable population density and the occurrence of both phenomena of density and of dispersion of settlements at the same time (Formato and Russo, 2014), which make the territorial development somewhat chaotic. Furthermore, congestion and urban chaos are the dominant characteristics, especially in the outlying areas. For this reason, the urban conditions of the suburbs

of Naples are among the main concerns of the city. In this area, there are numerous environmental and social problems, for which the search for a solution is one of the main challenges that the city has to face (Morelli and Salvati, 2010). Moreover, the MAN has an irregular development due to the lack of an integrated plan of coordination of the entire territory, but a succession of sectorial plans. This led to the presence of a fragmented territory, often caused by the succession of illegal settlements and by a continuous of built up soils, interrupted by poorly connected rural areas.
Anyway, despite the problematic context of the present case study, there is also great potential of development, thanks to the territorial variety, the presence of high quality landscapes and many economic, cultural and environmental resources.

Definitely, metropolitan areas require suitable planning instruments because their environmental conditions are more critical and these instruments could be better applied if supported by useful evaluation methodologies. Therefore, it is necessary to build a solid knowledge base able to support the decision making phase not only at the metropolitan level but also at different and smaller scales, according to the variety of the territory. The aim is to enhance the capabilities that the territory is already able to offer and to act on the weaknesses in order to create environmental, economic and social win-win solutions.

Facing the specific merit of the selected case study, it corresponds to part of the Homogeneous Territorial District (in Italian “Ambito Territoriale Ottimale” - ATO) n.1, linked to the management of urban waste. It is a territory characterized by the combination of valuable elements and at the same time elements characterized by a high degree of fragility together with a considerable concentration of peri-urban areas. The latter are characterized by the symbiotic interaction between rural/natural ecosystems and urban ecosystems (Zhu et al., 2017), habitually seen as residual areas lacking in identity and autonomy and usually located near large urban agglomerations (Gonçalves et al., 2017). Peri-urban areas deal with hybrid portion of territory, sometimes characterized by densely urbanized areas, agricultural land, discontinuous campaigns, as well as abandoned territories, pervaded by degraded ecosystems, with high levels of pollution (REPAiR, 2015).

In particular, in the South area (Naples, Casoria, Volla, Cercola, Casalnuovo di Napoli) the main feature is the presence of abandoned land linked to the presence of former refineries and oil depots with a consequent intense level of pollution of soils and aquifers. The East area (Caivano, Acerra, Frattaminore, Crispano, Cardito, Afragola) is characterized by an under-utilization of agricultural land and the presence of huge infrastructural systems (Fig. 27).

Fig. 27: FA differences

3.5.1 Urban ecosystem health in MAN and FA: a first analysis of the territory

Before moving to the thesis focus and to the introduction of the LCA model, an analysis of the ecosystem health of the territory just described has been carried out, in relation to the MAN and to the FA.
The Land Cover of the above mentioned territory is represented in Fig. 28.

As previously specified, «indicators and measurement systems are an essential tool for ensuring management targets are reached [...]» (Zhang et al., 2006, p.5).
Based on the three components of urban ecosystem health (see paragraph 1.2), a set of drivers was associated to each of the three urban health categories in question

and according to this reference framework, a system of indicators has been developed with the aim of identifying their territorial distribution (Tab. 1-3).

A “positive direction” has been established for each indicator, because according to the kind of data, some (negative) indicators must be minimised, while others must be maximised, in order to improve the degree of health of the urban ecosystem.

Indicators, that are vital elements in developing awareness of urban problems (Stanners and Bourdeau, 1995) have been spatially represented through maps using GIS. Some of these maps refer to the 92 municipalities in the MAN, while others refer to the census areas, according to the kind of available data: some examples are reported (Fig. 29; Fig. 30).
Numerical data derives from Census of 2011 realized by the Italian National Institute of Statistics (in Italian “Istituto Nazionale di Statistica” – ISTAT) and from some Regional and sectorial plans, together with reports and previous studies (Carone et al., 2017). These indicators have been normalised and rasterised to make them comparable each other.

In order to obtain a smaller number of variables and to avoid redundancy, a Principal Component Analysis (PCA) has been carried out: this analysis, suitable for quantitative variables, represents a variable reduction procedure appropriate when measures have been obtained on a consistent number of observed variables.
This kind of technique replaces the original variables by a smaller number of derived variables, called “principal components”, formed by linear combinations of the originals (Joliffe, 2014), therefore, they represent a weighted sum that combines different variables in a single construct. In particular, PCA is a method for multivariate analysis that transforms a set of *m* correlated variables into a new set of *m* uncorrelated variables that can be called “components”. In the form of linear combinations, these allow a better understanding of data (Harris et al., 2015). In addition, the smaller number of constructs are independent, then orthogonal to one another in space and are sorted in ascending order of variance.
PCA is able to balance the aim of the synthesis with that of minimising the loss of information and the number of principal components is equal to the number of observed variables. In addition, the total variance, i.e. the sum of the variances, is kept in the transition from the observed variables to the principal components.

PCA is suitable for quantitative variables and it has been applied in different fields of research related to human and physical geography and with different objectives (Comber et al., 2016; Faraji Sabokbar et al., 2014; Lloyd, 2010; Sanders et al.,

2015), but also in relation with geology (Yang and Cheng, 2015) or oceanography (Moskalik et al., 2014).
Therefore, PCA allows representation of the multivariate nature of data, identifying their structure using a relatively smaller number of dimensions.
Considering too many principal components or including a low number of them can determine a wrong interpretation of results. It is important, then, to know which variables contribute more to the definition of the principal components, obtaining a reduction of the problem dimensionality and optimising results.

An example related to agriculture is reported: in detail, the driver is formed by 8 indicators representing the original variables. The analysis has been carried out in GIS and the components correspond to the 8 input layers. The results are formed by a covariance matrix between the layers (Tab. 4) a correlation matrix (Tab. 5) and a table of eigenvalues and eigenvectors (Tab. 6).

We can observe that for the present application, a value of cumulative variance of about 80% is chosen (Tab. 7; Fig. 31). In fact, it is necessary to obtain a reduced number of principal components compared to the original indicators but at the same time, able to significantly represent the considered phenomena. For this aim, among the criteria used for the selection of the principal components, it has been chosen the method according to which only the components that represent the 80-90% of the total variability have to be considered, in order to include the right number of variables.
Another advantage of this approach has been to consider linearly independent variables for subsequent processing.

A further important aspect is linked to the necessity to adopt multiple scales for the assessment of urban ecosystems, that are complex and open systems linked with their surroundings through energy and material flows together with information circulation (Su et al., 2012).
At the local scale, the urban ecosystem is composed of multiple subsystems; at the regional scale it is possible to observe different urban ecosystems that interact with each other. At the national scale it is possible to observe different regions or urban ecosystems with different roles and finally at the global scale there are influences from international development trends and long-term systemic characteristics of human-environment relations. (Su et al., 2012).
In the present application, the focus is on the local scale at different levels: the general layer of the MAN and a smaller level related to the above described FA.

As it is possible to notice, indicators are essential tools as they allow to synthesise complex information on the territorial functions and to represent certain aspects concerning the state of the environment, monitoring and analysing the territorial flows (Fry et al., 2009).
In the specific case, the indicators are selected in relation to the territorial characteristics, without however neglecting the availability of data.

The "vigour" dimension has been mainly associated to economic activities, tourism and agriculture, as well as landscape and cultural heritage.

The "organisation" dimension is linked to the functioning of society in terms of population, built heritage, or mobility and transport.

Finally the "resilience" dimension has been especially associated to environmental components linked to hydrosphere, biosphere, geosphere, environmental certification, waste, natural and anthropogenic hazards, safety and human health.

Considering cities as adaptive systems, resilience assessment is able to connect landscape, society and land use with adaptive capacities, providing an important advantage (Ahern, 2011) and «quantifying resilience is particularly motivated by the need to support design and decision making» (Tran et al., 2017, p. 73).
According to Tran et al. (2017), an important factor to be considered is related to the temporal aspect: that is the necessity to consider the ability of the system to adapt itself over time, considering the evolution of its characteristics and the stressors over its entire life. Starting from this aspect, the proposed application aims to analyse the urban ecosystem health according to the actual state, providing an informative base from which it will be possible to shape future scenarios, taking informed decisions, ensuring a sustainable future urban development and acting in a specific manner where the level of urban ecosystem health is lower.

Dimensions	Drivers	Indicators	Positive direction	Source
Vigour	**Economy and tourism**	Employment rate	MAX	Italian National Institute of Statistics
		Unemployment rate	min	
		Number of local units compared to inhabitants (15-64 years old)	MAX	
		Number of employees in local units compared to inhabitants (15-64 years old)	MAX	
		Average taxable income per capita	MAX	Sole24Ore magazine
		Number of beds in hotels	MAX	Italian National Institute of Statistics
		Number of other forms of accommodation	MAX	
	Agriculture	Percentage of total agricultural surface compared to territorial surface	MAX	Italian National Institute of Statistics
		Percentage of used agricultural surface compared to total agricultural surface	MAX	
		Percentage of irrigated surface compared to used agricultural surface	MAX	
		Percentage of irrigable surface compared to used agricultural surface	MAX	
		Number of farms compared to used agricultural surface	MAX	
		Number of farmhouses compared to used agricultural surface	MAX	
		Surface percentage used by biological farms compared to used agricultural surface	MAX	
		Surface percentage used by farms with typical local productions compared to used agricultural surface	MAX	
	Landscape and cultural heritage	Percentage of areas of historical, cultural and environmental interest compared to total surface	MAX	Province of Naples
		Average monthly number of visitors in museums, monuments and state archaeological areas	MAX	MiBACT

Tab. 1: indicators for vigour, De Toro and Iodice, 2018

Dimensions	Drivers	Indicators	Positive direction	Source
Organisation	**Population**	Old age index	min	Italian National Institute of Statistics
		Number of families compared to inhabitants	MAX	
		Percentage of households in home ownership compared to total resident households	MAX	
		Percentage of apartments with 6 or more inhabitants	MAX	
		Number of foreigners per 100 inhabitants	MAX	
		Population density	min	
	Built heritage	Percentage of used buildings compared to total	MAX	Italian National Institute of Statistics
		Percentage of buildings built before 1945	MAX	
		Percentage buildings built between 1945 and 2000	MAX	
		Percentage of buildings built after 2000	MAX	
		Percentage of buildings with bearing walls	MAX	
		Percentage of buildings made of reinforced concrete	MAX	
		Percentage of buildings in other materials (wood, steel, etc.)	MAX	
	Mobility and transports	Percentage of people who travel daily outside the municipality of residence compared to total	min	Italian National Institute of Statistics
		Number of buses per 10,000 inhabitants	MAX	www.comunu-italiani.it
		Number of railway stations on 100 Km^2	MAX	E.A.V. State Railways
		Number of stops of underground lines, funiculars, cable cars and hydrofoils over surface of 100 Km^2	MAX	E.A.V., ANM, Metrò del Mare
	Society	Number of non profit institutions per 10,000 inhabitants	MAX	Campania Region
		Percentage of inhabitants engaged in voluntary activities in non-profit institutions compared to total	MAX	
		Number of social, cultural and recreational association per 10,000 inhabitants	MAX	
		Number of groups and joint purchasing networks for 10,000 inhabitants	MAX	
		Number of associations of social assistance, health and social emergency relief per 10,000 people	MAX	
		Percentage of graduated inhabitants compared to total population	MAX	

Tab. 2: indicators for organisation, De Toro and Iodice, 2018

Dimensions	Drivers	Indicators	Positive direction	Source
Resilience	Atmosphere	Annual diffuse emissions of SO_x per capita	min	Air quality plan, Campania Region
		Annual diffuse emissions of NO_x per capita	min	
		Annual diffuse emissions of CO per capita	min	
		Annual diffuse emissions of COV per capita	min	
		Annual diffuse emissions of PM10 per capita	min	
	Hydrosphere	Coverage of aqueduct	MAX	Water protection plan, Campania Region
		Annual consumption of drinking water per person	min	
		Coverage of sewerage network	MAX	
		Coverage of purification	MAX	
		Annual load of BOD5 spilled per capita	min	
		Annual load of nitrogen (N) spilled per capita	min	
		Annual load of phosphorous (P) spilled per capita	min	
	Biosphere	Percentage of the Site of SCIs compared to total surface	MAX	Italian Ministry of Environment
		Percentage of the SPAs compared to total surface	MAX	
		Percentage of areas belonging to natural parks compared to total surface	MAX	
		Percentage of forest area compared to total surface	MAX	
	Geosphere	Percentage of areas of urban consolidation and environmental rehabilitation compared to total surface	MAX	Province of Naples
		Percentage of degraded areas subject to recovery and environmental redevelopment compared to total surface	MAX	
		Percentage of soil used for urban uses compared to total surface	min	
		Percentage of areas for services and public facilities and/or public interest compared to total surface	MAX	
		Number of historic parks and gardens open to the population for 10,000 inhabitants	MAX	
		Proportion of spaces for the community compared to residential surfaces	MAX	
		Percentage of buildings used for productive, commercial, office/service, industry, tourism/hospitality services compared to total number of buildings	MAX	

Tab. 3: indicators for resilience, De Toro and Iodice, 2018

Dimensions	Drivers	Indicators	Positive direction	Source
Resilience	**Environmental certification**	Percentage of companies certified EMAS compared to total	MAX	Italian Ministry of Environment
		Percentage of organisations/companies certified UNI EN ISO 14001 compared to total	MAX	Italian Ministry of Environment
		Percentage of INES factories compared to total	min	Italian Ministry of Environment
	Waste	Percentage of separate collection of total municipal solid waste	MAX	Campania Region
		Annual per capita production of municipal solid waste	min	Campania Region
		Number of incinerators	min	Campania Region
		Number of installations for waste treatment	MAX	Campania Region
	Natural and anthropogenic hazards	Volcanic risk exposure (high, medium and low risk)	min	Civil Protection
		Exposure to air pollution (areas of renovation, observation and maintenance)	min	Campania Region
		Number of establishments at risk of major accident	min	Campania Region
		Number of contaminated sites	min	Campania Region
		Number of potentially contaminated sites	min	Campania Region
		Percentage of areas crossed by fire compared to total	min	Campania Region
	Safety and human health	Number of enterprises registered or requesting registration to the list of enterprises not subject to criminal attempt of infiltration compared to total number of enterprises	MAX	Italian National Institute of Statistics; Prefecture – Territorial Office for the government of Naples
		Number of criminal organizations compared to total number of inhabitants	min	Italian National Institute of Statistics
		Number of road deaths per 100 accidents	min	Italian National Institute of Statistics; Campania Region
		Number of cancer deaths per 10,000 inhabitants	min	Higher Institute of Health
		Number of hospitalisations per 10,000 inhabitants	min	Higher Institute of Health

Tab. 3 (continuation): indicators for resilience, De Toro and Iodice, 2018

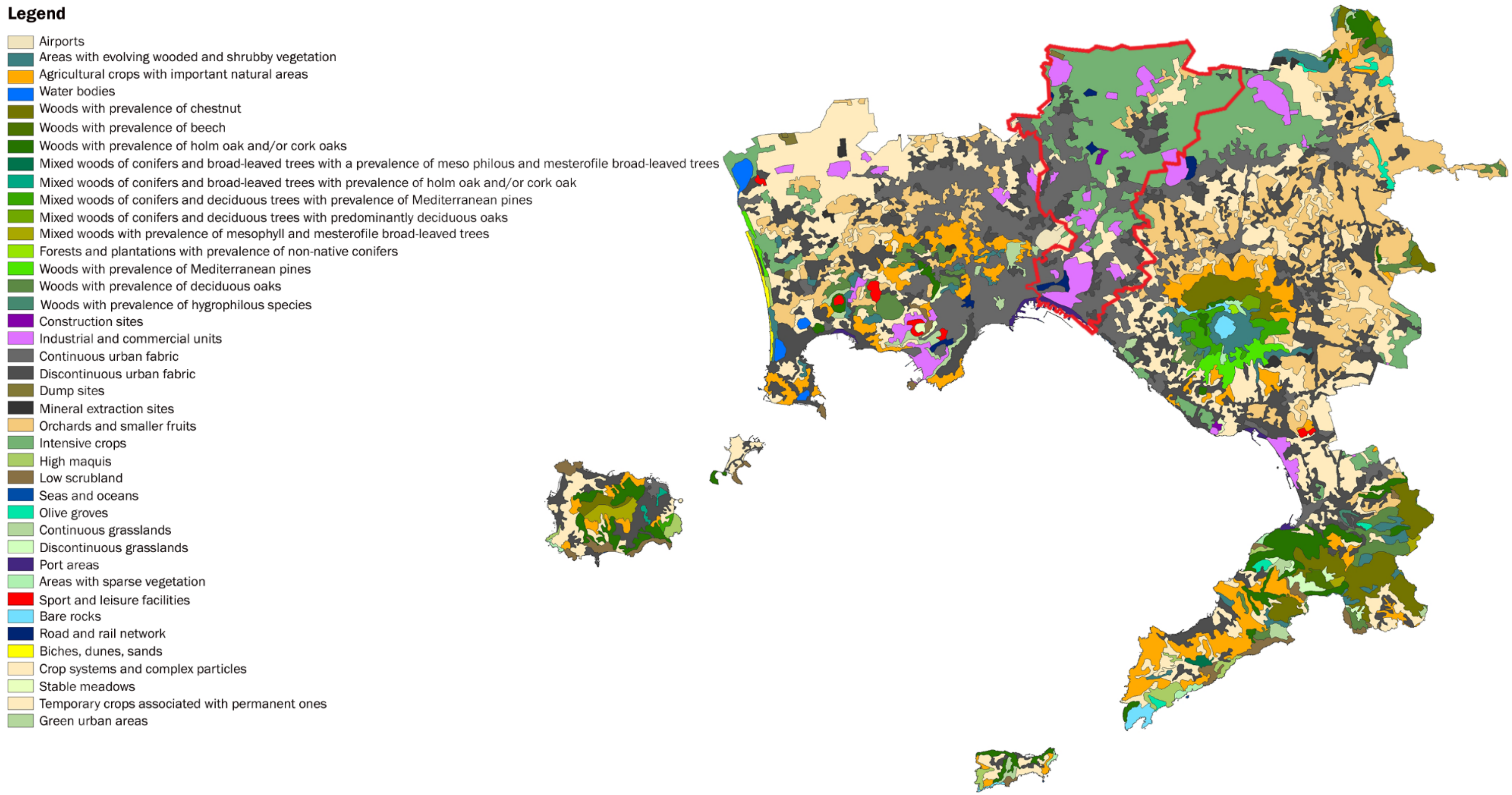


Fig. 28: Corine Land Cover for the MAN with a focus on the FA, De Toro and Iodice, 2018

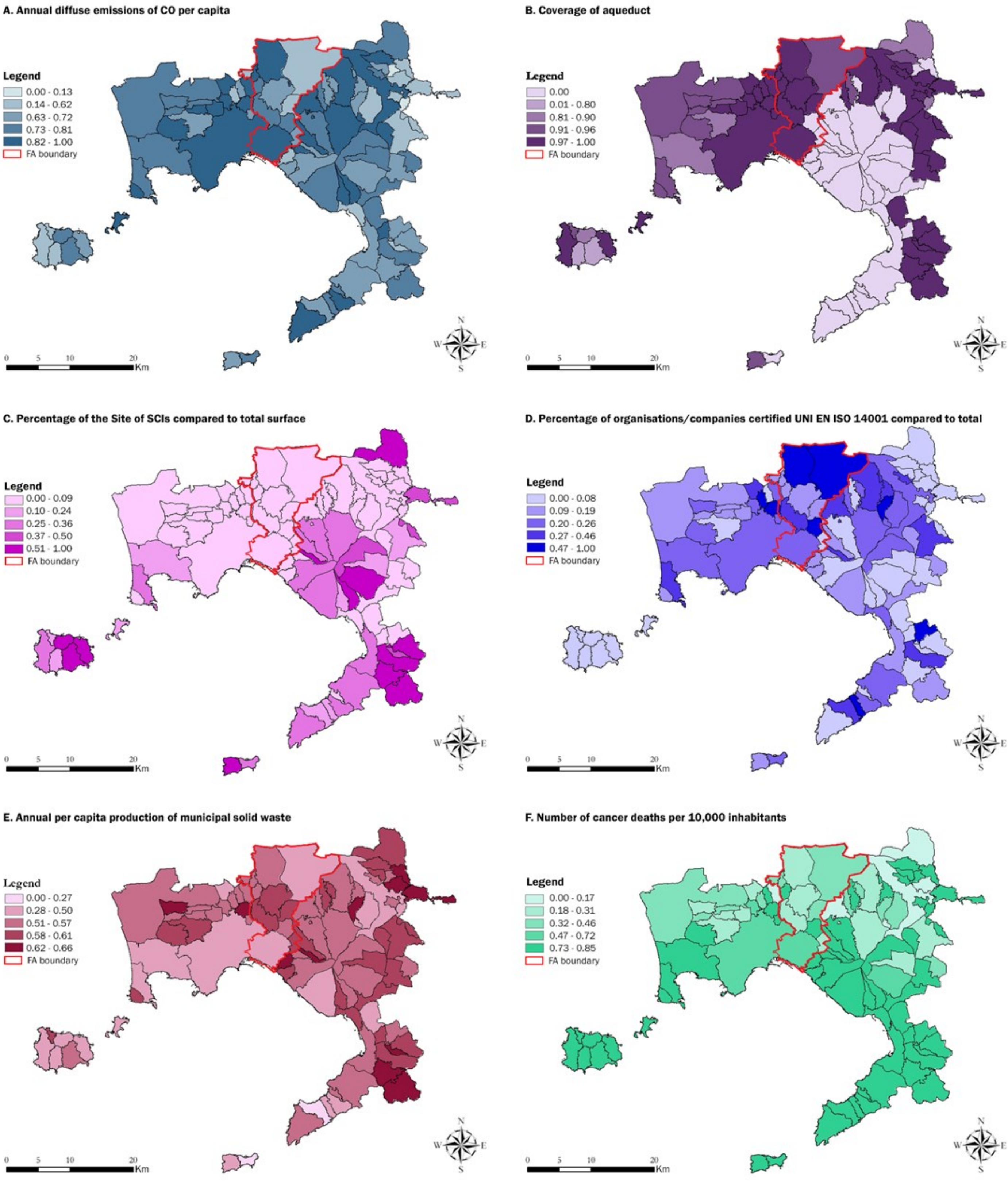


Fig. 29: spatial representation of urban health ecosystem indicators, De Toro and Iodice, 2018

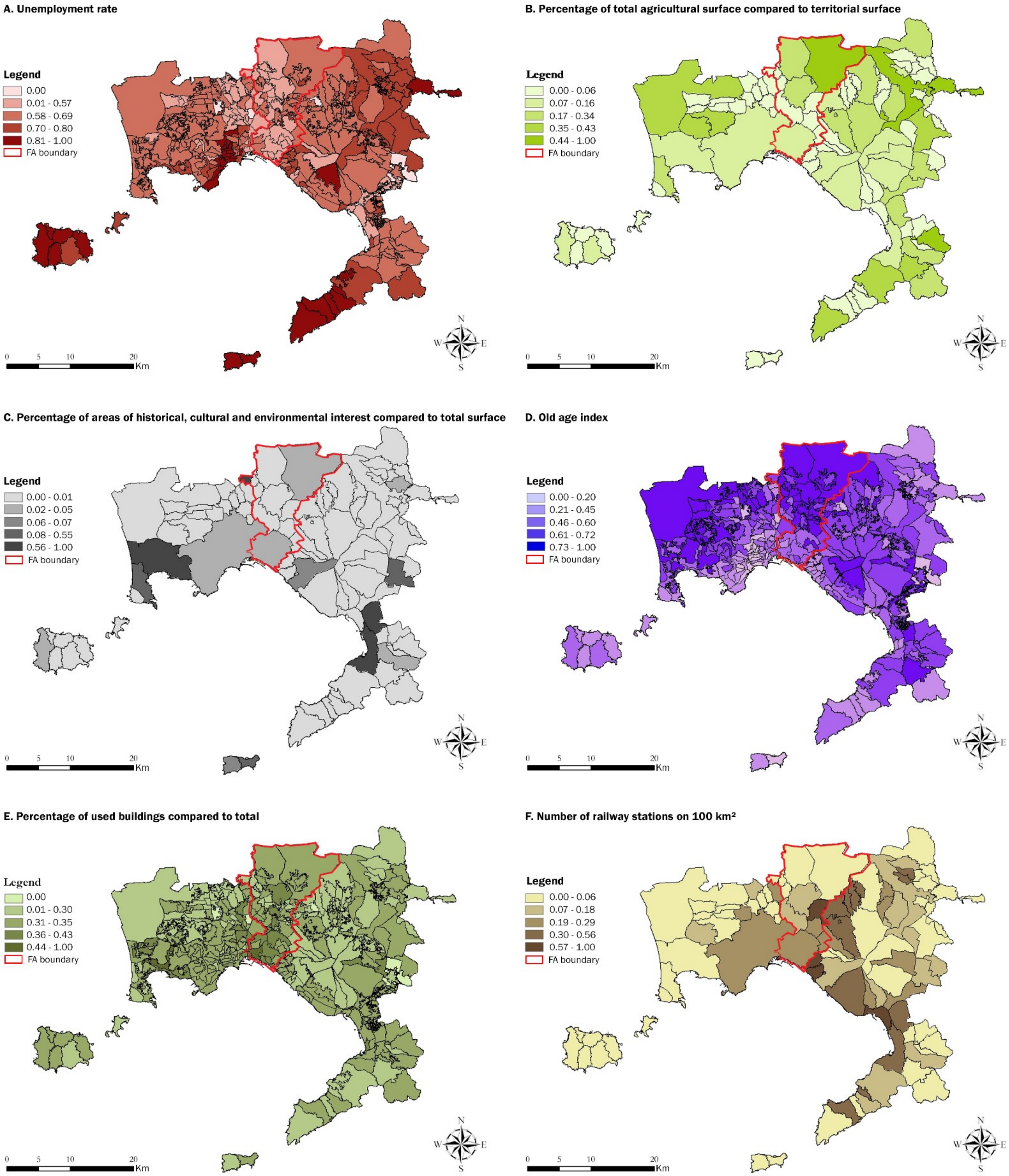


Fig. 30: spatial representation of urban health ecosystem indicators, De Toro and Iodice, 2018

Covariance Matrix								
Layer	1	2	3	4	5	6	7	8
1	1,025070e-002	2,507881e-005	4,159372e-003	2,697214e-003	-4,946195e-003	-4,713255e-004	-2,830477e-004	-3,761803e-003
2	2,507881e-005	4,218607e-003	4,913194e-003	4,708464e-003	-3,821828e-003	-1,309377e-003	8,405030e-005	-2,771580e-003
3	4,159372e-003	4,913194e-003	2,500272e-002	2,325620e-002	-9,291456e-003	-2,023934e-003	-7,486715e-004	-9,533971e-003
4	2,697214e-003	4,708464e-003	2,325620e-002	2,796302e-002	-6,208651e-003	-2,282532e-003	-1,003767e-003	-9,950546e-003
5	-4,946195e-003	-3,821828e-003	-9,291456e-003	-6,208651e-003	1,481656e-002	1,485170e-003	-4,349429e-005	6,697409e-003
6	-4,713255e-004	-1,309377e-003	-2,023934e-003	-2,282532e-003	1,485170e-003	2,419281e-003	4,914788e-004	1,126295e-003
7	-2,830477e-004	8,405030e-005	-7,486715e-004	-1,003767e-003	-4,349429e-005	4,914788e-004	1,567495e-003	6,071999e-004
8	-3,761803e-003	-2,771580e-003	-9,533971e-003	-9,950546e-003	6,697409e-003	1,126295e-003	6,071999e-004	1,489303e-002

Tab. 4: PCA related to agriculture driver: covariance matrix, De Toro and Iodice, 2018

Correlation Matrix								
Layer	1	2	3	4	5	6	7	8
1	1,00000	0,00381	0,25981	0,15931	-0,40135	-0,09465	-0,07061	-0,30446
2	0,00381	1,00000	0,47839	0,43351	-0,48341	-0,40986	0,03269	-0,34966
3	0,25981	0,47839	1,00000	0,87953	-0,48274	-0,26023	-0,11959	-0,49407
4	0,15931	0,43351	0,87953	1,00000	-0,30502	-0,27751	-0,15161	-0,48760
5	-0,40135	-0,48341	-0,48274	-0,30502	1,00000	0,24806	-0,00903	0,45086
6	-0,09465	-0,40986	-0,26023	-0,27751	0,24806	1,00000	0,25238	0,18764
7	-0,07061	0,03269	-0,11959	-0,15161	-0,00903	0,25238	1,00000	0,12567
8	-0,30446	-0,34966	-0,49407	-0,48760	0,45086	0,18764	0,12567	1,00000

Tab. 5: PCA related to agriculture driver: correlation matrix, De Toro and Iodice, 2018

Eigenvalues and Eigenvectors								
Number of Input Layers: 8	Number of Principal Component Layers: 8							
PC Layer	1	2	3	4	5	6	7	8
Eigenvalues								
	0,06061	0,01591	0,00844	0,00777	0,00302	0,00233	0,00194	0,00111
Eigenvectors								
Input Layer								
1	0,13743	-0,47548	0,12640	0,81705	0,20934	0,06381	0,14718	0,04386
2	0,14262	-0,05424	0,07903	-0,35085	0,55231	0,39743	0,50732	0,35639
3	0,61159	0,16621	0,25443	0,04085	-0,3928	0,59058	-0,15904	-0,05897
4	0,62694	0,43885	-0,03385	0,11450	0,23636	-0,57147	0,13129	0,02023
5	-0,28580	0,65056	-0,41108	0,41585	0,11462	0,36247	0,09296	-0,00024
6	-0,06401	0,02343	-0,03634	0,08340	-0,63083	-0,15880	0,50385	0,55683
7	-0,02256	-0,01643	0,04895	-0,05104	-0,15259	0,00815	0,64480	-0,74505
8	-0,32768	0,35596	0,85977	0,10981	0,08085	-0,07705	0,01299	0,04488

Tab. 6: PCA related to agriculture driver: eigenvalues and eigenvectors, De Toro and Iodice, 2018

Layers	Eigenvalues	Percentage	Cumulative variance
1	0,06061	59,93276	59,93
2	0,01591	15,73223	75,66
3	0,00844	8,34569	84,01
4	0,00777	7,68318	91,69
5	0,00302	2,98626	94,68
6	0,00233	2,30397	96,98
7	0,00194	1,91832	98,90
8	0,00111	1,09760	100,00
TOT	**0,10113**	**100,00000**	

Tab. 7: PCA related to agriculture driver: results, De Toro and Iodice, 2018

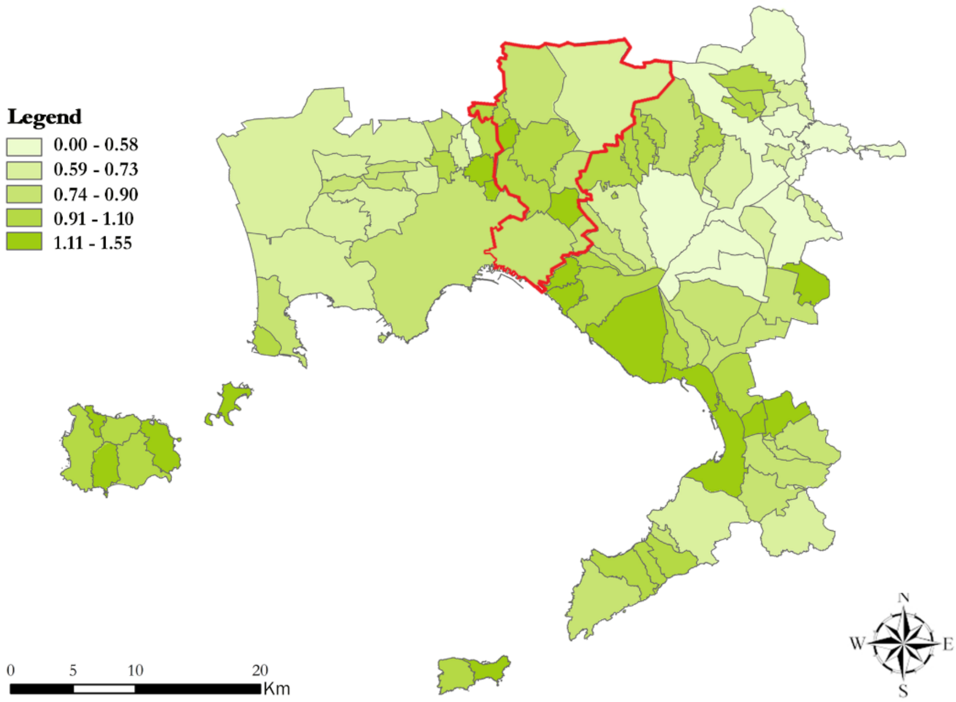


Fig. 31: PCA results according to the percentage of used agricultural surface compared to total, De Toro and Iodice, 2018

3.5.1.1 Urban ecosystem health in MAN and FA: results

After the selection of data, weights have been assigned, considering equal weights both for the drivers and for the principal components. The evaluation has been carried out using VectorMCDA (Rocchi et al., 2015) associated to geoTOPSIS, as a plugin of QGIS.

In general, the TOPSIS (Technique for Order Preference by Similarity to Ideal Solution) method (Hwang and Yoon, 1981) assumes as a basic concept that the preferable option should have the “minor distance” from the “ideal solution” and the “maximum distance” from the “non-ideal solution”. This method uses the geometrical interpretation of distance, referring to the Euclidean distance, and it is possible to rank the options with reference to the ideal and non-ideal. The final ranking of options is obtained through comparison among relative distances.
In particular, VectorMCDA assumes that each geographical object is a single geo-alternative and geoTOPSIS implements the ideal point algorithms, based on the TOPSIS model, and returns a map showing the arrangement of the various geographical alternatives (Fig. 32).

