H2020 MSCA-ITN-2018

ReTraCE Project

Realising the **Tra**nsition towards the **C**ircular **E**conomy

D2.3

Environmental, economic, and social implications of Circular Economy implementation at the *meso* and *macro* level: a selection of case studies

This project has received funding from the European Union's Horizon 2020 research and innovation programme under the Marie Sklodowska-Curie Innovative Training Network (H2020-MSCA-ITN-2018) scheme, grant agreement number 814247 (ReTraCE).

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Acronyms

C&DW – Construction and Demolition Waste

CCP - Climate change potential

CE – Circular Economy

EMA – EMergy Accounting

EU – European Union

EU28 – Pre-Brexit composition of the European Union, consisting of 28 countries: Belgium, Bulgaria, Czech Republic, Denmark, Germany, Estonia, Ireland, Greece, Spain, France, Croatia, Italy, Cyprus, Latvia, Lithuania, Luxembourg, Hungary, Malta, The Netherlands, Austria, Poland, Portugal, Romania, Slovenia, Slovakia, Finland, Sweden, and the United Kingdom.

FEP - Freshwater eutrophication potential

FETP - Freshwater ecotoxicity potential

FRSP - Fossil resource scarcity potential

GDA – Green Deal Agreement

GDP – Gross domestic product

HCTP - Human carcinogenic toxicity potential

HNCTP - Human non-carcinogenic toxicity potential

IRP - Ionising radiation potential

LCA – Life Cycle Assessment

LUP - Land use potential

MEP - Marine eutrophication potential

METP - Marine ecotoxicity potential

MRSP - Mineral resource scarcity potential

OFEP - Ozone formation, Terrestrial ecosystems potential

OFHP - Ozone formation, Human health potential

PMFP - Fine particulate matter formation potential

SODP - Stratospheric ozone depletion potential

SWOT - Strengths, Weaknesses, Opportunities, and Threats

TAP - Terrestrial acidification potential

TETP - Terrestrial ecotoxicity potential

WCP - Water consumption potential

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Executive Summary

The specific goal of the ReTraCE project is the training of a new generation of experts in different aspects related to Circular Economy (CE), across a wide range of methodological, economic, environmental, technological issues. For this to happen, these issues need to be applied to different scales, being aware of the different problems associated to size as well as spatial and time scales.

Not all methods are designed to operate at all scales as well as to answer to all kinds of questions. Further, investigating different scales can only provide information and answers that are scale–specific. Therefore, while the micro–scale allows to understand costs and benefits that are strictly related to a given process (e.g. CO_2-eq emissions associated to producing a cell phone, a vehicle, a bottle of wine), investigating the meso (e.g. agriculture, livestock farming, transportation) and macro (e.g. regional or country specific economies or international trade) scales may more likely provide information and advices about investments, policy making, regulations and consequences of CE implementation.

Deliverable D2.2 focused on micro scale case studies; the present D2.3 expands the picture towards informed planning, regulation and policy making, in order to prevent the risk of misunderstanding CE as just a more efficient waste management process. CE helps design a broader picture for appropriate use of resources, cleaner production and consumption, decreased waste generation, increased well–being and more environmentally aware lifestyles. *Meso* and *macro*-CE studies focus on a different societal development, on a different understanding of and respect for environmental services and natural capital, and finally on the implementation of decision–making procedures as participatory processes involving all citizens and stakeholders. Just as an example, expanding a micro scale case study (for which positive results may have been identified) to the larger scale of the region, country or planet (through meso and macro scale studies) may immediately point out that some solutions – although technologically feasible – may not be viable and require a different approach to the problem.

In particular, the present Deliverable summarises the following achievements, challenges and policy solutions:

- Single method studies tend to focus on only one sustainability dimension, while literature reviews and integrated assessments better capture all dimensions of sustainability.
- Micro and meso level assessment methods, such as LCA, support and strengthen macro level methods, such as EMA, when properly combined. Integration of methods across scales should be favoured, in order to develop an appropriate set of tools to understand the existing complexity and face resource demand.

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- Compared with micro case studies, sectoral (agriculture, manufacturing, transportation, etc.) and more global (regional, national, transnational) levels better capture the needed policy actions, their socio-economic and environmental consequences, the challenges to be faced, the relation with lifestyles and well–being.
- Policy-oriented analyses highlight the importance of aligning all stakeholders, including researchers and policymakers.

The implementation of CE practices and policies is strongly influenced by the local context; assessments are hard to generalise. However, some of the case studies described in the present D2.3 provide a reliable basis to go beyond the specificity of local cases and promote effective large–scale CE strategies towards:

- Deepening and understanding policy options;
- Exploring aspects of non-renewable resource use, responsibility for impacts, fairness in trade;
- Expanding the evaluation to all aspects of urban life;
- Assessing the large variability of waste, food waste, agricultural residues, and wastewater recovery.

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Preamble

This deliverable summarises the research - focused on assessing the potential, the viability, the advantages, and the challenges of a transition to the circular economy at the *meso* and *macro* levels - that has been conducted as part of Work Package 2 of the ReTraCE project. A similar overview of the studies performed at the *micro*-level can be found in Deliverable 2.2.

An overview of the studies (submitted, published, or in-press) that have been included in D2.3 is presented in Table 1. The overview is divided in different Sections (Policies and Economic Evaluations; Non–Renewable Resources; Urban Systems; Bio–Based Processes). These Sections do not claim to be complete or exhaustive of all the aspects involved in Circular Economy (CE).

The papers listed in the four sections provide a spectrum of the diversity of the problems to be faced, the involved scales to be considered and the tools to be applied in CE planning and policy–making.

Just as an example, the column "Evaluation Method(s) Applied" illustrates the variety of involved approaches (spanning from traditional environmental assessment methods to SWOT analyses and scenario simulations). A similar variety can be retrieved in the columns concerned with sustainability frameworks and economic sectors.

Table 1 – Studies considered in this deliverable.

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Sustainability Perspectives	*Region/Country*	*Sector*	*Evaluation Method(s) Applied*	*Reference*
Policies and Economic Evaluations				
Environmental, Social and Economic	International - EU and National - Italy	Multiple	Literature Review and Case Study	Ghisellini et al. (2021)
Environmental, Social and Economic	Regional - Campania, Italy	Government and Academics	Literature Review and Survey	Van Langen et al. (2021)
Environmental, Social and Economic	National - Netherlands	Multiple	Qualitative Policy Analysis	Van Langen and Passaro (2021)
Non-Renewable Resources				
Environmental and Economic	National - China	Iron and Steel	LCA	Liu et al. (2020)
Environmental and Economic	National - China	Steel	EMA	Liu et al. (2021)
Urban Systems				
Environmental, Social and Economic	Regional – Metropolitan City of Napoli, Italy	Urban Green Areas	LCA and i-Tree Canopy	Santagata et al. (2021a)
Environmental and Social	Regional – Metropolitan City of Napoli, Italy	Water and energy consumption	Literature Review and Simulation	Casazza et al. (2020)
Environmental and social	Regional – Metropolitan City of Napoli, Italy	Construction and demolition	Literature Review and i-Tree Canopy + SWOT Analyses	Cristiano et al. (2021)
Economic	Regional - Sheffield, UK	Household waste	Case Study	Zaharudin et al. (2021)
Bio-based Processes				
Environmental and Economic	International – Africa and China	Agriculture and Biogas	Literature Review	Tiegam et al. (2021)
Environmental, economic and social	International – EU28	Food waste recovery	LCA and EMA	Santagata et al. (2021b)
Environmental	Regional - Campania, Italy	Agroindustry - Milk Production	EMA	Oliveira et al. (2021b)
Environmental and economic	Regional - Campania, Italy	Wastewater Treatments	Literature review	Colella et al. (2021)

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1. Introduction

CE, in contrast to the current linear economy, is seen as a paradigm able to foster sustainable development by ensuring economic, social, and environmental benefits (Ellen MacArthur Foundation, 2012; Webster, 2017). It has been adopted throughout the EU at all levels over the last decade (European Commission, 2020, 2015). There are, however, concerns that implementing CE may lead to rebound effects that might lead to higher resource consumption and, as a consequence, damage the environment even more (Zink and Geyer, 2017). Many implementation patterns follow an economically focused eco-modernism, namely the idea that Nature should be "protected" by means of further human (technological) intervention and regulation, an approach to CE that might not deliver decreased reliance on virgin resource consumption (Genovese and Pansera, 2020). If CE ought to bring environmental and social benefits, besides economic ones, it is crucial to assess potential practices to be implemented in a careful way. The three dimensions of sustainability (environmental, economic, and social) coupled with the most often mentioned pillars of Circular Economy (regenerative planning, renewable resource use, reusing and recycling, CE governance) should be evaluated through appropriate methods within an integrated framework, as exemplified in Figure 1 (Oliveira et al., 2021a). Figure 1 shows several accounting methods that should be implemented across time and spatial scales to address a multiplicity of questions and problems. As described in the previous Deliverable D2.1 and by Oliveira et al. (2021a), for this to happen, methods need to be selected according to the scale as well as integrated in order to complement to each other when needed. In the present deliverable, a number of studies are summarized in which some methods are used according to the scheme of Figure 1, along with some additional ones (for example, i–Tree Canopy Modelling and SWOT) required by the complexity of the selected real-world problems.

Furthermore, the present work highlights not only a problem of interaction among methods but also issues deriving from the need to integrate evaluations happening across different dimensions and scales. Case-studies discussed in D2.2 have provided an ideal micro-foundation which is at the basis of the expansion of scales which will be presented here. Based on the micro-level analysis conducted in previous work, the interaction among local processes and larger production sectors (e.g., diversity of local wine farms contributing to the national winery sector, co-products valorisation, waste management and trade, and vice versa) is better understood.

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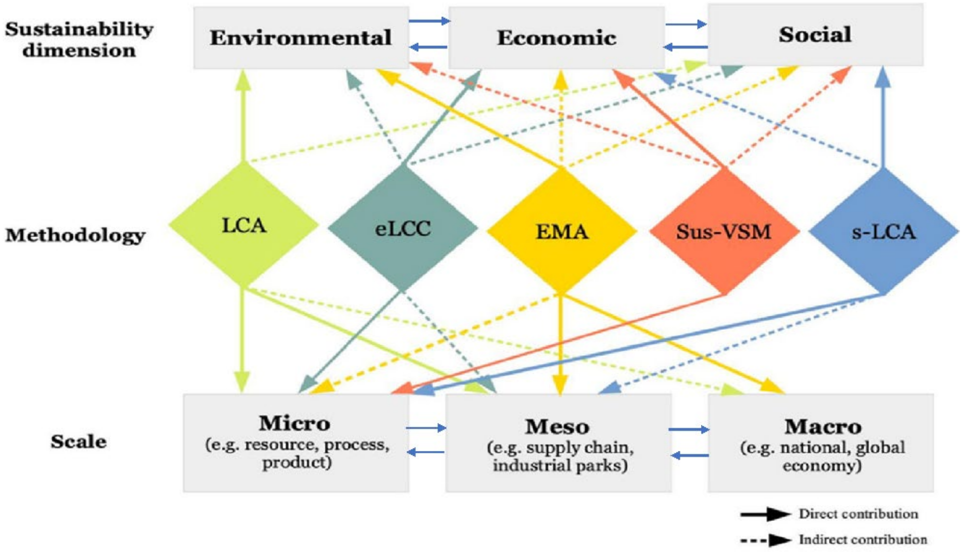

Figure 1 – Integrated assessment framework after Oliveira et al. (2021a).