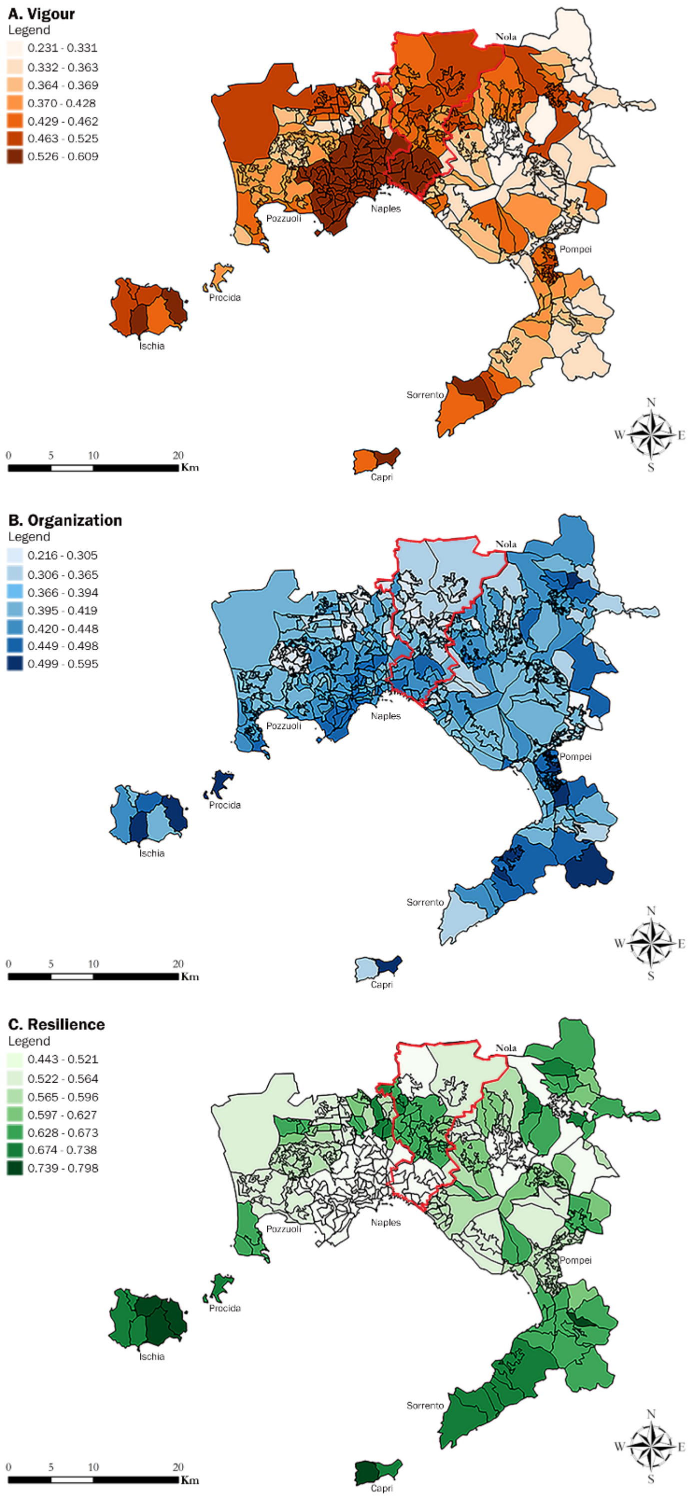


Fig. 32: results according to the geoTOPSIS method, De Toro and Iodice, 2018

The weights assignment can be made either directly or by calculation, using the Analytic Hierarchy Process method (AHP) (Saaty, 1980).
The ideal point, on which the model is based, identifies the target value assigned to a particular criterion, representing the optimal value at which the decision maker would tend.

In general, for a given problem, its ideal solution, that represents the best score for each criterion, is calculated according to its minimisation and maximisation (Munier, 2011). By way of example, equal weights are assigned to the various criteria, reserving the possibility of assigning different weights according to the specific priorities of the application context. The same is true for the definition of the ideal point, which is strictly linked to the decision-making sphere in question and to its ideal solution and could be defined by decision-makers according to some specific targets, such as urban standards, etc.

In the cartographic representation of the results obtained, it is possible to observe the choice of using 7 classes, generated by the model, that represents the different level of “vigour”, “organisation” and “resilience”, from “very low” to “very high”, with some intermediate values, to diversify the results also according to the variety of urban landscapes that characterise the MAN and the FA.
The results do not represent an absolute value, but can vary according to the available indicators, the weights assignment, the drivers selected and the purposes of the evaluation. Furthermore, they do not present a ranking between the various municipalities, but represent a comparative method, in order to highlight both positive and negative aspects related to the territorial configuration.

Analysing the results, it is possible to observe the territorial distribution of the components of urban health that have been taken into account.
In particular, it is possible to make some reflections; for example, the component of “vigour” is mainly concentrated in Naples, Ischia Island, Capri Island, Sorrento and Pompeii, mainly because of tourism and partially in Nola, due also to the presence of some enterprises. The component of “organisation” shows a more fragmented territorial distribution, taking into account diversified aspects, such as population, transport and built heritage. Finally, “resilience”, that is formed especially by environmental indicators, is concentrated mainly in the islands of Ischia, Capri, Procida and also in Sorrento, while the municipality of Naples shows a very low level of resilience because of the high concentration of pollution. The same aspects qualify FA, with a medium level of vigour, organisation and resilience, revealing environmental, economic and social problems but also great potentialities of improvement.

Therefore, it is possible to notice that “resilience assessment” can be integrated with “vigour assessment”, representing the urban system’s level of activity, and “organization assessment”, representing the structure of population and the way in which society manages its daily activities.
These three components, if declined and interpreted properly, are able to capture all the components that contribute to the functioning and the connotation of the urban system.

Ecosystem health is an essential measure to assess the functioning of urban ecosystems, especially considering human activity as one of the biggest driver of environmental changes.
As a matter of fact, climate change, land use change and biodiversity loss, together with many other environmental issues, represent a practical demonstration of the effect of human activity (Lu et al., 2015).

The peculiarity of the present application lies in the importance of analysing the current condition of the urban ecosystem, because only by carefully evaluating the status quo, it will be possible to think about the planning and management of the future development of the territorial system.

Definitely, it is possible to observe the necessity of intervening in the municipality of Naples that, because of its low level of resilience, could be in need of a better calibration of green and blue infrastructures, improving air quality and hydrosphere, or reducing soil consumption and improving waste management, acting definitely on the drivers belonging to the category of resilience.
Another reflection on the results could be the necessity of improving the economic component in the municipalities characterised by a lower level of vigour, exporting the business and touristic models that make Naples and the islands richer from this perspective.
These are only some general examples of actions that could be implemented using this informative base to make the decision-making phase transparent and aware.

Moreover, «for a given urban ecosystem, the relationship with adjacent cities and the position in the national development scenario will contribute to an objective understanding of its urban ecosystem health status. However, it does not provide insight into the internal situation of the urban ecosystem itself. Therefore, urban ecosystem health assessment at multiple scales is necessary, through which comprehensive suggestions can be given for urban regulation and management».

In addition «urban ecosystem health assessments can provide many valuable references for urban management, including status quo assessment and problem identification, optimization of urban planning and management schemes, and effect evaluation of schemes» (Su et al., 2012, p. 6-7).

CHAPTER FOUR

Construction of the baseline scenario

4.1 Construction and Demolition Waste (CDW): definitions, characterization and main potentialities

Premise

After having introduced in the first part of the thesis the general literary framework and having carried out an initial analysis of the territory, putting into practice the concept of urban ecosystem health, the main application focus is introduced in the present chapter.

As it will be seen, this is represented by a multi-scale application (having previously already underlined the importance of multi-scalarity in the territorial analysis) linked to LCA in relation to CDW first for the entire Campania Region and then for the FA and for a smaller scale related to a single building assumed as an example.

LCA has been very often used to facilitate the identification of the best waste management scenarios, in order to prevent or minimize negative impacts on ecosystems, natural resources and human health (Ekvall et al., 2007; Laurent, 2015; Manfredi et al., 2011; Penteado and Rosado, 2015).

4.1.1 General information and composition

The application of sustainable development principles can influence and improve the sustainability of urban ecosystems and among this principles there is that of Waste Management (WM) (Dizdaroglu, 2015).

As already mentioned, the Neapolitan case study selected for REPAiR has chosen as key waste flows to analyse, two categories that collect territorial interest: Organic Waste (OW) and Construction and Demolition Waste (CDW).
The present thesis intends to focus the attention on the second category, which is linked to the legal and illegal transformation of the territory and requires the need to monitor the construction and demolition processes and to intervene on the recovery of the built heritage.

CDW belongs to the category of Special Waste (SW), which in turn is divided into hazardous and non-hazardous one. The CDW flow is produced during the life cycle of a project, that can be summarised in three main phases (Wu et al., 2014):

– construction;

– usage/maintenance;
– demolition.

The Regional Plan for the Management of Special Waste in Campania (in Italian "Piano Regionale di Gestione dei Rifiuti Speciali – PRGRS)[19] (2012) estimates an annual production of CDW equal to about 3 million tons. CDW therefore represents a considerable item in the balance of SW produced in Campania, constituting around 40% of the total (ISPRA, 2017). Therefore, it is strictly necessary that the public administrations commit themselves to ensure a sustainable collection and recycling of this flow (Blengini and Garbarino, 2010), which represents a great opportunity to develop sustainable recycling and reuse practices for non-hazardous waste, that constitutes a fundamental resource for the regeneration of territories in crisis.

As stated by Gálvez-Martos et al. (2018), CDW does not have a very high impact in comparison with other kind of flows, anyway its environmental impact is a very important concern in term of logistics and land occupation and as a consequence, its management represents a priority for most environmental programmes around the world, in particular in Europe. As a matter of fact, when it is not properly managed, CDW can severely impact the environment, economy as well as social activities (Duan et al., 2015; Marzouk and Azab, 2014; Ortiz et al., 2010; Penteado, C. S. G., Rosado, 2015; Yuan et al., 2012).

The analysed CDW flow, identified through the European Waste Catalogue (EWC)[20] code n. 17, is formed by the following categories:

1. bricks and concrete, formed by the following groups of categories:
   170101: concrete;
   170102: bricks;
   170107: mixtures of concrete, bricks, tiles and ceramics other than those mentioned in 170106.

2. soil, formed by the following groups of categories:
   170504: soil and stones other than those mentioned in 170503;
   170506: dredging spoil other than those mentioned in 170505;
   170508: track ballast other than those mentioned in 170507.

[19] http://www.regione.campania.it/regione/it/tematiche/magazine-ambiente/piano-regionale-di-gestione-dei-rifiuti-urbani-2016?page=1
[20] http://www.nwcpo.ie/forms/EWC_code_book.pdf

3. metals, formed by the following groups of categories:
   170402: aluminium;
   170405: iron and steel;
   170401: copper bronze brass;
   170403: lead;
   170404: zinc;
   170406: tin;
   170407: mixed metals;
   1704011: cables other than those mentioned in 170410.

4. 170103: tiles and ceramics;

5. 170201: wood;

6. 170202: glass;

7. 170203: plastic;

8. 170302: bituminous mixtures other than those mentioned in 170301;

9. 170302: insulation materials other than those mentioned in 170601 and 170603;

10. hazardous, formed by the following groups of categories:
    170605: construction materials containing asbestos;
    170801: gypsum-based construction materials contaminated with dangerous substances;
    170902: construction and demolition wastes containing PCB;
    170903: other construction and demolition wastes (including mixed wastes) containing dangerous substances;
    170106: mixtures of, or separate fractions of concrete, bricks, tiles and ceramics containing dangerous substances;
    170204: glass, plastic and wood containing or contaminated with dangerous substances;
    170301: bituminous mixtures containing coal tar;
    170409: metal waste contaminated with dangerous substances;
    170410: cables containing oil, coal tar and other dangerous substances;
    170503: soil and stones containing dangerous substances;
    170601: insulation materials containing asbestos;

170603: other insulation materials consisting of or containing dangerous substances;
170303: coal tar and tarred products.

11. 70802: gypsum-based construction materials other than those mentioned in 170801;

12. 170904: mixed construction and demolition wastes other than those mentioned in 170901, 170902 and 170903.

Each of these categories is subject to specific regulations and allows giving rise to useful practices of recycling and regeneration of the territory.

4.1.2 Excavated hearts and rocks

Indeed, a particular category of CDW is represented by soil, known as “excavated earths and rocks” (in Italian “terre e rocce da scavo”), whose management is subjected to a new Regulation which is part of the Presidential Decree 13 June 2017, n. 120[21]. In particular, earth and rocks deriving from excavation that meet certain requirements may be classified as by-products and, in the form of “second raw material” (in Italian “Materia Prima Seconda” - MPS), may be subjected to a Plan of Use that establishes the possibility of use in plans of environmental recovery. In order to be classified as by-products and not as waste, these materials must be used in small sites and without treatments other than normal industrial practice, meeting environmental quality requirements. In addition, they must be generated during the construction of a work whose main purpose does not concern the production of such material.

4.1.3 Recycling standards and possible potentialities

Considering the CDW supply chain, the starting point is represented by the phase of extraction of raw materials from quarries and then move on to the production and consumption phases, which, as already specified, can derive from four types of activities at least:

– construction and demolition activities;

[21]http://www.bosettiegatti.eu/info/norme/statali/2017_0120.htm

– illegal construction and demolition activities;
– activities of micro home renovations carried out independently;
– other activities.

As far as the WM phase is concerned, of the 7 million tons of special waste produced in Campania, as previously underlined, about 3 million tonnes are represented by CDW. Therefore, given the huge quantity, with the Directive 2008/98/EC[22], Europe establishes the need to guarantee a recovery of 70% of the total CDW by 2020.
Therefore:

«collection and recycling of construction and demolition waste should not be considered a stand-alone activity, but should rather be framed in a wider context of resource and waste management. One advantage of recycling is landfill avoidance, which implies saving of waste dump capacity, i.e. space: a very important and scarce resource nowadays in Italy» (Blengini and Garbarino, 2010, p. 1021).

More in depth, some best practices could be represented by the reduction of this kind of waste generation, the minimization of transport impacts, the maximization of reuse and recycling through the improvement of the quality of second raw materials as well as the optimization of the environmental performances of the methods of treatment (Gálvez-Martos et al., 2018).

With this purpose, a useful practice for encouraging the achievement of the European standard could be that of "selective demolition", which is still little applied, but holds great potential for the application of the CE principles. Indeed, where the traditional demolition consists in the production of waste that is largely sent to landfill and minimally recovered, selective demolition allows the separation of waste from the place of production, increasing the level of recyclability of waste.

Moreover, another important potentiality that lies in this flow is that of aggregates recycling. This activity has the primary advantage of reducing the materials sent to landfill and, at the same time, of transforming them into secondary products, which can be used as a substitute or together with natural aggregates for different purposes depending on their quality, giving life to a "sustainable supply chain". This process would reduce input flows and at the same time output products, creating the conditions for the transition from a "linear UM" to a "circular UM".

[22] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:32008L0098

Currently the local recycling of aggregates allows the production of mainly low quality recycled aggregates, used for road foundations, fills and environmental restorations. Therefore, it would be advisable to invest in the recycling chain through the production of high quality aggregates to be used also in the construction sector.
However, there are numerous obstacles to the activation of this procedure, not only of an economic nature, but also due to the lack of confidence in using materials deriving from waste. Another problem concerns the lack of taxation on mining activities, which, if activated, could guarantee competitive prices to recycled materials compared to virgin ones. To the listed obstacles, it is added the lack of "End of Waste Criteria"(Delgado Sancho et al., 2010) for the CDW, i.e. the criteria that specify when a certain type of waste ceases to be such and can again be classified as a product .
Despite the above obstacles, there are numerous potential of development thanks to some initiatives such as the "Green Public Procurement" (GPP) and "Minimum Environmental Criteria" (in Italian "Criteri Ambientali Minimi" - CAM), which encourage the possibility of improving the recycled industry and streamline the entire production supply chain, generating as a consequence positive repercussions on the territory.

4.1.4 Data traceability

Finally, as regards the traceability of data, it is possible to collect information on waste streams through the analysis of the so-called Environmental Declaration Model (in Italian "Modello Unico di Dichiarazione Ambientale" - MUD), which represents a declaration made by waste treatment plants, producers and transporters at the corresponding Chamber of Commerce.
MUD specifies the producers and the location where they send the produced quantities, while at the same time the receiving plants have to declare the quantities they receive and the treatments they operate.

Definitely:

«the knowledge of regional waste generation trend can help the policy-makers to formulate practical regulations and make effective decisions. In addition, the number and volume of waste treatment sites to be established can be determined according to this information» (Wu et al., 2014, p.1686).

Anyway, with reference to local units with less than 10 employees, MUD is able to cover only about 10% of the produced waste and for this reason it is necessary to

cross data from different sources and adopt techniques to estimate the missing part. As, indeed, stated in the article 189 of the Legislative Decree n.152/2006[23], only organizations and companies that produce hazardous waste and those that produce non-hazardous waste with more than ten employees are obliged to present this declaration. To this, it is added the impossibility of tracing illegal spills, which are quite relevant in Campania Region. It is therefore clear that for the sectors that are entirely exempted from the reporting obligation and for those characterized by a high presence of small businesses, the development of the MUD database can not provide complete information on the production of non-hazardous waste. Indeed, of the about 3 million tons only about 1,7 million tons are tracked through the MUD waste cadastre from the Campania regional agency for environmental protection (in Italian “Agenzia Regionale per la Protezione Ambientale in Campania” – ARPAC) as production data.
Therefore, a methodology based on the quantification of waste production related to the number of employees has been used. This methodology was performed exclusively to supplement the information taken from the MUD database for local units with fewer than 10 employees.

Fig. 33 represents the comparison between the traditional and the integrated management of the CDW flow.

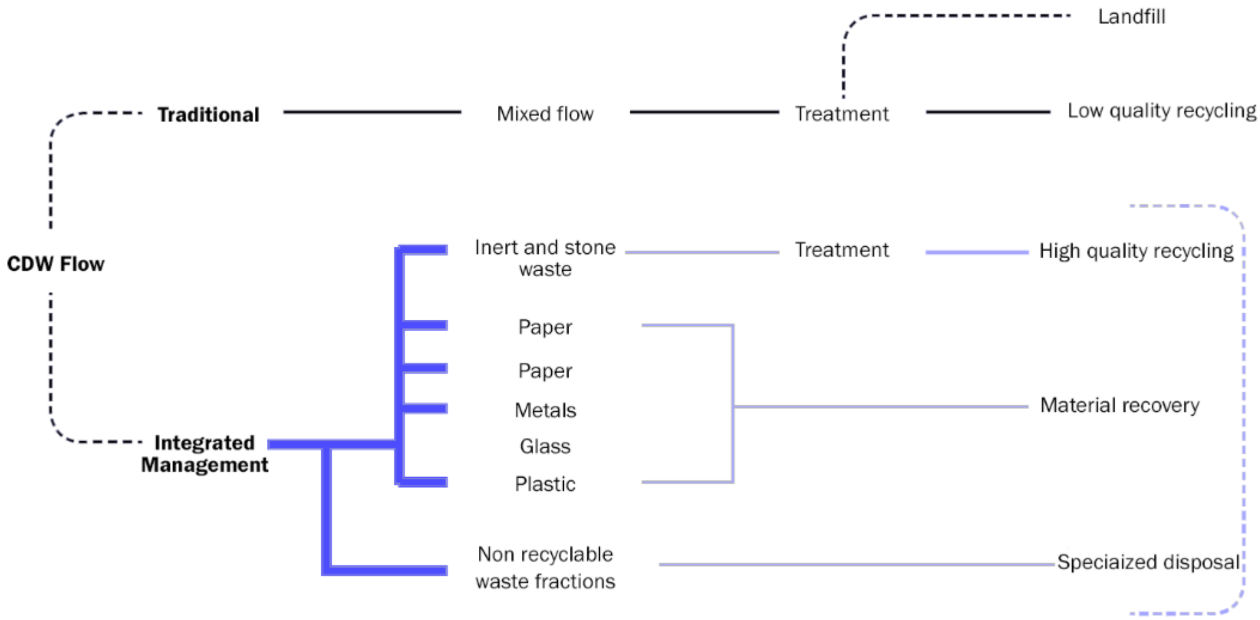


Fig. 33: traditional and integrated management of CDW flow, adapted from Baiocco et al., 2018

[23] http://www.camera.it/parlam/leggi/deleghe/06152dl.htm

As it is possible to notice, there are also other fractions of the waste flow that can be subjected to material recovery, apart from the inert component. Anyway, these fractions in a medium flow composition are generally represented by low quantities. The recycling potential is therefore fundamental, especially for the component represented by the aggregates.

4.2 Methodology for the construction of the baseline scenario

Above all, decision making in WM «requires clear goals, appropriate methods and reliable data» (Taelman et al., 2017a, p. 6). The methodology used for the experimental application consists in the initial construction of a baseline LCA model for the assessment of the impacts related to the treatment of CDW with reference to the year 2015, adopting a multi-scale approach.
Actually, «as the impacts of environmental problems have multi-scale characteristics, assessment needs to be considered on all scales to provide efficient information of urban ecosystem sustainability» (Dizdaroglu, 2015, p. 120).
This model is part of the Work Package (WP) n.4 of the REPAiR project, which is focused on the impact assessment. A first result concerns the entire Campania Region and then moves on to the FA (Fig. 34).

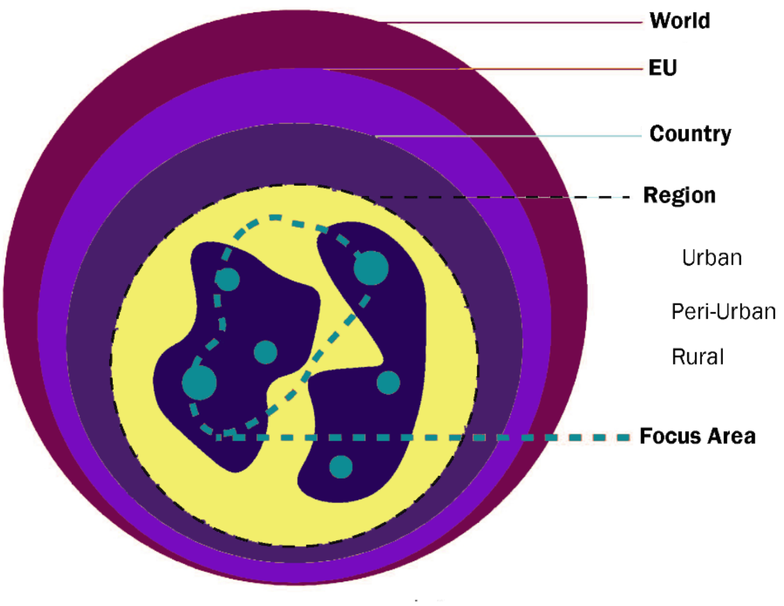


Fig. 34: multi-scaling model, adapted from Geldermans et al., 2017

Therefore, the amount of waste generated in Campania Region and subsequently in the FA by its population during one year represents the starting point of the LCA, and it also represents the FU (Taelman et al., 2017b).
Considering that a huge amount of waste that is produced in the Region and in the FA is treated outside their borders, it is very important to trace the locations of the different WM processes, introducing a distinction between foreground system and background system (see also paragraph 3.3 and fig. 22). The first one includes WM processes that take place inside the FA or Campania Region as well as WM processes that take place outside the FA or Campania Region. The second one includes the supply chain processes that support the foreground system (Taelman et al., 2017a). Each process of the supply chain generates a certain amount of waste and alter at the same time the territorial performances, generating *wastescapes* (see paragraph. 3.3).

4.2.1 LCA model for Campania Region

The LCA model has been realized using the software EASETECH - Environmental Assessment System for Environmental Technologies - developed at the Technical University of Denmark (DTU) (Clavreul et al., 2014). One of the main «aim of EASETECH is to perform LCA of complex systems handling heterogeneous material flows. EASETECH models resource use and recovery as well as environmental emissions associated with environmental management in a life-cycle context» (Taelman et al., 2017c, p.51).

For the present model, the FU is represented by the treatment of one tonne of CDW. The starting point for the model elaboration (Fig. 35-36) is the waste generation, represented through the percentage of the various fractions that make up the totality of the flow (Tab.8).

In Tab.9 it is possible to read the quantities according to the EWC codes and the relative treatment plants in which they are sent. The present data were obtained by the Campania regional agency for environmental protection[24].

The system boundaries related to the end of life phase of CDW are represented in Fig. 37.
System boundaries include all the processes of treatment since the waste enters the system management up to their exit from the system as emission (solid, liquid or

[24] https://www.arpacampania.it/

gaseous) or as secondary raw material, while the impacts associated with the production of waste are excluded. However the approach used is the expansion of boundaries of the system, for which they were included in the analysis also the avoided raw materials thanks to the recovery and use of secondary resources coming from recycling processes. (Borghi et al., 2017).
These fractions are sorted according to the treatments that they undergo in six different categories of plants, which are the following (Tab.10):
– incinerator;
– stationary recycling plant;
– recycling plant;
– anaerobic digestion plant;
– bottom ash landfill;
– chemical physical biological plant

In Italy, selective demolition practices at the construction site are still not widespread, even if they could be useful in increasing the waste quality, determining a more homogeneous flow sent to the various plants, with a lower level of impurities.
Anyway, the greater quantities of CDW sent to recovery plant are represented by mixed CDW, which is treated in combination with minor flows, such as bituminous mixture, gypsum-based waste as well as waste containing cement, bricks, tiles and ceramics (Borghi et al., 2017). Mixed CDW is a mixture of non-hazardous CDW, i.e. a set of waste belonging to the various EWC codes of the non hazardous component.

As far as storage is concerned, it is necessary to specify that storage is always a temporary (more or less time consuming) operation, as waste can be stored for a maximum of one year before being sent to recovery or disposal.
Moreover, analysed waste flows comprise direct flows, that are directly sent to plants and secondary ones that derive from intermediate management operations.

Two main typologies of data have been considered for the model inventory construction:
– primary data coming from ARPA Campania, as already specified;
– secondary data obtained from the Ecoinvent[25] database, version 3.4, that integrates primary data with missing information.

It will be demonstrated that LCA represents a relevant tool in order to improve the level of knowledge of the environmental profile of the CDW management system and together with the elaboration of scenarios of comparison, can provide useful data for improving the decision-making process (Penteado and Rosado, 2015).

[25] https://www.ecoinvent.org/

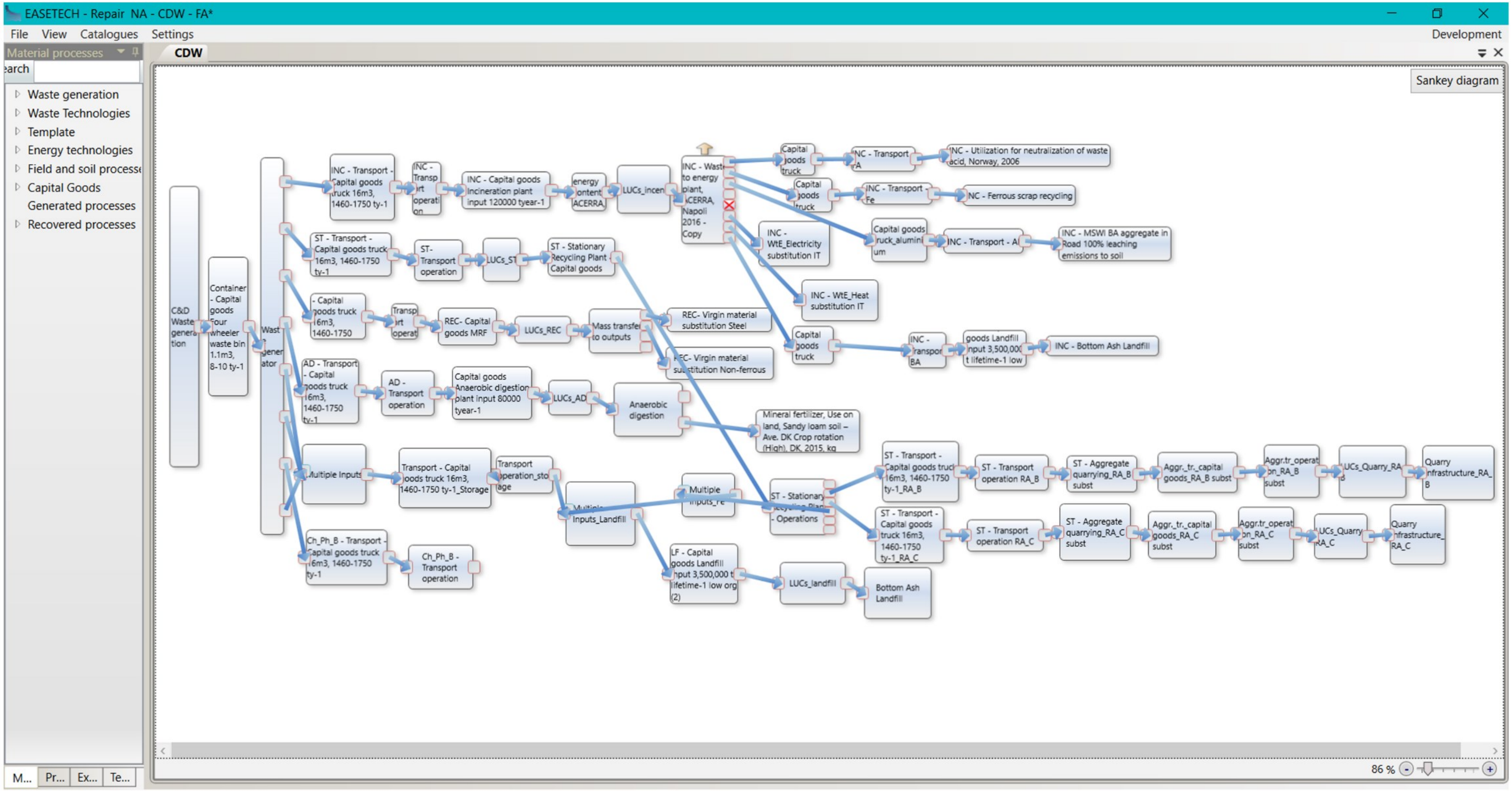


Fig. 35: the LCA model for Campania Region elaborated with EASETECH software

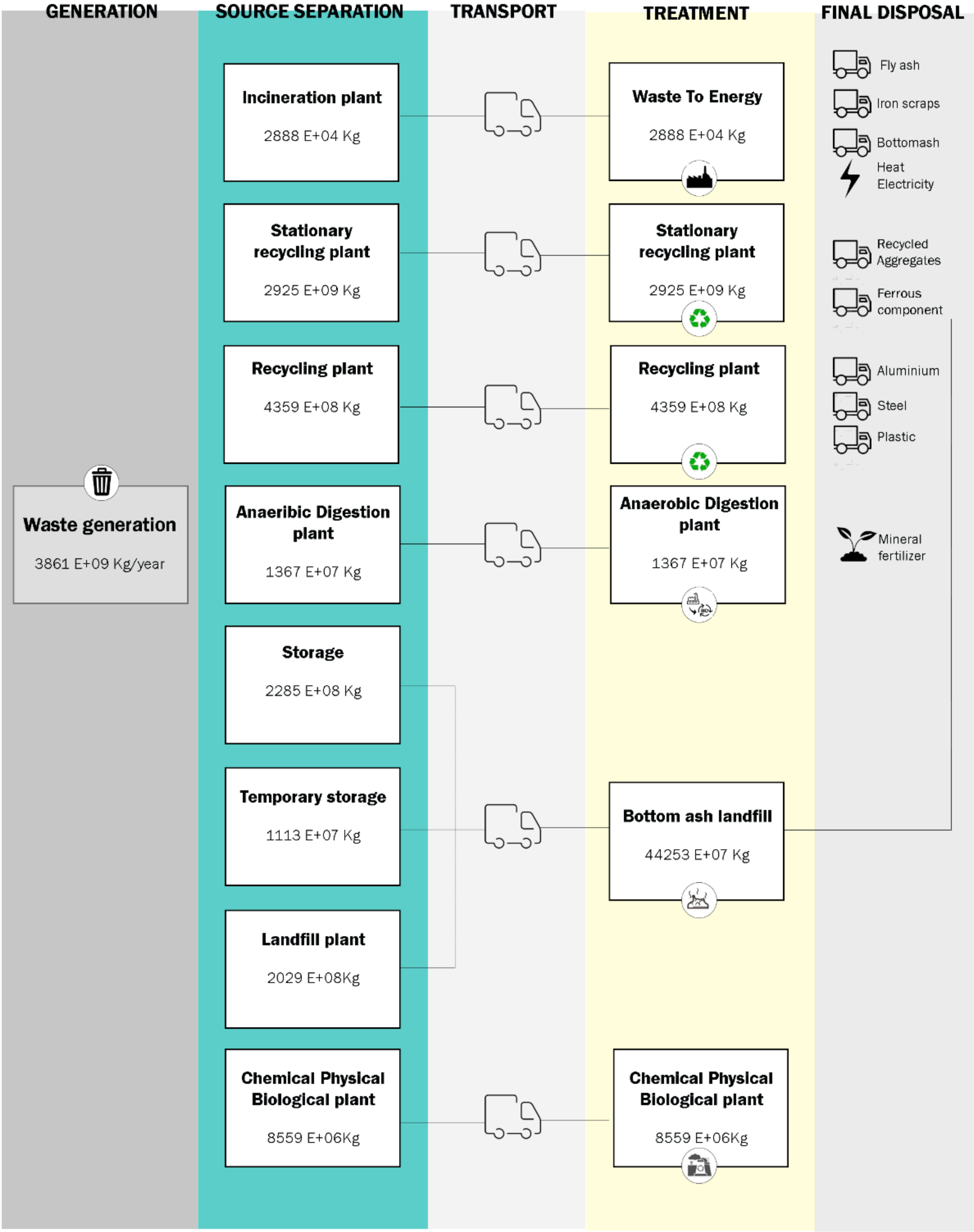


Fig. 36: LCA model for Campania Region schematisation

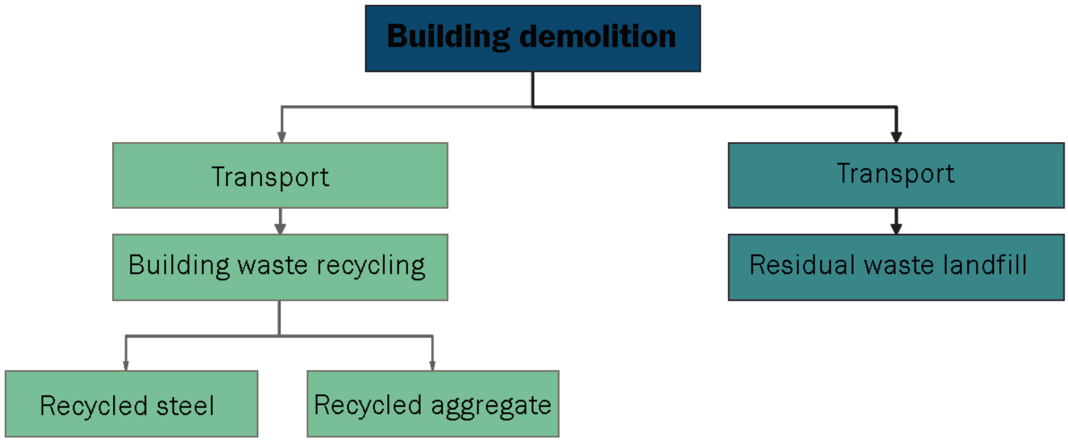


Fig. 37: system boundaries, adapted from Blengini, 2009

Material Fractions	%
Hard plastic	0.05
Aluminium	0.57
Bitouminus mixture	10
Ferrous scrap	11
Clear glass	0.03
Hazardous CDW	0.68
Other metals	1.5
Mixed CDW	35.4
Insulation materials	0.06
Stones, concrete	4.8
Ceramics	0.05
Wood	0.19
Gypsum	0.14
Soil	34.6

Tab. 8: material fractions: quantities and composition of the CDW flow for Campania Region, year 2015 (%)

Anaerobic Digestion Plant and Chemical Physical Biological Plant receive a small humid fraction that is contained in the general CDW flow. Anyway, in general there is no direct emission from CDW and the generation of leachate can be considered negligible, taking into account instead the emissions coming from process-specific impacts related to energy, land use and infrastructure (Penteado and Rosado, 2015).