With this in mind, under the ReTraCE project several studies have been conducted, focusing on the *meso* and *macro* levels. Summarising them in this deliverable helps clarify how meso- and macro- levels can be investigated by means of the selected approaches indicated in Figure 1 above and in D2.1. The studies have been grouped according to four overarching themes (Table 1):

- Policy and economic evaluations;
- Non-renewable resources;
- Urban systems;
- Bio–resources.

The four groups of studies do not claim to be exhaustive of the topics and interests at stake. They only identify some of the aspects involved in CE design and development (policy-making, renewable and non-renewable resources, urban systems as main resource recipients) in order to see how the interplay of dimensions, methods, and scales designed in Figure 1 applies and works. A deep and clear understanding of the mutual interplay of dimensions, accounting methods, and scales, may help CE implementation and policy-making and prevent planning mistakes, rebound effects, illusory growth patterns.

The aim is to identify, through the synthesis of these studies, relevant lessons for researchers, policy-makers, and other stakeholders that rely on meso and/or macro level analyses. More specifically, we aim to identify how well the integration of assessment methods can capture the sustainability dimensions at the *meso* and *macro* levels, that are expected to contribute to well–being and environmental integrity.

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1.1 Methods

In the four groups of case studies from Table 1, the subjects, the methods and the results that characterize each case are summarised. Oliveira et al. (2021a) and the previous Deliverable D.2.1 (Coleman et al., 2020) have already described and discussed the main accounting methods needed to properly measure the transition towards the CE, so that the interested reader can find in the above documents an exhaustive description of all methodological procedures used in the present Deliverable. However, CE transition also involves several groups of stakeholders (citizens, environmental organizations, policy-makers, businesses, and researchers, among others) as well as several typologies of sustainability dimensions (Figure 1), so that a multifaceted approach is required. Stakeholders interested in applying methods and roadmaps towards sustainable production and consumption will need to understand the merits and the limits of each approach, not to run the risk to expect all the desired results (environmental impacts, resource demand, renewability, time scale, boundaries, economic cost-benefits assessment, etc.) from one approach only and be therefore disappointed in case of insufficient information.

Each evaluation method can address specific scales (*micro*, *meso* and *macro* levels) and sustainable dimensions due to the specific objectives for which it was designed (Oliveira et al., 2021a). Only the simultaneous or sequential use of them, to measure, monitor and manage, avoids reductionist approaches and provides a more comprehensive understanding of the transition in so supporting decision-making tasks (Ghisellini et al., 2016; Santagata et al., 2020). Moreover, while evaluating *meso* and *macro* levels, the impact of reductionist (single) approaches should not be disregarded – only integrated assessments holistically evaluate synergies intrinsic to human and environmental matters (Keller, 2019).

Among all methods cited in deliverable D2.1, those more appropriate for the specific goals of the studies, sectors, and perspectives have been selected in D2.2 and D2.3. The criteria upon which these methods were employed are discussed in Section 3.

As a consequence, in this deliverable D2.3 studies are shown that integrate the following methods:

- EMA and LCA, mostly used to evaluate the *meso* and *macro* levels of diverse sectors and regions/countries (Liu et al., 2021, 2020; Oliveira et al., 2021b; Santagata et al., 2021b, 2021a).
- i-Tree Canopy, a georeferenced based system supported data collection, integrated to cost-benefit economic analysis and LCA to estimate land cover by buildings and urban forest as

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well as the related environmental impacts and functions (Cristiano et al., 2021; Santagata et al., 2021a).

- SWOT, an evaluation method based on expert evaluation about four categories of positive and negative factors (Strengths, Weaknesses, Opportunities, and Threats) integrated to i–Tree Canopy, LCA, and literature review (Cristiano et al., 2021).
- Literature reviews were used to describe the state of the art of the investigated case studies and as starting points to build scenarios for further CE development, policies, and collaborative work. (Casazza et al., 2020; Colella et al., 2021; Cristiano et al., 2021; Ghisellini et al., 2021; Tiegam et al., 2021).

2. Case studies

As mentioned above, this deliverable puts together different aspects of the research performed about circular economy at meso and macro scales. The summarized case studies are listed in Table 1 and, of course, cannot be considered an exhaustive list of all the possible CE-related topics.

There are however some main features we would like to point out here, before starting the summary of achieved (or pursued) results:

i) The complexity of Circular Economy policies and case studies. Getting out of a linear business model means being able to address several environmental, economic, technological, social challenges, which are not easy and not necessarily easily accepted by stakeholders, businesses and policy–makers.

ii) The interlinkage among different cases and situations (urban and rural environment, resource management including waste, transportation from production to use sites, human health, job issues, among others), which affect each other and are not easily managed together.

iii) The need for appropriate planning of micro (specific local case studies), meso (e.g. locally integrated systems, production sectors) and finally macro cases (e.g. regional, national and transnational economies) in order to ensure support from lower to higher levels and vice versa.

iv) The unavoidable evolution of each investigated situation, due to technological progress and social dynamics. Nothing is forever.

v) The risk for greenwashing attitudes and/or rebound effects capable to partially or completely cancel the expected results.

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As a consequence, national, EU or UN policies always need monitoring, testing, regulating, and discussing actions, in order to ensure the comparison of expected and achieved results, a clear calculation of costs and benefits as well as a clear awareness of societal justice (who pays the costs and who gets the benefits).

2.1 Policies and economic evaluations

Most studies concerning CE options, processes, proposals, sooner or later end up with requesting or foreseeing "appropriate policy-making" initiatives. Therefore, going deeper in the meaning of CE policy aspects is a crucial task that cannot be ignored. In the policies and economic evaluations, several methods are suitable for further consideration within the domain of social sciences. In particular, we present in this Section 2.1 three contributions developed during the first period of the ReTraCE project. The first contribution reviewed the Keynesian economics, in the light of the EU Green Deal (European Commission, 2019a, b) and the Global Green New Deal (UNEP, 2009) proposals, as a Keynesian expansionary policy and its potential to promote circular economy. A case study of how this type of economic proposal is being implemented in Italy is proposed by Ghisellini et al. (2021). A second contribution is a survey performed amongst CE scholars, economists, and CE policymakers in Italy's Campania region to explore if and to what extent they have divergent views on the CE meaning, transition process, and its governance (drivers, barriers, role of CE policies), integrated by a comprehensive literature review on how different stakeholders view CE meaning and perspectives (Van Langen et al., 2021). A third study focuses specifically on the adoption of Dutch policy instruments aimed at promoting the transition to a greener society. The study highlights that the pioneering policy instruments adopted in the Netherlands under the label of Dutch Green Deal are considered positively, as they constitute a lever to strengthen the national innovation system. The study is carried out by reviewing the related public documentation (Van Langen and Passaro, 2021).

2.1.1 Revisiting Keynes in the light of the transition to circular economy

Ghisellini et al. (2021) analyse the ideas of Keynes and how they fit in the transition to the CE. They specifically look at how state intervention, supplemented by changes in the behaviour of consumers, firms, and institutions can create a virtuous cycle of welfare development. This would require governments to support the deconstruction of the neoliberal establishment in economy and society that came to dominate the developed countries since the 1980s, as consumers and firms on their own cannot afford to bring this change. Green New Deal plans adopted currently worldwide (USA, China, India, South Korea, Brazil, Chile) (UNEP, 2009; Barbier, 2019; IRENA, 2019) as well as in Italy and

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European Union within the European Green Deal (European Commission 2019a, b; European Commission, 2020a) are evaluated to bring this new Keynesian expansionary policy that would replace the current neoliberal model. In particular, in EU, CE is one of the main building blocks of the Green Deal contributing to trigger the transition to a cleaner and more competitive Europe and the achievement of the EU's 2050 climate neutrality targets (European Commission, 2020a).

Within the green economy transition, the European Union has supported several projects over the years that can be framed with the so-called current "European Green Deal" (European Commission, 2019a, b). Table 1 lists some of these projects. Further, the European Commission recently (January 2020) presented to the EU Parliament a proposal of 1,000 billion Euro investment plan over the next 10 years, in order to make EU the first green continent worldwide (European Commission, 2020a). This promotes a Keynesian–oriented expansionary policy not only aiming at increased employment opportunities but also and overall at a CE-oriented environmental integrity and resource regeneration. To better understand how the Keynesian framework can be redesigned towards environmental goals and a CE perspective, a case study of Italy is used to clarify to what extent Italy applies a Keynesian Green New Deal to promote the development of renewable energies, urban regeneration, the protection of biodiversity and seas, and to fight climate change.

An overview of a potential Italian Green New Deal oriented towards urban regeneration (UR) is provided in Figure 2, where the above-mentioned Green New Deal building blocks are detailed by listing the investments provided to Urban Regeneration initiatives. It appears that a revised Keynesian paradigm can be implemented by redesigning the current role of public institutions (as well as responsible stakeholders) towards well–being and environmental integrity. The European Green New Deal as well as national similar initiatives can be evaluated as a kind of Keynesian expansionary policy capable to go beyond unconstrained neoliberalism paradigm and accepting the environmental limits.

Table1 - EU funded projects in the sectors of the European Green Deal (Ghisellini et al 2021 based on data by European Commission, 2020b)

Goal of the project	**Activities**	**Country/s**	**Policy funding**
Creation of new economic opportunities in former mining towns	Transformation of a former coal mine into a cultural area including a museum, a congress centre and a new concert hall; creation of opportunities in construction, tourism, cultural and food services sector.	Poland	Cohesion policy funding

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Helping citizens and businesses to cut CO_2 emissions and reduce energy bills	installation of solar panels on private homes; renovation of multi-apartment buildings; energy efficiency investments in industrial companies.	Lithuania	European Investment Bank guaranteed by the European Fund for Strategic Investments
Investments in new environmentally friendly technologies	Substitution of harmful refrigerants in commercial refrigerators to reduce GHGs, increase energy efficiency and reduce costs.	Italy, Spain and Romania	EU's LIFE programme
Reskilling of workers from coal industry regions	Provision of training in welding; Teaching to handle machines such as fork-lift trucks; Help workers to obtain a driving license for small trucks and lorries.	Czechia (Czech Public Employment Service in Nord-Moravia)	European Social Fund
Reduction of car emissions	Reduction of the weight of vehicles on the road by replacing heavier car manufacturing materials with lighter and renewable components.	Poland and Italy	EU's LIFE programme
Support to social housing	Building 524 affordable and energy-efficient social housing units	Spain	European Investment Bank guaranteed by the European Fund for Strategic Investments

In some ways, Keynes' claims about the need for Governmental intervention to support welfare would translate into a "dig hole and plant trees" statement instead of just "filling holes again".