Plant typology	EWC Code																	
	170101	170102	170103	170106	170107	170201	170202	170203	170204	170301	170302	170303	170401	170402	170403	170404	170405	170406
#ErrorMUD	5,842.55		0.60		5,059.68	320.23	32.31	138.28	188.80	628.61	21,545.38		443.19	447.27	21.25		27,862.90	
#NotDefined	2,192.47	53.00	579.04		711.81	134.43	6.73	229.94	193.74	2,015.13	9,868.54		462.07	1,532.76	13.54	5.23	20,667.57	
Chemical-Physical- Biological Plant	28.50		1.38	7.04	22.88	40.58	8.51	63.91	282.94	3,616.09	279.45	3.56		0.39		0.21	72.54	
Composting (anaerobic digestion) Plant																		
Disposal Plant	5.33					14.71	1.83	10.50	0.09	587.31	117.66	3.24					30.22	
Incineration Plant										75.23								
Landfill Plant	234.28			160.80	193.92						3.22							
Material Recover Plant	142,137.89	541.83	1,086.44		36,250.13	4,380.22	965.99	1,795.10	5,741.28	3,418.72	388,581.88		23,667.26	22,348.20	1,376.06	113.06	391,764.14	8.72
Storage Plant	4,301.11	56.82	48.16		2,059.03	2,687.99	342.41	1,242.88	160.63	5,984.87	20,749.91	0.04	4,612.56	5,603.29	221.68	5.10	88,162.05	0.15
Temporary Storage Plant	177.87		1.78	30.44	26.72	198.50	35.98	199.91	28.44	5,773.11	1,216.50	0.67		5.14	0.03		118.83	
Grand Total	**154,920.00**	**651.65**	**1,717.40**	**198.28**	**44,324.17**	**7,776.66**	**1,393.76**	**3,680.52**	**6,595.92**	**22,099.08**	**442,362.53**	**7.51**	**29,185.07**	**29,937.04**	**1,632.57**	**123.60**	**528,678.25**	**8.87**

Tab. 9: CDW quantities and treatment plants for Campania Region, year 2015 (tons)[26]

Plant typology	170407	170409	170410	170411	170503	170504	170506	170508	170601	170603	170604	170605	170801	170802	170902	170903	170904	Grand Total
#ErrorMUD	369.84			185.83	138.41	32,078.59			42.65	175.02	35.28	1,917.54		98.73		330.37	113,106.14	**211,009.43**
#NotDefined	418.92		3.57	241.88		65,910.58	99.48		0.03	113.39	749.50	933.36		165.85	3.12	93.88	69,856.46	**177,256.00**
Chemical-Physical- Biological Plant	26.68	946.02	5.13	1.32	7,898.50	4,501.34	3,411.66		42.65	325.11	237.56	162,432.68		11.07		413.18	3,370.82	**188,051.70**
Composting (anaerobic digestion) Plant																	18.92	**18.92**
Disposal Plant		0.95		2.28	84.24	0.09			6.20	75.33	26.20	517.85	0.08	13.12		31.47	26.96	**1,555.67**
Incineration Plant																		**75.23**
Landfill Plant					371.68	46,651.09			7.01	19.06	22.81	7,516.40		5.63		26.10	7,132.22	**62,344.22**
Material Recover Plant	11,607.37	1.42	2.93	18,833.81	8,102.39	1,076,360.34	46,731.61	82,729.29		53.90	991.53	265.12		3,720.59		329.32	1,269,813.18	**3,543,719.71**
Storage Plant	2,239.64	8.94	1.97	3,897.62	134.69	267,734.38			13.90	341.47	1,048.51	585.46		1,657.83		81.92	92,449.80	**506,434.83**
Temporary Storage Plant	0.14	37.86	2.10	15.34	160.68	20,580.56			87.14	533.60	765.15	2,722.18	0.20	64.97		55.10	6,970.29	**39,809.22**
Grand Total	**14,662.58**	**995.19**	**15.71**	**23,178.07**	**16,890.59**	**1,513,816.96**	**50,242.75**	**82,729.29**	**199.58**	**1,636.87**	**3,876.54**	**176,890.58**	**0.28**	**5,737.79**	**3.12**	**1,361.35**	**1,562,744.79**	**4,730,274.92**

Tab. 9 (continuation): CDW quantities and treatment plants for Campania Region, year 2015 (tons) [27]

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[26] The presented data, officially transmitted by ARPA Campania, are the result of the processing phase elaborated by Dr. Pasquale Inglese, collaborator of the REPAiR project, during the year 2016-2017

[27] "Error MUD" presents some compilation errors in the data format and "Not defined" is a category without any definition. Both the categories are sent to landfill for ease of interpretation and in the absence of other kind of information

Fraction name	Plant typologies									
	Mobile	Semi-Mobile	Incineration	Stationary	Recycling	Anaerobic Digestion	Storage	Temporary Storage	Ch ph Bio	Landfill
Bitouminus mixture	0%	0%	0%	91.8%	0%	0%	4%	0.1%	0.05%	4.05%
Clear glass	0%	0%	0%	0%	65%	0%	33.1%	0.62%	0.62%	0.66%
Hazardous CDW	0%	0%	0.11%	0%	48.1%	0%	11.10%	16.9%	0%	23.79%
Mixed CDW	0%	0%	0%	89.6%	0%	1%	4.32%	0.03%	0.02%	5.03%
Insulation materials	0%	0%	0%	0%	29.9%	0%	19.9%	22.8%	5.2%	22.2%
Other metals	0%	0%	0%	0%	86.3%	0%	13%	0.02%	0.02%	0.66%
Ferrous scrap	0%	0%	0%	0%	80.97%	0%	16.8%	0.03%	0.03%	2.17%
Stones, concrete	0%	0%	0%	93.3%	0%	0%	4.5%	0%	0.01%	2.19%
Ceramics	0%	0%	0%	63.6%	0%	0%	2.5%	0.12%	0.05%	33.73%
Wood	0%	0%	0%	0%	58.6%	0%	39.6%	0.08%	0.29%	1.43%
Gypsum	0%	0%	0%	0%	75.5%	0%	20.7%	0.92%	0.20%	2.68%
Aluminium foil and containers	0%	0%	0%	0%	80.98%	0%	17.7%	0.03%	0%	1.29%
Soil	0%	0%	0%	87.7%	0%	0%	4.09%	0.38%	0.58%	7.25%
Hard plastic	0%	0%	0%	0%	49%	0%	29%	6%	0%	16

Tab. 10: fractions in relation to the treatment plants for Campania Region, year 2015 (%)

4.2.1.1 LCA model for Campania Region: transport

As stated by Mercante et al. (2012), transport represents a crucial phase and in this case, many treatments of flows generated in Campania take place outside the Region (Tab. 11).

This has determined the need to apply a weighted average in relation to the kilometres travelled to reach the plants and the quantities sorted to them. It will be seen indeed, that the impacts due to transport are quite high.

For the movements that occur internally in the Region, it is considered an average of 70 km, while for the movements in the FA an average of 30 Km and the following results have been obtained according to each plant[28]:

– stationary recycling plant: 106 Kg*Km for the Region and 70 Kg*Km for the FA;
– incineration plant: 70 Kg*Km for the Region and 30 Kg*Km for the FA;[29]
– anaerobic digestion plant: 601 Kg*Km for both the Region and the FA;
– landfill plant: 210 Kg*Km for the Region and 182 Kg per Km for the FA;
– chemical physical biological plant: 262 Kg*Km for the Region and 262 Kg*Km for the FA;
– recycling plant: 106 Kg*Km for the Region and 70 Kg*Km for the FA.

[28] In order to facilitate the calculation, a centroid-centroid distance from the original Region to the destination Region was considered
[29] This value is lower because the flows are sent to the incineration plant in Acerra municipality, that is part of the selected Focus Area

Origin-Destination	Distance m	Distance km	#ErrorMUD	#NotDefined	Chemical-Physical- Biological Plant	Anaerobic Digestion Plant	Disposal Plant	Incineration Plant	Landfill Plant	Stationary Recycling Plant	Recycling Plant	Storage Plant	Temporary Storage Plant
Campania - Abruzzo	198,858.95	198.86		156.91	882,630.00				338,640.00	586,200.00	3,877,230.00	335,870.00	
Campania - Basilicata	169,198.33	169.20	57.09	589.93	251,040.00				2,825,640.00	4,798,400.00	3,189,990.00	263,500.00	
Campania - Calabria	348,632.61	348.63	1,005.36	5.16	623,550.00		1.80		1,171,320.00	40,957,740.00	1,588,750.00	25,218,000.00	20,286.91
Campania - Campania	0.00	0.00	204,520.18	135,708.76	1,202,480.00		178.80	75.23	340,459,050.00	2,828,084,230.00	351,172,120.00	344,308,970.00	17,018.85
Campania - Emilia-Romagna	601,259.79	601.26	1,763.19	75.24	9,766,560.00	18,920.00			1,838,431.000	9,339,850.00	26,065,910.00	3,678,620.00	90.22
Campania - Friuli Venezia Giulia	758,551.88	758.55	21.16						21,160.000	39,610.00	14,030.00	420.00	
Campania - Lazio	229,081.60	229.08	2,358.98	2,292.83	162,920,340.00		307.09		12,647,530.00	53,498,160.00	120,185,400.00	2,981,190.00	241.18
Campania - Liguria	796,149.64	796.15		244.86					245,360.00	1,176,550.00	162,990.00	954,600.00	
Campania - Lombardia	771,673.08	771.67	337.17	941.48	871,090.00		365.96		1,644,602.000	6,617,620.00	34,942,880.00	5,276,910.00	649.48
Campania - Marche	394,463.06	394.46	0.56	258.44	1,672,650.00		296.47		710,430.00	877,260.00	4,205,950.00	18,550.00	1,401.34
Campania - Molise	84,755.19	84.76	21.72		330.00				259,000.000	967,620.00	181,390.00	90.000	0.09
Campania - Piemonte	845,622.55	845.62	537.98	43.82	10,640.00		0.40		704,320.00	3,692,600.00	1,961,120.00	26,200.00	10.86
Campania - Puglia	192,717.86	192.72		147.98	3,006,360.00		6.62		41,633,380.00	95,892,800.00	5,337,170.00	392,710.00	36.57
Campania - Sardegna	691,345.65	691.35		65.65	2,236,500.00				134,690.00	2,063,360.00	162,420.00	30,180.00	2.14
Campania - Sicilia	640,098.30	640.10	23.66	36,540.28	162,950.00		18.06		36,621,180.00	165,741,000.00	424,090.00	146,552,180.00	34.97
Campania - Toscana	471,885.60	471.89	340.83	7.87	429,970.00		207.56		7,726,810.00	56,162,180.00	3,081,790.00	11,107,560.00	21.22
Campania - Trentino-Alto Adige	809,708.69	809.71								2,870.00	23,930.00		
Campania - Umbria	360,680.57	360.68	1.10	149.75			28.02		178,866.000	117,880.00	4,276,160.00	35,530.00	15.39
Campania - Veneto	670,856.69	670.86	20.44	27.05	144,890.00		144.89			4,867,160.00	7,982,010.00	3,661,640.00	

Tab. 11: origin and destinations of CDW flows, year 2015

4.2.1.2 LCA model for Campania Region: land use

Another important analysis that has been carried out for the elaboration of the present model is that relative to land use.
A soil in natural conditions is able to provide ecosystem services, but soil is also improperly transformed by human activities, creating a strong competition between use of soil for agricultural, industrial and urban purposes and natural ecosystems, making it an increasingly limited resource (Torricelli and Gargari, 2015b).

Land use in general refers to human activities carried out in a certain land cover. Therefore, it concerns the functional dimension and the socio-economic activities that characterize a certain area.

In LCA, land use is divided in two categories: “land occupation” and “land transformation”; the first one refers to the continuous use of an area for a certain human activity, while the second one represents a change in use or management of soil caused by human action, referring to the change from one category of land use to another. Both human activities and natural processes can cause land transformation (Torricelli and Gargari, 2015b).
Consequently, for each of the treatment plants considered, the evolution of land use in relation to the life cycle of soil was analysed, taking into account land transformations and land occupations.

In this regard, it is important to introduce the difference between direct Land Use Change (dLUC) and indirect Land Use change (iLUC). The first one represents the transformation caused directly by the expansion of a certain land use activity, while the second one represents the transformation caused indirectly from the competitive use of the land, beyond the borders of the system studied and which is attributable to the system studied. For example, the conversion of land use from food production to biofuels will determine in another territory the conversion of land use characterized by a different production to food production, in order to balance the change.

Therefore, in the model the following dLUC have been considered:

– *Incineration*
occupation: industrial area for 20 years (average duration);
transformation from annual crop;
transformation to industrial area;

– *Stationary Recycling plant*
occupation: industrial area for 20 years (average duration);
transformation from annual crop;
transformation to industrial area.

– *Recycling plant*
occupation: industrial area for 20 years (average duration);
transformation from annual crop;
transformation to industrial area.

– *Anaerobic Digestion plant*
occupation: industrial area for 20 years (average duration);
transformation from annual crop;
transformation to industrial area.

– *Landfill plant*
occupation: dump site for 20 years (average duration);
transformation from annual crop;
transformation to dump site.

– *Quarries*
occupation: mineral extraction site 35 years (average duration);
transformation from pasture man made;
transformation to mineral extraction site.

4.2.1.3 LCA model for Campania Region: Recycled Aggregates and avoided quarries

A separate discussion is linked to the production of Recycled Aggregates (RA) (see also paragraph 4.2).
The model compares indeed the impacts related to the production of RA and the impacts related to gravel extraction during the quarrying activity, in order to quantify the impacts that can be avoided if the recycled ones are used, leading to a gradual reduction in the extractive activity from quarries. Indeed the avoided impacts deriving from the replacement of recycling aggregates with natural materials can be up to 10 times in terms of CO_2 equivalent and 8 times for what concerns primary energy consumption (Penteado and Rosado, 2015).

According to the Regional Plan for mining activities (in Italian "Piano Regionale Attività Estrattive" – PRAE) (2006)[30], it is necessary to pursue a progressive reduction in the collection of natural materials from quarries.
This can happen through the reuse of alternative materials and through the use of excavated earth and rocks, to the extent permitted by the current legislation, in order to obtain the double result of limiting the opening of new quarries and reducing the need of landfills for aggregates, which represent further land consumption.
The exploitation of raw materials coming from quarries determines, in fact, a real degradation and impoverishment of the territory. In the same way, in the Code of the contracts there are some provisions for containing the excessive use of natural resources and for facilitating the use of green procurement through evaluation of life cycle costs, including the disposal and recovery phase[31]. Furthermore, the heavy use of natural resources is one of the main challenges that European cities have to face (Giovannetti and Pagliacci, 2010).
Therefore, as far as the RA production chain is concerned, it has been possible to obtain inventory data tracing the flows treated in the stationary recycling plants that produce mainly RA of type B and C.
Type B is characterized by a medium quality and it is generally used for airport and harbour construction, while type C is characterized by a low quality and it is generally employed for environmental filling as well as rehabilitation of depleted quarries and landfill sites (Blengini and Garbarino, 2010).
In order to be accepted on the building site, and in order to be subsequently used, RA need to respect specific technical and environmental requirements[32] [33]. It is also important to reduce transport distances for RA, as transport is a considerable process in the balance of environmental impacts, being the largest responsible and risking to make recycling not beneficial (Penteado and Rosado, 2015).

As far as the quarry activity is concerned, according to Legambiente (2017), in Campania there are about 48 active quarries and 123 abandoned quarries especially because of the economic crisis and the building sector crisis. The material extracted in the province of Naples that can be replaced by RA is represented by limestone, that according to PRAE is extracted in two complexes of quarries located in Casamarciano and Roccarainola.

[30] http://www.sito.regione.campania.it/lavoripubblici/Elaborati_PRAE_2006/indice_prae_2006.asp
[31] http://www.bosettiegatti.eu/info/norme/statali/2016_0050.htm
[32] http://www.arpa.veneto.it/temi-ambientali/rifiuti/file-e-allegati/normativa/circ_5205_2005.pdf
[33] https://www.albonazionalegestoriambientali.it/Download/it/NormativaNazionale/004-DM_05.02.98.pdf

Fig. 38 represents the totality of quarries in Campania Region with a focus on limestone ones.

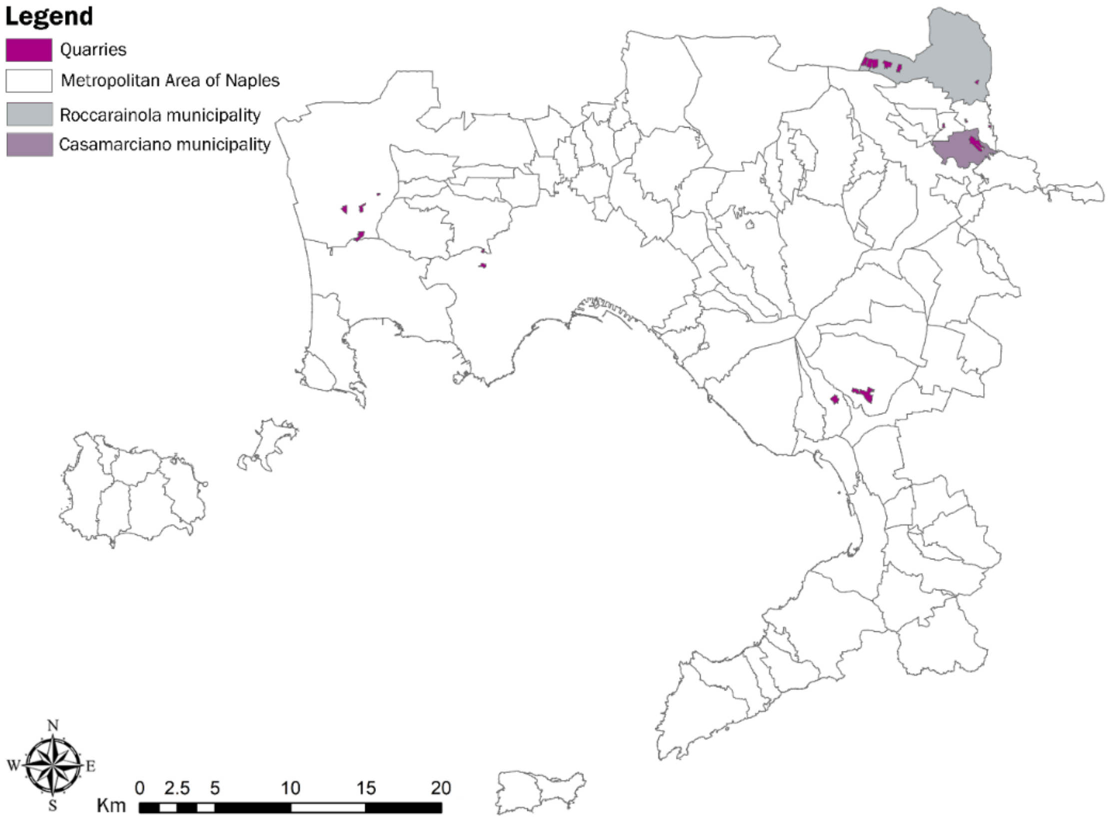


Fig. 38: quarries in the province of Naples

For the quarries analyses, it has been considered: (Tab.12):

– the type of material extracted, represented by limestone[34];
– the quantity of material extracted (Kg/y), calculated by dividing the average annual production of calcareous material with the number of quarries, in relation to the surface;
– the surface (m^2);
– the m^2 necessary to extract 1 Kg of material;
– the recycled aggregates substituting, that, as specified above, can be of type B and C, considering a substitution ratio of 1:1 between natural aggregate and recycled aggregates of the same type.

[34] The other quarry complexes present in Campania are instead sites of extraction of the following materials: pozzolana, yellow ignimbrite, Neapolitan yellow tuff, lava stone. These materials are not considered suitable for the production of natural aggregates

As far as dLUC is concerned, the following transformations have been taken into account:

- the original land use before the opening of the quarry (arable land or pasture);
- the transformed land use, represented in the model by mineral extraction site;
- the occupation time as mineral extraction site, calculated consulting the mining activity authorization and possible exceptions to the time limits for the disposal of quarry sites;
- the total quantity of material extracted (Kg/year x year of activity).

Quarry	Type of material extracted	Quantity of material extracted Kg/y	Surface m²	m²y/Kg	Substituted aggregated	Transformation from	Transformation to	Occupation	Year of activity	Kg/year * year of activity
Casamarciano	limestone	1232000000	368500	2.99E-04	TYPE B/C	arable land, unspecified use	mineral extraction site	mineral extraction site	28	3.45E+10
Roccarainola_1	limestone	878576261	241000	2.74E-04	TYPE B/C	pasture, man made	mineral extraction site	mineral extraction site	45	3.95E+10
Roccarainola_2	limestone	131239607	36000	2.74E-04	TYPE B/C	pasture, man made	mineral extraction site	mineral extraction site	45	5.91E+09
Roccarainola_3	limestone	109366339	30000	2.74E-04	TYPE B/C	pasture, man made	mineral extraction site	mineral extraction site	45	4.92E+09
Roccarainola_4	limestone	318985157	87500	2.74E-04	TYPE B/C	pasture, man made	mineral extraction site	mineral extraction site	45	1.44E+10
Roccarainola_5	limestone	273416000	75000	2.74E-04	TYPE B/C	pasture, man made	mineral extraction site	mineral extraction site	45	1.23E+10
Roccarainola_6	limestone	145822	40000	2.74E-01	TYPE B/C	unspecified	mineral extraction site	mineral extraction site	45	6.56E+06
Total Roccarainola		**1710000000**	**509500**	**2.98E-04**	**TYPE B/C**	**pasture, man made**	**mineral extraction site**	**mineral extraction site**	**45**	**7.70E+10**
Absolute total		**2940000000**	**878000**	**2.99E-04**	**TYPE B/C**		**mineral extraction site**	**mineral extraction site**	**37**	**1.09E+11**

Tab. 12: limestone quarries characterization for the province of Naples

4.2.1.4 LCA model for the Focus Area

In a multi-scale perspective, the same model has been secondly built for the Focus Area, in order to compare the results, and as it will be seen in the following chapters, there will be a further change of scale with the creation of an example scenario based on a single building.

The procedure followed for the Region was repeated in the same way, re-aggregating the quantitative information in the same model (Tab. 13-15).

Material Fractions	%
Bitouminus mixture	5.3
Clear glass	0.06
Hazardous CDW	4.6
Mixed CDW	44.4
Insulation materials	0.13
Other metals	2.5
Ferrous scrap	17.8
Stones, concrete	5.7
Ceramics	0.03
Wood	0.4
Gypsum	0.28
Aluminium foil and containers	0.96
Soil	17.7
Hard plastic	0.14

Tab. 13: material fractions: quantities and composition of the CDW flow for the Focus Area, year 2015 (%)

Fraction name	Plant typologies									
	Mobile	Semi-Mobile	Incineration	Stationary	Recycling	Anaerobic Digestion	Storage	Temporary Storage	Ch ph Bio	Landfill
Bitouminus mixture	0%	0%	0%	84%	0%	0%	2.8%	0.07%	0%	13.1%
Clear glass	0%	0%	0%	0%	73%	0%	25%	2%	0%	0%
Hazardous CDW	0%	0%	0.02%	0%	39%	0%	9%	11%	31%	10%
Mixed CDW	0%	0%	0%	74%	0%	0%	5%	0%	1%	20%
Insulation materials	0%	0%	0%	0%	28	0%	28%	10%	8%	26%
Other metals	0%	0%	0%	0%	73	0%	24%	0%	0%	3%
Ferrous scrap	0%	0%	0%	0%	68	0%	24%	0.08%	0%	7.9%
Stones, concrete	0%	0%	0%	85.7%	0%	0%	3.6%	0.01%	0%	10.70%
Ceramics	0%	0%	0%	79.1%	0%	0%	8.7%	0%	0%	12.10%
Wood	0%	0%	0%	0%	51.3%	0%	37%	5.90%	0.14%	5.70%
Gypsum	0%	0%	0%	0%	57%	0%	38%	1%	0%	4%
Aluminium foil and containers	0%	0%	0%	0%	67%	0%	28%	0.07%	0%	4.90%
Soil	0%	0%	0%	81.9%	0%	0%	10.8%	0%	0%	7.30%
Hard plastic	0%	0%	0%	0%	49%	0%	29%	6%	0%	16%

Tab. 14: percentages of fractions in relation to the treatment plants for the Focus Area, year 2015

Plant typology	EWC Code																	
	170101	170102	170103	170106	170107	170201	170202	170203	170204	170301	170302	170303	170401	170402	170403	170404	170405	170406
#ErrorMUD	3489				256	106		46	25	354	5112		48	59	7		7	
#NotDefined	795	9	26		150	65		130		996	117		187	363	1	5	5	
Chemical-Physical- Biological Plant				7		4		4	238	2005	105			0			44	
Composting (anaerobic digestion) Plant																		
Disposal Plant								4	0	32							2	
Incineration Plant										7								
Landfill Plant			26		5													
Material Recover Plant	33282	23	169		4360	1553	336	552	3985	2018	34248		6436	4961	418	22	94	
Storage Plant	1050	1	19		529	1120	113	327		2772	1144		2936	2055	48	1	33	
Temporary Storage Plant				5	4	179	11	64	15	3245	28			5			117	
Grand Total	**38616**	**33**	**240**	**12**	**5304**	**3027**	**461**	**1127**	**4263**	**11429**	**40754**		**9607**	**7443**	**473**	**28**	**138.18**	

Tab. 15: CDW quantities and treatment plants for the Focus Area, year 2015 (tons)

Plant typology	170407	170409	170410	170411	170503	170504	170506	170508	170601	170603	170604	170605	170801	170802	170902	170903	170904	Grand Total
#ErrorMUD	159			48	34	1404			30	154		180		24		330	49632	**68491**
#NotDefined	40			67		6247			0	29	255	179		72		60	15428	**29867**
Chemical-Physical- Biological Plant	22	918		1	7179	459	6		15	147	75	80		1		333	2584	**14227**
Composting (anaerobic digestion) Plant																	19	**19**
Disposal Plant				0	3	0			3	43	9	129		0		14		**241**
Incineration Plant																		**7**
Landfill Plant						1953						965					5185	**8122**
Material Recover Plant	2971			4462	7355	96051	57			20	275	90		1246		329	255	**570**
Storage Plant	727			1610	0	14835		16391		114	276	57		823		75	16	**78**
Temporary Storage Plant					40	1			32	167	97	513		13		0	257	**4795**
Grand Total	**3919**	**918**		**6188**	**14611**	**120.95**	**63**	**16391**	**80**	**689**	**986**	**2193**		**2179**		**1141**	**343.77**	**774507**

Tab. 15 (continuation): CDW quantities and treatment plants for the Focus Area, year 2015 (tons)

4.2.2 LCC model

In parallel with the creation of the LCA model, which allows the assessment of the environmental impacts linked to the current management of CDW, a cost model through a financial (or conventional) LCC approach has been constructed in order to examine the possible economic impacts related to the management and treatment of this flow.

LCC methodology is a financial assessment formed by aggregated costs that take in consideration the whole system life cycle (Taelman et al., 2017c). Indeed:

«while waste LCA provides a systematic framework for accounting for environmental impacts associated with waste management, most decisions related to the real-life implementation of waste technologies in modern societies are affected by economic constraints. For decision-makers, the lack of a balanced economic assessment alongside traditional LCA results therefore limits the value of the LCA itself, as economic priorities are then de-coupled from environmental aspects» (Martinez-Sanchez et al., 2015, p. 343).

In general, the economic assessment of waste management systems is a field still not very developed. Furthermore, it is possible to identify three main typologies of stakeholders in every waste management system (Martinez-Sanchez et al., 2015):
– waste generators;
– waste facility operators;
– waste authorities.

As described still by Martinez-Sanchez et al. (2015), there are two types of costs:
– external, also called "externality costs", that happen outside the economic system and have no direct monetary value in the market ;
– internal, that can be measured in market prices.

The overall costs that society has to face in order to manage waste derive from the sum of internal and external costs, representing the so-called "social costs". Furthermore still Martinez-Sanchez et al. (2015) clarify the distinction between:
– budget costs, that are the ones incurred by waste agents such as households as well as the technologies and facilities operating in the system and that comprise cost for bags, bins, capital goods, materials and energy consumption, labour costs material and energy sales. This type of cost can be "one-off" and this means that it occurs only once in the lifetime of the technology (such as the capital investment)

or it can be "recurring", such as operational and maintenance costs; lump sums are converted into annuities and annuities are divided by the annual usage rate of the technology (Martinez-Sanchez et al., 2015), as expressed in the following formula:

$$A = \frac{\mathrm{P}}{\left[\frac{(1+ir)^n - 1}{ir(1+ir)^n}\right]}$$

where *P* is the present value, *n* and *ir* represent the economic lifetime of the technology or the piece of equipment and the interest rates.
Budget costs comprise operational and maintenance costs that can be fixed (such as labour, maintenance and insurance) or variable (such as electricity consumption).
- transfers, representing monetary flows in the form of taxes, fees, etc.
- externality costs, that are the costs to society and can be both environmental and non-environmental, such as "disamenities", i.e. what reflects an unpleasant character. Externality costs are described by two parameters: an economic one, that represents the accounting price per unit of environmental emission and a physical parameter that represents the unit environmental emission (Martinez-Sanchez et al., 2015).

As far as the model structure is concerned, the waste system is divided into activities that characterize each technology and each activity is then disaggregated into relevant cost items.
Therefore, for each activity the relative cost items have been analysed considering two parameters:
- a physical parameter, representing the quantity of a cost item that is necessary in order to collect, treat or dispose one tonne of waste;
- an economic parameter, representing the unit cost of the cost item.

Multiplying the two parameters it is possible to obtain the unit cost.
For example, if it is necessary 1 l of diesel to collect one tonne of waste and 1 l of diesel costs 0.1 €, it is necessary to consume 0.1 € of diesel in order to collect one tonne of waste.

In order to obtain the overall costs of the system, the costs associated with all the activities included in the scenario have been summed (Martinez-Sanchez et al., 2015). All the costs are converted to the Net Present Value (NPV) and system boundaries correspond with those of LCA.

In a conventional LCC the budget and transfer costs for n activities of a scenario are obtained as follows:

$$Conventional\ LCC\ = \sum_{i=1}^{n} [W_i * \ (UBC_i\ + UT_i)]$$

where *Wi* is the amount of waste input for the activity i, *UBCi* represents the unit budget cost of the activity i and *UTi* is the unit transfer of the same activity i.

Fig. 39 reports an example of cost values related to transport operation for the incineration plant.

Additionally, in order to obtain fixed costs per item involved in the treatment of one tonne of waste (€/tonne), the annual costs (€/year) are divided by the annual usage rate of the plant, as already previously specified.
As far as variable costs is concerned, the physical amounts are multiplied by the unit price of the item, in order to obtain variable costs per item involved in the treatment of one tonne of waste.

Definitely, summing the costs associated with all activities included in the analysed scenario, the LCC of the waste system is obtained.
Moreover, it is possible to observe that a "bottom-up" approach is adopted, i.e. for each technology the relative cost items are firstly calculated and then follows a calculation of the single technology cost and finally the cost related to the entire scenario.

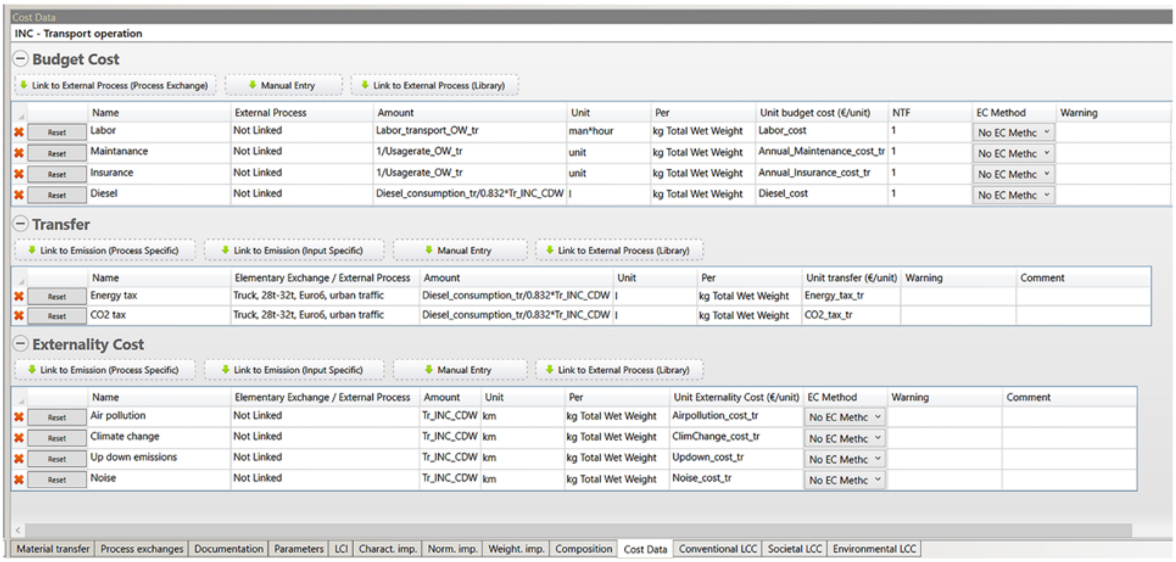


Fig. 39: incineration transport costs through the LCC model

4.2.2.1 Disamenities costs

As far as externality costs are concerned, and focusing in particular on disamenities (comprising visual impacts, but also other negative aspects due to the presence of waste treatment plants, such as noise and smell), they are calculated in general through the Hedonic Price Method (HPM) (Rosen, 1974).
It is demonstrated that the impact on the house prices decreases as the distance between the house and the disamenity increases, reaching 0 at a defined distance.