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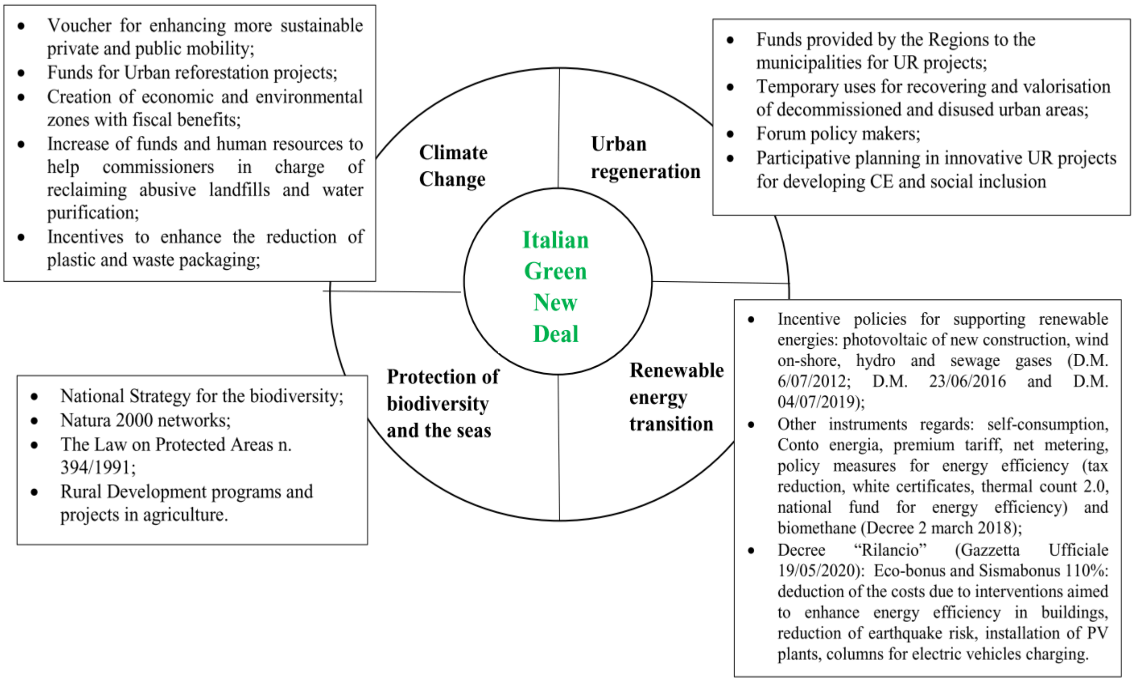

Figure 2 – Overview of Italian Green New Deal by Ghisellini et al. (2021).

2.1.2 Beyond the Circular Economy: exploring the consequences of expected and unexpected scenarios

The study from Van Langen et al. (2021) consists of two parts. First, there is a literature review section on how different stakeholders perceive CE. Second, there is a survey-based research section to learn more of the understanding several specific stakeholders have. More specifically, CE researchers, economists, and policymakers in Italy's Campania region were surveyed, with the used questions shown in Table 2. Though the three groups are mostly overlapping in their understanding of CE, they do see some different barriers and drivers for a transition to the CE. While the group of researchers understands the transition to come from a more holistic top-down approach, the economists and policymakers envision a mostly bottom-up approach that has a heavy focus on recycling. The paper concludes by stating these differences between CE researchers on the one side and economists and policymakers on the other side should be bridged.

Table 2 – Overview of questions used in survey, adapted from Van Langen et al. (2021)

SECTION	QUESTION

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A – DEMOGRAPHY	Questions to understand the background of respondents.
B – CE AWARENESS	What does Sustainable Development mean, for you?
	What does Circular Economy mean, for you?
	Which aspect/s is/are more important in Circular Economy?
	Which are the more important expectations from Circular Economy?
	How far are we from Circular Economy implementation, in your opinion?
C – DRIVERS AND BARRIERS	What are possible obstacles from engaging in Circular Economy?
	What do you think have to change in the circular economy process?
	If the transition from a linear economy to Circular economy is to become a success, who should be, in your opinion, responsible in taking the initiatives forward?
	What policy instruments do you think would be necessary for the drive towards Circular Economy?

While this paper does not contain an assessment of a CE implementation in itself, it does provide a good job of showing the differing expectations between CE researchers, economists, and policy-makers. Policy-makers are mostly interested in economic growth and look at more classical indicators such as GDP or job creation, whereas CE researchers are more interested in a holistic approach and show less preference for a specific dimension of sustainability. Economists are somewhat in the middle, but still mostly focused on economic interests. There does seem to be a clear consensus that policy-makers will be one of the main driving forces for the transition to the CE. For that reason, CE research must consider the economic aspects of any CE implementation. Policy-makers, however, have to start considering a wider range of indicators if they want to create a sustainable transition and not fall for a rebound effect.

2.1.3 The Dutch Green Deals policy. Applicability to Circular Economy policies

Van Langen and Passaro (2021) analysed the Dutch Green Deals Policy instrument to learn how it has been used to aid the transition to a CE in the Netherlands. By reviewing the publicly available documentation on 231 Green Deal Agreements (GDAs), agreements aimed at loosely defined green initiatives that required that formalised cooperation between the Dutch national government and one or more firms and/or local/regional governments on a meso- or macro-level contribute to the improvement of the CE related innovation processes. Those agreements that are aimed at CE concepts (50 out of 231 or 22%) were further investigated. A total of 9 different themes (the amount of GDAs per theme is shown in Table 3, 20 different industries, and ten types of action to be undertaken by the Dutch national government were identified within these Green Deals and basic statistics on these findings are in the paper. There seems to be a correlation between the number of Green Deals that were related to CE and the introduction of a national CE plan by a new government

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after 2012. Recycling seems to be the dominant focus of most Green Deals that are focused on CE, even though from an environmental perspective, it is not always preferable. While construction is the most often encountered industry (16% of all CE-related GDAs are in the construction industry), the Green Deal agreements were quite evenly spread over many industries. The paper concludes by stating that the Dutch policy instrument seems successful in aiding the transition to a CE.

Table 3 – Overview of themes to which GDAs are related, adapted from Van Langen and Passaro (2021)

Theme	*GDAs**	*GDAs that are CE related*	*% of GDAs that are CE related*
Resources	62	35	56%
Biobased Economy	67	14	21%
Climate	10	2	20%
Water	17	3	18%
Construction	46	8	17%
Food	27	3	11%
Energy	135	13	10%
Biodiversity	42	3	7%
Mobility	35	2	6%
Total of GDAs	231	50	22%

[*] A GDA can be related to more than one theme

2.2 Non-renewable resources

Non-renewable resource use is, in itself, a weakness for any national and transnational economy. Sooner or later, the non-renewable basis will shrink, and prices go up, the environmental impacts will increase with scarcity (just think of the need to extract fossil oil from deeper reservoirs and minerals from reservoirs covered by forests, presently protected as biodiversity sanctuaries), other competitors will show up, and economic freedom of Governments and society will be constrained by big corporations controlling resource extraction, processing, and trade. Until national and transnational economies are based on non-renewable, sustainability is just a dream and trade is just a fight over scarcity. Iron and steel are a typical non-renewable resource, on which any societal infrastructure is based (housing, vehicles, railways, and an uncountable number of devices). The studies discussed in this Section deal with iron and steel as fundamental resources for all economies (characterized by a non–negligible environmental impact all over their entire life cycle) and have China as scope, a country largely depending on imports from abroad (mainly Australia and Brazil); also, China has been among the first countries to include CE within its policy strategies.

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2.2.1 Environmental and economic-related impact assessment of iron and steel production. A call for shared responsibility in global trade.

In this first study, Liu et al. (2020) evaluated the Chinese iron and steel sector, starting from the iron ores extraction and processing, analysing the Chinese global trade and pointing out the necessity of shared responsibility from China and other importing countries on preventing or repairing the environmental damage (LCA emissions) also supporting the environmental recovery in the mining of exporting countries. In order to compare the economic and environmental costs and benefits associated with the production and trading of ferrous materials, Liu et al. (2020) used Life Cycle Analysis to generate the "unit GDP impact intensity", assessing the correlation between economic activity and pollution. The top 5 iron ore mining countries are Ukraine, Australia, South Africa, Brazil, and Canada. At the same time, Russia, South Korea, Italy, India, Germany, China, Canada, Brazil, Ukraine, and Turkey are the top 10 steel-producing countries, representing each group, 70% of the total iron ores and steel exports volumes in 2018 (Liu et al., 2020). Russia is the main exporting country for steel, while Brazil, Canada, Australia, Ukraine, and South Africa export iron ores (South Africa and Canada presenting the worst environmental results). US, Italy, and Germany are net importers of steel, while China is a net importer of iron ores. Turkey and India import scraps, and the UK is highlighted as a net exporter for scrap (Figure 3).

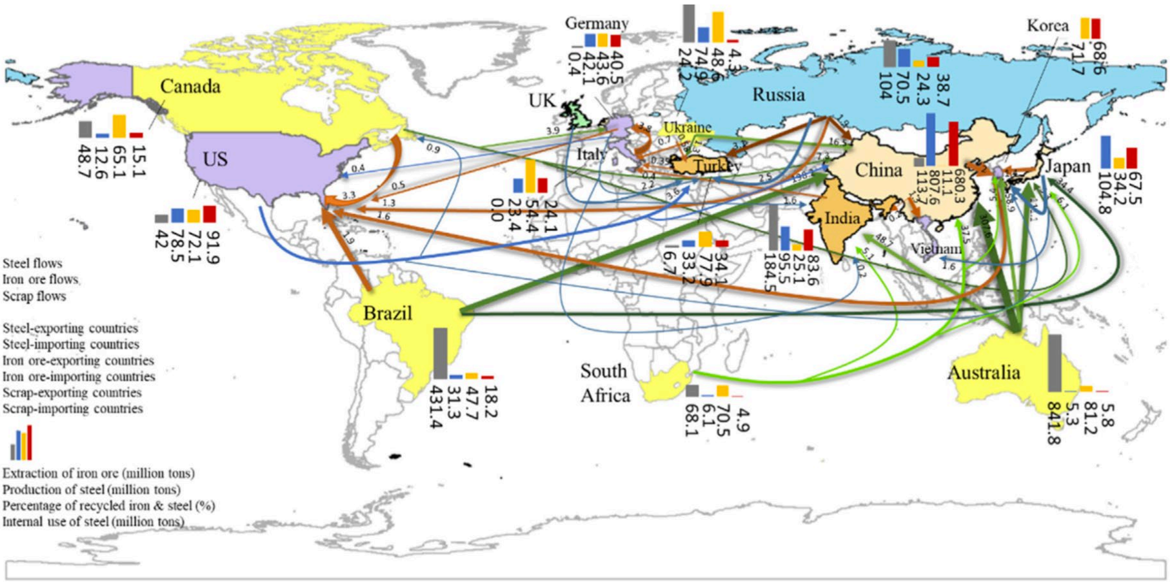

Figure 3 – Iron and steel global trade market, identifying by different colours the importing and exporting countries by type of material (iron ore and steel), showing the amount extracted, steel produced, iron and steel recycle rates, and internal use of steel (Liu et al., 2020).