The application of HPM:

«allows including local disamenities-related impacts in the framework, quantifying externalities to estimate the induced cost of waste management facilities on nearby properties» (Taelman, et al., 2017c, p. 32).

The methodology usually considers the variation in property prices at different distance ranges (0-1 Km, 1-2 Km, 2-3 Km, 3-4 Km, 4-5 Km) until a maximum distance beyond which WM facilities do not affect market prices anymore.

If it is possible to obtain information on the market values as well as on some characteristics of the properties (for example: size, typology and people living), it can be applied a linear regression, as proposed by Rivas Casado et al. (2017). In the absence of information on the characteristics of housing, a simplified formula proposed by European Commission (2014) can be applied.

According to European Commission (2014), the result is a negative impact represented by a fixed amount that does not change with the amount of waste that is disposed of or treated. Therefore, disamenity costs represent a fixed externality, but it can be represented as a cost per tonne of waste for a specific necessity such as that of comparing different scenarios.

A detailed explanation about the formulas is present in Fig. 40, representing a flow diagram that expresses the phases that will be followed in REPAiR project for the calculation of landscape disamenities.

If the lack of data concerning the market values of the properties to be analysed is shown, it is possible to use a different evaluation method, such as that of Willingness To Pay (WTP) (Varian, 1992), that represents a direct method in which through a survey, people are asked to express their WTP in monetary terms.

More in depth, Contingent Valuation Method (CVM) is a direct method (stated preference) in which people are asked through a survey to establish their WTP in order to avoid a certain cost, simulating a real market. Econometric techniques are applied to calculate the average WTP from the survey results. The aim of these surveys is to monetize visual impacts and disamenities in general.

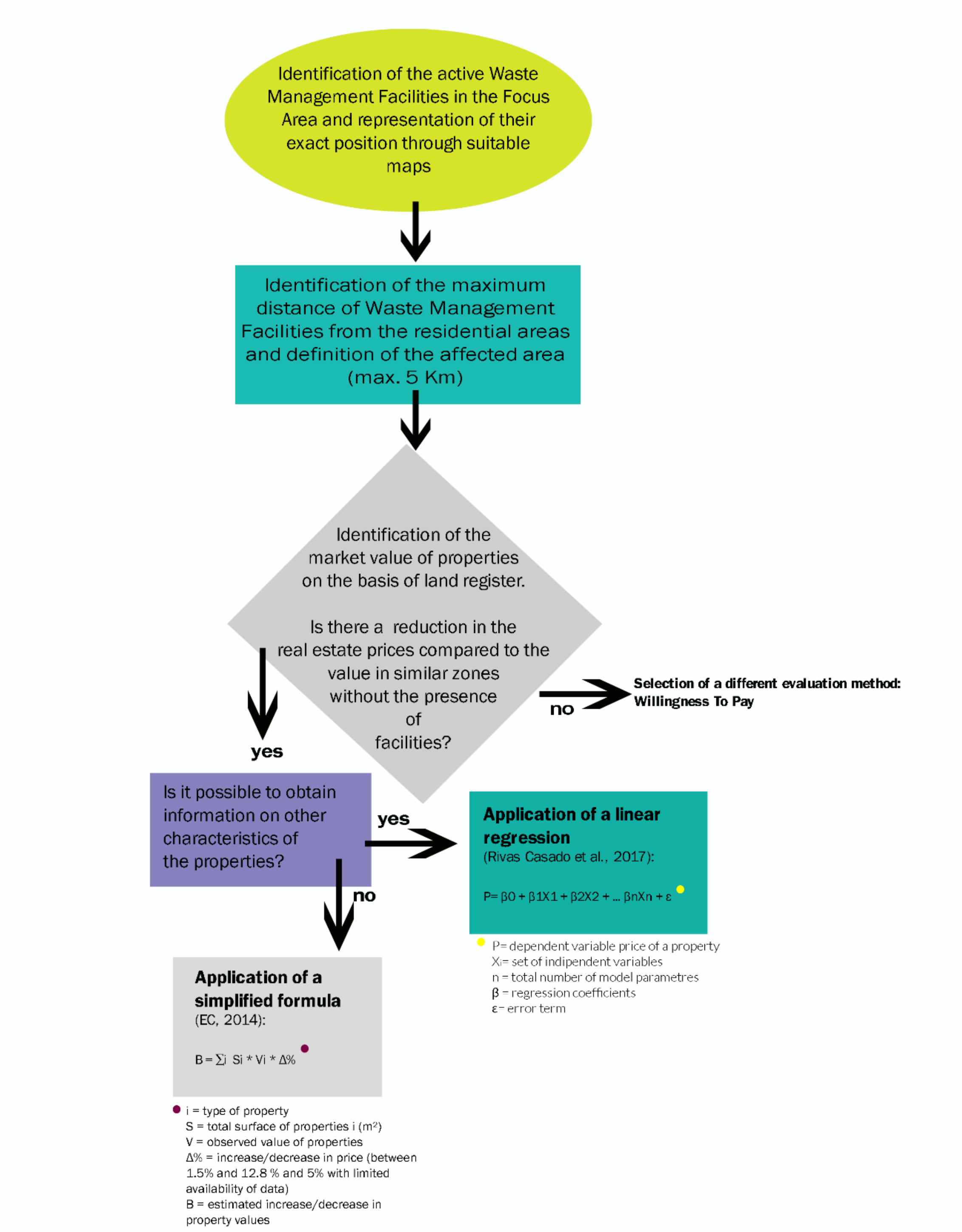


Fig. 40: flow diagram for disamenities calculation

4.3 Results for the baseline scenario

Interpretation of results is a key phase of each LCA and it is crucial in order to develop recommendations and provide decision-makers with clear information, supporting the decision making process.

4.3.1 LCA results for Campania Region

4.3.1.1 Life Cycle Impact Assessment

Firstly:

«Life Cycle Impact Assessment (LCIA) is the third phase of LCA according to the ISO 14040 standard, following the goal and scope definition and the inventory analysis and preceding the interpretation phase. It has the purpose to translate the elementary flows from the life cycle inventory into their potential contributions to the environmental impacts that are considered in the LCA and thus to support the interpretation phase where the questions posed in the goal definition are answered» (Haushild and Uijbregts, 2015, p.1).

The impact categories selected for the representation of results are midpoint. Midpoint indicators are expressed by impact categories with their “characterization”, while moving to the indicators endpoints, midpoint indicators, following the phase of characterization, require a normalization process in order to be aggregated into homogeneous categories of damage.
The method selected is “ILCD recommended – 2013 Prosuit Global NR_DTU resource w/o LT” and the impact categories are the following:
- climate change, that is a global impact category;
- ozone depletion, that is a global impact category;
- human toxicity (cancer effects and non cancer effects), that is a local impact category due to a series of phenomena such as: air emissions linked to population density, for pollutants related to breathing as well as some forms of intensive and extensive agriculture, emissions in off-shore waters like lakes, ocean, rivers and finally emissions in the agricultural and non-agricultural soil;
- particulate matter, linked to atmospheric dust, fine dust, total suspended dust;
- ionizing radiation, that is a local impact category linked to the same phenomena causing human toxicity;

- photochemical ozone formation, that is a local impact category linked to population density;
- terrestrial acidification, that is a regional impact category linked to emissions in air and soil;
- eutrophication terrestrial, that is a regional impact category linked to emissions in air and soil;
- eutrophication freshwater, that is a regional impact category linked to emissions in air and water;
- eutrophication marine, that is a regional impact category linked to emissions in air and water;
- ecotoxicity freshwater, that is a local impact category linked to air and off shore water emissions;
- depletion of abiotic resources (fossil and elements), that is due to resource extraction;
- land use, that is a local impact category.

4.3.1.2 Land use impact category

Focusing on the category of land use, as stated by Vidal Legaz et al. (2016, p.1):

«in the last 15 years, substantial efforts have been made to improve the assessment of the impacts on land use derived from production supply chains. This includes the impact of both land interventions, i.e. occupation and conversion of land – the latter referred to as transformation in a LCA context».

As already previously specified, two land use elementary flows can determine habitat and biodiversity changes: land transformation and land occupation (Milà i Canals et al., 2007). In the first case, human activities convert the current land use/cover in order to make it appropriate for a new use. Some examples can be deforestation to establish pasture, or also converting natural grassland into cropland, determining a transformation of land quality. In the second case, during land occupation, the new land use takes place and land quality evolves again. These processes can determine a loss/gain of species richness as well as other modifications in the ecosystem composition. At the end of these processes, there could be a restoration phase, (Teillard et al., 2016).

Soil quality is related to the capacity of soil to carry out its functions, sustaining plant and animal productivity as well as water and air quality, promoting plant and animal health (Doran, 2002), delivering therefore its ecosystem services.
Different impact methods have been taken into consideration with regard to land use. The first is represented by "Eco-indicator 99", which is a Dutch method developed by Pré (Product Ecology Consultants[35]), that allows to evaluate the impacts on biodiversity. More precisely, «Eco-Indicator 99 is a weighting method that converts inventory results into a single score comprehensive environmental indicator that encompasses human health, ecosystem quality and use of resources» (Blengini, 2009, p.320).

The second method is called "Soil Organic Matter" (SOM) (Milà i Canals et al., 2007), that is able to evaluate the impacts on soil quality deriving from land occupation and land transformation.

The other two considered methods are "Ecological Footprint" and "Ecosystem Damage Potential". The latter assesses impacts of land use on species diversity, correlating them with land use types, including data on the diversity of plant species and threatened plant species (Koellner and Scholz, 2008).
As far as Ecological Footprint is concerned, as already previously specified, it represents the biologically productive land and water required by a population in order to produce the resources it consumes and absorb part of the generated waste. In a LCA context it is defined as «the sum of time integrated direct land occupation and indirect land occupation, related to nuclear energy use and to CO2 emissions from fossil energy use, clinker production (e.g. CO_2 emitted when burning the limestone for cement production)» (Jungbluth, 2010, p. 73).

Finally, the last method is "Impact 2002+", developed at Swiss Federal Institute of Technology in Lausanne that takes in account only land occupation

4.3.1.3 Discussion about results

For the analysis of results, the processes have been aggregated as follows:
- transport induced;
- transport avoided, related to the recycling chain;
- processing induced, related to the plants functioning;

[35] https://www.pre-sustainability.com/

- products and processing avoided, related to the recovery of electricity, material and heath through the recycling processes;
- LUCs (iLUC+dLUC) induced;
- LUCs (iLUC+dLUC) avoided;
- disposal, related to landfilling processes;
- other, comprising processes not previously specified.

Results express the impacts related to the treatment of one tonne of CDW, that represents the FU selected for the model.

At a first glance, (Fig. 41) it is possible to observe that one of the highest contributions to some impact categories such as climate change is linked to transport.
This is because, as already ubderlined, some flow portions are treated in plants located outside Campania Region (see Tab. 11) and for the calculation an average sum has been applied according to the quantity transported and to the kilometres travelled.

Furthermore, it is possible to introduce two other reflexions: the first concerns the large environmental savings related to the metal component present in the flow. This fraction is not the dominant feature of a CDW flow, and therefore, despite the fundamental environmental saving, it is examined separately. Consequently, ferrous metals are separated by iron removers and destined for recycling; the ferrous material is sent to a first selection plant and later to the steel mill for production of secondary steel. Anyway, as stated by Blengini (2009), steel scraps always have the possibility to be recycled into good quality steel bars that present the same characteristics of the virgin ones.

Another reflection is linked to the recycling aggregates chain, which could be implemented through the production of recycled aggregates of type A, that can be produced by stationary recycling plants already present on the territory. The latters are characterized by a high quality and can be used for concrete and road construction.
Experience shows that nature and characteristics of the CDW flow in input into the recovery facilities significantly influence the characteristics and final performances of the resulting RA. Therefore, in order to get good quality RA, that can be more palatable on the market, it is necessary to improve the characteristics of CDW through selective demolition techniques (Borghi et al., 2017; European Commission, 2016).

Definitely, recycle and re-use of secondary materials in the construction sector offer a real possibility of achieving the objectives of CE. Waste can become a new resource, allowing at the same time the minimization of the waste quantities disposed of in landfill, saving as well natural mineral resources and allowing the reduction of environmental impacts related to mining and to WM in general (Borghi et al., 2017).
The production activity of natural aggregates is very impacting from the environmental point of view, indeed it is performed in two distinct phases: the extraction of the material from the deposits and the subsequent processing in plants for the production of different types of aggregate required by the market.
The convenience of recycling is also demonstrated by the process energy required for production. Indeed the process energy for the production of 1 ton of virgin aggregate is 51.3 Mj/ton, while the process energy required for the production of 1 ton of recycled aggregate is 37.1 Mj/ton (Kofoworola and Gheewala, 2009).
Furthermore, as land is becoming an ever increasing scarce resource, the avoided landfilling of demolition waste represents a very important environmental and economic benefit (Blengini, 2009), as well the avoided quarrying activity.

Despite this, it is important to bear in mind that recycling materials can not totally substitute natural ones, considering some issues such as decay of quality and loss of mass. For these reasons, it is important to consider the joint utilisation of recycled and natural aggregates (Blengini, 2009).
In addition, «the selection of materials, design of building features and choice of construction techniques can significantly lower environmental burdens that can be ascribed to the building shell, and they can greatly influence the subsequent use phase, for instance by reducing the energy requirement for heating and cooling purposes. Moreover, the selection of the building materials that can more effectively be recycled at the end-of-life, as well as the choice of proper beneficiation processes, could further lower the full life cycle impacts» (Blengini, 2009, p.328).
Definitely the waste minimization strategy based on recycling offers multiple benefits, not only related to the reduction of demand for new resources and reduction of landfills, but also reduction of transport and production energy costs as well as positive social impacts reflected in employment, health and quality of life (Tam and Tam, 2006).

Anyway, there are different factors that today hinder the widespread use of RA, like the distrust of construction companies against recycled materials due to their origin from waste, a lack of knowledge of their real performances but also the low cost and the wide availability of virgin materials in the territory. It would be necessary to encourage the use of RA (Borghi et al., 2017) by making operational the current regulatory instruments, such as DM 203/2003[36] which imposes the uses of a minimum amount of 30% of recycled materials in the construction of public works. It is also important to share information on the technical performances of RA in order to improve the awareness (Borghi et al., 2017).

At this point, it is necessary to specify that LCA has been performed according to a baseline scenario and that it is used in REPAiR in order to evaluate the reduced environmental impact that will derive from the implementation of EIS (Eco-Innovative Solutions).

As LCA is a comparative tool and at this point, in REPAiR advances, it is not possible to have EIS yet, an example comparison scenario has been introduced. This scenario is based on the hypothesis of sending the total flow to landfill, without any distinction. Therefore, results are presented on the base of this exemplificative scenario of comparison (Fig. 41; Fig. 42).

In the results figure, it is demonstrated the convenience of not sending all the CDW flow to landfill, as it is possible to observe the higher environmental impact of the landfill scenario for all the impact categories as well as the lack of environmental savings. For example for climate change impact category it is possible to observe a result of 8.39 E+00 Kg CO_2 Eq. for the total scenario and 3.26 E+01 Kg CO_2 Eq for the landfill one, almost four time higher.

Definitely, from the results of this scenario it is possible to highlight the benefits arising from the recovery actions that are already implemented at regional level. Despite this, the benefits associated with these recycled actions (in terms of avoided impacts) are not able to totally compensate for the impacts on the environment deriving from the other management and treatment phases of the flow, especially transport phase.

The management system could be further improved by reducing the amount of CDW disposed of in landfill, through the introduction of more elevated taxes or the prohibition of disposal for those fractions with high recycling potentialities.

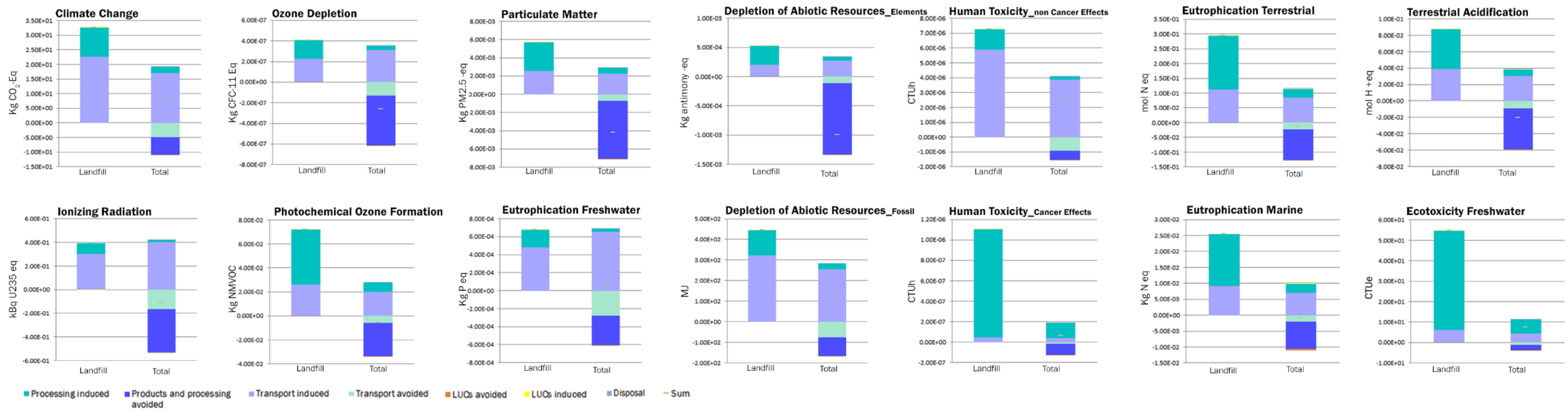
Other actions that would bring to an overall environmental benefit on the system should be undertaken to minimize waste transportation and all the intermediate steps through a more strategic localization of plants on the territory and a better spatial distribution of the flow among the various plants (Borghi et al., 2017).

As far as land use is concerned, Trigaux et al., (2017) underline the difference between primary and secondary land use. The first is represented by the building

[36] http://www.bosettiegatti.eu/info/norme/statali/2003_0203.htm

footprint, while the second is associated with the resource extraction, production, transport and end of life treatment of construction products.
In the present application both primary and secondary land uses have been assessed: on the one hand, secondary land use is represented in Fig. 41 and in the present case is only due to the end of life treatment. On the other hand, primary land use is represented by the plant and the quarry footprint in relation to two types of intervention: land occupation and land transformation. As already specified, «land occupation occurs when a specific land use type is maintained over a period of time, leading to a delay in the recovery of land to its potential natural state, while land transformation refers to a change in the land use type» (Trigaux et al., 2017, p.596).

Detailed about impacts according to each single process in the scenario are represented in Appendix A1.



FU: 1000 Kg of CDW

Fig. 41: LCA results for the baseline scenario of Campania Region, year 2015[37]

[37] Data come from Ecoinvent 3.4 and from ARPA Campania

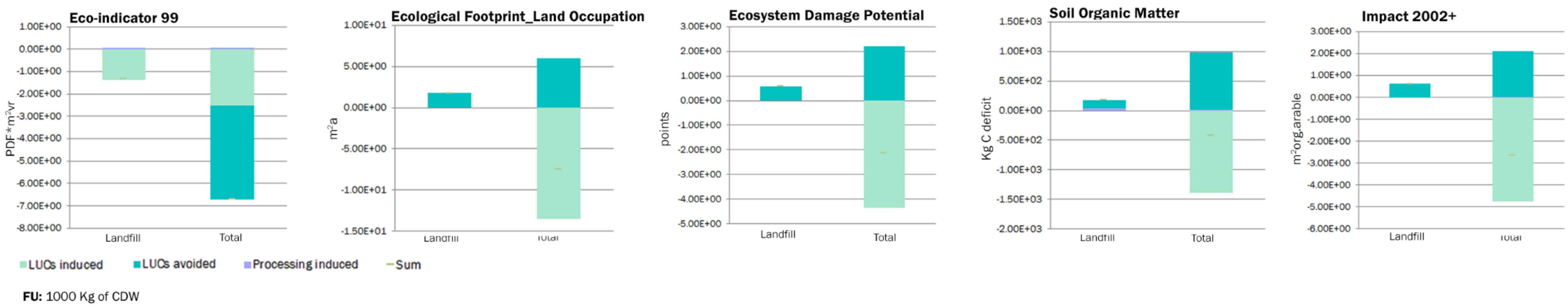


Fig. 42: land use results for the baseline scenario of Campania Region, year 2015[38]

[38] Data come from Ecoinvent 3.4 and from ARPA Campania

4.3.2 Focus on some materials according to their possible reuse

In the following chapter it is presented a brief and general description of the fractions composing an average CDW flow, according to their recyclability potential and to the material properties.

4.3.2.1 Metallic materials

Metal materials can be melted and reused for other uses. The process can be repeated almost indefinitely. 40% of the world steel production is constituted from recycled materials (scrap iron), for which steel appears to be, in quantity, the most recycled material in the world: 350 million tons/year.
The recycling of aluminium allows saving 95% of the energy required for producing it starting from the raw material. At this stage, the decontamination of the material from other substances is very important (Baiocco et al., 2018).

4.3.2.2 Concrete

Concrete is one of the most abundant building materials in the CDW flow. It is characterized by a very low economic value with a very high specific weight. In order to make convenient the recycling of concrete, it is necessary that the recycling plant is near the site of provenance, even better if in the building site itself.
In the process of demolition and recycling, it is strictly necessary to separate the ferrous parts from the inert ones. This happens because currently it does not seem convenient to recover the demolished reinforced concrete to get another concrete of equal performance. The established practice provides the reuse of the recycled material for the construction of works for which lower performances are required. Therefore, as already previously specified, the demolished concrete is generally reused for road foundations, as a material filling and so on.
Despite this, there are many potentialities of improvement of the quality of recycled aggregates, thanks to new scientific recycling methodologies according to which it is possible to completely recycle the material and its basic components: cement and aggregates (Baiocco et al., 2018).

4.3.2.3 Glass

Unlike other materials, glass can be recycled endlessly without losing its properties, generating numerous advantages. Glass recycling also reduces the amount of waste to be retained or disposed of in landfills, allowing a possible saving on transport costs and waste disposal. Ultimately, with the recycling processes it seems possible to reduce energy consumption (Baiocco et al., 2018).

4.3.2.4 Wood

For the reuse of wood waste, it is necessary to make a distinction based on the origin. For the waste arising from the production of the finished element (flakes, shavings, sawdust) the process of reuse ends with the realization of agglomerates of wood or with the production of combustible material (wood chips, pellets, etc.). For waste coming from the use and consumption of the material collected through separate collection, the reuse is mainly dedicated to production of wood or composite agglomerates. The discarded material is selected and cleaned up from foreign bodies. Currently, 95% of post-consumer wood waste is started up at plants for the production of wood agglomerates for the furniture industry. Furthermore, a part of the wood waste is recycled as cellulose pulp for the production of paper. Given the ease of processing wood, this can be recycled for several times for the realization of panels for the construction sector (Baiocco et al., 2018).

4.3.2.5 Stone materials

The size of blocks or slabs of stone, including their thickness, could determine the possibility of reuse. The stone blocks that are not particularly damaged can be cut into small size and reused as facing elements.
The very damaged sheets can be reduced to granules or powder to be used in others kinds of applications (Baiocco et al., 2018).

4.3.3 LCC results for Campania Region

Results of LCC are reported in Fig. 43. It is possible to observe that the total cost of the conventional LCC of the baseline scenario is equal to about 21 €/tonne (due to the sum of budget and transfers).

It is possible to observe the costs for the disposal of CDW are mainly due to transport (comprising both operation and capital goods) and plant processing. Also in this case, as in LCA, results have been compared with costs coming from the "landfill scenario", i.e. hypothesizing to send the flow entirely to the landfill plant. In this way, it is possible to observe that the total cost would be much higher (about 64 €/tonne), demonstrating not only the environmental, but also the economic convenience of limiting the waste quantity to be sent to landfill. At this point, it is necessary to specify that capital goods represent durable goods that are used for the production of other goods and services and in the case of the LCA and LCC models, they represent for example trucks, building, equipment and so on. Brogaard and Christensen (2016) underline the environmental importance of capital goods and the subsequent necessity to insert them in every model, since they contribute to the overall cost as well.Furthermore, in the final graphic, according to the aggregation done, it is not possible to observe the contribute of each single plant. For this reason, it is specified here that the most contributing plant are the stationary recycling plant and the landfill one, as they receive a bigger quantity of waste. Detailed cost information are provided by Appendix A1 related to cost data.

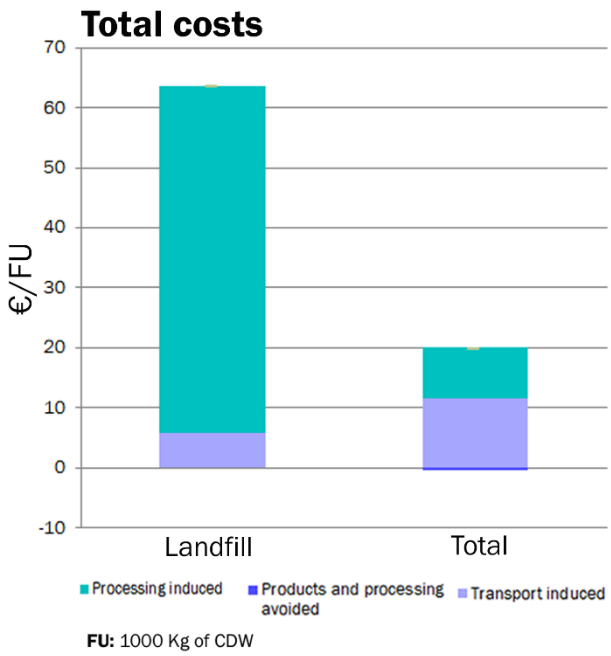


Fig. 43: LCC results for the baseline scenario of Campania Region, year 2015

4.3.4 LCA results for the Focus Area

The same elaboration has been carried out for the FA, for which, following the same procedures elaborated for the Region, the results are shown (Fig. 44; Fig. 45).

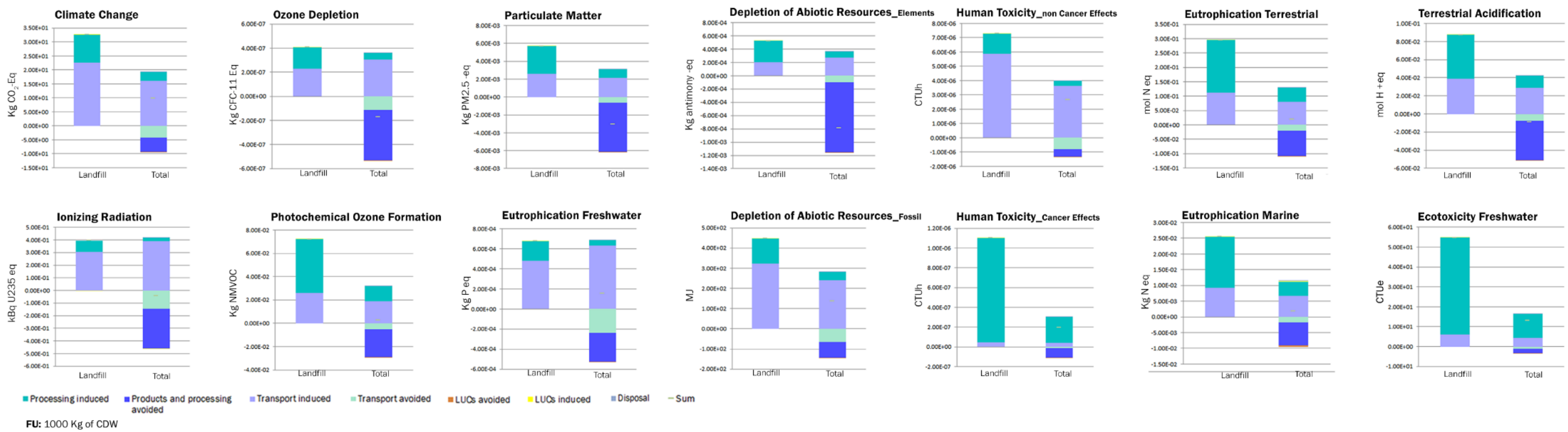


Fig. 44: LCA results for the baseline scenario of the Focus Area, year 2015[39]

[39] Data come from Ecoinvent 3.4 and from ARPA Campania

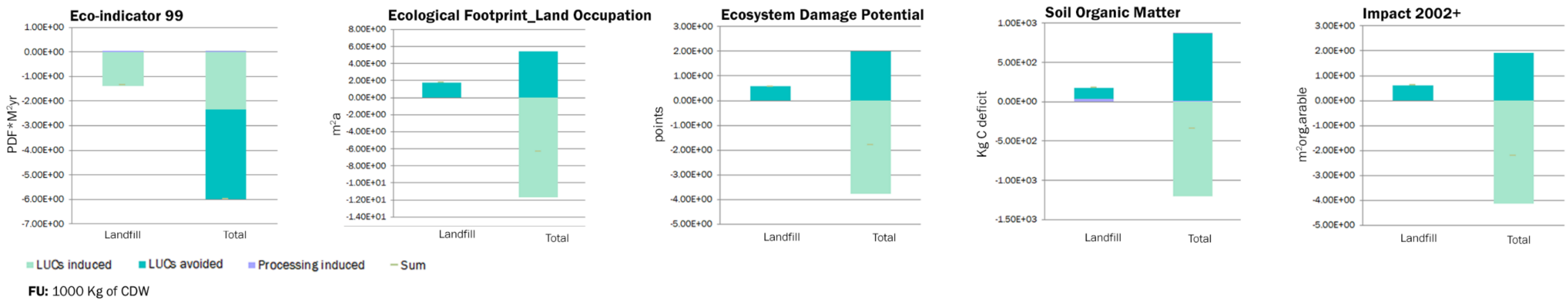


Fig. 45: land use results for the baseline scenario of the Focus Area, year 2015[40]

[40] Data come from Ecoinvent 3.4 and from ARPA Campania

4.3.5 LCC results for the Focus Area

Fig. 46 shows the results of LCC for the Focus Area. The overall cost for treating one tonne of waste is equal to about 26 €. Therefore, there is, indeed, a bigger contribute from the landfill plant (with a total of about 16 €) and this means that in the FA, even if the total produced flow is lower than the one produced in the entire Region (about 3 millions for the Region and about 7 thousands for the Focus Area), there is a higher concentration of flows sent to landfill. This represents a useful result also for the development of EIS, meaning that to a smaller scale it does not necessarily correspond a lower cost. As far as the landfill scenario is concerned, the total cost for treating one tonne of CDW is equal to about 64 €, as it happens in the Region.

Definitely, it can be necessary to improve the recycling practices, in order to determine a cost reduction in the FA, with a general repercussion on the entire Region.
More details are provided by Appendix A1.

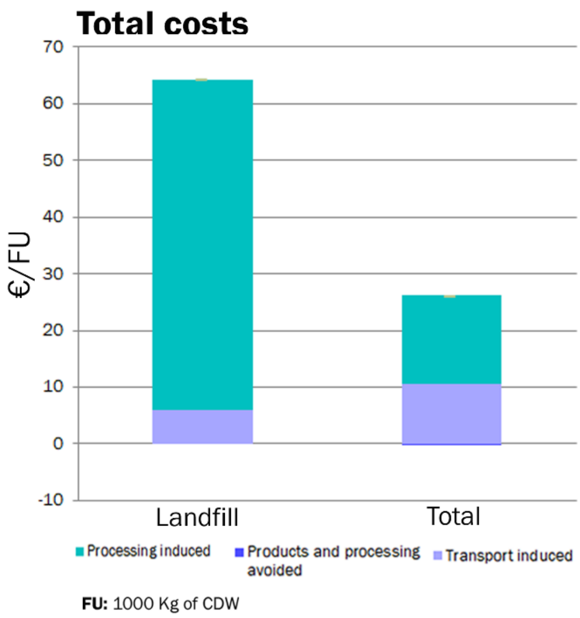


Fig. 46: LCC model results for the baseline scenario of the Focus Area, year 2015

4.3.6 Characterization

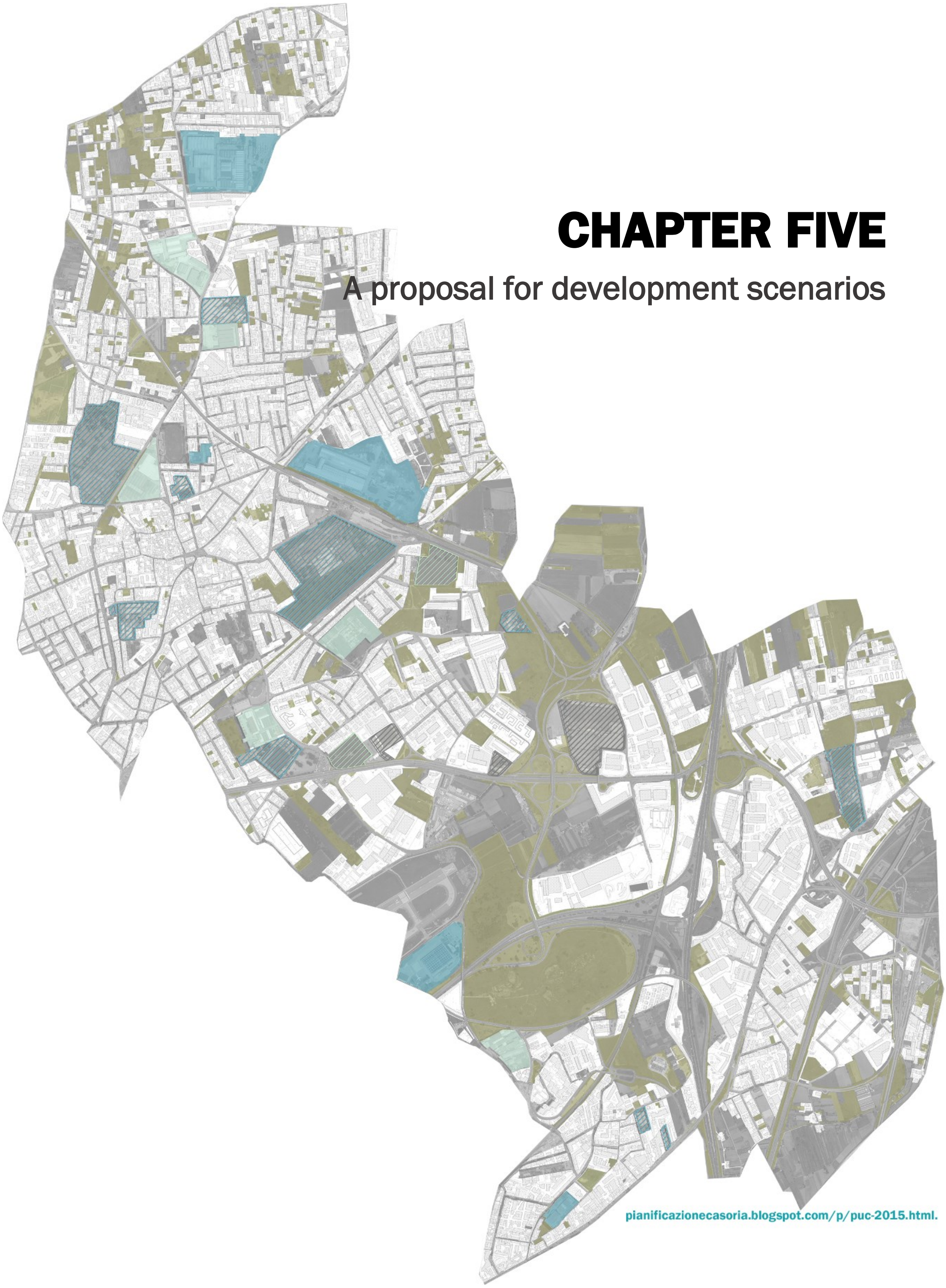
Results are obtained through the use of characterization factors. Characterization in general is the quantification of contributions to the different impact categories. Therefore, for each substance it is assessed its ability to contribute to the impact by means of “characterisation factors”; the latter are substance specific and are assessed for all substances which contribute to a determined impact.