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The environmental impacts were assessed by LCA associated with the economic performance of steel production, meaning that "net importing countries (mainly China and the United States) should also take responsibility for the impacts generated in the supply chain by their iron/steel production partners". Thus far, the authors called for shared environmental responsibility in global trading due to toxicity, climate change, and water depletion associated with traded resources. Importing resources from other countries also means sharing the responsibility of working together for decreasing pollution, promoting environmental remedial actions, sharing know-how and technology.

2.2.2 The environmental and economic sustainability in key sectors of China's steel industry chain: an application of the Emergy Accounting approach

In this second iron and steel case study, Liu et al. (2021) analysed the sustainability of and the urgent need for scrap recycling in the steel sector from an environmental point of view (EMA), also suggesting decreased use of non-renewable resources and technological improvements to go beyond steel use in some sectors. In so doing, the transition to CE would become a possible path, not just a dream. The study also points out the huge advantage of China (as any other country importing cheap primary resources) in iron ore imports. In 2019, China's steel market produced and consumed 950 million tons, with a 9.6% increment from past years. This increase promoted social benefits by economic development. However, extraction and processing of resources require land, infrastructures, energy, direct and indirect labour, and release large amounts of chemicals (CO2, dioxins, etc) which affect the environment and well–being. Calculating the environmental cost of resources at the scale of the Biosphere, according to the supply-side framework of the Emergy Accounting Approach (EMA) helps to understand the (low) renewability and the (low) sustainability of the iron and steel chain, despite its huge importance for a national economy. Liu et al. (2021) aimed to create a suitable set of indicators based on EMA to assess different scenarios of iron extraction and import from outside, followed by primary and secondary steel production. The study evaluated all the production steps from extraction to pelletising, sintering, puddling, primary steel production (BOF, Blast Oxygen Furnace), and secondary steel production (Electric Arc Furnace), to finally assessing the sustainability of steel-using sectors. Calculated indicators point out that the most important sectors that use steel in China (housing and transportation) cannot be considered sustainable if they do not rely on secondary (recycled) steel much beyond the present 11%. The production phases of primary steel (BOF) and secondary steel from scraps (EAF) are described in Figure 4. The diagram shows iron extraction and imports from abroad, which are then further processed within China. Resources used for processing imply a very intensive convergence into the final product, thus indicating the large demand for

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biosphere support by the entire steel industry in China (and the world). The final result of the entire evaluation is the calculation of the Unit Emergy Values (UEV) of the products in each step, translating into a kind of environmental price at the scale of the biosphere. The evaluation of the scenarios, designed to test the different percentages of EAF (scraps recycling), showed that high use of steel from scraps improves the environmental performance in the still not sustainable steel industry. The authors suggested an increase of collection and recycling rates coupled with efforts to limit iron and steel use and replace new products and technologies. This study states as crucial the involvement of business, policymakers and society to select more sustainable production models, different consumption patterns and technology development to diminish the burden on the biosphere related to the natural resources' turnover. The issue is that non-renewable resources will never be able to be the basis for a sustainable society. Iron and steel are only typical examples of many other minerals, metals and fuels that certainly support an economic growth but cannot ensure this growth to be forever and without limits. The EMA study about steel not only points out the need for increased recycling (which is only a fraction of the CE concept), but clearly calls for preliminary design of a different way of building, transporting, processing, consuming (which is the most important aspect of CE), relying on different materials, on expanding the life of resources, and producing and consuming in a way that requires less non-renewable resources.

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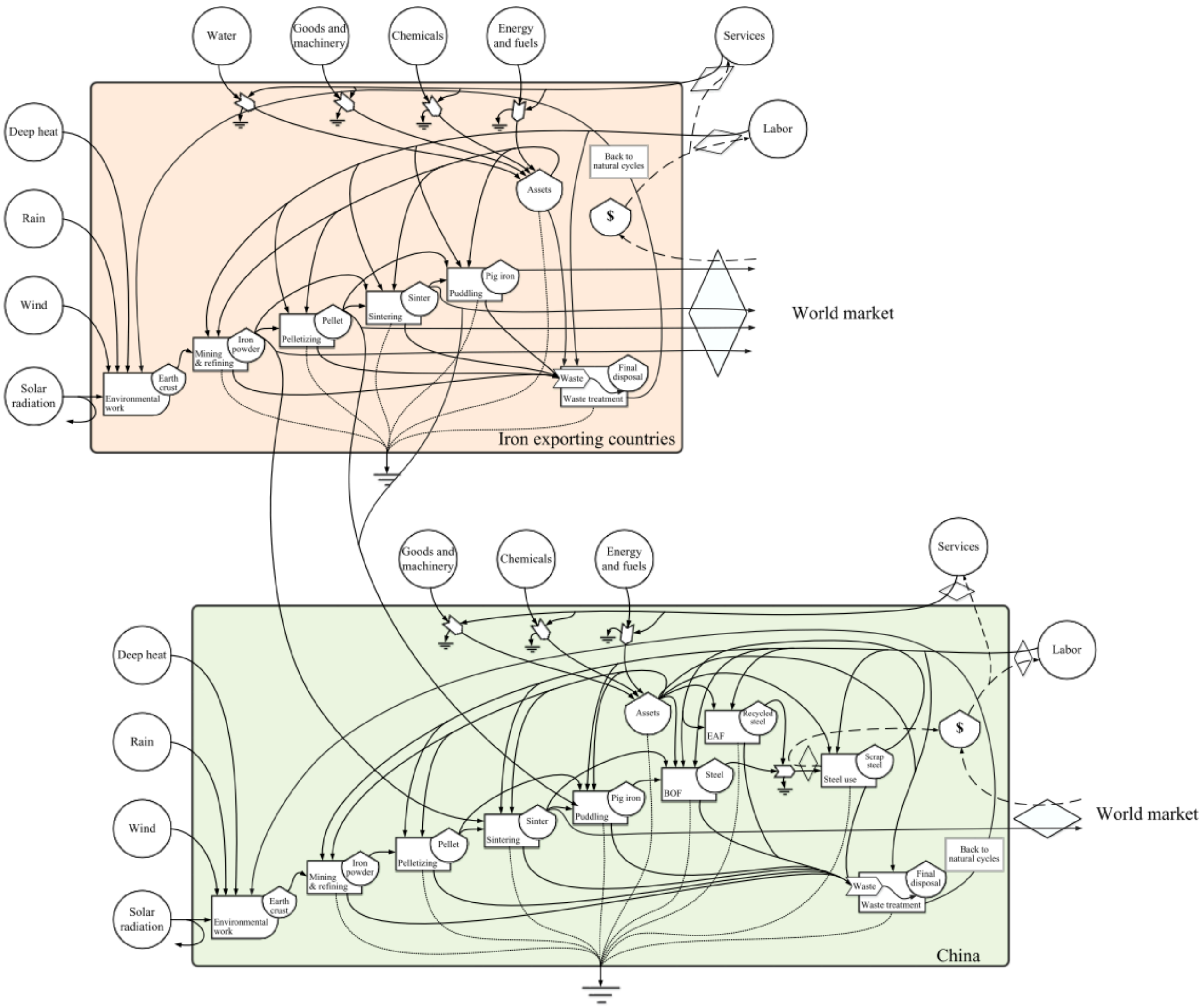

Figure 4 – System diagram of the steel sector in China, from the steel mining on the exporting countries (orange) and the connections to the Chinese industry (green) to produce primary steel (BOF) and recycling pathways from scraps (EAF) (Liu et al., 2021).

Finally, calculating the Emergy Benefit Ratio (EBR) indicator, a ratio of the emergy imported through the primary resource to the emergy associated to the money paid for, China gets 3.2 times Emergy benefits from importing (cheap) iron from other countries while also using its own minerals internally to develop the economy. Exporting countries, under market pressures, sell primary products at a low price, disregarding the environmental impacts, the jobs generated by the transformation of resources in manufactured products generating higher income in other countries. All in all, Emergy indicators clearly show that international market does not implement fair exchange of wealth when trade is measured in monetary units. Measuring in environmental units (units of emergy) identifies winners and losers in international trade and calls for more appropriate use of non-renewable resources, which is an important feature of Circular economy.

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2.3 Urban systems

Currently, 55% of the urban population lives in urban areas. This share is foreseen to be increasing in the next decades. Also, urban systems are the most important recipients of manufactured products and resource use (including embodied land). As such, cities appear the "default" systems to be analysed and possibly improved if sustainability if CE patterns need to be implemented. Some important characteristics of urban systems should be carefully evaluated against more sustainable patterns, namely their demand for energy (transport, air conditioning, cooking, other electric uses), for food (land use, agricultural production, manufacturing), for water (direct and indirect uses, wastewater) as well as waste generation and disposal (landfilling, recycling, composting, conversion to bio-energy), and finally, behavioural patterns that might affect resource use, planning, recovering. The food, energy, water, waste nexus (FEWW) is going to be the crucial and most addressed topic within sustainability and CE research and policy-making. No wonder this Deliverable D2.3 covers several aspects dealing with preventive design, renewable resource, and environmental services use, reuse and recycling, governance. The investigated urban systems are represented by four different sectors, orienting the result of the analyses towards supporting urban planning and management: urban green areas (Santagata et al., 2021a), households' energy and resources consumption (Casazza et al., 2020), generated wastewater (Zaharudin et al., 2021), and recovery and recycling of construction waste (Cristiano et al., 2021).

2.3.1 Socioeconomic and environmental benefits of urban green areas: a joint application of i-Tree and LCA approaches

There is a "hidden" circularity that should be always kept in mind in planning sustainability patterns, i.e. the environmental services provided or promoted by trees in association with solar energy, deep heat, and gravitational potential. Trees are the main "actors" of water evapotranspiration, CO_2 and other pollutants uptake, temperature regulation, topsoil and flooding regulators, aesthetic values, shelter for urban biodiversity, among other benefits. Such a hidden circularity favors well–being and environmental integrity, with direct and indirect economic benefits. This article is a partnership between the ReTraCE Project and the Metropolitan City of Napoli, Italy, within an ambitious project, named "O.B.C.– Oxygen Common Good", to plant 3 million trees within the metropolitan city limits. This study was mainly focused on Napoli, due to the special opportunity of the OBC project, but results have been compared with other interesting achievements in Italian, European, and Extra European cities, among which, for example, Sao Paulo (Brazil), London (UK) and Chicago (USA).

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The main goal was to evaluate the social, economic, and environmental benefits of an urban forest, once again within a CE perspective. The currently most representing soil coverages are broad-leaved forest (≈21%), the non-irrigated arable land (≈17%), the complex cultivation patterns (≈15%), the fruit trees and berry plantations (≈12%), the continuous and discontinuous urban fabric (respectively ≈12% and ≈8%), and the industrial or commercial units (≈2.5%) (Figure 5). Santagata et al. (2021a) used i-tree Canopy software (i-Tree, 2006) and LCA to estimate the tree coverage and the potential benefits and avoided emissions within the still available and convertible spaces, also comparing with literature data.

Urban green areas or urban trees, identified as commons due to their irreducibility to private property call for protection, restoration, and preservation of public policies, provide quality of life and wellbeing, sustainable development, urban resilience, and climate change mitigation (Calfapietra and Cherubini, 2019; Lucarelli, 2011; Mancuso, 2019; Obama, 2010; Roeland et al., 2019).

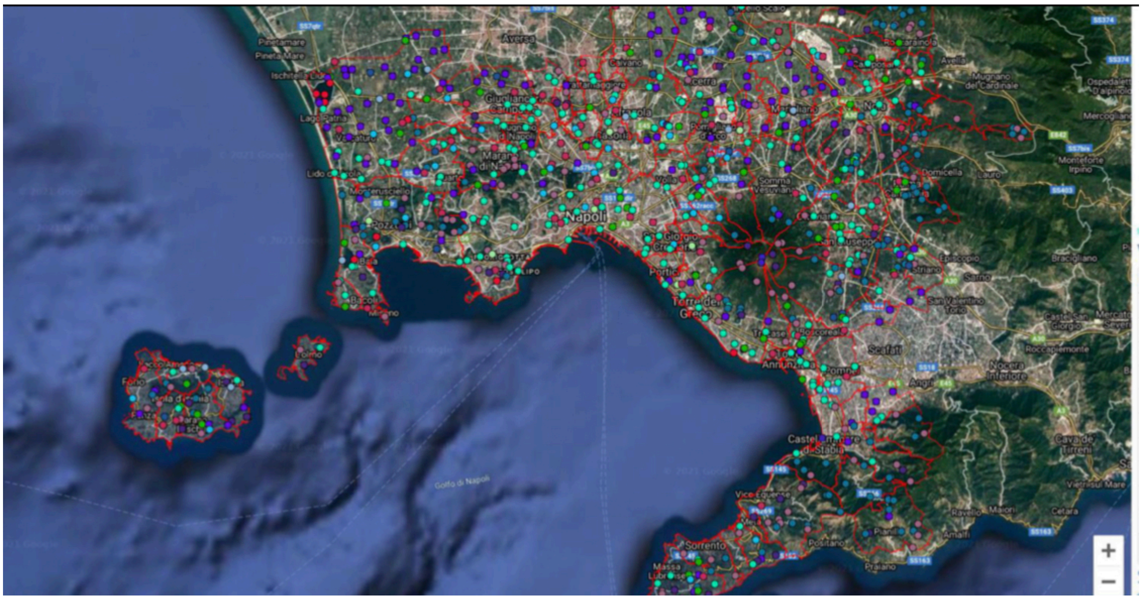

Figure 5 – Metropolitan City of Napoli: 803 points assessed by i-Tree Canopy to identify the land cover.

The results highlight that an increase of 16% of tree cover offers 51% pollutant removal, carbon sequestration, and stormwater management. These benefits were related to less than half of the desired plantation due to the absence of free areas for planting trees which calls for public planning and incentives on converting areas already designated to other uses. Moreover, the annual estimated economic benefits are around USD 18 per citizen and USD 99,117 per square kilometre of tree cover.

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2.3.2 Simulation of scenarios for urban household water and energy consumption

As mentioned above, demand for energy (fuels and electricity) as well as for water by urban systems is an important weakening factor in urban metabolism, in that makes cities heavily dependent on imports and, more than that, on indirect imports from large surrounding areas. This makes Circular Economy a hard objective to achieve and requires very informed planning and behaviors to decrease such dependences. Non–fossil resources will certainly have to be regulated and their consumption decreased, but there is no doubt that demand for electricity, fuels and water can be faced through appropriate planning (photovoltaic electricity, solar thermal modules, urban waste conversion into fertilizers and biogas, and all possible kinds of recycled materials to decrease production energy demand for virgin materials). Awareness and planning are the most crucial steps, and they are much more important in that urban systems are the recipients of the largest fractions of manufactured goods of all kinds. The ability to generate scenarios for policy-making is therefore a crucial exercise. Based on a review of the available scientific literature of households' consumption, Casazza et al. (2020) created scenarios linking household processes of energy, water, and food consumption to the citizens' behaviours (only possible due to the extensive and comprehensive literature review), providing viable solutions for consumption and demand management. The authors proposed a long-term dynamic model based on the influence of residents' daily behaviours and practices on the household end-uses (Figure 6).

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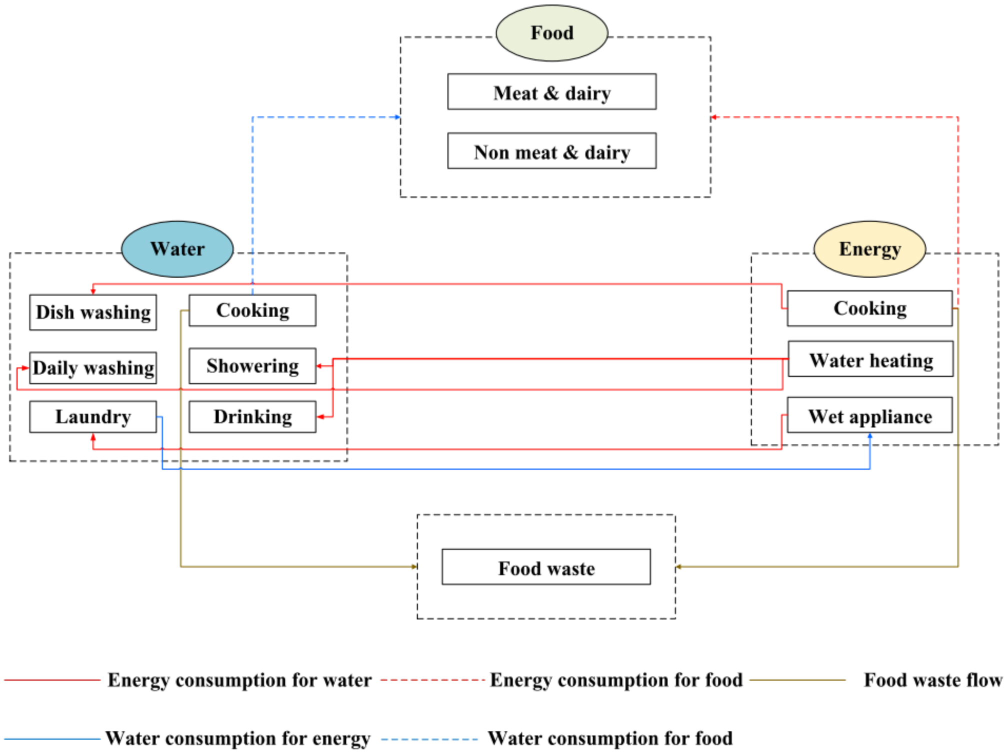

Figure 6 – Food, energy and water household Nexus model proposed by Casazza et al. (2020).

The scenarios were built focusing on increasing household awareness (by providing knowledge on adopting resource-saving appliances through newspapers, TV advertisements, and posters) and the effectiveness of these actions by simulating the reduction of daily washing length, frequency of shower, meat and dairy consumption, and conscious consumption of resources.

Results showed that price regulation mainly affects the excess gas consumption, while water and electricity are less affected. Instead, awareness (education and communication actions) has a positive impact on reducing water consumption. Simulations are powerful instruments to support the planning and implementation of actions.

2.3.3 Construction and demolition waste in the Metropolitan City of Naples, Italy: State of the art, circular design, and sustainable planning opportunities

The 2018 production of waste in Italy, including municipal waste, accounts for about 143.5 million ton, according to the most recent official report (ISPRA, 2020). Construction and demolition waste account for 61.0 million tons, namely 42.5% of the total. This means that their recovery would significantly contribute to decrease the environmental impacts associated to mineral mining and processing. A special focus is therefore needed on this special category, the treatment of which is likely

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to contribute to a successful CE implementation. Cristiano et al. (2021) analysed the construction and demolition sector in the Metropolitan City of Napoli, Italy, to provide management information to the public power proposing solutions for promoting the CE in the sector. i-Tree Canopy software, based on GIS data and National Database were used to estimate the stock of building materials. On the other hand, the SWOT analyses (Figure 7), based on a Panel of Academic experts and the Literature Review, identified the weakness, strengths, opportunities, and threats supporting the definition of strategies for policymaking.

Strenghts	**Opportunities**
• S1: Capacity of recovering the generated C&DW; • S2: Monitoring system of C&DWM; • S3: Academic research involved in the transition to CE for C&DW.	• O1: European and Italian legislation for the transition to CE in C&DW sector; • O2: Product market changes in the neighbourhood provinces
Weaknesses	**Threats**
• W1: Heterogeneous composition of C&DW flows; • W2: The low demand for recycled products; • W3: Lack of a traceability of recycled products in the whole life cycle; • W4: Underestimated amount of annual C&DW flows.	• T1: Lack of subsidies or other incentives for RA development and low landfilling charges; • T2: High availability of extractive sites and low penalties; • T3: Negative image and presence of illegal activities

Figure 7 – SWOT Analyses of construction and demolition waste in the Metropolitan City of Napoli (adapted from Cristiano et al., 2021)

The integration of evaluation methods provided an overview of the existing buildings, current materials stored and generation and management of C&DW at the macro scale of the Metropolitan City of Napoli, Italy pointing out solutions to promote CE in the construction sector, based on sustainable innovation, improvements on monitoring systems, support to research, supply chain cooperation and development, and increase knowledge towards CE transition practices, encouraging the use of recycled materials.

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2.3.4 A spatial interaction model for the representation of user access to household waste recycling centres

The paper by Zaharudin et al. (2021) developed a spatial interaction approach (based on a gravity model) that explains the mechanism through which users decide which recycling centre to patronise. The model was tested that with real-life data from the Sheffield city council districts provided by the English Local Authority.

The model was found to correlate with actual data, as shown in Table 4, and can thus predict the impact of modifying the network of recycling centres, useful for city planners. It is especially useful for planning the closure, downsizing, or expansion of household waste management sites in an urban region, helping to achieve higher efficiency. It is suggested for future research to integrate the developed spatial interaction model within a mathematical programming approach to better aid local authorities in planning locations and opening hours of recycling centres and apply the model in different national contexts.