Characterisation factors express quantitatively the relative importance of a specific intervention. As an example, the Global Warming Potential of Methane is equal to 22 Kg CO_2 eq (Huijbregts, 2018).
Characterisation happens through the multiplication of emissions and relevant characterisation factors and are often expressed considering a relative reference substance.

A different way of expressing results could be that of normalisation, in order to put a common scale across the different impact categories.

CHAPTER FIVE

A proposal for development scenarios



pianificazionecasoria.blogspot.com/p/puc-2015.html.

Premise

The LCA approach can acquire a territorial nature to the extent that it concerns one or more activities that take place in the territory and that in this case can be enclosed in the *wastescape* called "operational infrastructure of waste", i.e. the facilities dedicated to the waste storage and management.

This chapter presents a hypothesis of use of the LCA instrument in relation to the regeneration of disused industrial areas, choosing to carry out an experimental application focused on the *wastescape* identified in REPAiR as "settlement and building in crisis" (W4) (Geldermans et al.,2017) and in particular choosing the category of former industrial buildings.

5.1 Dismissed industrial areas in relation to settlement and building in crisis

According to ISTAT, about 3% of the entire Italian territory is occupied by abandoned industrial areas.
In Italy, there is a specific distinction between "dismissed industrial areas", that are areas in need of processes of redevelopment and "contaminated sites", that require processes of reclamation.
According to the Environmental Code, dismissed sites in general can be defined as sites were production activities ceased. Dismissed sites can be contaminated, potentially contaminated and non-contaminated.

In the last decades, because of the economic crisis and the changes in the productive sector (especially in the most advanced countries), there has been a progressive reduction of industrial activities. This process has determined the born of large dismissed areas with the presence of abandoned industrial buildings, very often located in peri-urban areas that are strategic for the urban development. As a consequence, the re-development of these areas constitutes a current problem of considerable interest, characterized by economic, social and environmental repercussions and it represents as well an unavoidable opportunity for the urban development and for the valorisation and re-connection of peri-urban areas. For this reason, new operational methods and techniques are required, in compliance with environmental compatibility (Arbizzani and Materazzi, 2012).

It is possible to add that when an industrial activity ceases, it leaves not only a physical vacuum, but it also continues to occupy the territory, polluting it with its residues.
Above all, since the mid-1980s, industrial dismissed areas have been recognized as a form of heritage to preserve as a demonstration of the cultural value that it is possible to attribute to productive activities and for this reason it is worth preserving and promoting this form of heritage.
The disused industrial areas are also generally already served by the main infrastructures and are often located near railway plants or important sections of the road network that can determine a good accessibility, therefore the return of these areas to the city can constitute an important occasion for the redesign of the local urban fabric[41].

Furthermore, the phenomenon of disposal, albeit in different ways and forms, concerns a large number of municipalities in the north-eastern part of the MAN. The recovery of abandoned industrial areas connected to the location of new important urban and productive functions, can be configured as a unitary intervention of metropolitan level, able to define places and relationships related to a large pool of users and able to renew and increase the points of reference in the vast territory (Miano, 2005).

The case study elaborated in this chapter introduces the territorial component as an object to relate to the LCA evaluation tool, choosing to focus the attention on the *wastescapes* identified in the REPAiR project (see paragraph 3.2).
In particular, the selected *wastescape* category is called “settlement and building in crisis” and it is formed by a series of subcategories represented by: vacant/underused, neglected or obsolescent buildings and settlements, urban settlements suffering from fatigue, informal settlements, urban lots in transformation, unauthorized buildings and settlements, confiscated assets.
The application is focused on the subcategory “vacant/underused buildings and settlements”, that is described as follows (Geldermans et al., 2017, p.17):

«vacancy and underusing phenomena can be the direct consequences of the urban decline, due to several factors in the organization of the territory. Economic changes/crisis could also cause abandonment of settlements, or of some parts of them. In this category, abandoned, vacant, underused, dismissed industrial, commercial, military buildings are also included. Examples are: a) brownfields; b)

[41] www.scienzainrete.it/contenuto/articolo/recupero-delle-aree-industriali-dismesse

abandoned historic buildings (farms, houses, mills); c) building blocks with high percentages of apartments and/or offices and/or commercial premises not leased; d) agricultural products (such as greenhouses or shelters)».

5.2 Methodology of research: ISTAT data and direct observations

The model of characterization presented in paragraph 3.3. is applied in order to characterize and spatially identify the selected *wastescape*.

5.2.1 Methodology of identification for the selected *wastescape*

First of all the correspondent land cover and land use that host vacant/underused industrial buildings are represented respectively by artificial land cover, in particular industrial and commercial units and industrial use (known as "industrial, commercial, public, military and private units") (Fig. 47-49). Combining land use and land cover, it is possible to select the correspondent LUF, represented by "residential and non land-based industry and services", according to the industrial activity, in particular the activity of production, with reference to the supply chain.

Various typologies of degradation processes can alter the available resources, that in this case are represented by the land that houses the industrial activities and by the building stock itself that is no longer able to perform the economic functions previously carried out. It is not easy to go back to the specific drivers that caused the disposal of these, but often the closure and the transfer of the plants are due to the contraction of the productive apparatus and the tendency to transfer the productive activities in countries with low labour costs. Therefore, it is possible to assume that drivers are represented especially by economic factors.
The final step of this methodology is represented by the selection of a performance indicator, that in this case is represented by the number of employees. Where the number of employees is equal to 0, it can be a potential abandoned industrial building, passing from the industrial productive service to the disservice of abandonment.

The data considered in this phase have as a source the industry and services census carried out by ISTAT[42], and indicate for each census section two relevant information for the purposes of the present survey:

[42] http://dati-censimentoindustriaeservizi.istat.it/Index.aspx

- number of local units
- number of employees.

These data were subsequently spatially coupled and represented in GIS (Fig. 50).
As it is possible to observe, the census sections represented in white are those that contain a number of employees between 0 and 5. Some, especially those of larger dimensions located in the northern part of the FA, are constituted by agricultural fields.

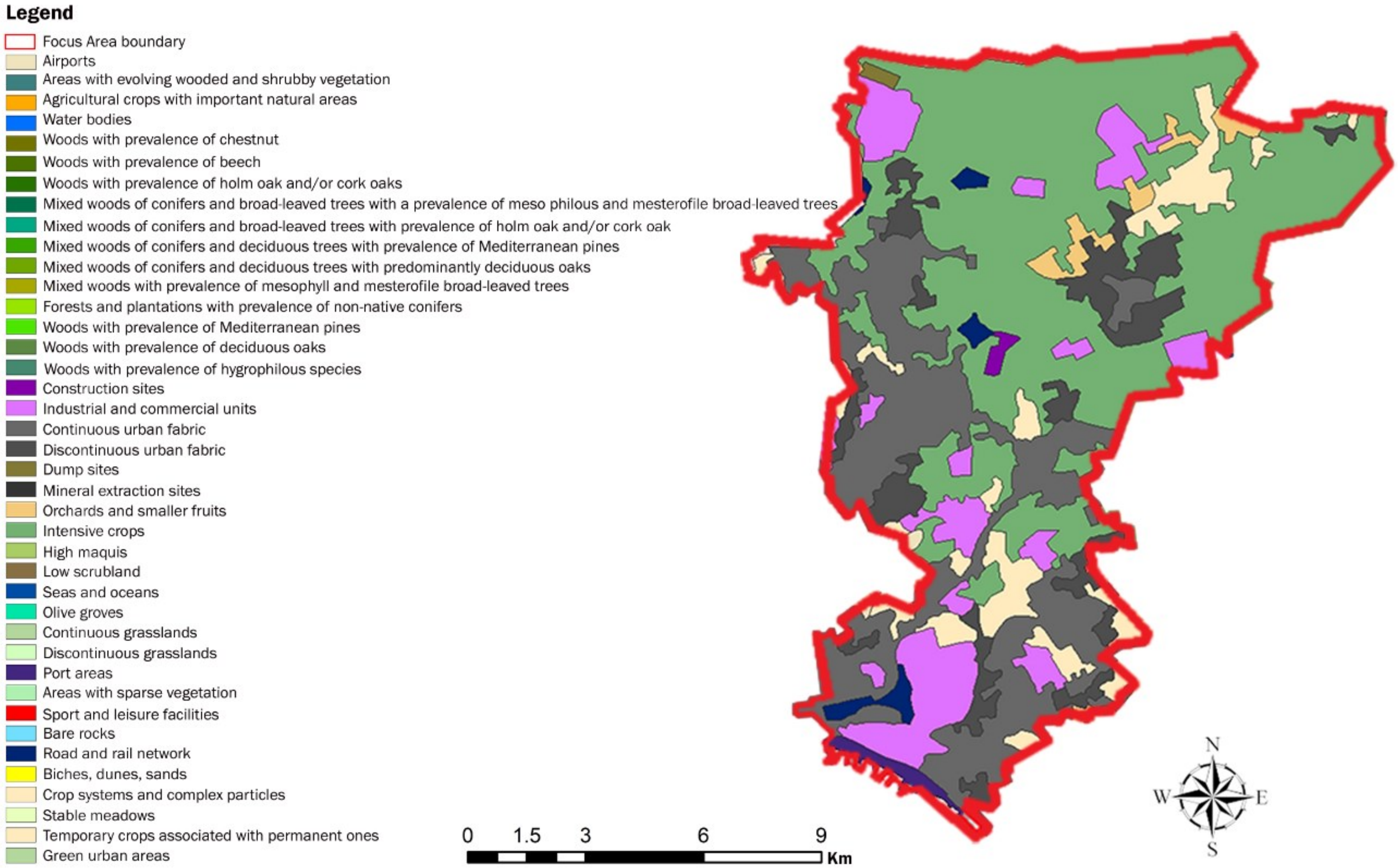


Fig. 47: Focus Area land cover based on the CLC, year 2012

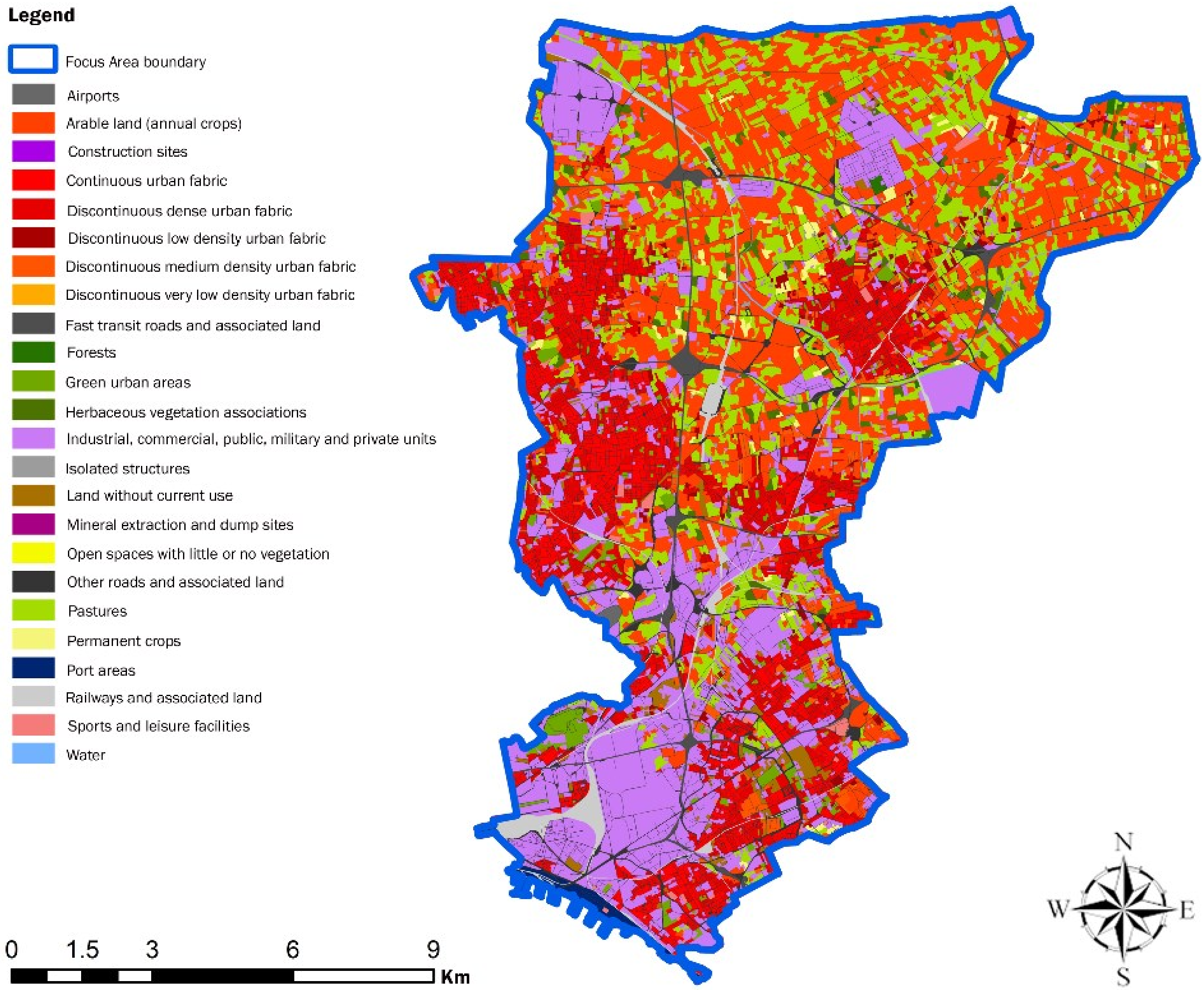


Fig. 48: Focus Area land use, based on Urban Atlas, year 2012

To complete the survey and get to the selection of the investigated *wastescape*, it was necessary to integrate aerial views through the use of Google Maps, making a first selection of all the areas potentially useful for the survey. To this was added a selection criterion that allowed to make a further reduction of the sections, excluding those that meet the following requirements:

– sections containing Roma settlements;
– sections containing plants;
– sections containing greenhouses;

– sections containing already demolished buildings.

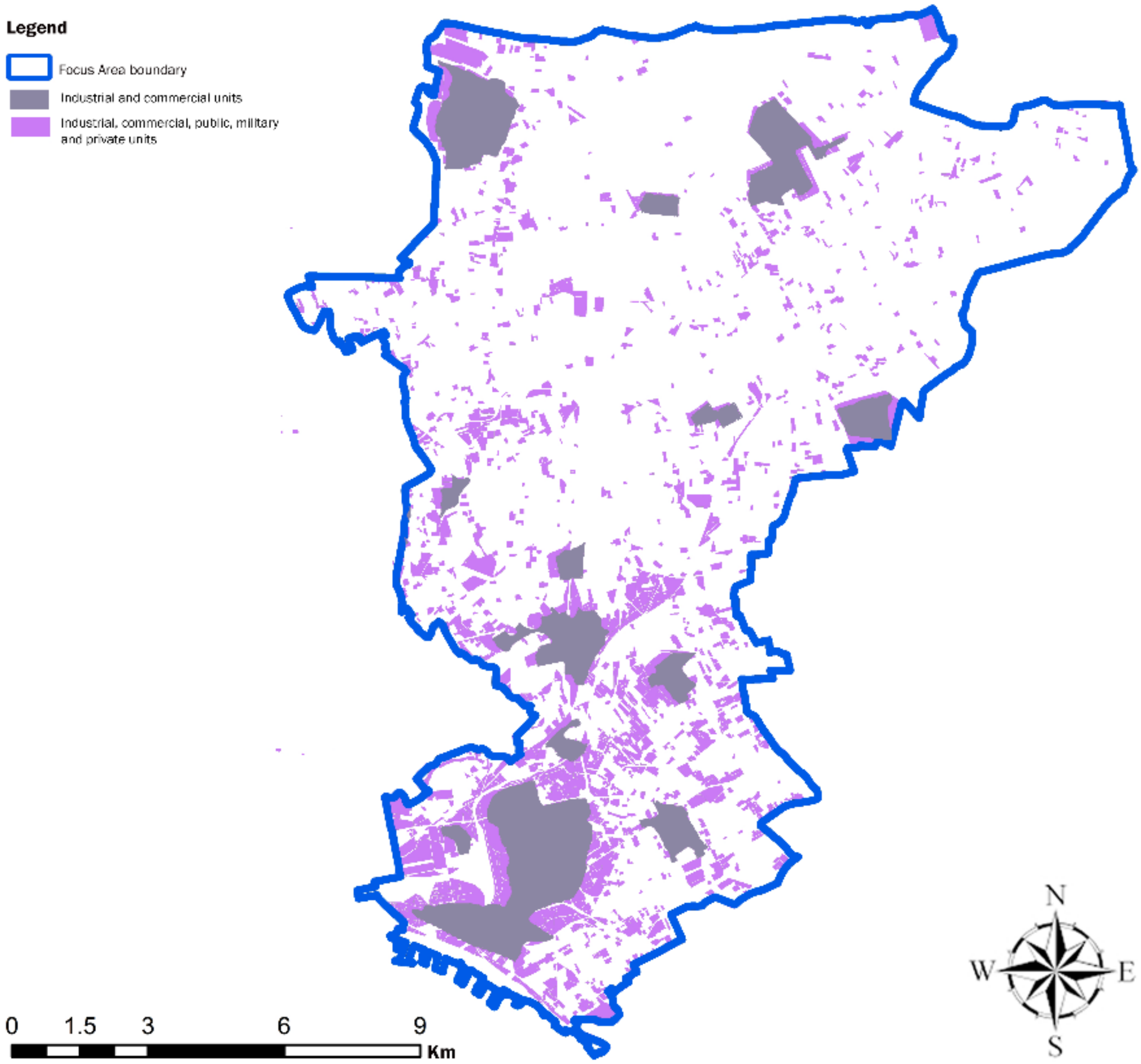


Fig. 49: combination of land use and land cover for the LUF identification

Consequently, the sections containing built structures in terms of large abandoned spaces, with abandoned industrial buildings characterized by lack of activity, or where there are often perimeter control activities have been examined.

The result of this methodology of selection is represented in Fig. 51, where the *wastescapes* “vacant/underused, industrial buildings and settlements” are spatially represented.

For the application, by way of example, the attention has been focused on one single *wastescape* that belongs to this category. Therefore, the following paragraph focus on the *wastescape* selected for the experimental LCA application, that is the former industrial plant known as “Rhodiatoce”, located in the Municipality of Casoria.

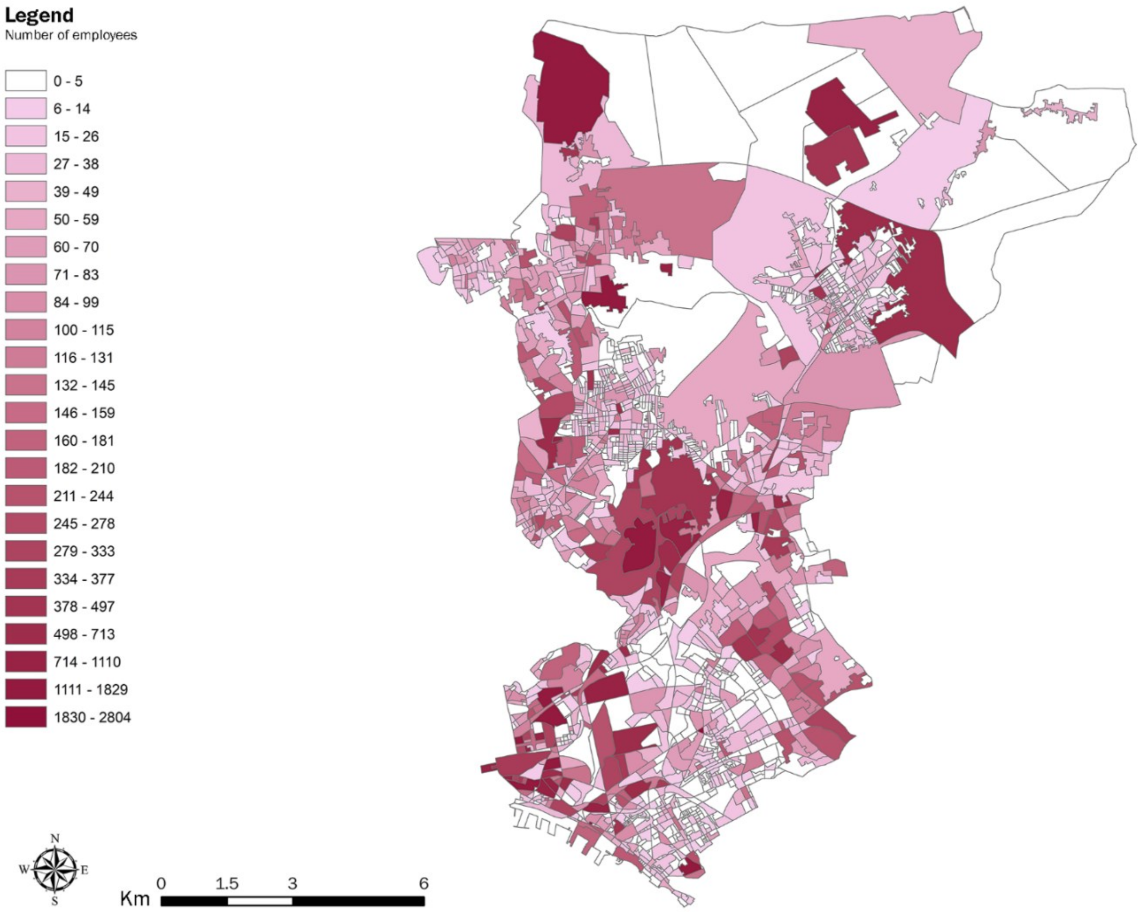


Fig. 50: number of employees in the FA

Fig. 51: vacant/underused, industrial buildings and Rhodiatoce former industrial plant in FA

5.2.2 Territorial location for Casoria Municipality[43]

Arranged at the edge of the Campania plain, but also in the immediate vicinity of the hilly system surrounding the city of Naples, the territory of Casoria constitutes a "point" of that flat system that, coming from the east, outlines its own autonomous configuration with respect to the territory of the Vesuvian slopes.
This particular geographical condition represents a strong factor of individuality, as attested by the regulatory tracings of Roman origin found in the axes of the center of

[43] The information present in this paragraph derive from the material provided by Prof. Pasquale Miano, Department of Architecture, University of Naples Federico II

the ancient Casoria plant, which are autonomous and rotated with respect to the neighbouring centres.
At the same time, the geography of the places is also an essential element to understand the importance of the territory of Casoria, as a point of confluence of the routes and flows coming from the north and east towards Naples.

Casoria (Fig.52; Fig. 53), located in the north-eastern suburban part of the Neapolitan area, is characterized by the presence of a series of dismissed areas that determine the existence of abandoned portion of territory and large urban voids without function that delineate a specific landscape, configuring itself as a real environmental issue.
A further problem indeed is due to the potential pollution of the soil, which gives rise to the possible need to implement remediation interventions.
With resolution no. 9 of 28/01/2016 the Municipal Urban Plan (in Italian "Piano Urbanistico Comunale" – PUC) of the Municipality of Casoria was adopted[44].

Fig. 54 shows a map that is part of PUC, with all the dismissed areas and production platforms located in the Municipality, while Fig. 55, still part of PUC, shows the structural invariants and the areas of potential transformability.

Casoria is represented by a landscape of abandoned factories, compact urban figures, with the background of Vesuvius, large "volumes", in the form of exceptions in the unitary, uncontrolled, variable fabric that surrounds them, as skeletons of monuments, as a fixed and resistant scene, in a territory of transformations.
One of the main problems to be addressed in view of a possible recovery of these areas is represented by the presence of polluted soils, which determine the need to carry out extensive reclamation operations before any type of intervention.
The crisis of urban production facilities in Casoria has determined in the city the consolidated presence of a system of places, spaces, buildings, an industrial landscape in transition, which takes on defined and recognizable characters within the urban system.
This industrial landscape has developed and at the same time died in an urban life cycle of around 30 years. A time that does not allow to compare the Casoria case to other major industrial companies in crisis and in transformation. A time that has, however, produced urban figures, often very labile and provisional, but also able to survive beyond the loss of vital functions.
Fences, large blocks, waiting areas, squares, technological elements depict today the fragments of a building process, which represented in the history of Casoria one of

[44] http://pianificazionecasoria.blogspot.com/p/puc-2015.html

the founding moments. The former Rhodiatoce industrial building is only one of the disused industrial sites known as: ex-Resia, ex-ADS, ex-Tubi Bonna, ex-Perlite.
These are 5 industrial areas, settled in the fifties around the urban centre of the city, which together have an extension of significant size, especially if compared to the limited extension of the municipal territory.

The presence of a significant amount of unused industrial areas is a feature that characterizes the current urban situation of Casoria.
The redevelopment of these abandoned areas can be seen in the context of a territorial reorganization, creating the possibility of establishing links between apparently autonomous elements of the urban fabric (Miano, 2005).

Fig. 52: the Municipality of Casoria

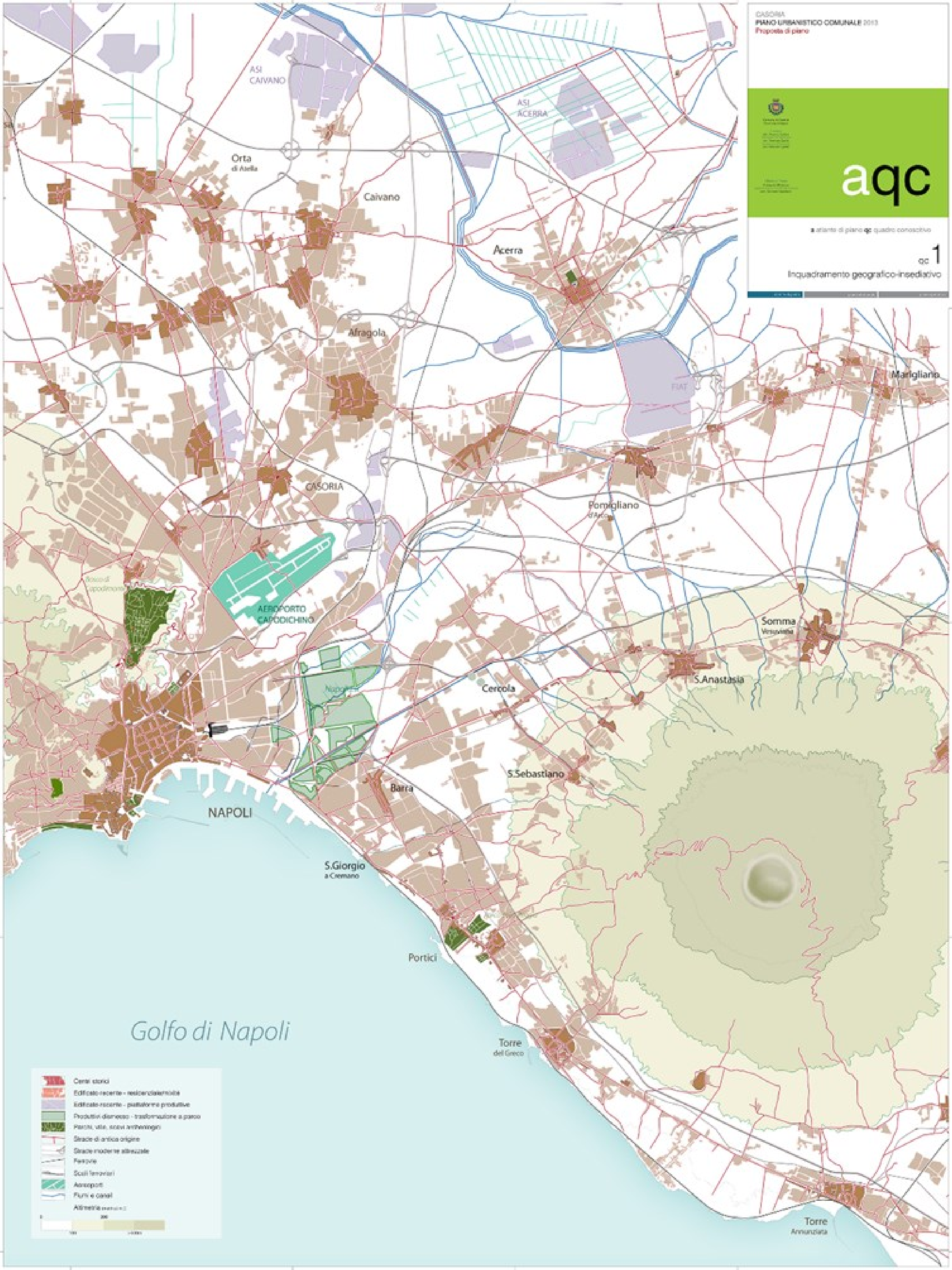


Fig. 53: planning framework for the Municipality of Casoria[45]

[45] pianificazionecasoria.blogspot.com/p/puc-2015.html.

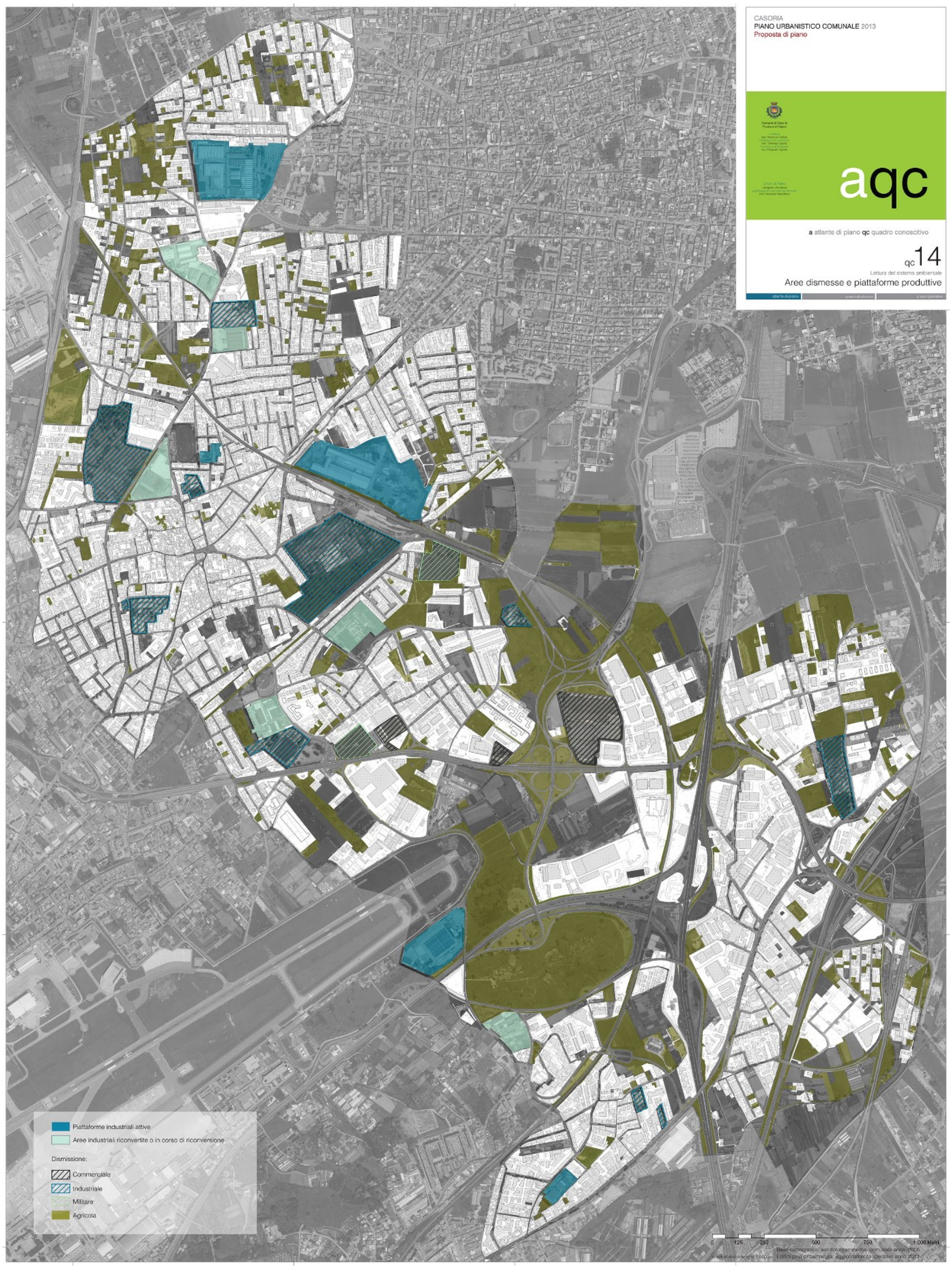


Fig. 54: dismissed areas and production platforms in Casoria[46]

[46] pianificazionecasoria.blogspot.com/p/puc-2015.html.