Table 4 – Error of spatial interaction model compared to survey results, adapted from Zaharudin et al. (2021).

HWRC	*Actual percentage distribution of users (A)*	*Predicted percentage distribution of users (B)*	*Absolute Error* $\vert B-A\vert$	*Absolute Percentage Error100* $\times \vert B-A\vert/A$
Beighton Road	22.94%	22.94%	0.00%	0.00%
Blackstock Road	29.77%	29.19%	0.58%	1.96%
Deepcar	09.50%	09.50%	0.00%	0.00%
Greaves Lane	11.28%	11.62%	0.35%	3.09%
Longley Avenue	26.52%	26.75%	0.24%	0.89%
		Mean Absolute Percentage Error (MAPE) =		1.19%

2.4 Renewable resources

As mentioned above, the main pillars of CE are regenerative planning, use of renewable resources, increased reuse and recycling, appropriate governance. Since non–renewable energy resources cannot be recycled nor regenerated in a short time, planning for decreased use is the only way to address their heavy impact. Instead, non–renewable mineral resources may also be partially addressed by recovering and recycling, investing some energy in the process. This means that using renewable resources becomes of paramount importance to address material resource recovery without, at the same time, investing non–renewable fossil energy. Further, also material resources (e.g. plastics) can be at least partially replaced by renewable ones (bio-polymers). This means that the development of some crucial CE pillars (planning and recycling) requires the parallel development of other pillars (use of renewable resources), with appropriate regulations to make this happen (CE governance). The fourth group of

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studies focuses on renewable resources as a source of both bioenergy and biomaterials, in addition to already known food production patterns.

A comprehensive literature review on biogas technologies utilised in Africa and China (Tiegam et al., 2021), an integrated LCA and EMA assessment of food waste treatment processes for energy and material recovery in the EU28 (Santagata et al., 2021b), an EMA evaluation of Campania's dairy sector (Oliveira et al., 2021b), and finally a literature review of wastewater management systems suitable for the Italian context (Colella et al., 2021) were performed as a possibly telling although not exhaustive series of case studies at meso and macro scales.

2.4.1 Technologies, challenges, and perspectives of biogas production in China and Africa

Tiegam et al. (2021) produced a review on biogas literature, specifically focusing on the Africa and China contexts, which are understudied. Biotechnology sees considerable delays in developments relevant to the context of developing countries, exacerbating issues with waste management. While China is now pioneering in biogas, African countries are still relying on more traditional technologies, which stops them from harnessing the potential of the vast quantity of biomaterials available to them, biofuels and waste form the main source of electricity production in Africa, as evidenced in Figure 8. The paper looks at the technologies used, challenges faced, and potential in the African and Chinese contexts. Especially in Africa, developments in biogas as a source of renewable energy can fight deforestation (since wood, for now, remains an important fuel source for households). Future research would look at the potential of by-products in the production of biogas fuels.

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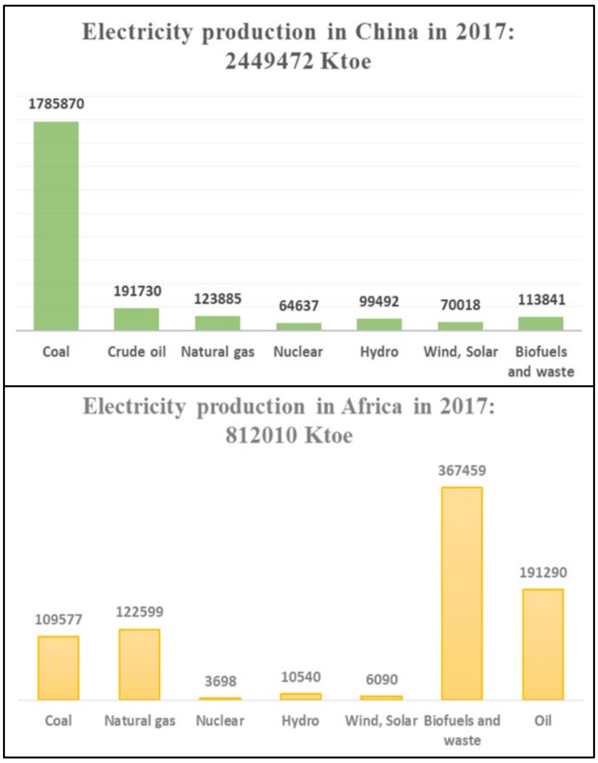

Figure 8 – Overview of the electricity mix of China and Africa, highlighting the importance of biofuels for Africa's electricity generation (Tiegam et al., 2021)

2.4.2 Food waste recovery pathways: Challenges and opportunities for an emerging bio-based circular economy. A systematic review and an assessment

Santagata et al. (2021b) accessed the Ecological performances of EU28 food waste treatment processes specifically, mixed food and animal waste pathways, using Life Cycle Assessment and Emergy Accounting methods to identify opportunities and constraints – assessing the environmental burdens and perspectives of the waste treatment alternatives, with focus on the recovery conversion processes (Figure 9).

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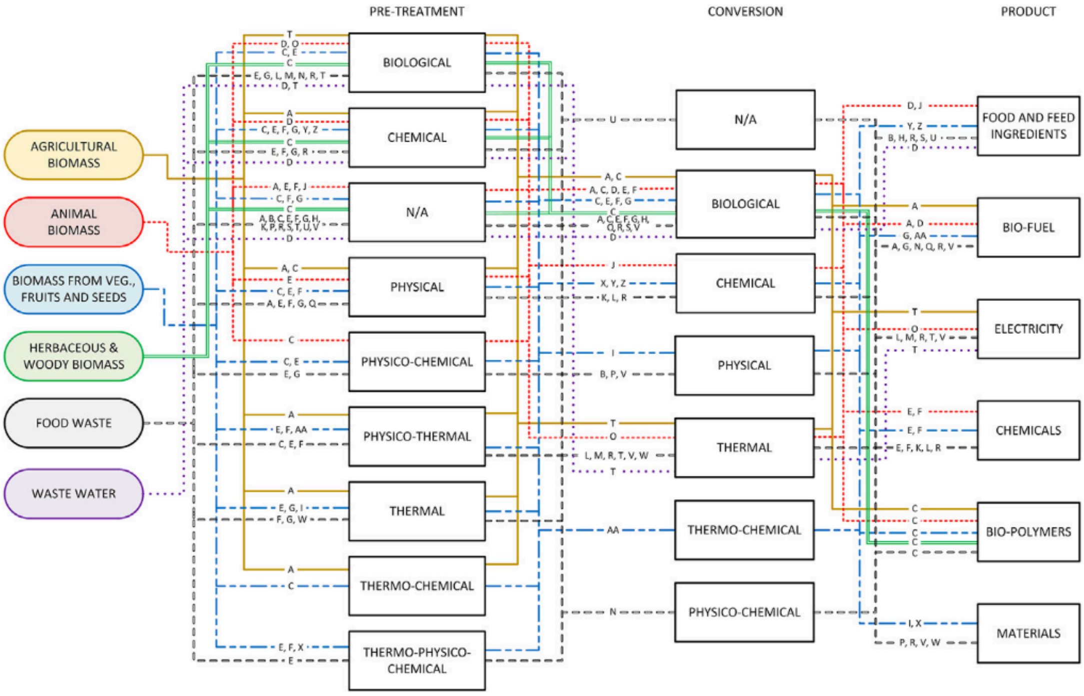

Figure 9 – Food waste recovery pathways (Santagata et al., 2021b).

The environmental impact (Figure 10.a.) of the biowaste treatment options related to animal biomass in this example, is smaller for incineration than the anaerobic digestion, while even lower is related to industrial composting. However, incineration has the worst performance from the natural resource's consumption perspective (Figure 10.b.), followed by industrial composting and anaerobic digestion. Incineration by-products of heat and electricity are harmful to the environment and human health. Anaerobic digestion produces biogas and digestate, reused as fertiliser into crops. The composting process generates a bio-fertiliser to be used in food or non-food crops. The authors state that waste recovery can reduce environmental pressure and create jobs by better management of resources and waste valorisation.

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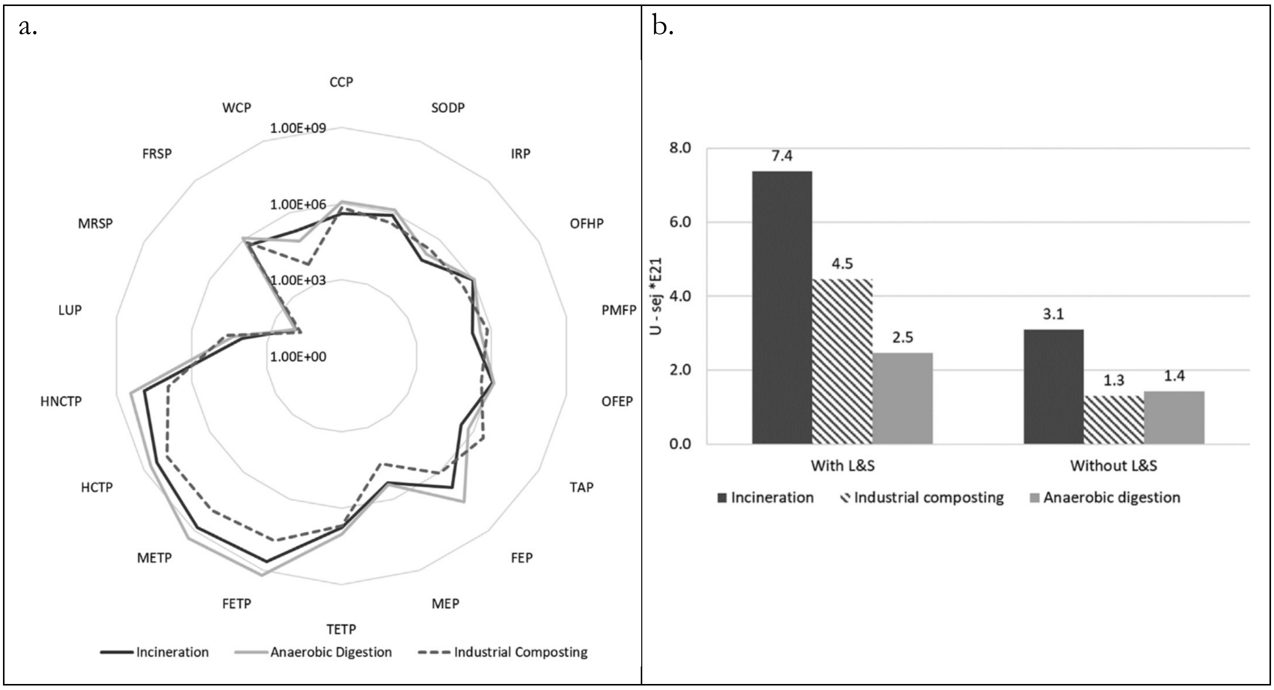

Figure 10 – a. LCA and b. EMA results for incineration, anaerobic digestion and industrial composting (Santagata et al., 2021b).