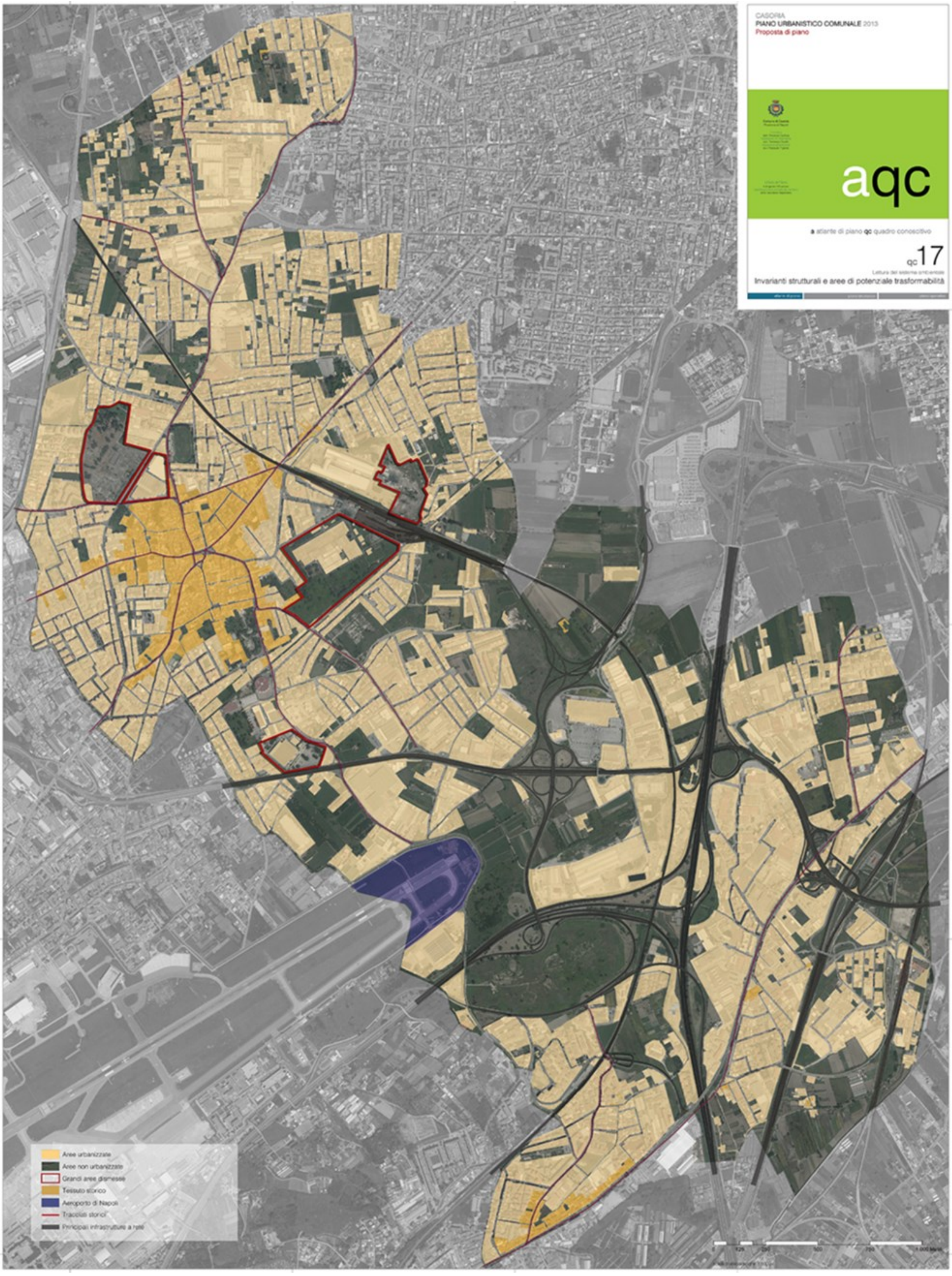


Fig. 55: structural invariants and areas of potential transformability in Casoria[47]

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[47] pianificazionecasoria.blogspot.com/p/puc-2015.html.

In the above figure, the areas surrounded by red represent the large abandoned areas of Casoria Municipality.

5.3 Rhodiatoce case study

The Rhodiatoce industrial plant for nilon production rises in 1928 and one of its branch was born in 1953 in the city of Casoria; its organization and distribution is accurately described in the book written by Miano (2005).

The industrial plant is located in a flat area close to the city of Naples, which at the time of the settlement had large amounts of groundwater able to meet the production needs and an excellent connection to the railway network. Over the years, the company has grown up to 1573 employees and the production of nilon was enlarged by that of terital. This change determines the need to expand the facilities and to build a second building consisting of a five-level block of hollow bricks. Between 1961 and 1967 another six-storey building was built for residential purposes, together with a new production hall for the spinning of the terital. Between 1967 and 1969 a restructuring program was started, including interventions related to access to the plant, services, networks and offices, also rationalizing the organizational structure and preparing an extension of the area covered and the physical concentration of the productive structures. A new building is then built for the terital flake spinning, a thermoelectric plant, new bases for demineralization plants, storage tank and neutralization of acid waters as well as a new building for a methane decompression booth.
In 1972 a further expansion took place with the construction of a thermoelectric power plant in steel and concrete, a new thermal power plant, new terital silos and the expansion of part of the production halls. In 1975 a training centre was also built, but in the same year the phase of cessation of production activities began.

The Rhodiatoce complex occupies an area of approximately 141.280 square meters and is characterized by a covered area of 46.500 square meters and a coverage ratio of 32%. This determines its appearance as a great void in an urban environment characterized by a strong heterogeneity and discontinuity (Fig. 56-58).
The area is bounded by two urban connection streets (Europa and Boccaccio streets) that create the northern and eastern border, while on the remaining sides the area is compressed by a residential building nucleus and by a complex of block buildings. These are elements characterized by strong heterogeneity that incorporates traces of artefacts in rural origin, modified by recent construction projects, which were

overlaid with small buildings of a productive nature, that ended up saturating the free parts of the lot.
As for the infrastructure connections, the area has good accessibility conditions. The fence wall, interrupted only in correspondence of the main entrance and of the service entrance, is continuous and made up of concrete panels with tufa buttresses placed in some stretches.
A main entrance, located on Via Europa, and a service access along Via Boccaccio, define the only points of interruption of the high curtain that delimits the area.
In particular, along via Boccaccio, the two enclosures that delimit the area of the ex-Rhodiatoce and the ex-Ads (that is another dismissed industrial building located in Casoria) delineate the image of a road closed between two walls for a continuous section of 270 meters, without interruption until the crossing with Piazza Dante.
Internally the area is characterized by a single large slightly inclined plane. The productive, directional and tertiary buildings are currently in a state of abandonment and some structures are characterized by high levels of degradation. A great heterogeneity defines the character of the open spaces of the area, in which it is possible to observe traces of foundations and surrounding walls of demolished buildings.
Some buildings along the internal streets are characterized by concrete beams and steel strip windows. The load-bearing structures of the production halls are mainly made of concrete, while the curtain walls, secondary partitions and internal partitions are in perforated blocks or solid bricks. The rest of the buildings is in concrete, with corrugated sheet roofs, flat roofs and roofs in rafters and bricks.

The production facilities of Rhodiatoce can be read as a unitary building formed by a set of defined blocks that form the individual parts. Completing the structure of the production area are the service buildings, the laboratories and the block of houses built on the terrace, which borders a large covered space that looks like a square.
The internal circulation is ensured by a wide road that delimits the edge of the complex, divided by a single central trunk with the function of separating the directional part of the complex from the most productive one, which extends towards the eastern limit of the lot.
Of great architectural interest is also the building called “T/2”, originally intended for the processing of the continuous wire Terital, consisting of load-bearing structures in concrete, with covers in different orders of vaults in reinforced concrete, surmounted by large windows in steel and glass.
The rest of the buildings are in concrete, plastered or covered in clinker, with corrugated sheet roofs, mainly flat roofs, rarely with a double sloping roof, and roofs in rafters and bricks. The floors are mainly in brick and concrete joists.

Regarding the urban classification, the area of Rhodiatoce falls for an area of 111,580 m² in the G area, commercial and tertiary, and for 29,678 m² in the H1 area, of equipment and services.
Under urban planning instruments, the G area is defined as an area destined to host commercial and service activities for the road network, as well as small artisan industries, sports and leisure facilities.
The H1 area is instead defined as an area destined to host facilities, services, collective activities and public spaces for parking and green areas[48].

Fig. 56: Rhodiatoce industrial plant: aereal view, Miano, 2005

[48] the information present refers to the town planning instruments in force at the time the project was drafted

Fig. 57: Rhodiatoce industrial plant, Miano 2005

Fig. 58: Rhodiatoce industrial plant: relief of the existing conditions, elaborated by the working group headed by Prof. Arch. Pasquale Miano

5.3.1 The life cycle of a building

Having previously specified how the territory is characterized by its own life cycle, it is necessary to underline that even the buildings, in the multi-scale perspective that has been adopted, are endowed with their own life cycle.
The life cycle of a building is based on the analysis of the practices that affect the whole path of life that a building undergoes in the course of some years.
The life of a building begins with the design phase, in which the costs and times are the items that most influence the result of the final project. In the next phase, the construction phase, the life cycle of materials, the times and the costs and the building site take on a particular relevance. After the construction, begins the period of use of the artefact in which different functions can be carried out with different subjects who perform maintenance works of the building. A possible next phase is that of abandoning the building. Some possible scenarios arise subsequently: it is possible a recovery of the building with the part of the disassembly in which the existing conditions are evaluated. It is also possible a complete demolition of the artefact, without a new construction, determining the necessity of the disposal of waste or also its recovery. Finally, the last alternative is the demolition of the building but a subsequent construction of a new building (Baiocco et al., 2018) (Fig. 59)

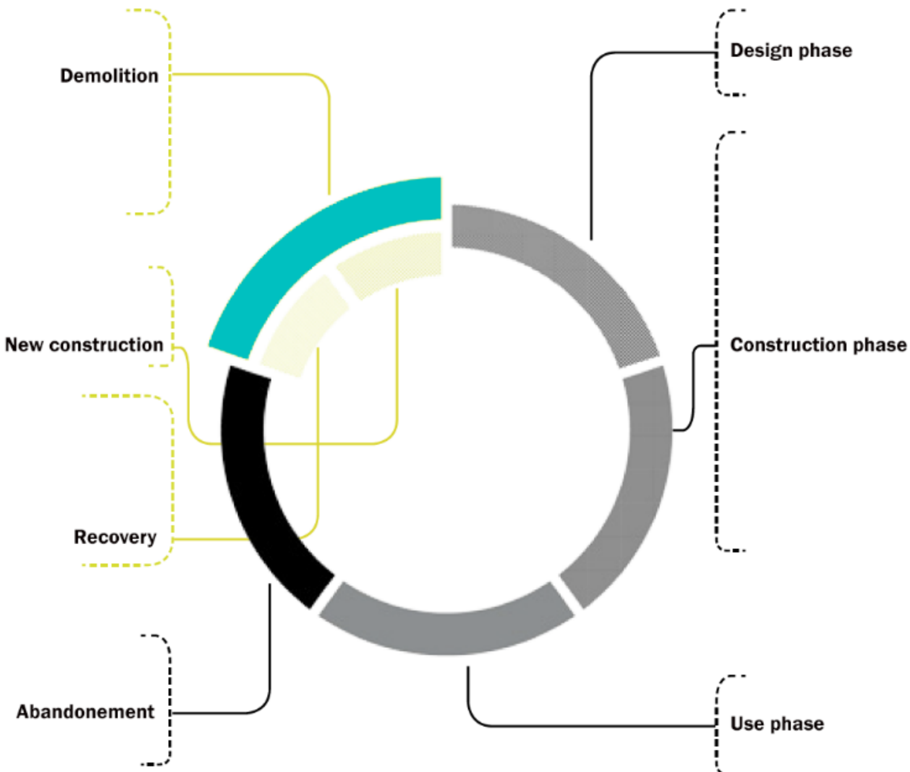


Fig. 59: the life cycle of a building, adapted from Baiocco et al., 2018

As far as the demolition phase is concerned, there are two possible alternative scenarios: the first concerns the total demolition of the building, without recovering the waste materials and the construction of a total new building. The second alternative is based on the demolition of the existing building and the construction of a new building by reusing part of the demolition materials.
The demolition phase and the way it is carried out depends strictly on the entire constructive process, underlining the necessity to consider the entire life cycle.
In the demolition phase, it is possible to take two opposite paths: the firs concerns the disposal of the material without the opportunity to recover it, while the second provides the possible recycling of the CDW and the disposal of the material that it is not possible recycle.
As a matter of fact, the disposal phase is very relevant and it is necessary to support this phase by accurate economic and environmental evaluation procedures (Baiocco et al., 2018).

LCA is able to provide a detailed picture of the environmental impacts coming from materials and buildings through science-based standardized metrics and in the same time LCC helps understanding the financial implications (Bruce-Hyrkäs et al., 2018).

5.4 CDW quantification

5.4.1 Project description

The objectives of this research work include the drawing up of guidelines, which, through the support of LCA, can define appropriate methods for the demolition and reconstruction of decommissioned buildings, choosing those solutions capable of minimizing environmental impacts, encouraging strategies of recycling and reuse of materials in a CE perspective[49].
It is important to collect reliable information on the expected quantities of CDW in order to facilitate the establishment of policies and alternative possible solutions (Ding and Xiao, 2014).
The project elaborated by the working group headed by Prof. Pasquale Miano of the Department of Architecture of Naples has been chosen to determine the quantization of CDW and concerns the creation of a productive pole for the book chain, with an area of public interest and public interest infrastructures (Fig. 60).

[49]However, among the aims there is not that of crossing over into the field of architectural design. For this reason it was decided to base the quantization of the CDW on the design solutions adopted by the working group that has as its leader Prof. Arch. Pasquale Miano

The articulated volume of the ex-fabric can be redesigned on the basis of new functional requirements, retaining its positional figurative value, determined by the permanence of the building over time; around this element it is expected the location of a large urban park. Some parts of the Rhodiatoce building, above all the production space characterized by a system of curvilinear beams on the roof, can be preserved and articulated on a system of blocks with a specific destination, connected by covered and open interconnection elements. In the entrance, there is the node for the commercial and exhibition area and inside the park it is foreseen the insertion of two buildings destined to infrastructures. In connection with the discourse of the City of the Book, the localization of the multifunctional centre of culture and free time is assumed, which performs social, cultural, exhibition, entertainment and commercial functions. In connection with one of the specific characteristics of the park, the idea of locating a centre for children is advanced, with many recreational and social activities. Therefore, the urban redevelopment project of the former Rhodiatoce area is based on the composition of a compact production "citadel" and a park that is suitably connected and interconnected in the context of the area accommodation. Fig. 61 presents the functional and dimensional information of the above-described project, underlining the new construction as well as the pre-existence.

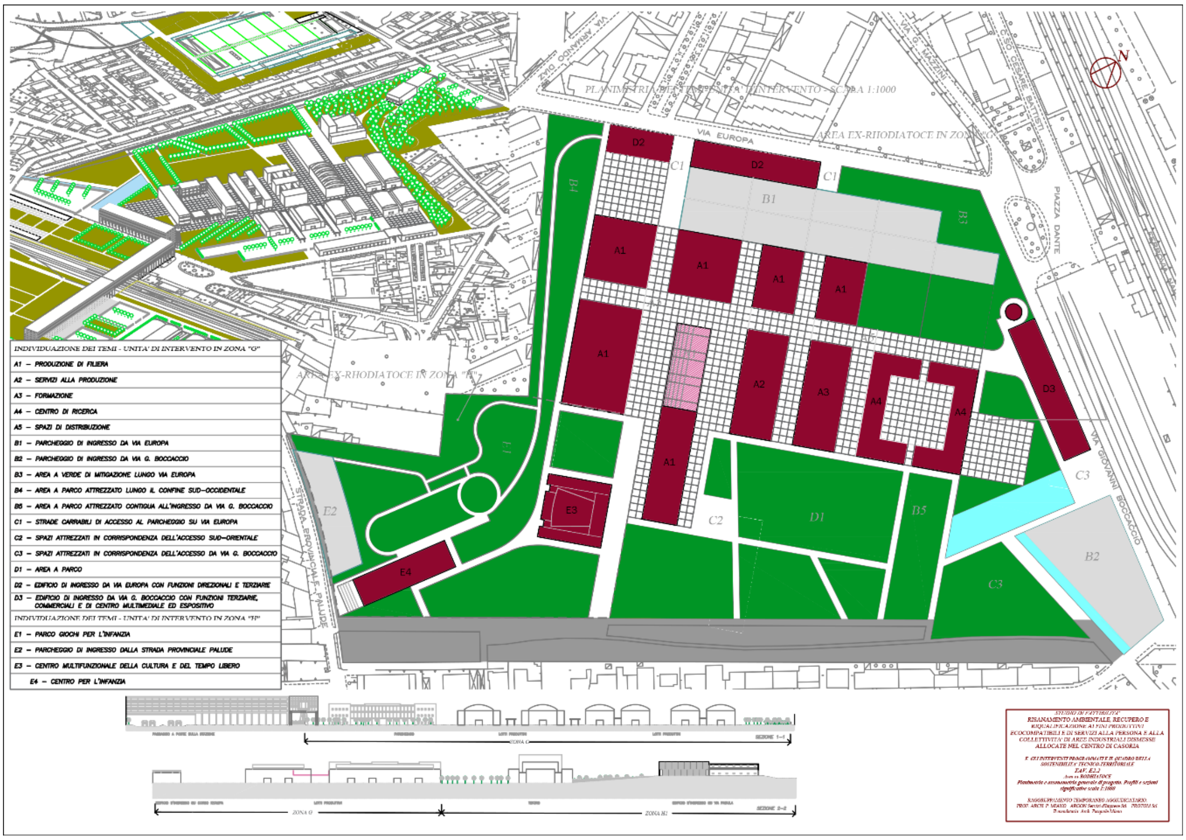


Fig. 60: redevelopment project elaborated by the working group headed by Prof. Arch. Pasquale Miano

Functional and dimensional information

1: Supply chain production, 3375 m²
2: Supply chain production, 2025 m²
3: Supply chain production, 2025 m²
4: Supply chain production, 1350 m²
5: Supply chain production, 1350 m²
6: Entrance building with tertiary, commercial functions and multimedia and expositive center, 3375 m²
7: Research center, 6900 m²
8: Training, 1350 m²
9: Production services, 1350 m²
10: Supply chain production, 1416 m² (pre-existing building)
11: Supply chain production, 2000 m²
12: Entrance building with directional and tertiary functions, 855 m²

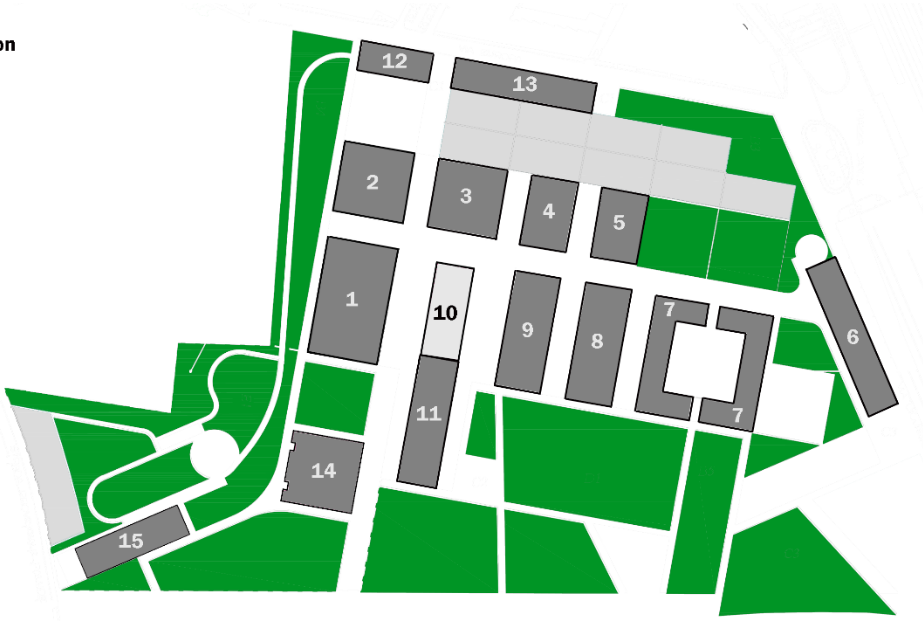


Fig. 61: functional and dimensional information of the project elaborated by the working group headed by Prof. Arch. Pasquale Miano

5.4.2 Calculation model

A clear tendency to rise for the next years for retrofitting and demolition activities is shown and since they have proven to generate more waste than construction activity (Coelho and De Brito, 2011), it is necessary to identify a suitable quantization model and to monitor the environmental impacts.
In order to choose the calculation model that best meets the needs of the present case study, an analysis of the existing methods was carried out.

CDW quantification represents a fundamental prerequisite in order to implement a successful WM. Wu et al. (2014) propose an analytical review of the existing quantification methods, introducing a first distinction between quantification at two different levels:

- at regional level, with the aim of quantifying CDW of all projects in a particular region.
- at project level, that has the aim of forecasting CDW quantities in a single project.

Therefore, it is possible to deduce that the first part of the case study concerns the first method (see chapter 4) that is the quantization of the CDW flows produced in Campania Region and in the Focus Area over a period of one year, while in this

chapter, adopting a multi-scale approach, it is elaborated the second type of quantization.
Waste generation activities can be divided in the following typologies (Wu et al., 2014):

- construction of new buildings;
- civil and infrastructural works;
- demolition of old buildings, that is the activity analysed in the present chapter.

Still Wu et al. (2014) identify six major categories of quantification methodologies:

- Site Visit method (SV), in which it is possible to adopt both direct measurement, through which the waste produced is measured on site and indirect measurements, such as truck load records and on-site interviews as well.
- Generation Rate Calculation (GRC) method, that is based on the waste generation rate for a particular activity unit (for example Kg/m^2) and the amount of total units. This category of methods can comprise per capita multiplier, financial value extrapolation and area-based calculation. The latter can be estimated by multiplying the generation rate and the total area.
- Lifetime Analysis (LA) method that is based on material mass balance and on the principle according to which the amount of demolition waste must equal the mass of the construction. This methodology is divided in building lifetime analysis and material lifetime analysis.
- Classification System Accumulation (CSA) method, that is based on a platform for quantifying different specified materials.
- Variables Modelling (VM) method is based on the principle according to which CDW quantification and generation depend on a series of variables such as economic indicators, construction areas, etc. Very interesting can be the quantification framework based on an “Activity Based Waste Generation” (Wimalasena et al., 2010), according to which the total CDW quantity can derive from the sum of the waste quantities produced in each construction activity.
- other methodologies, such as method based on chemical characteristics or method based on fix percentages of the purchased materials.

These methodologies can be adopted either individually or in combination, depending on the needs. Wu et al. (2014) suggest the scheme of Fig.62 in order to facilitate the selection of the correct calculation methodology.

As far as site visit is concerned, this method could be the most precise but it is time consuming and costly and it could be characterized by significant barriers (Franklin Associates, 1998).

The first factor to determine for the application of the calculation model is represented by waste characterization and for the present case study, it is assumed the same characterization represented by the Regional and Focus Area case studies (see paragraph 4.2) as well as the introduction of some specific corrective measures based on the characteristics of the building in question.
Secondly, the main factor for the estimation of CDW arising from the demolition activity is represented by the Waste Generation Rate (WGR), that depends on the quantity of material developed from different sources (Ghosh et al., 2016).

Different quantification formulas have been proposed in the literature; for example Kofoworola and Gheewala (2009) suggest to apply for construction waste the quantification model based on the following formula :

$$Q_x = A * G_{av} * P_x$$

whereas Q_x represent the quantity (tons), A is the area of activity, G_{av} is the waste generation rate and P_x is the percentage of waste material. In particular, they found that in Thailand the average waste generation rate is 21.38 Kg/m^2 for new residential projects and 18.99 Kg/m^2 for non-residential projects.

Ding and Xiao (2014) propose to separate Demolition Waste (DW) from Construction Waste (CW), suggesting the following formulas.

$$DW = DW_r + DW_{nr} = DA_r * \sum_k F_t * F_{sr} * G_{dr} + DA_{nr} * \sum_k F_t * F_{snr} * G_{dnr}$$

where DW_r and DW_{nr} (tons/year) represent the amount of demolition waste caused by regional residential and non-residential demolition activity. DA_r and DA_{nr} (m^2/year) represent the demolished floor area of both residential and non-residential buildings. F_t is a proportion value representing the proportion of demolished buildings constructed in different decades. F_{sr} and F_{snr} represent the percentage of a structure type for a specific decade and finally G_{dr} and G_{dnr} represent the demolition waste intensity (tons/m^2) for residential and non-residential buildings.

$$CW = CW_r + CW_{nr} = CA_r * \sum_k F_{sr} * G_{cr} + CA_{nr} * \sum_k F_{snr} * G_{cnr}$$

whereas CW_r and CW_{nr} (tons/year) are the amount of the construction waste produced by regional residential and non-residential construction or innovation activity. Car and CA_{nr} (m^2/year) represent the construction floor areas of both residential and non-residential buildings. G_{cr} and G_{cnr} represent the construction

waste intensity expressed in (tons/m^2) and finally F_{sr} and F_{snr} represent the percentage of various structure types, while k is the number of waste materials.
Therefore, in a renovation activity there are both activity of demolition and of construction and in general the amount deriving from demolition activities is significantly higher (Masudi et al., 2012).
Martínez Lage et al. (2010) propose the following model:

$$R_{build} = \sum_{counties}(Rci + Rri + Rdi) = \sum_{counties}(Cc * Sci + Cr * Sri + Cd * Sdi)$$

where R_{build} is the CDW debris generated during a given year distributed over counties. Rc is the waste from new construction, Rr is the waste coming from renovation activities, and Rd is the waste from demolition. Sc is the total surface area for new construction, Sr is the surface area for renovation and Sd is the surface area for demolition. Cc is the waste quantity per surface area for new construction, while Cr is the waste per surface area for renovation and finally Cd is the waste per area for demolition. The above model was applied in Galicia and it was estimated a quantity of 80 Kg/m^2 of CDW for new construction work, 1350 Kg/m^2 of waste for demolition work and finally 90 Kg/m^2 for renovation work.
In the case of lack of data, it is possible to adopt the above assumptions. In this perspective, also Coelho and De Brito (2011) propose the CDW generation estimates for housing and commercial buildings from demolishing, retrofitting and new construction, represented in Tab. 16.

Definitely, in relation to the available data and on the basis of the short excursion on the CDW quantization methods, it is considered appropriate to choose the method indicated by Wu et al. (2014) as “area based calculation” linked to the “generation rate calculation” category (see Fig. 62). As stated by Martínez Lage et al. (2010) and Ding and Xiao (2014), CDW is the sum of Construction and Demolition Flow as well as the waste produced by retrofitting or renovation activities.

Therefore, on the basis of the above project proposal, there is only one building that is renovated, while the remaining structure is transformed and rebuilt. As far as new construction and retrofitting, the WGR presented by Martínez Lage et al. (2010) is adopted. The latter, as already specified, is represented by 90 Kg/m^2 for renovation/recovery activities (Renovation Waste - RW), 80 Kg/m^2 of total construction area for new construction activities (Construction Waste – CW) and 1350 Kg/m^2 for demolition activities (Demolition Waste – DW).

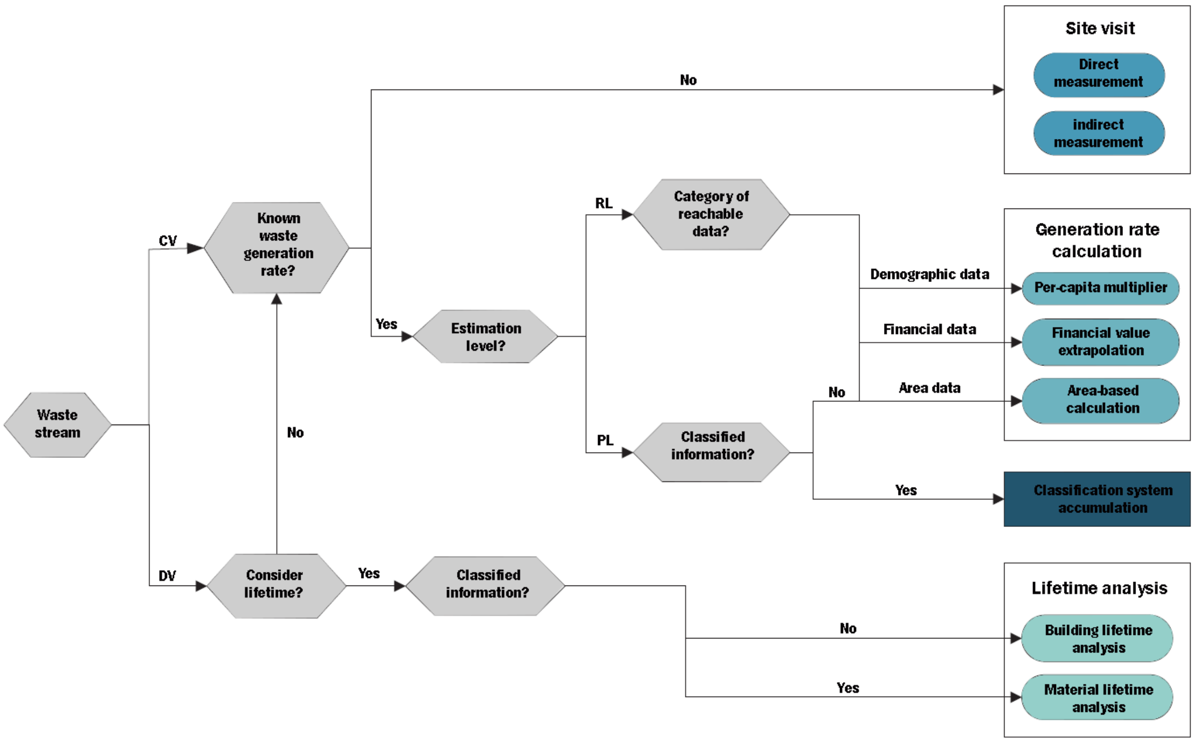


Fig. 62: scheme for the calculation model selection, adapted from Wu et al. 2014

Type of operation	Type of building				
	Housing			Commercial	
	Kg/m^2 (1)	Kg/m^2 (2)	Kg/m^2 (3)	Kg/m^2 (2)	Kg/m^2 (3)
Demolition	2210	1964	1265	2982	2054
Retrofitting	746.2	445.5	347.3	409.5	315.4
New construction	190.3	167.9	114.3	132	89.8

Notes: (1) m^2 of living area (2) m^2 of useful area (3) m^2 of total construction area

Tab. 16: CDW generation estimates for housing and commercial buildings, Coelho and De Brito, 2011

The choice to adopt these indicators compared to others is due to the similarity of the Spanish context, in which the application is localized, compared to the Italian one. It is, therefore, necessary to specify that these are forecast estimates based on broad indicators and which naturally determine plausible but not effective results. To this end, it would be necessary to use the "direct measurement" method during the actual construction and demolition phases linked to the building transformation processes envisaged for the future.

Therefore adopting the formula proposed by Kooworola and Gheewala, (2009), it is expected that:

$$CW = A_{nc} * 80\ Kg/m^2 = 24240\ m^2 * 89.8\ Kg/m^2 = 2.176.752\ Kg \text{ to total CW}$$

where A_{nc} is the total area of new construction

$$RW = A_{rc} * 90\ Kg/m^2 = 1416\ m^2 * 315.4\ Kg/m^2 = 447\ Kg \text{ of total RW}$$

where A_{rc} is the total area of the renovated building

$$DW = A_{dc} * 1350\ Kg/m^2 = 46000\ m^2 * 1350\ Kg/m^2 = 62.100.000\ Kg$$

where A_{dc} = is the total area of the demolished building.

Therefore the total CDW flow is:

CW + RW + DV = (2176.752 + 447 + 62.100.000) Kg = **64.277.199 Kg** of total CDW flow.

As regards the quantitative information related to the individual flows, the percentage considered for the flow produced in the Region and in FA is basically maintained and it is considered representative of an average CDW flow. Anyway, some adjustments are necessary according to the specificities of the building.
Therefore, on the basis of these two information, namely on the one hand the flow produced in Campania and the temporal and constructive characteristics of the building that create the necessity to eliminate some fractions and to make a general calibration, the CDW fractions are the ones represented in Tab. 17.

Material Fractions	%
Bitouminus mixture	1
Clear glass	2
Hazardous CDW	1
Mixed CDW	14
Insulation materials	1
Ferrous scrap	15
Stones, concrete	30
Ceramics	0.5
Wood	0.35
Gypsum	0.15
Soil	35

Tab. 17: material fractions for Rhodiatoce scenario

After the identification of the quantities, it is assumed that the various flows undergo the same treatment as those analysed for the Region and the Focus Area, both from a quantitative as well as from a typological point of view.
As a result, a new evaluation is carried out.

5.5 LCA and LCC models for Rhodiatoce: results and discussion

LCA, as already specified, is a comparative tool, therefore it is again supposed to compare the results of the current scenario with those deriving from the assumption of sending all the flow to the landfill plant.

This is of course a hypothetical scenario, which serves only to create a basis of comparison. Therefore, if all the flows were sent to landfill without distinction, the impacts would be significantly higher.
As a consequence, the impacts can be lowered adopting an integrated management of the flow, that consists in improving the recycling performance of all those materials that enjoy the possibility of being re-used in all the phases, avoiding disposal (form cradle to cradle approach).

The baseline scenario has the objective of providing knowledge on the management of CDW in its current state and will serve as a basis for comparing the scenarios that will arise through the implementation of Eco-Inovative Solutions.
The latter may in fact also come into play with regard to the demolition practices of individual buildings, thus modifying the functioning of the global flow.

In Fig. 63 and Fig. 64 it is possible to observe the results of LCA for Rhodiatoce renovation formed both by construction and demolition activities with renovation activities, recognizing all the assumptions made, which could be overcome with a more detailed knowledge of the building and with a quantification of the flow based on direct field visits.

Finally, in Fig. 65 the results for LCC are reported.

Detailed results are provided in Appendix A3.