2.4.3 Environmental assessment of milk production from local to regional scales

The environmental impact of livestock activities is attributed to GHG emission of ruminant activities and manure management; additionally, pastures contribute to the decrease of biodiversity by converting natural areas in pastures causing erosion, desertification and water contamination (IPCC, 2019, Reynolds, 2006; O'Mara, 2011). Notwithstanding, milk, and meat provide essential nutrients to human metabolism, their consumption are connected to human diseases (cardiovascular diseases and cancer) (Joint WHO/FAO/UNU Expert Consultation., 2007; WHO, 2018; González et al., 2020; Wang et al., 2020). As most studies evaluate the processes under human control, Oliveira et al. (2021b) used Emergy Accounting (EMA) to evaluate the Regional Dairy Sector in Campania Region, Italy, from the donor-side perspective, pointing out the consumption of the natural resources of the sector. The Campania Region concentrates 74% of the buffalo cattle in Italy. The 697,446 animals (43% buffalos, 28% cows, 29% sheep, and 0.04% goats) produced around 393.000 ton of milk in 2018 (52.7% of cow's and 46.7% buffalo's milk) (ISTAT, 2020a). The Corinne Land Cover (2018) a georeferenced systems (GIS) database, was used to obtain the regional territorial data. The dairy sector in this region is characterized by different small companies, family business management, low automation, and predominant craftsmanship in milk processing dairies (Sabia et al., 2018). The evaluated system boundaries and inputs considered are shown in Figure 11.

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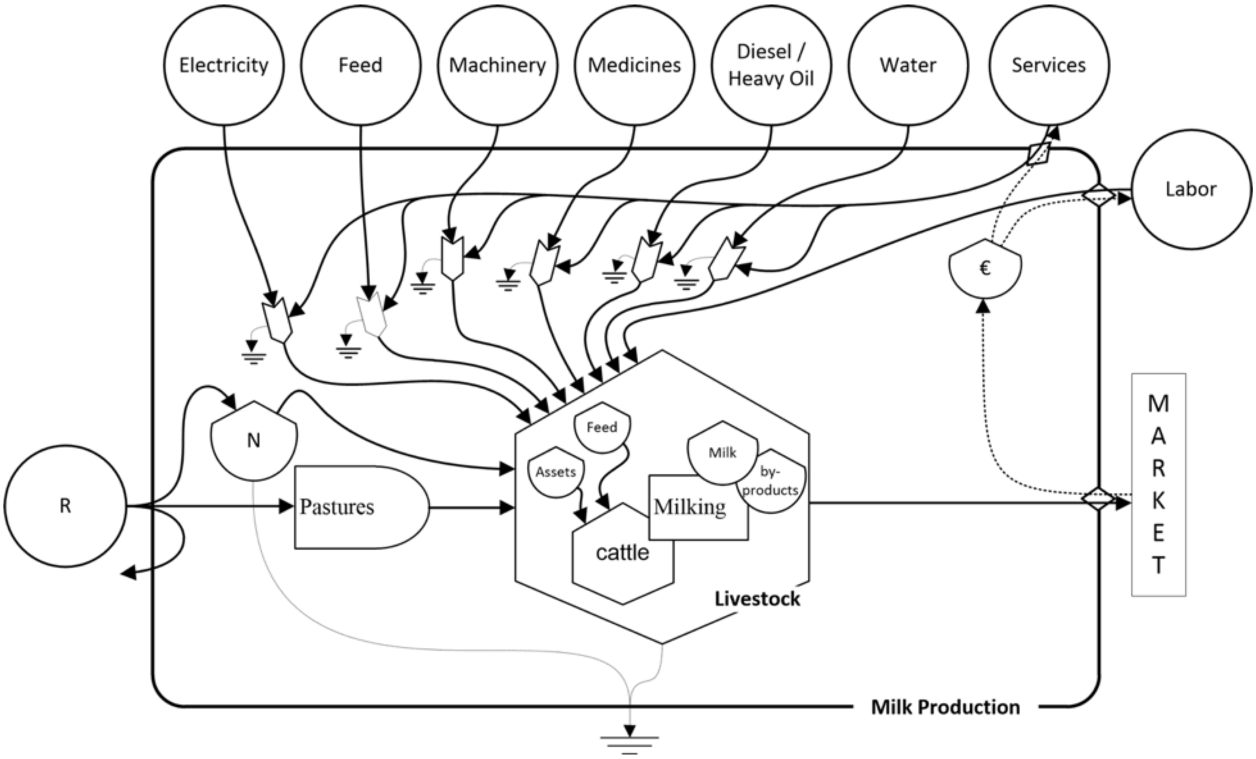

Figure 11 – System diagram of dairy livestock sector in Campania Region, Italy. Where R represents the Renewable Local Inputs (sun insolation, geothermal heat, tidal energy, wind, wave energy, and rain); N, the Non-renewable Local Inputs (loss of topsoil – erosion); Pastures are represented as a producer while livestock, as a consumer (Oliveira et al., 2021b).

Considering the heterogeneous profile of dairy farms within this Region, results of the livestock sector shows feed to be the most impacting input flow (Figure 12), due to the assessment based on statistical data (Ribaudo, 2011) which forced the assumption that all feed is purchased, disregarding that some farms are independent and produce their feed. This latter assessment pointed out the fertilizers as the major consumer of natural resources of the Campania Region's agriculture production (Ghisellini et al., 2014). Therefore, the authors argued as an opportunity for method's integration (GIS and EMA), allowing a more precise estimate data and improved the results by including the distinguish of productive models – self-produced feed and the use of chemical fertilizers or manure produced by the cattle applied to the fodder production (Agostinho et al., 2008). Moreover, this work presents an update of EMA algebra to allow an appropriate evaluation of circularity by avoiding double counting and correctly allocating driving resources to by-products.

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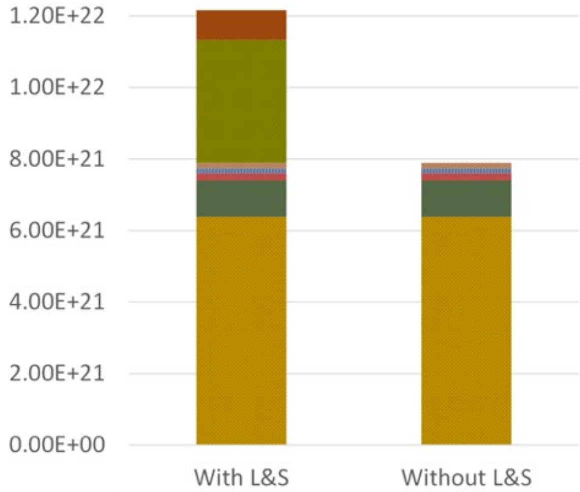

	With L&S	Without L&S
Human Labor	6.8%	
Services	28.3%	
Others	1.3%	2.0%
Electricity	1.1%	1.7%
Erosion	1.6%	2.5%
Natural Renewables	8.4%	12.9%
Feed - Average Mix	52.5%	80.9%

Figure 12 – The milk production in Campania Region evaluated by the natural resources consumption perspective: Emergy inputs (sej year^{-1}) and percentage contribution (Oliveira et al., 2021b).

2.4.4 Challenges and opportunities from circular wastewater management. The case of Campania Region, Italy.

Wastewater management was the topic discussed by Colella et al. (2021) under the CE paradigm, which is expected to promote the recycling, reuse, and recovery of products and by-products and the reduction of wastewater from more efficient processes. Unlike most of Europe, where many industries can recycle and reuse water, many Italy regions haven't consolidated a sustainable wastewater management system.

From the literature review (schematized in Figure 13), the most promising wastewater treatment processes used for resources and energy valorisation, suitable scenarios for Campania Region, Italy (Figure 14), were proposed, evaluated, and discussed:

(a) Microbiological treatment of fish canning wastewater to generate biodegradable polymers: reducing the emissions by 25%.

(b) Recovery of phosphorus from wastewater by precipitation to be used as fertiliser: the benefits are reducing resources consumption and water eutrophication.

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(c) Nitrogen removal and recovery from wastewater plants, by anaerobic ion exchange processes: a considerable potential to provide economic and environmental performance through design and process optimisation.

(d) Microalgae wastewater treatment for electricity generation: can reduce carbon emission and costs of biofuels produced by microalgae biomass.

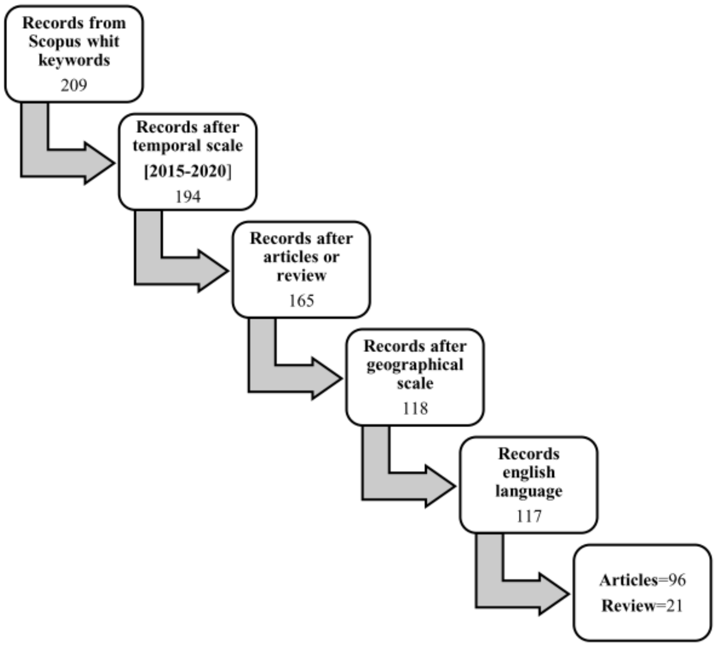

Figure 13 – Literature review framework – keywords: "circular AND economy AND wastewater" (Colella et al., 2021).

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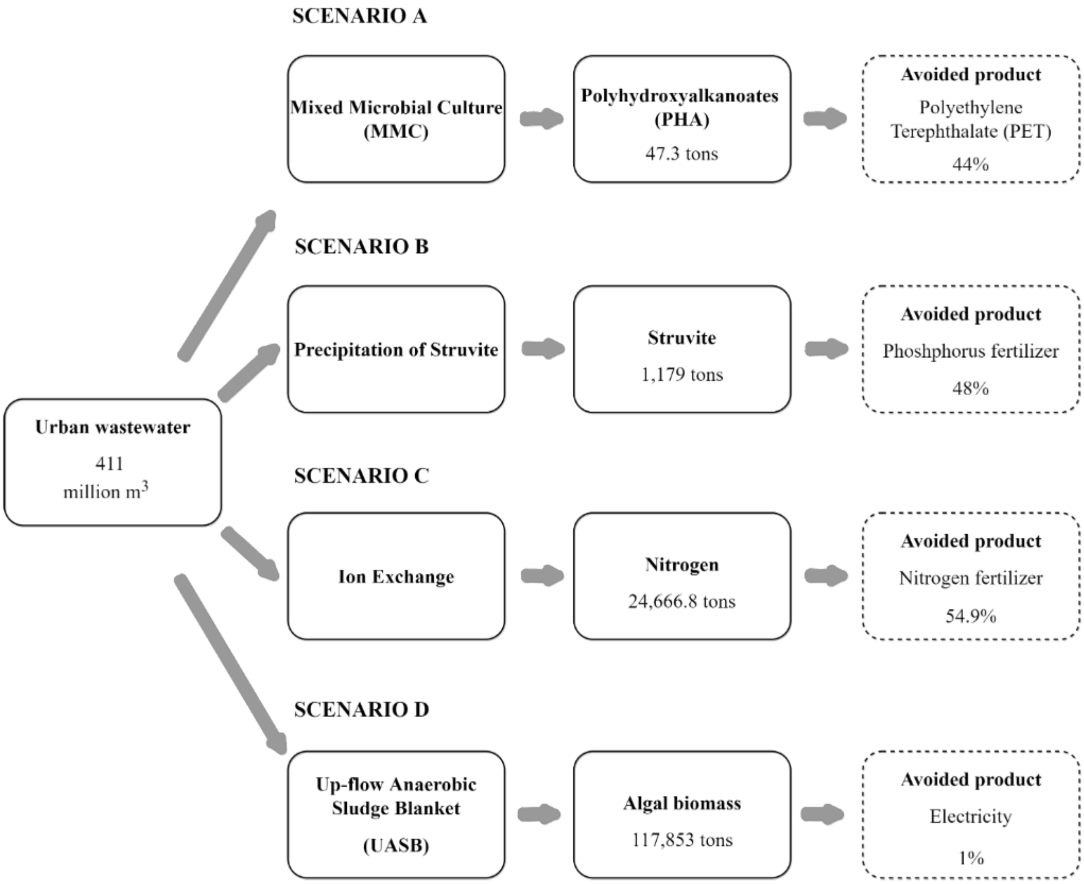

Figure 14 – Recovered products from Campania Region's wastewater and avoided products (Colella et al., 2021).

3. Final results and discussion

As mentioned above, the main reference for appropriate framing of the work described in this Deliverable are Table 1 and Figure 1, as a follow-up to Deliverables D2.1 and D2.2. Figure 1 describes the horizontal interplay of the different sustainability dimensions (environmental, economic, and social), along with the much-needed integration of the different methods and the reciprocal support and feedback of the different scales (micro, meso and macro). At the same time, Table 1 provides a picture of selected studies within different sectors to show how methods can be integrated and applied to assess and discuss the sustainability of diverse economic sectors in various countries/regions. Further, Table 5 provides an overall picture of identified environmental, economic, social impacts/measures, with CE features/potential pointed out by each study. Table 5 is the central result of this D2.3, in that summarizes still open problems, interactions among case studies, expected benefits.

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The environmental impact of CE transition has been the most investigated perspective. EMA provides an assessment of natural resources regeneration while discussing regional milk production, waste treatment options, steel production, and recycling. The adoption of EMA shows the potential benefits deriving from efficient resource use, along with recycling and reusing patterns. LCA focuses on a large number of footprints (water, land, carbon footprints, among others). The resulting picture from LCA use is that we can identify several fragilities of each sector and try to convert weakness into strength. The most important result is that LCA can be considered the centre of any sectorial or whole economy evaluation, by building around LCA footprints several other very telling assessments, such as EMA, literature surveys, i–Tree assessments, among others. A second important issue is the support that lower levels (e.g. micro) provide to higher ones (e.g. meso) and the vice versa feedback options.

The studies based on literature reviews brought more comprehensive and holistic evaluations, including the social dimension, calling for urban regeneration and a cultural shift to create well–being and finally modelling scenarios based on citizens' consumption behaviours (please see also Table 5). Related to environmental concerns, these studies discussed the development of renewable energies, the protection of seas and biodiversity, the reduction of landfilling, the problems of climate change and desertification, the need for preserving natural capital. The economic impacts are related to production efficiency (lower costs of resources and valorisation of waste), avoiding economic losses, and increasing GDP.

From a broader perspective, the potential of CE policy was also evaluated by investigating the performance of existing Green Deal policies. In contrast, other studies in Table 5 advocate for better planning and management of resource consumption and waste generation and disposal through reusing and recycling by-products and recovering energy from technological options.

Some studies call for special attention, such as the ones from Liu et al. (2021, 2020). As mentioned above, these studies do not limit to identify impacts and step-by-step costs of the iron and steel chain. Instead, they expand their view to globalized trade of resources, the extraction, and processing of which is most often the source of huge impacts in the exporting country rarely compensated by trade monetary payments. Shared responsibility (technological and know-how exchanges, reciprocal support in environmental matters, fair sharing of economic benefits) and increased recycling to alleviate the pressure on the environment are discussed and carefully evaluated in their consequences. The second study (Santagata et al. (2021a), merging evaluation methods (LCA, monetary cost–benefits and i-tree Canopy) assigning monetary value to intangible aspects, translates the environmental functions provided by urban trees into tangible tools for policymakers.

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Some cases studies apply the same method to different processes, sectors, areas. Other studies in the above list of Table 1 use more than one method, in parallel or sequence. Again, according to Figure 1, the summarized papers provide a comprehensive picture of the previously mentioned interplay among scales, dimensions, methods, showing the policymaking capability and power of the developed (or developing) integrated tool. We are convinced that a careful reading of the above-listed studies clarifies the needed roadmap from rhetoric to implementation, i.e., from greenwashing to radical changes.

All in all, the suggested procedure, as emerging from Oliveira et al. (2021) and the studies listed in Table 1, is mainly based on a preliminary application of the LCA Goal and Scope and inventory steps. In so doing, all aspects related to goal, context, quality of data, boundaries, inflows and outflows are firstly addressed. If the goal is only comparing two different alternatives at a local scale, the continuation of the LCA procedure to evaluate the LCA impacts and potential alternatives would be the best choice. If the goal is using the investigated case(s) as the basis for policy design, then LCC and EMA would come out as the second and third methods to be applied, so that economic (regional and country scale) and environmental (Biosphere scale) perspectives can be explored (from micro to meso and macro) and support policy-making. Within this procedure (LCA=> LCC=> EMA) several other methods are very useful, such as literature review and surveys for better understanding of the state of the art, Sus–VSM for careful mapping of waste generation over the different LCA production steps, i–Tree Canopy for land cover exploration, and finally SWOT and present policy analyses to identify actual opportunities and matching with already implemented policies.

3.1 Lessons learned and concluding remarks.

From the studies performed (so far) within Work Package 2 of the ReTraCE project, a large number of lessons can be learned. First of all, each case study provides specific results that help understand how and to what extent a process at whatever scale, provides benefits and impacts and to what extent needs improvements. Secondly, when different processes at whatever scale are confronted, new implications related to CE implementation can be drawn:

- Policy-oriented analyses highlight the importance of engaging all stakeholders, towards maximizing benefits and minimizing impacts, being aware that the perfect situation is impossible (e.g., LCA will never provide only positive impacts).

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- Focused literature reviews provide a way to integrate assessments and better cover all dimensions of sustainability as an alternative to integrating assessment methods within a single study.
- Developing a suitable method for meta-analysis or other forms of research synthesis of sustainability indicators should be considered for future research to provide a framework for literature reviews covering differing economic, social, and environmental assessment methods.
- CE implementations are strongly influenced by their local context and assessments are hard to generalise. However, the interplay of dimension, methods and scales was found very beneficial for better understanding of potential more profitable options.
- Single method studies tend to focus on only one sustainability dimension, while literature reviews and integrated assessments better capture all dimensions of sustainability.
- *Micro* and *meso* level assessment methods, such as LCA, strengthen macro level methods, such as EMA, when properly combined. If studies focus on the reciprocal interplay of scales, methods and dimensions, the resulting policy tool will be much more useful to policy makers.

In conclusion, to properly assess the transition to CE and make sure this transition is sustainable on the economic, social, and environmental dimensions, it is essential to use multiple assessment methods. CE is increasingly becoming mainstream, adopted by both governments and companies, as a new way to strengthen economies through better utilisation of resources but face the risk of a rebound effect that might increase the use of resources. To better include all sustainability dimensions and levels of scale (micro, meso, and macro), a study needs to either integrate several assessments to put the environmental and social impacts next to any economic evaluation or a literature review can combine these dimensions in one study.

A framework for integration has been developed (Oliveira et al., 2021a), that aims to guide future research on integrating several well developed environmental assessment methods. Literature reviews are also an important tool to promote an integrated sustainability assessment of CE patterns. The studies presented in this deliverable prove that the framework proposed by Oliveira et al. (2021a) is suitable to help understand the different situations and design appropriate CE policies.

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Table 5 – Outputs of analysed Case Studies.

References	Impacts			CE features/potential
	Environmental	Social	Economic	
Policies and Economic evaluations				
Ghisellini et al. (2021)	renewable energies development, biodiversity and the protection of the seas, and climate change	Urban regeneration	Anti-cyclical government investments	Economic Theory - Keynes
Van Langen et al. (2021)	Reduce landfill	Job creation	GDP growth	Moving beyond recycling
Van Langen and Passaro (2021)	Reduction of resource and energy use and lower emissions	Job creation, re-education and reintegration programs	Higher-income jobs and GDP growth	Green Deals policy as an instrument for the transition to CE
Non-renewable Resources				
Liu et al. (2020)	Emissions (LCA)		Economic performance (GDP)	Shared responsibility between producer and consumer countries
Liu et al. (2021)	Water footprint and natural resources consumption and carbon footprint		Higher-income	Advantages of recycling and country independence
Urban Systems				
Santagata et al. (2021a)	Avoided emissions, increase of biodiversity, crops and livestock productivity, Climate change address	Wellbeing	Price of environmental functions provided	Carbon's cycle
Casazza et al. (2020)	Resource's conservation	Citizen's behaviour		Reduce resource's consumption
Cristiano et al. (2021)	Preserve natural capital and optimise resource's yield	Cultural shift		Waste reduction and resources efficiency, Urban planning and policies
Zaharudin et al. (2021)			Reduced cost of operating waste collection centres	planning closures, downsizing, or expansion of household waste management
Renewable Resources				
Tiegam et al. (2021)	Combat desertification		Utilise biowaste for cheaper energy/fuel production	by-products' potential in the biogas fuels production
Santagata et al. (2021b)	Natural resources consumption perspective	Job creations	Avoid economic losses	Resource's management and food waste management
Oliveira et al. (2021b)	Natural resources consumption perspective			Reuse of by-products
Colella et al. (2021)	Emissions reduction		Waste valorisation	Recovery of compounds from wastewater

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