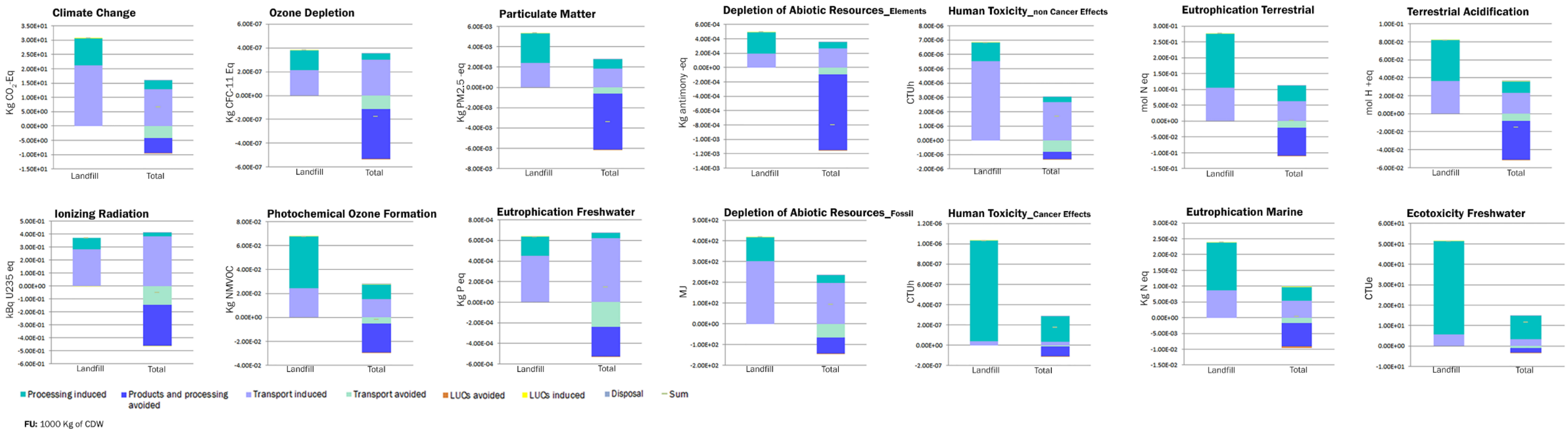


Fig. 63: LCA results for Rhodiatoce case study

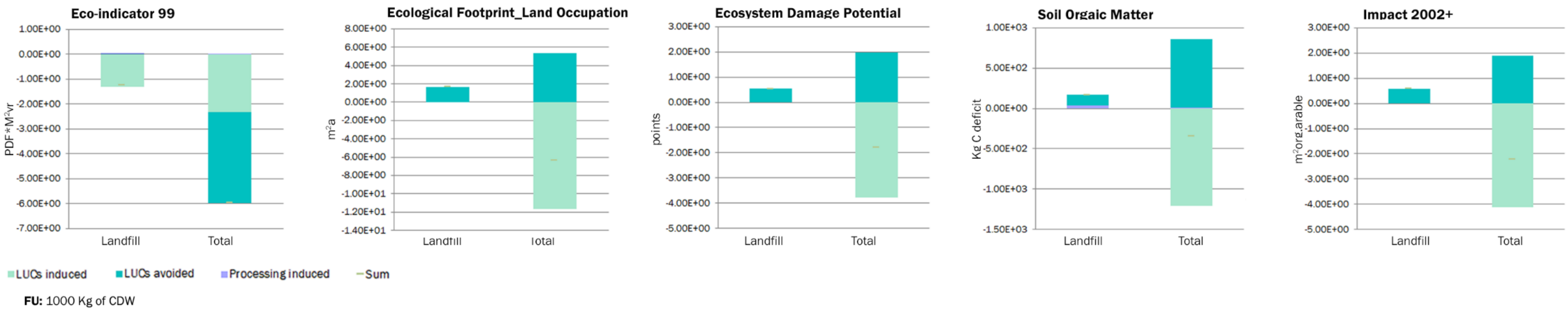


Fig. 64: LCA results for Rhodiatoce case study: land use impact categories

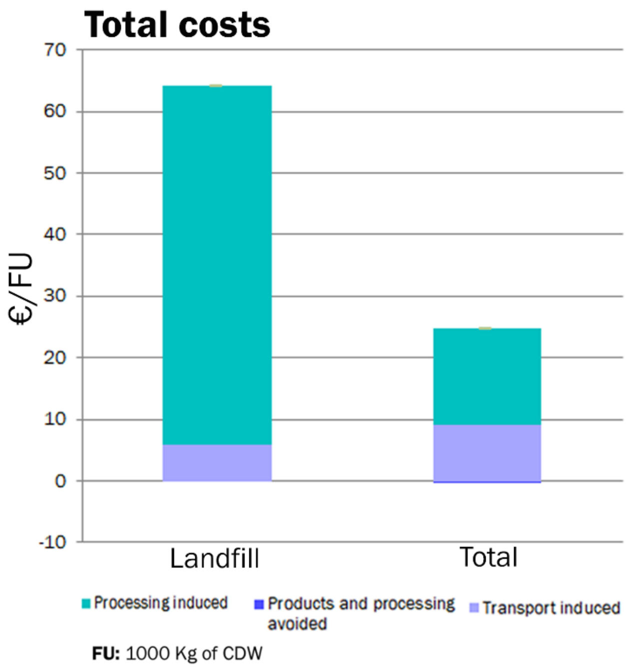
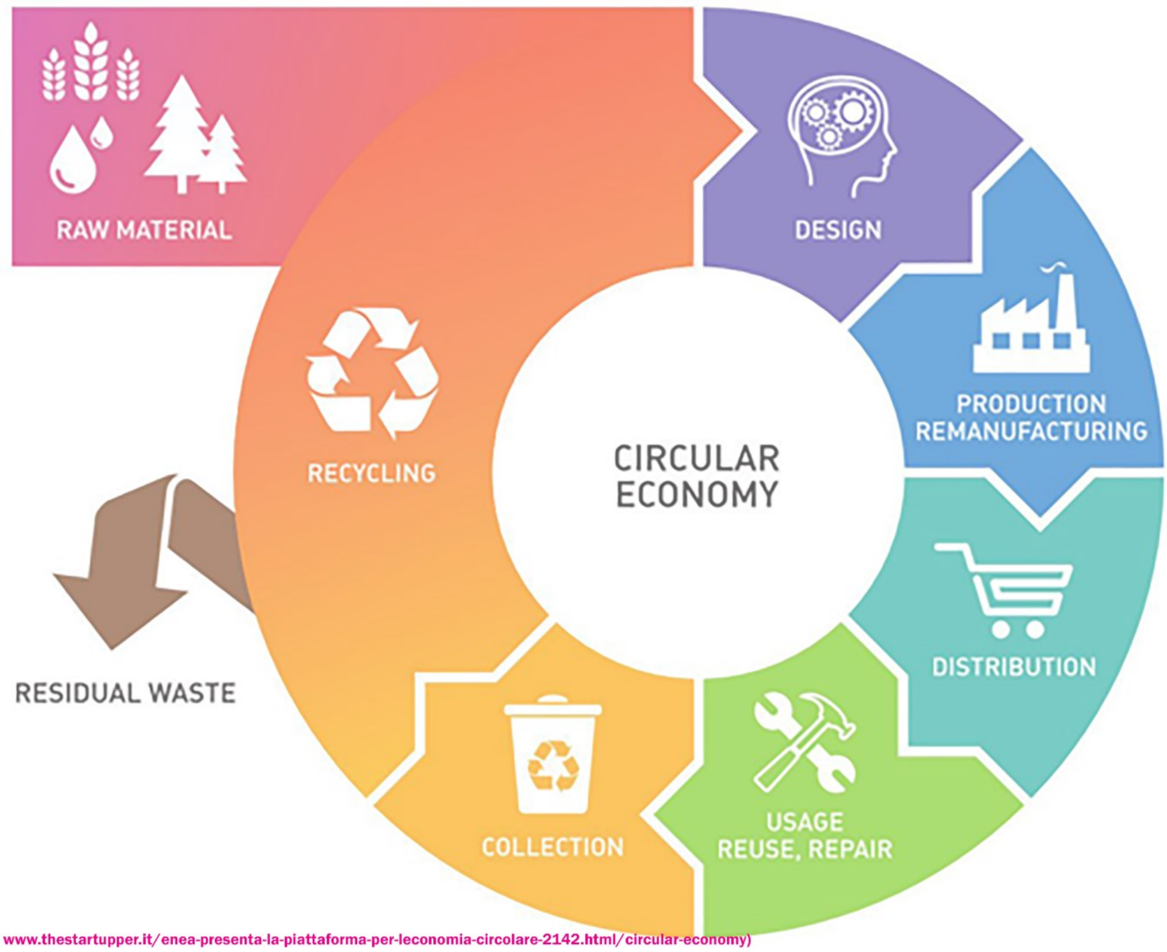


Fig. 65: LCC results for Rhodiatoce case study, year 2015

As it possible to observe in the above figure, the total cost for treating one tonne of waste deriving from Rhodiatoce renovation is about 24 € per Functional Unit.
As far as the landfill scenario is concerned, the total cost/FU is equal to about 64 €, demonstrating again the economic as well environmental convenience of reducing as much as possible the flow quantity to be sent to landfill, promoting recycling practices, saving non-renewable natural mineral resources and reducing the economic and environmental impacts due to mining activities.

CHAPTER SIX

Conclusions



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Premise

The present thesis is composed of various experimental parts and the aim of the final chapter is to retrace the steps described in the previous chapters in order to draw the appropriate reflections and conclusive remarks.

6.1 Main conclusions

6.1.1 The research question

First of all, «waste-disposal infrastructure offers peri-urban areas of Italian cities and towns services like incinerators, landfills, waste-recycling plants, waste-water processing plants, along with former industrial areas waiting for SIN[50] reclamation. The situation is different in Campania where the public institution's inadequate regulation of waste treatment and disposal plants was accompanied by a concatenation of forms of criminality, poverty and fragility of the sociocultural capital, acting as a driver for improper land use. It is hardly surprising that the result was the vicious mechanism that favoured the concealing of waste or its stocking in open spaces and in agricultural, former industrial, commercial, or, more in general, non-residential areas » (Palestino, 2017, p. 141).
Moreover, the diffused urbanization models, in their change from the late twentieth century until today, give us a city in an unlimited expansion, based on a linear growth economy that is incapable of incorporating environmental values, based on the production-consumption-waste paradigm. The concept of continuous and unlimited growth has produced negative effects on the city, which materialize themselves in the production of resulting urban spaces, abandoned areas, landscapes of waste, together with the difficulty of managing a cycle of production-consumption increasingly linked to the unsustainable generation of waste. A condition of always greater widespread and intensified risks that weaken the relations between cities, living spaces and the environment (Russo, 2018).

The thesis begins from defining the object of research, represented by urban ecosystems as formed by the interaction of anthropic and ecological components. Urban ecosystems are characterized by complex social-ecological interactions where sustainable choices made in one place can create social, economic or environmental problems elsewhere (McPhearson et al., 2016).

[50] Sites of National Interest (in Italian "Siti di Interesse Nazionale" – SIN)

Subsequently, the concept of ecosystem health has been introduced, in order to outline a framework of knowledge of the territory under examination. Human activity is a significant cause of global environmental changes, creating many environmental issues such as climate change, land use change or also reduction in the biodiversity level (Lu et al., 2015).

Urban ecosystems, in their complexity, like living organisms, have their own metabolism, whose functioning is linked to the presence of input and output streams. Hence the concept of UM has been introduced and described, then moving on to the subsequent identification of UM assessment methods and underlining the importance of life cycle methods. This is because the territory, like living organisms, is not only endowed with its own metabolism but is also marked by the succession of life cycles that are shaped by metabolic flows.

The instrument that canonically is used for the life cycle evaluation is that of LCA, which, as we have seen, is used to assess the environmental impacts of goods and services in all phases of their life cycle (from cradle to grave).
However, since this thesis is of a territorial nature, the present research has continued to investigate the field of LCA applied to the territory. It is clear that there are already some well-defined approaches, such as that of the "territorial LCA" (Loiseau et al., 2012, 2013, 2014, 2018). Despite this, LCA applied to the territory turned out to be a still open field, susceptible to further experimentations.

Starting from these assumptions, it was possible to outline the research question. The latter focuses on the metabolic waste streams, in particular on CDW flow, and on the life cycles of the territory that are now exhausted but on which regenerative potentials are inherent.
Therefore, a path has been defined aimed at applying LCA to the territory, following the distinction proposed by Loiseau et al. (2018). According to this clarification, it is possible to distinguish the dual nature of territorial LCA: the first concerns the assessment of the impacts of all production and consumption activities which take place in a given territory, the second concerns the assessment of the impacts linked to a single activity that is anchored in the territory.
A multi-scale approach is adopted, as cross-city comparison at multiple scales is a key quality to understand and analyse the complexity of social-ecological interactions (McPhearson et al., 2016).

Taking into account the massive demand for new infrastructures, a CE perspective is adopted in the possibility of re-using the dismissed built heritage in a sustainable way, developing opportunities to adopt «[…] ecologically based design, architecture and planning in development and governance processes» (McPhearson et al., 2016, p.199).

6.1.2 Urban ecosystem health

The central part of the thesis, prior to the application of LCA, is based on a territorial analysis of the ecosystem health that characterizes both the MAN and the FA, starting from the combination of MCDA and GIS for the development of a SDSS.
As a matter of fact, it is important to analyse the current condition of urban ecosystems, because only by a detailed knowledge and evaluation of the status quo, it will it be possible to think about the planning of future scenarios of development for metropolitan areas. Therefore, evaluation is a strategic activity at all levels and in different phases; in the present case, evaluation “ex ante” is a very useful instrument to analyse all the components before starting the planning activity. In a second phase, evaluation “ex post” could be used to examine how a development scenario is able to meet the goal of minimising or maximising the selected indicators, assessing the quality of the process and introducing the necessary corrective actions. Indeed, in order to ensure an effective planning process, there is a need to measure all the variables, defining adequate quantitative and qualitative indicators.

Consequently, an urban ecosystem health assessment method is carried out, translating the concept of ecosystem health from the ecological sphere to the urban vision, identifying a suitable set of indicators associated with the usual categories of vigour, organisation and resilience that characterise the concept of ecosystem health. Taking into account the possibility of putting the problem at different scales, a SDSS through the integration of MCDA and GIS, by specifically applying the geoTOPSIS method is built.
Therefore, the evaluation criteria are associated with the geographical entities and are represented by maps, providing an important support to the analysed question, thanks to the quantification and visualisation of decision criteria. Furthermore, the method of PCA is used in order to reduce the initial number of indicators, showing that with the use of an appropriate evaluation method, these data, applied to the MAN and to the FA, provide a classification of the territory according to its level of ecosystem health.

This analysis then allows a solid knowledge base that can support the various stages of decision-making at different scales, in order to exploit and enhance the capabilities already present and at the same time act on the weaknesses, creating win-win solutions from the economic, ecological and social perspective, regarding sustainable development.

Therefore, having focused on implementing the first part of the proposed research on urban ecosystem health, applied within the described framework, a substantial difference compared to the already proposed models consists of considering “vigour”, “organisation” and “resilience” not as indicators but as macro-dimensions within which to understand the drivers to which the appropriate reference indicators correspond, including social, economic, ecological, environmental and institutional aspects (Michael et al., 2014).

6.1.3 LCA model

The second territorial component of this research is linked to waste territories (*wastescapes*), investigated within REPAiR project, to which this thesis is connected. A methodology aimed at identifying the waste territories has been developed and the same methodology has been tested and applied in order to identify the *wastescape* related to the abandoned industrial buildings, to which the flow of CDW investigated in LCA is connected.

The importance of the LCA approach in the construction of sustainability analysis is demonstrated to the extent that it is possible to integrate different methods and competences to be used in the dynamics of the transformation processes of the territory (Torricelli, 2015a).
In turn, the LCA tool is used to evaluate the impacts related to the treatment of CDW in a multi-scalar perspective: first in relation to the entire Campania Region, subsequently in relation to the FA selected as a case study and finally in relation to an example *wastescape* linked to the hypothetical demolition and reconstruction of the former Rhodiatoce factory located in Casoria.

Considering the importance of the decision-making process as a key element, another key aspect lies in the multidimensional and multi-scalar proposed approach, that represents a fundamental prerogative (Fig. 66).
This is because it is highly important to deepen the analysis of certain problematic contexts, to identify the significant phenomena and the spatial processes that need to be decoded, increasing the level of awareness in the decision-making process.

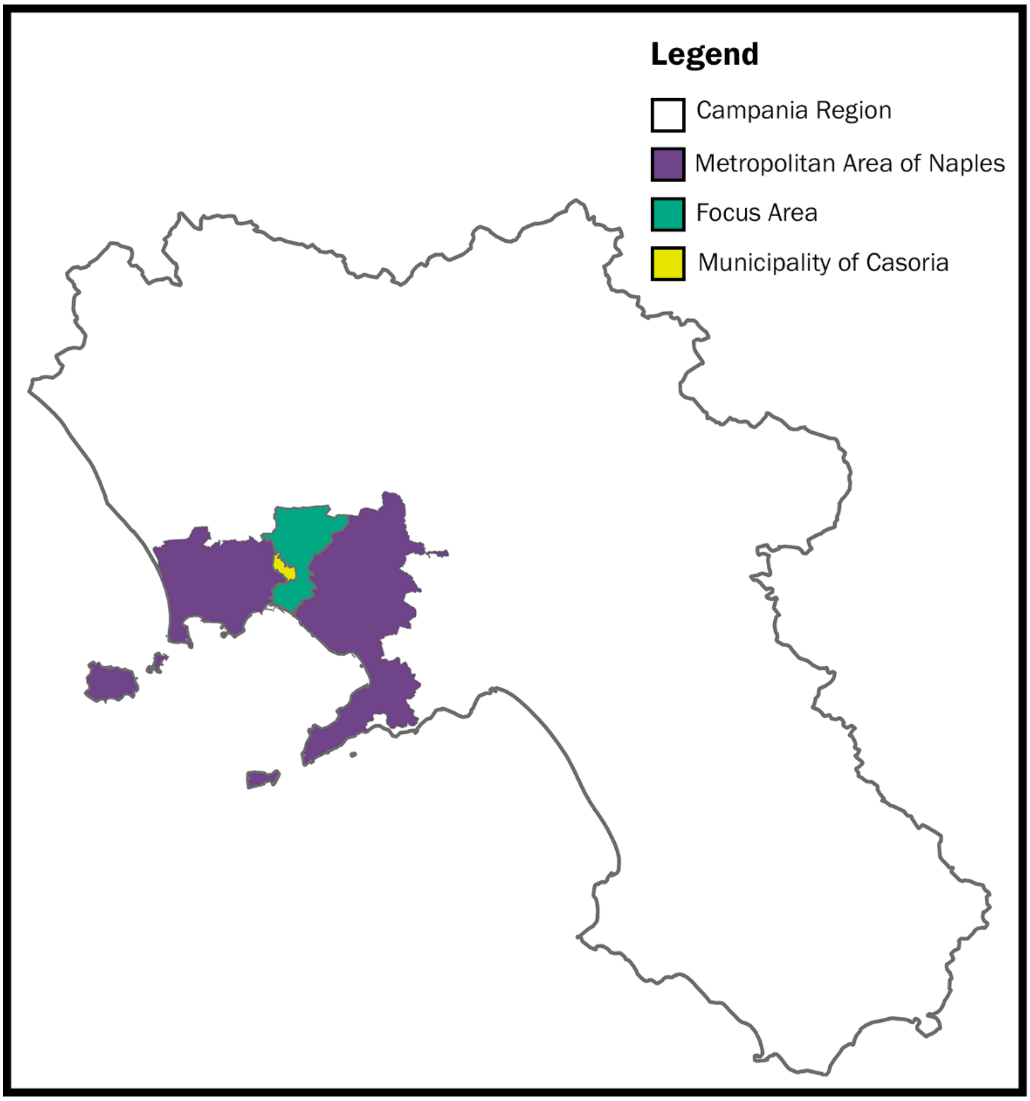

Fig. 66: from Campania Region to Casoria Municipality

6.1.4 A reflection on some impact categories

The territory is seen as a set of socio-cultural, economic and ecosystem services. In this regard, a relevant category of midpoint impact for the purposes of a LCA territorially connoted is represented by land use.

A soil in natural conditions is able to provide mankind with ecosystem services that allow their livelihoods, while instead inappropriate transformations of land use cause negative impacts in this regard, also generating effects on climate change, biodiversity and ecosystem health (Incerti et al., 2011; Torricelli and Gargari, 2015b). So it is necessary to analyse the landscape structure and its land uses, in order to spatially represent the distribution of ecosystems and the services they provide and in order to guarantee the survival of the species and the conservation of nature (Burke, 2000). As a matter of fact, many of the impacts on the provision of ecosystem services are influenced by changes in land uses, which may lead to fragmentation and loss of ecosystem functions (Scolozzi et al., 2012). Moreover, urban expansion and the consequent landscape modifications are important drivers in the alteration of environmental impacts related to land use and they are a principal cause of biodiversity losses, reducing ecosystem services as a further consequence (Foley et al., 2005; Tscharntke et al., 2005).

The relationship between ecosystems and urban settlements is complex and multifaceted; non-urbanized areas are part of the agricultural and green infrastructure that produces ecosystem services[51]. These are outdoor areas with significant levels of vegetation, mainly semi-natural (peri-urban) areas that, especially in urban contexts, represent the last remnants of the natural ecosystem. These areas provide multiple services: they preserve biodiversity, contribute to the sequestration of CO_2, reduce air and noise pollution, regulate the microclimate, reduce the effects of heat islands, influence housing prices, and have also recreational values useful for well-being, health and social security.
The consequences of climate change in urban ecosystems underline the importance of ecosystem functions and mitigation and adaptation actions should be used (La Rosa and Privitera, 2013).

The unsustainable use of soil is a factor that increases the vulnerability to climate change. Therefore, another fundamental category of midpoint impact is precisely represented by climate change, which affects both human health and the natural environment. It is recognized that urban ecosystems, being responsible for 70% of global emissions, play a central role in the fight against climate change, as they exalt the drivers responsible for the same and also give space to action through initiatives aimed at urban cooperation. Furthermore, climate change determines impacts on crop productivity as well as on food availability (Godfray et al., 2010; Wheeler and Von Braun, 2013). Moreover it has serious consequences on the distribution of species, the phenology of organisms and the functioning of plant communities (Parmesan and Yohe, 2003).
Most of the population lives in urban ecosystems, to this it is possible to add the continuous processes and models of urbanization, and the concentration of services and infrastructures in urban areas. These factors make urban ecosystems like hot spot causing a significant percentage of greenhouse gas emissions. However, many

[51] https://www.millenniumassessment.org/en/index.html

of the urban environmental protection actions are characterized by the lack of guidance or limited support from the various government levels.

The assessment of the effects that climate change can have on the system can occur through alterations of well-defined and measurable elements that can be used as indicators in LCA. The latter provide information on the occurrence of a given change and especially on the direction and entity of the same. These indicators will have to meet certain requirements, such as measurability and transparency, in order to be easily understood by decision-makers.

The interaction between urban ecosystems and climate is complex and needs to be deepened in order to prepare the most appropriate policies to implement adaptive capacity and reduce the vulnerability to the effect of this phenomena, which in urban ecosystems is high due to a series of factors such as population density, land use and the presence of economic activities sensitive to climate variables , such as that related to WM.

Starting from these factors, «a broader knowledge base also ensures that policy makers and companies have a solid basis for making decisions that fully reflect environmental limits, risks, uncertainties, benefits and costs. The current knowledge base for environmental policy is based on monitoring, data, indicators and assessments mostly related to the implementation of legislation, formal scientific research and science and citizen initiatives. However, there are gaps between available and necessary knowledge to meet emerging policy demands. These gaps call for action to expand the knowledge base for policy and decision making in the future» (EEA, 2015, p. 166).

6.1.5 Concluding remarks

LCA is generally defined as the «compilation and evaluation of the inputs, outputs, and potential environmental impacts of a product system throughout its life cycle [...]» (Hellweg and Milà i Canals, 2014, p. 1109), therefore it has been typically used to assess specific product systems. Despite this, today it is possible to improve the application of this tool, in order to enhance its potentialities for the study of urban ecosystems.

The application proposed in this research has implemented a territorial LCA of type A (Loiseau et al., 2018) in order to link the activity of WM and its consequential impacts to the regeneration of wasted landscapes formed by abandoned industrial buildings.

The importance of the territorial component is linked to different aspects: first of all as far as LCA is concerned, the activity of WM is anchored in the analysed territory and the geographical component is especially linked to the position of the waste treatment plants. The latter influences the impacts of transport, considering that a notable quantity of the flow is treated outside Campania Region. This aspect and the high impacts linked to transport can determine a new reasoning regarding a different organization of the way in which the flow is sorted on the territory.

Furthermore, another territorial aspect is that related to land use in relation to land occupation and land transformation, as the territory with its own life cycle is characterized by the alternation of different land uses and primary land use and its evolution represent an important aspect to consider.

In addition, it is important to underline the necessity to improve the recycled aggregates chain in order to reduce quarry activities. The results demonstrate the high savings that it is possible to obtain through this recycling activity, especially after analysing the damages produced on the territory by an intense mining activity.
At this point the GIS comes into play, which has been used to identify, through some methodological steps and thanks to the support of ISTAT data, the abandoned industrial buildings in the territory of the FA.

This procedure serves to demonstrate how the LCA and LCC tools can prove to be useful in supporting the regeneration of the territory, and in this case to support the demolition and reconstruction of the abandoned buildings, suggesting to the decision makers good practices of demolition and reconstruction, such as that of selective demolition.
This example also shows that the same procedure could be repeated in the same territory or even in different territories to identify and support the redevelopment of the abandoned building heritage.
Definitely, the foundations were laid for the creation of an environmental and economic control tool, which can support decision makers engaged in the regeneration of the territory, overcoming the concept of a city subject to unlimited growth and a linear economy based on the paradigm of *production – consumption – waste* (Russo, 2018).

The goal was to demonstrate that the LCA tool is flexible and can be easily used for different purposes and at different territorial scales, taking into consideration various and heterogeneous activities that characterize the functioning of the territory, becoming an operative tool for both private and public sectors involved in the territorial regeneration.

Defining an integrated evaluation framework that, in a multidimensional perspective, takes into account the environmental, social, economic and cultural aspects, can implement the evaluation phase connected to planning for environmental problems.

6.1.6 What's next?

The research proposed a first possible association of LCA as a tool to support the regeneration of the territory, but it is also open to future advances.
First of all, it is possible to take into account all the other *wastescapes* in order to calculate the total amount of CDW that would come out of the regeneration of abandoned industrial buildings coming from the FA.
Secondly, it is also possible to focus on other activities that take place on the territory or on other types of metabolic flows, to support the regeneration of other types of *wastescapes*.
The real step forward, however, would consist in the geographical mapping of impacts, which is linked to the distribution of pollutants in the air. Indeed, the combination of the results of an LCA evaluation with models of territorial mapping of emissions is an innovative development line in relation to the issue of geographisation of environmental impact indicators (Gargari, 2015).

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APPENDIX A1: BASELINE SCENARIO FOR CAMPANIA REGION

impact categories for each plant according to processes

Incineration Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.8E-03	2.0E-11	4.9E-12	8.0E-10	3.2E-07	1.9E-05	3.3E-06	5.2E-06	1.5E-05	1.9E-08	1.2E-06	8.1E-04	3.8E-02	2.5E-08	-1.2E-05	0.0E+00	3.4E-07	-8.5E-05	0.0E+00
Transport avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Processing induced	3.4E-04	2.9E-11	1.4E-10	2.0E-10	5.7E-07	1.7E-05	1.5E-06	2.6E-06	4.8E-06	2.3E-08	4.2E-07	1.7E-03	4.9E-03	1.5E-07	-7.6E-06	9.8E-06	3.6E-06	5.4E-04	3.4E-06
Products and processing avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
LUCs induced	4.9E-05	9.3E-13	1.3E-13	7.6E-13	1.6E-08	-5.6E-09	9.8E-08	2.4E-07	9.9E-07	1.2E-09	3.7E-07	8.4E-06	1.2E-04	5.5E-10	-2.3E-03	5.8E-03	2.1E-03	9.5E-01	2.0E-03
LUCs avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Disposal	4.4E-04	8.2E-12	4.7E-11	2.4E-11	1.4E-07	4.2E-06	2.0E-06	2.1E-06	7.7E-06	8.6E-09	7.0E-07	2.1E-03	5.3E-03	1.4E-08	2.3E-06	0.0E+00	1.0E-07	1.5E-03	0.0E+00
Other	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sum	**6.4E-02**	**5.8E-11**	**1.9E-10**	**1.0E-09**	**1.0E-06**	**4.1E-05**	**6.9E-06**	**1.0E-05**	**2.8E-05**	**5.2E-08**	**2.7E-06**	**4.7E-03**	**4.8E-02**	**1.9E-07**	**-2.3E-03**	**5.8E-03**	**2.1E-03**	**9.5E-01**	**2.0E-03**

Stationary Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	1.35E+01	2.78E-07	3.41E-08	2.94E-06	1.83E-03	3.58E-01	1.59E-02	2.42E-02	6.64E-02	5.85E-04	5.56E-03	3.50E+00	2.05E+02	2.45E-04	2.16E-03	0.00E+00	4.18E-03	2.26E+00	0.00E+00
Transport avoided	-4.81E+00	-1.31E-07	-1.39E-08	-9.22E-07	-7.21E-04	-1.67E-01	-5.75E-03	-8.84E-03	-2.36E-02	-2.76E-04	-2.00E-03	-1.21E+00	-7.60E+01	-1.15E-04	-1.02E-03	0.00E+00	-1.98E-03	-1.07E+00	0.00E+00
Processing induced	8.63E-01	1.46E-08	2.49E-09	9.82E-09	2.38E-04	7.67E-03	1.67E-03	1.52E-03	5.68E-03	6.05E-06	5.44E-04	7.84E-02	1.04E+01	1.54E-05	5.70E-04	7.69E-04	4.15E-04	1.81E-01	2.70E-04
Products and processing avoided	-6.03E+00	-4.82E-07	-1.12E-07	-6.17E-07	-6.37E-03	-3.66E-01	-2.80E-02	-5.02E-02	-1.03E-01	-3.32E-04	-8.51E-03	-2.53E+00	-8.93E+01	-1.21E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	4.89E-02	9.20E-10	1.30E-10	7.56E-10	1.58E-05	-5.60E-06	9.72E-05	2.38E-04	9.89E-04	1.24E-06	3.67E-04	8.32E-03	1.22E-01	5.51E-07	-2.30E+00	5.74E+00	2.12E+00	9.45E+02	2.02E+00
LUCs avoided	-6.58E-02	-1.24E-09	-1.75E-10	-1.02E-09	-2.12E-05	7.54E-06	-1.31E-04	-3.20E-04	-1.33E-03	-1.67E-06	-4.94E-04	-1.12E-02	-1.64E-01	-7.41E-07	-4.22E+00	-1.35E+01	-4.35E+00	-1.39E+03	-4.76E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**3.47E+00**	**-3.21E-07**	**-8.92E-08**	**1.41E-06**	**-5.02E-03**	**-1.67E-01**	**-1.62E-02**	**-3.34E-02**	**-5.45E-02**	**-1.74E-05**	**-4.54E-03**	**-1.68E-01**	**4.99E+01**	**-1.07E-03**	**-6.52E+00**	**-7.77E+00**	**-2.22E+00**	**-4.47E+02**	**-2.74E+00**

Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	3.84E+00	4.56E-08	7.86E-09	9.73E-07	4.52E-04	6.02E-02	4.44E-03	6.68E-03	1.91E-02	9.61E-05	1.57E-03	1.04E+00	5.54E+01	4.09E-05	3.49E-04	0.00E+00	6.76E-04	3.66E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	-5.00E+02	-9.08E-04	-7.06E-08	-2.63E-06	-8.08E-02	-1.90E+01	-4.62E-01	-1.54E+00	-1.62E+00	-6.66E-06	-1.38E-01	8.36E-01	-3.73E+03	3.56E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**-4.96E+02**	**-9.08E-04**	**-6.27E-08**	**-1.65E-06**	**-8.04E-02**	**-1.90E+01**	**-4.58E-01**	**-1.53E+00**	**-1.60E+00**	**8.94E-05**	**-1.36E-01**	**1.88E+00**	**-3.68E+03**	**4.09E-05**	**3.49E-04**	**0.00E+00**	**6.76E-04**	**3.66E-01**	**0.00E+00**

Anaerobic Digestion Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	4.05E-01	1.69E-09	6.59E-10	1.15E-07	4.12E-05	2.48E-03	4.61E-04	6.86E-04	2.03E-03	3.58E-06	1.65E-04	1.14E-01	5.58E+00	1.63E-06	1.21E-05	0.00E+00	2.35E-05	1.27E-02	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	1.05E-02	1.11E-09	2.90E-09	4.50E-09	1.41E-05	4.17E-04	4.52E-05	7.38E-05	1.49E-04	6.04E-07	1.29E-05	3.68E-02	1.39E-01	3.32E-06	-1.24E-04	2.56E-04	9.92E-05	1.95E-02	9.02E-05
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	2.62E-04	5.02E-12	8.29E-13	4.51E-12	8.90E-08	7.55E-08	5.26E-07	1.29E-06	5.30E-06	7.94E-09	1.97E-06	4.81E-05	6.78E-04	3.17E-09	-1.23E-02	3.07E-02	1.13E-02	5.05E+00	1.08E-02
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**4.16E-01**	**2.80E-09**	**3.56E-09**	**1.20E-07**	**5.53E-05**	**2.90E-03**	**5.06E-04**	**7.62E-04**	**2.18E-03**	**4.19E-06**	**1.79E-04**	**1.51E-01**	**5.72E+00**	**4.95E-06**	**-1.24E-02**	**3.09E-02**	**1.15E-02**	**5.08E+00**	**1.09E-02**

Landfill Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	3.04E+00	3.06E-08	5.93E-09	7.92E-07	3.46E-04	4.09E-02	3.50E-03	5.26E-03	1.51E-02	6.46E-05	1.24E-03	8.30E-01	4.34E+01	2.77E-05	2.33E-04	0.00E+00	4.52E-04	2.44E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	1.37E+00	2.43E-08	1.44E-07	1.89E-07	4.23E-04	1.24E-02	6.28E-03	6.57E-03	2.48E-02	2.68E-05	2.20E-03	6.62E+00	1.69E+01	4.36E-05	7.02E-03	0.00E+00	3.15E-04	4.48E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	2.06E-03	3.87E-11	5.47E-12	3.18E-11	6.63E-07	-2.36E-07	4.09E-06	1.00E-05	4.16E-05	5.22E-08	1.54E-05	3.50E-04	5.12E-03	2.32E-08	-1.89E-01	2.41E-01	7.78E-02	1.96E+01	8.48E-02
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	4.41E+00	5.50E-08	1.50E-07	9.81E-07	7.70E-04	5.33E-02	9.78E-03	1.18E-02	4.00E-02	9.15E-05	3.46E-03	7.45E+00	6.03E+01	7.13E-05	-1.82E-01	2.41E-01	7.86E-02	2.44E+01	8.48E-02

Chemical Physical Biological Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	3.40E-02	4.24E-10	6.93E-11	9.52E-09	4.26E-06	4.91E-04	4.13E-05	6.74E-05	1.78E-04	3.80E-07	1.46E-05	1.00E-02	4.64E-01	4.82E-07	-3.54E-04	0.00E+00	5.45E-06	-2.96E-03	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	3.40E-02	4.24E-10	6.93E-11	9.52E-09	4.26E-06	4.91E-04	4.13E-05	6.74E-05	1.78E-04	3.80E-07	1.46E-05	1.00E-02	4.64E-01	4.82E-07	-3.54E-04	0.00E+00	5.45E-06	-2.96E-03	0.00E+00

APPENDIX A1: BASELINE SCENARIO FOR CAMPANIA REGION

impact categories for each plant according to processes

Total Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	1.69E+01	3.11E-07	4.07E-08	3.86E-06	2.22E-03	4.02E-01	1.99E-02	3.02E-02	8.37E-02	6.54E-04	6.98E-03	4.45E+00	2.54E+02	2.75E-04	2.04E-03	0.00E+00	4.67E-03	2.52E+00	0.00E+00
Transport avoided	-4.81E+00	-1.31E-07	-1.39E-08	-9.22E-07	-7.21E-04	-1.67E-01	-5.75E-03	-8.84E-03	-2.36E-02	-2.76E-04	-2.00E-03	-1.21E+00	-7.60E+01	-1.15E-04	-1.02E-03	0.00E+00	-1.98E-03	-1.07E+00	0.00E+00
Processing induced	2.24E+00	4.00E-08	1.49E-07	2.04E-07	6.76E-04	2.05E-02	8.00E-03	8.17E-03	3.06E-02	3.35E-05	2.76E-03	6.73E+00	2.73E+01	6.25E-05	7.46E-03	1.03E-03	8.32E-04	4.68E+00	3.64E-04
Products and processing avoided	-6.03E+00	-4.82E-07	-1.12E-07	-6.17E-07	-6.37E-03	-3.66E-01	-2.80E-02	-5.02E-02	-1.03E-01	-3.32E-04	-8.51E-03	-2.53E+00	-8.93E+01	-1.21E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	5.13E-02	9.65E-10	1.36E-10	7.93E-10	1.65E-05	-5.77E-06	1.02E-04	2.49E-04	1.04E-03	1.30E-06	3.85E-04	8.72E-03	1.28E-01	5.78E-07	-2.51E+00	6.02E+00	2.21E+00	9.70E+02	2.12E+00
LUCs avoided	-6.58E-02	-1.24E-09	-1.75E-10	-1.02E-09	-2.12E-05	7.54E-06	-1.31E-04	-3.20E-04	-1.33E-03	-1.67E-06	-4.94E-04	-1.12E-02	-1.64E-01	-7.41E-07	-4.22E+00	-1.35E+01	-4.35E+00	-1.39E+03	-4.76E+00
Disposal	4.41E-04	8.25E-12	4.65E-11	2.36E-11	1.35E-07	4.22E-06	2.01E-06	2.06E-06	7.74E-06	8.61E-09	6.98E-07	2.14E-03	5.28E-03	1.40E-08	2.28E-06	0.00E+00	1.02E-07	1.46E-03	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**8.39E+00**	**-2.63E-07**	**6.44E-08**	**2.52E-06**	**-4.19E-03**	**-1.11E-01**	**-5.88E-03**	**-2.07E-02**	**-1.22E-02**	**7.87E-05**	**-8.83E-04**	**7.44E+00**	**1.16E+02**	**-9.93E-04**	**-6.72E+00**	**-7.49E+00**	**-2.13E+00**	**-4.16E+02**	**-2.64E+00**

Landfill Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.26E+01	2.28E-07	4.40E-08	5.89E-06	2.57E-03	3.04E-01	2.60E-02	3.91E-02	1.12E-01	4.80E-04	9.22E-03	6.16E+00	3.22E+02	2.06E-04	1.73E-03	0.00E+00	3.36E-03	1.82E+00	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	1.01E+01	1.78E-07	1.06E-06	1.39E-06	3.11E-03	9.08E-02	4.61E-02	4.82E-02	1.82E-01	1.97E-04	1.62E-02	4.86E+01	1.24E+02	3.20E-04	5.16E-02	0.00E+00	2.31E-03	3.29E+01	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	1.51E-02	2.84E-10	4.02E-11	2.34E-10	4.87E-06	-1.73E-06	3.00E-05	7.35E-05	3.06E-04	3.84E-07	1.13E-04	2.57E-03	3.76E-02	1.70E-07	-1.39E+00	1.77E+00	5.71E-01	1.44E+02	6.23E-01
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**3.26E+01**	**4.06E-07**	**1.10E-06**	**7.27E-06**	**5.69E-03**	**3.95E-01**	**7.21E-02**	**8.74E-02**	**2.95E-01**	**6.77E-04**	**2.55E-02**	**5.48E+01**	**4.46E+02**	**5.26E-04**	**-1.34E+00**	**1.77E+00**	**5.77E-01**	**1.79E+02**	**6.23E-01**

APPENDIX A1: BASELINE SCENARIO FOR CAMPANIA REGION

Cost Data

Stationary Recycling Plant	Unit	Total	Transport Capital Goods	Stationary Recycling Plant Capital goods	Stationary Recycling Plant Operations	Transport operation RA_C	Aggregate quarrying_RA_C subst	Aggr.tr_operation_RA_C subst	Transport operation	Transport Capital Goods	Aggr._tr_Capital Goods_RA_C subst
Budget Cost	€	8.94	0.66	1.31	0.29	1.96	-0.31	1.96	1.91	0.59	0.59
Transfers		1.8	0	0	0	0.38	0	0.38	1.03	0	0
Total cost		10.74	0.66	1.31	0.29	2.34	-0.31	2.34	2.94	0.59	0.59

Recycling Plant	Unit	Total	Transport operation	Transport Capital Goods
Budget Cost	€	1.2	1.01	0.19
Transfers		0.48	0.48	0
Total		1.68	1.49	0.19

Landfill Plant	Unit	Total	Landfill Capita Goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital Goods
Budget Cost	€	8.82	7.02	0.35	1.31	0.13
Transfers		0.35	0	0.35	0	0
Total cost		9.17	7.02	0.7	1.31	0.13

Incineration Plant	Unit	Total	INC Capital goods	Incineration Plant operations	WtE Electricity substitution	Transport operation	Transport Capital Goods	Transport - FA - Capital Goods	Transport FA	Transport BA-Capital Goods	Transport BA	INC - Bottom Ash Landfill
Budget Cost	€	0.02	0	0	0.01	0	0	0	0	0	0	0
Transfers		0	0	0	0	0	0	0	0	0	0	0
Total		0.02	0	0	0.01	0	0	0	0	0	0	0

Anaerobic Digestion Plant	Unit	Total	Transport operation	Transport Capital goods
Budget Cost	€	0.02	0.01	0
Transfers		0	0	0
Total		0.02	0.01	0

Landfill Scenario	Unit	Total	LF Capital goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital goods
Budget Cost	€	61.64	49.05	2.48	9.18	0.94
Transfers		2.5	0	2.5	0	0
Sum		64.14	49.05	4.98	9.18	0.94

Total costs	Unit	Total	Transport induced	Processing induced	Products and processing avoided
Budget Cost	€	18.98	9.35	9.93	-0.3
Transfers		2.62	2.62	0	0
Total		21.6	11.97	9.93	-0.3

APPENDIX A2: BASELINE SCENARIO FOR THE FOCUS AREA

impact categories for each plant according to processes

Incineration Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	4.8E-04	3.6E-12	8.5E-13	1.4E-10	5.4E-08	3.5E-06	5.7E-07	8.9E-07	2.5E-06	3.4E-09	2.0E-07	1.4E-04	6.4E-03	4.5E-09	-2.2E-06	0.0E+00	6.1E-08	-1.5E-05	0.0E+00
Transport avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Processing induced	6.1E-05	5.3E-12	2.6E-11	3.6E-11	1.0E-07	3.1E-06	2.7E-07	4.8E-07	8.7E-07	4.2E-09	7.7E-08	3.2E-04	8.9E-04	2.8E-08	-1.4E-06	1.8E-06	6.6E-07	9.9E-05	6.3E-07
Products and processing avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
LUCs induced	8.9E-06	1.7E-13	2.4E-14	1.4E-13	2.9E-09	-1.0E-09	1.8E-08	4.3E-08	1.8E-07	2.3E-10	6.7E-08	1.5E-06	2.2E-05	1.0E-10	-4.2E-04	1.0E-03	3.9E-04	1.7E-01	3.7E-04
LUCs avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Disposal	8.0E-05	1.5E-12	8.5E-12	4.3E-12	2.5E-08	7.7E-07	3.7E-07	3.7E-07	1.4E-06	1.6E-09	1.3E-07	3.9E-04	9.6E-04	2.6E-09	4.1E-07	0.0E+00	1.9E-08	2.6E-04	0.0E+00
Other	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sum	1.2E-02	1.0E-11	3.5E-11	1.8E-10	1.8E-07	7.4E-06	1.2E-06	1.8E-06	4.9E-06	9.4E-09	4.7E-07	8.5E-04	8.3E-03	3.5E-08	-4.2E-04	1.1E-03	3.9E-04	1.7E-01	3.7E-04

Stationary Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	9.81E+00	2.40E-07	2.69E-08	1.99E-06	1.41E-03	3.07E-01	1.17E-02	1.79E-02	4.82E-02	5.05E-04	4.07E-03	2.50E+00	1.53E+02	2.11E-04	1.87E-03	0.00E+00	3.62E-03	1.96E+00	0.00E+00
Transport avoided	-4.16E+00	-1.14E-07	-1.20E-08	-7.98E-07	-6.25E-04	-1.45E-01	-4.98E-03	-7.65E-03	-2.04E-02	-2.39E-04	-1.73E-03	-1.05E+00	-6.58E+01	-9.94E-05	-8.85E-04	0.00E+00	-1.72E-03	-9.28E-01	0.00E+00
Processing induced	7.47E-01	1.26E-08	2.16E-09	8.50E-09	2.06E-04	6.64E-03	1.45E-03	1.32E-03	4.92E-03	5.23E-06	4.71E-04	6.79E-02	8.96E+00	1.33E-05	4.94E-04	6.65E-04	3.59E-04	1.57E-01	2.34E-04
Products and processing avoided	-5.22E+00	-4.17E-07	-9.68E-08	-5.34E-07	-5.51E-03	-3.17E-01	-2.42E-02	-4.34E-02	-8.89E-02	-2.88E-04	-7.37E-03	-2.19E+00	-7.73E+01	-1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	4.23E-02	7.97E-10	1.13E-10	6.55E-10	1.36E-05	-4.85E-06	8.42E-05	2.06E-04	8.57E-04	1.08E-06	3.18E-04	7.20E-03	1.05E-01	4.77E-07	-1.99E+00	4.97E+00	1.84E+00	8.18E+02	1.75E+00
LUCs avoided	-5.70E-02	-1.07E-09	-1.51E-10	-8.81E-10	-1.84E-05	6.53E-06	-1.13E-04	-2.77E-04	-1.15E-03	-1.45E-06	-4.28E-04	-9.69E-03	-1.42E-01	-6.42E-07	-3.65E+00	-1.17E+01	-3.76E+00	-1.21E+03	-4.12E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	1.16E+00	-2.78E-07	-7.99E-08	6.68E-07	-4.52E-03	-1.48E-01	-1.61E-02	-3.20E-02	-5.65E-02	-1.66E-05	-4.67E-03	-6.71E-01	1.85E+01	-9.27E-04	-5.65E+00	-6.73E+00	-1.92E+00	-3.87E+02	-2.37E+00

Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	3.22E+00	3.83E-08	6.60E-09	8.16E-07	3.79E-04	5.05E-02	3.72E-03	5.61E-03	1.60E-02	8.06E-05	1.32E-03	8.72E-01	4.65E+01	3.43E-05	2.93E-04	0.00E+00	5.67E-04	3.07E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	-4.20E+02	-7.52E-04	-5.86E-08	-2.15E-06	-6.74E-02	-1.58E+01	-3.88E-01	-1.29E+00	-1.36E+00	-5.52E-06	-1.16E-01	7.80E-01	-3.13E+03	2.95E-08	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	-4.16E+02	-7.52E-04	-5.20E-08	-1.33E-06	-6.70E-02	-1.57E+01	-3.85E-01	-1.28E+00	-1.34E+00	7.51E-05	-1.14E-01	1.65E+00	-3.08E+03	3.43E-05	2.93E-04	0.00E+00	5.67E-04	3.07E-01	0.00E+00

Anaerobic Digestion Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.05E-01	8.52E-10	3.33E-10	5.83E-08	2.08E-05	1.25E-03	2.33E-04	3.47E-04	1.03E-03	1.81E-06	8.32E-05	5.75E-02	2.82E+00	8.24E-07	6.14E-06	0.00E+00	1.19E-05	6.44E-03	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	5.29E-03	5.62E-10	1.46E-09	2.27E-09	7.10E-06	2.11E-04	2.28E-05	3.73E-05	7.54E-05	3.05E-07	6.51E-06	1.86E-02	7.02E-02	1.68E-06	-6.28E-05	1.29E-04	5.01E-05	9.88E-03	4.56E-05
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	1.33E-04	2.54E-12	4.19E-13	2.28E-12	4.50E-08	3.82E-08	2.66E-07	6.54E-07	2.68E-06	4.01E-09	9.93E-07	2.43E-05	3.42E-04	1.60E-09	-6.22E-03	1.55E-02	5.73E-03	2.55E+00	5.46E-03
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	2.10E-01	1.42E-09	1.80E-09	6.06E-08	2.79E-05	1.46E-03	2.56E-04	3.85E-04	1.10E-03	2.12E-06	9.07E-05	7.61E-02	2.89E+00	2.50E-06	-6.28E-03	1.56E-02	5.80E-03	2.57E+00	5.50E-03

Landfill Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	5.54E+00	5.59E-08	1.08E-08	1.44E-06	6.31E-04	7.46E-02	6.38E-03	9.59E-03	2.76E-02	1.18E-04	2.26E-03	1.51E+00	7.92E+01	5.05E-05	4.25E-04	0.00E+00	8.24E-04	4.46E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	2.48E+00	4.40E-08	2.61E-07	3.43E-07	7.67E-04	2.24E-02	1.14E-02	1.19E-02	4.49E-02	4.86E-05	3.99E-03	1.20E+01	3.05E+01	7.91E-05	1.27E-02	0.00E+00	5.70E-04	8.13E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	3.73E-03	7.02E-11	9.91E-12	5.77E-11	1.20E-06	-4.27E-07	7.41E-06	1.81E-05	7.54E-05	9.47E-08	2.80E-05	6.34E-04	9.28E-03	4.20E-08	-3.43E-01	4.37E-01	1.41E-01	3.56E+01	1.54E-01
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	8.03E+00	1.00E-07	2.72E-07	1.79E-06	1.40E-03	9.70E-02	1.78E-02	2.15E-02	7.26E-02	1.67E-04	6.28E-03	1.35E+01	1.10E+02	1.30E-04	-3.30E-01	4.37E-01	1.42E-01	4.42E+01	1.54E-01

Chemical Physical Biological Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	4.87E-01	6.15E-09	9.97E-10	1.36E-07	6.12E-05	7.12E-03	5.92E-04	9.68E-04	2.55E-03	5.52E-06	2.10E-04	1.44E-01	6.65E+00	7.00E-06	-5.14E-03	0.00E+00	7.92E-05	-4.29E-02	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	4.87E-01	6.15E-09	9.97E-10	1.36E-07	6.12E-05	7.12E-03	5.92E-04	9.68E-04	2.55E-03	5.52E-06	2.10E-04	1.44E-01	6.65E+00	7.00E-06	-5.14E-03	0.00E+00	7.92E-05	-4.29E-02	0.00E+00

APPENDIX A2: BASELINE SCENARIO FOR THE FOCUS AREA

impact categories for each plant according to processes

Total Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	1.60E+01	3.03E-07	3.90E-08	3.63E-06	2.13E-03	3.90E-01	1.89E-02	2.88E-02	7.94E-02	6.30E-04	6.62E-03	4.21E+00	2.41E+02	2.69E-04	-2.84E-03	0.00E+00	4.54E-03	2.37E+00	0.00E+00
Transport avoided	-4.16E+00	-1.14E-07	-1.20E-08	-7.98E-07	-6.25E-04	-1.45E-01	-4.98E-03	-7.65E-03	-2.04E-02	-2.39E-04	-1.73E-03	-1.05E+00	-6.58E+01	-9.94E-05	-8.85E-04	0.00E+00	-1.72E-03	-9.28E-01	0.00E+00
Processing induced	3.23E+00	5.72E-08	2.64E-07	3.53E-07	9.81E-04	2.93E-02	1.29E-02	1.33E-02	4.99E-02	5.41E-05	4.47E-03	1.21E+01	3.96E+01	9.41E-05	1.32E-02	7.96E-04	9.80E-04	8.29E+00	2.80E-04
Products and processing avoided	-5.22E+00	-4.17E-07	-9.68E-08	-5.34E-07	-5.51E-03	-3.17E-01	-2.42E-02	-4.34E-02	-8.89E-02	-2.88E-04	-7.37E-03	-2.19E+00	-7.73E+01	-1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	4.62E-02	8.70E-10	1.23E-10	7.15E-10	1.49E-05	-5.24E-06	9.19E-05	2.25E-04	9.35E-04	1.17E-06	3.47E-04	7.86E-03	1.15E-01	5.21E-07	-2.34E+00	5.42E+00	1.98E+00	8.56E+02	1.91E+00
LUCs avoided	-5.70E-02	-1.07E-09	-1.51E-10	-8.81E-10	-1.84E-05	6.53E-06	-1.13E-04	-2.77E-04	-1.15E-03	-1.45E-06	-4.28E-04	-9.69E-03	-1.42E-01	-6.42E-07	-3.65E+00	-1.17E+01	-3.76E+00	-1.21E+03	-4.12E+00
Disposal	8.01E-05	1.50E-12	8.46E-12	4.28E-12	2.46E-08	7.68E-07	3.66E-07	3.74E-07	1.41E-06	1.56E-09	1.27E-07	3.88E-04	9.59E-04	2.55E-09	4.15E-07	0.00E+00	1.86E-08	2.65E-04	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**9.89E+00**	**-1.71E-07**	**1.95E-07**	**2.65E-06**	**-3.03E-03**	**-4.20E-02**	**2.51E-03**	**-9.12E-03**	**1.98E-02**	**1.58E-04**	**1.91E-03**	**1.31E+01**	**1.38E+02**	**-7.88E-04**	**-5.99E+00**	**-6.28E+00**	**-1.78E+00**	**-3.40E+02**	**-2.21E+00**

Landfill Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.26E+01	2.28E-07	4.41E-08	5.89E-06	2.57E-03	3.04E-01	2.60E-02	3.91E-02	1.13E-01	4.80E-04	9.23E-03	6.17E+00	3.23E+02	2.06E-04	1.73E-03	0.00E+00	3.36E-03	1.82E+00	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	1.01E+01	1.79E-07	1.06E-06	1.39E-06	3.11E-03	9.09E-02	4.62E-02	4.83E-02	1.82E-01	1.97E-04	1.62E-02	4.86E+01	1.24E+02	3.21E-04	5.16E-02	0.00E+00	2.31E-03	3.30E+01	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	1.51E-02	2.84E-10	4.02E-11	2.34E-10	4.87E-06	-1.73E-06	3.01E-05	7.35E-05	3.06E-04	3.84E-07	1.14E-04	2.57E-03	3.76E-02	1.70E-07	-1.39E+00	1.77E+00	5.72E-01	1.44E+02	6.24E-01
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	3.27E+01	4.07E-07	1.10E-06	7.28E-06	5.69E-03	3.95E-01	7.22E-02	8.74E-02	2.95E-01	6.78E-04	2.55E-02	5.48E+01	4.47E+02	5.27E-04	-1.34E+00	1.77E+00	5.78E-01	1.79E+02	6.24E-01

Stationary Recycling Plant	Unit	Total	Transport Capital Goods	Stationary Recycling Plant Capital goods	Stationary Recycling Plant Operations	Transport operation RA_C	Aggregate quarrying_RA_C subst	Aggr.tr_operation_RA_C subst	Transport operation	Transport - Capital Goods	Aggr._tr_Capital Goods_RA_C subst
Budget Cost	€	7.27	0.53	1.06	0.23	1.59	-0.26	1.59	1.55	0.48	0.48
Transfers		1.46	0	0	0	0.31	0	0.31	0.84	0	0
Total cost		8.73	0.53	1.06	0.23	1.9	-0.26	1.9	2.39	0.48	0.48

Recycling Plant	Unit	Total	Transport operation	Transport Capital Goods
Budget Cost	€	1	0.84	0.16
Transfers		0.4	0.4	0
Total		1.40	1.24	0.16

Landfill Plant	Unit	Total	Landfill Capita Goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital Goods
Budget Cost	€	15.2	12.1	0.61	2.26	0.23
Transfers		0.61	0	0.61	0	0
Total cost		15.81	12.1	1.22	2.26	0.23

Chemical Physical Biological Plant	Unit	Total	Chemila Physical Biological Plant Operations	Ch_Ph_B -Transport operation
Budget Cost	€	0.06	0.02	0.05
Transfers		0	0	0
Total		0.06	0.02	0.05

Total costs	Unit	Total	Transport induced	Processing induced	Products and processing avoided
Budget Cost	€	23.04	7.63	15.67	-0.26
Transfers		2.47	2.47	0	0
Sum		25.51	10.1	15.67	-0.26

Landfill Scenario	Unit	Total	LF Capital goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital goods
Budget Cost	€	61.64	49.05	2.48	9.18	0.94
Transfers		2.5	0	2.5	0	0
Sum		64.14	49.05	4.98	9.18	0.94

APPENDIX A3: RHODIATOCE SCENARIO
impact categories for each plant according to processes

Incineration Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	4.8E-04	3.6E-12	8.5E-13	1.4E-10	5.4E-08	3.5E-06	5.7E-07	8.9E-07	2.5E-06	3.4E-09	2.0E-07	1.4E-04	6.4E-03	4.5E-09	-2.2E-06	0.0E+00	6.1E-08	-1.5E-05	0.0E+00
Transport avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Processing induced	6.1E-05	5.3E-12	2.6E-11	3.6E-11	1.0E-07	3.1E-06	2.7E-07	4.8E-07	8.7E-07	4.2E-09	7.7E-08	3.2E-04	8.9E-04	2.8E-08	-1.4E-06	1.8E-06	6.6E-07	9.9E-05	6.3E-07
Products and processing avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
LUCs induced	8.9E-06	1.7E-13	2.4E-14	1.4E-13	2.9E-09	-1.0E-09	1.8E-08	4.3E-08	1.8E-07	2.3E-10	6.7E-08	1.5E-06	2.2E-05	1.0E-10	-4.2E-04	1.0E-03	3.9E-04	1.7E-01	3.7E-04
LUCs avoided	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Disposal	8.0E-05	1.5E-12	8.5E-12	4.3E-12	2.5E-08	7.7E-07	3.7E-07	3.7E-07	1.4E-06	1.6E-09	1.3E-07	3.9E-04	9.6E-04	2.6E-09	4.1E-07	0.0E+00	1.9E-08	2.6E-04	0.0E+00
Other	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
Sum	1.2E-02	1.0E-11	3.5E-11	1.8E-10	1.8E-07	7.4E-06	1.2E-06	1.8E-06	4.9E-06	9.4E-09	4.7E-07	8.5E-04	8.3E-03	3.5E-08	-4.2E-04	1.1E-03	3.9E-04	1.7E-01	3.7E-04

Stationary Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	9.81E+00	2.40E-07	2.69E-08	1.99E-06	1.41E-03	3.07E-01	1.17E-02	1.79E-02	4.82E-02	5.05E-04	4.07E-03	2.50E+00	1.53E+02	2.11E-04	1.87E-03	0.00E+00	3.62E-03	1.96E+00	0.00E+00
Transport avoided	-4.16E+00	-1.14E-07	-1.20E-08	-7.98E-07	-6.25E-04	-1.45E-01	-4.98E-03	-7.65E-03	-2.04E-02	-2.39E-04	-1.73E-03	-1.05E+00	-6.58E+01	-9.94E-05	-8.85E-04	0.00E+00	-1.72E-03	-9.28E-01	0.00E+00
Processing induced	7.47E-01	1.26E-08	2.16E-09	8.50E-09	2.06E-04	6.64E-03	1.45E-03	1.32E-03	4.92E-03	5.23E-06	4.71E-04	6.79E-02	8.96E+00	1.33E-05	4.94E-04	6.65E-04	3.59E-04	1.57E-01	2.34E-04
Products and processing avoided	-5.22E+00	-4.17E-07	-9.68E-08	-5.34E-07	-5.51E-03	-3.17E-01	-2.42E-02	-4.34E-02	-8.89E-02	-2.88E-04	-7.37E-03	-2.19E+00	-7.73E+01	-1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	4.23E-02	7.97E-10	1.13E-10	6.55E-10	1.36E-05	-4.85E-06	8.42E-05	2.06E-04	8.57E-04	1.08E-06	3.18E-04	7.20E-03	1.05E-01	4.77E-07	-1.99E+00	4.97E+00	1.84E+00	8.18E+02	1.75E+00
LUCs avoided	-5.70E-02	-1.07E-09	-1.51E-10	-8.81E-10	-1.84E-05	6.53E-06	-1.13E-04	-2.77E-04	-1.15E-03	-1.45E-06	-4.28E-04	-9.69E-03	-1.42E-01	-6.42E-07	-3.65E+00	-1.17E+01	-3.76E+00	-1.21E+03	-4.12E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	1.16E+00	-2.78E-07	-7.99E-08	6.68E-07	-4.52E-03	-1.48E-01	-1.61E-02	-3.20E-02	-5.65E-02	-1.66E-05	-4.67E-03	-6.71E-01	1.85E+01	-9.27E-04	-5.65E+00	-6.73E+00	-1.92E+00	-3.87E+02	-2.37E+00

Recycling Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.74E+00	3.25E-08	5.61E-09	6.94E-07	3.22E-04	4.29E-02	3.16E-03	4.76E-03	1.36E-02	6.85E-05	1.12E-03	7.41E-01	3.95E+01	2.91E-05	2.49E-04	0.00E+00	4.82E-04	2.61E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	-3.24E+02	-7.66E-08	-1.02E-08	1.30E-06	-2.75E-02	-9.76E-02	-3.20E-01	-6.31E-01	-1.23E+00	-6.12E-07	-1.05E-01	4.85E+00	-2.20E+03	-9.28E-11	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	-3.21E+02	-4.41E-08	-4.59E-09	2.00E-06	-2.72E-02	-5.47E-02	-3.16E-01	-6.26E-01	-1.22E+00	6.79E-05	-1.04E-01	5.59E+00	-2.16E+03	2.91E-05	2.49E-04	0.00E+00	4.82E-04	2.61E-01	0.00E+00

Anaerobic Digestion Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00

Landfill Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.51E+00	5.25E-08	6.38E-09	5.45E-07	3.43E-04	6.74E-02	2.96E-03	4.51E-03	1.24E-02	1.10E-04	1.04E-03	6.50E-01	3.82E+01	4.62E-05	4.07E-04	0.00E+00	7.89E-04	4.27E-01	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	2.37E+00	4.21E-08	2.50E-07	3.28E-07	7.34E-04	2.14E-02	1.09E-02	1.14E-02	4.30E-02	4.65E-05	3.82E-03	1.15E+01	2.92E+01	7.57E-05	1.22E-02	0.00E+00	5.46E-04	7.78E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	3.57E-03	6.71E-11	9.48E-12	5.52E-11	1.15E-06	-4.09E-07	7.09E-06	1.74E-05	7.22E-05	9.06E-08	2.68E-05	6.07E-04	8.88E-03	4.02E-08	-3.29E-01	4.19E-01	1.35E-01	3.41E+01	1.47E-01
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	4.88E+00	9.47E-08	2.56E-07	8.73E-07	1.08E-03	8.89E-02	1.39E-02	1.59E-02	5.54E-02	1.57E-04	4.88E-03	1.21E+01	6.74E+01	1.22E-04	-3.16E-01	4.19E-01	1.36E-01	4.23E+01	1.47E-01

Chemical Physical Biological Plant	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	4.94E-01	6.16E-09	1.01E-09	1.38E-07	6.18E-05	7.13E-03	6.00E-04	9.79E-04	2.59E-03	5.52E-06	2.12E-04	1.46E-01	6.74E+00	7.01E-06	-5.14E-03	0.00E+00	7.92E-05	-4.29E-02	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	4.94E-01	6.16E-09	1.01E-09	1.38E-07	6.18E-05	7.13E-03	6.00E-04	9.79E-04	2.59E-03	5.52E-06	2.12E-04	1.46E-01	6.74E+00	7.01E-06	-5.14E-03	0.00E+00	7.92E-05	-4.29E-02	0.00E+00

Total Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	1.28E+01	2.99E-07	3.43E-08	2.68E-06	1.82E-03	3.82E-01	1.52E-02	2.33E-02	6.31E-02	6.21E-04	5.32E-03	3.30E+00	1.97E+02	2.64E-04	-2.87E-03	0.00E+00	4.49E-03	2.34E+00	0.00E+00
Transport avoided	-4.16E+00	-1.14E-07	-1.20E-08	-7.98E-07	-6.25E-04	-1.45E-01	-4.98E-03	-7.65E-03	-2.04E-02	-2.39E-04	-1.73E-03	-1.05E+00	-6.58E+01	-9.94E-05	-8.85E-04	0.00E+00	-1.72E-03	-9.28E-01	0.00E+00
Processing induced	3.12E+00	5.48E-08	2.52E-07	3.36E-07	9.41E-04	2.81E-02	1.23E-02	1.27E-02	4.79E-02	5.17E-05	4.29E-03	1.15E+01	3.82E+01	8.90E-05	1.27E-02	6.67E-04	9.05E-04	7.93E+00	2.35E-04
Products and processing avoided	-5.22E+00	-4.17E-07	-9.68E-08	-5.34E-07	-5.51E-03	-3.17E-01	-2.42E-02	-4.34E-02	-8.89E-02	-2.88E-04	-7.37E-03	-2.19E+00	-7.73E+01	-1.05E-03	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	4.59E-02	8.64E-10	1.22E-10	7.10E-10	1.48E-05	-5.26E-06	9.13E-05	2.23E-04	9.29E-04	1.17E-06	3.45E-04	7.81E-03	1.14E-01	5.17E-07	-2.32E+00	5.39E+00	1.97E+00	8.52E+02	1.90E+00
LUCs avoided	-5.70E-02	-1.07E-09	-1.51E-10	-8.81E-10	-1.84E-05	6.53E-06	-1.13E-04	-2.77E-04	-1.15E-03	-1.45E-06	-4.28E-04	-9.69E-03	-1.42E-01	-6.42E-07	-3.65E+00	-1.17E+01	-3.76E+00	-1.21E+03	-4.12E+00
Disposal	8.01E-05	1.50E-12	8.46E-12	4.28E-12	2.46E-08	7.68E-07	3.66E-07	3.74E-07	1.41E-06	1.56E-09	1.27E-07	3.88E-04	9.59E-04	2.55E-09	4.15E-07	0.00E+00	1.86E-08	2.65E-04	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	**6.55E+00**	**-1.78E-07**	**1.77E-07**	**1.68E-06**	**-3.38E-03**	**-5.16E-02**	**-1.65E-03**	**-1.51E-02**	**1.54E-03**	**1.46E-04**	**4.20E-04**	**1.16E+01**	**9.26E+01**	**-7.98E-04**	**-5.97E+00**	**-6.31E+00**	**-1.79E+00**	**-3.44E+02**	**-2.22E+00**

Landfill Scenario	CC	OD	HT_CE	HT_nCE	PM	IR	POF	TA	ET	EF	EM	Efr	DAR_F	DAR_E	LU_E99	EF_LO	EDP_LO_LU	SOM	IMPACT 2002_LO
Transport induced	2.11E+01	2.13E-07	4.13E-08	5.51E-06	2.41E-03	2.85E-01	2.44E-02	3.66E-02	1.05E-01	4.50E-04	8.64E-03	5.78E+00	3.02E+02	1.93E-04	1.62E-03	0.00E+00	3.15E-03	1.70E+00	0.00E+00
Transport avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Processing induced	9.42E+00	1.67E-07	9.90E-07	1.30E-06	2.91E-03	8.51E-02	4.32E-02	4.52E-02	1.71E-01	1.84E-04	1.51E-02	4.55E+01	1.16E+02	3.00E-04	4.83E-02	0.00E+00	2.16E-03	3.08E+01	0.00E+00
Products and processing avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
LUCs induced	1.42E-02	2.66E-10	3.76E-11	2.19E-10	4.56E-06	-1.62E-06	2.81E-05	6.88E-05	2.86E-04	3.59E-07	1.06E-04	2.41E-03	3.52E-02	1.59E-07	-1.30E+00	1.66E+00	5.35E-01	1.35E+02	5.84E-01
LUCs avoided	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Disposal	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Other	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Sum	3.06E+01	3.81E-07	1.03E-06	6.82E-06	5.33E-03	3.70E-01	6.76E-02	8.18E-02	2.76E-01	6.34E-04	2.39E-02	5.13E+01	4.18E+02	4.93E-04	-1.25E+00	1.66E+00	5.41E-01	1.68E+02	5.84E-01

Stationary Recycling Plant	Unit	Total	Transport Capital Goods	Stationary Recycling Plant Capital goods	Stationary Recycling Plant Operations	Transport operation RA_C	Aggregate quarrying_RA_C subst	Aggr.tr_operation_RA_C subst	Transport operation	Transport Capital Goods	Aggr._tr_Capital Goods_RA_C subst
Budget Cost	€	7.27	0.53	1.06	0.23	1.59	-0.26	1.59	1.55	0.48	0.48
Transfers		1.46	0	0	0	0.31	0	0.31	0.84	0	0
Total cost		8.73	0.53	1.06	0.23	1.9	-0.26	1.9	2.39	0.48	0.48

Recycling Plant	Unit	Total	Transport operation	Transport Capital Goods
Budget Cost	€	1	0.84	0.16
Transfers		0.4	0.4	0
Total		1.40	1.24	0.16

Landfill Plant	Unit	Total	Landfill Capita Goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital Goods
Budget Cost	€	15.2	12.1	0.61	2.26	0.23
Transfers		0.61	0	0.61	0	0
Total cost		15.81	12.1	1.22	2.26	0.23

Chemical Physical Biological Plant	Unit	Total	Chemila Physical Biological Plant Operations	Ch_Ph_B -Transport operation
Budget Cost	€	0.06	0.02	0.05
Transfers		0	0	0
Total		0.06	0.02	0.05

Total costs	Unit	Total	Transport induced	Processing induced	Products and processing avoided
Budget Cost	€	23.04	7.63	15.67	-0.26
Transfers		2.47	2.47	0	0
Sum		25.51	10.1	15.67	-0.26

Landfill Scenario	Unit	Total	LF Capital goods	Transport operation	Bottom Ash Landfill Operations	Transport Capital goods
Budget Cost	€	61.64	49.05	2.48	9.18	0.94
Transfers		2.5	0	2.5	0	0
Sum		64.14	49.05	4.98	9.18	0.94

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