H2020 MSCA-ITN-2018

ReTraCE Project

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

D2.4

Methods and Indicators for Material Stream Identification

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

AD - Anaerobic Digestion

CE - Circular Economy

EC - European Commission

EEE - Electrical and Electronic Equipment

EMA - Emergy Accounting

EU - European Union

e-waste - electronic waste

LCA - Life Cycle Assessment

MFA – Material Flow Accounting

NACE - Nomenclature statistique des Activités économiques dans la Communauté Européenne

QCA - Quantitative Content Analysis

USD - United States Dollar

WEEE - Waste Electrical and Electronic Equipment

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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, and technological issues. Within Work Package 2 of the ReTraCE project, experts are looking at assessment methods to better understand the environmental impact involved in CE-related processes.

In this deliverable, a new methodological approach is proposed for material stream identification in the transition towards a CE. A *mixed methods evidence synthesis* approach is used to combine quantitative and qualitative studies already performed by Work Package 2 of the ReTraCE project. To the best of our knowledge, this established method has not yet been used for the specific use of material stream identification in a CE context. Following a short introduction, an overview of the method is provided, results are presented, discussed, and relative findings are summarised in the conclusion. The studies used for this deliverable can be found in the preamble; a detailed overview with the studies, the material stream they cover, and their used methods is provided in Table 1.

Highlights:

- Mixed method synthesis can help in material stream identification, bringing new insights to existing studies.
- While methods like Life Cycle Assessment and Emergy Accounting on their own are successful in identifying promising material streams for the transition to Circular Economy, more results are gained from combining quantitative and qualitative studies. As such, presented results are typically based on 2-3 studies.
- Besides identifying material streams, the used approach can help in prioritising material streams for policy makers.
- Starting with an overview of the methodologies and indicators used in each study is a good starting point to find topics on which papers can strengthen and/or complement each other.

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Preamble

This deliverable will look into the methods and indicators used to identify material streams in the transition to the CE, as encountered in the research conducted by researchers that are involved with Work Package 2 of the ReTraCE Project. This report then combines these studies in a mixed methods evidence synthesis as a novel approach for material streams identification in the field of CE. An overview of the studies (submitted for publication or already published) that have been included in D2.4 is presented in Table 1. While wide in scope, the studied industries, material streams, and methodologies do not claim to be complete or exhaustive.

Table 1. Overview of the studies used for making this report, highlighting the industries, material streams, and methodologies covered by each study.

Study	*Industry (NACE rev2. code)*	*Material Stream*	*Methods used*
(Ghisellini et al., 2019a)	Agriculture, Forestry and Fishing (A)	Food (General)	QCA
*(Ncube et al., 2021*b*)*	Agriculture, Forestry and Fishing (A)	Wine by-products	LCA
(Ncube et al., 2020)	Agriculture, Forestry and Fishing (A)	Olive Oil by-products	LCA
*(Ncube et al., 2021*a*)*	Agriculture, Forestry and Fishing (A)	Flyash	LCA
(Santagata et al., 2021)	Agriculture, Forestry and Fishing (A)	Air Pollution	i-Tree and LCA
(Santagata et al., 2020)	Agriculture, Forestry and Fishing (A)	Food (General)	LCA and EMA
(Tiegam et al., 2021)	Agriculture, Forestry and Fishing (A)	Biogas	Literature Review
(Portarapillo, 2021)	Agriculture, Forestry and Fishing (A)	Limoncello by-products	LCA
(Borzelli, 2021)	Agriculture, Forestry and Fishing (A)	Limoncello by-products	LCA
*(Oliveira et al., 2021*a*)*	Agriculture, Forestry and Fishing (A)	Dairy by-products	LCA and EMA
(Ghisellini et al., 2019d)	Manufacturing (C)	EEE (general)	QCA
(Georgantzis Garcia & van Langen, 2021)	Manufacturing (C)	EEE (general)	Literature Review, Statistical Analysis and Taxonomy Building
(Bruno et al., 2021)	Manufacturing (C)	EEE (general)	Case Study
(Ghisellini et al., 2019c)	Water Supply; Sewerage, Waste Management and Remediation Activities (E)	Wastewater (General)	QCA
(Catone et al., 2021)	Water Supply; Sewerage, Waste Management and Remediation Activities (E)	Wastewater (Algae)	Literature Review
(Colella et al., 2021)	Water Supply; Sewerage, Waste Management and Remediation Activities (E)	Wastewater (General)	QCA and Literature Review
*(*Ncube et al., 2021c*)*	Construction (F)	Building Materials (Bricks)	LCA
(Cristiano et al., 2021)	Construction (F)	Building Materials (General)	QCA, i-Tree and SWOT
(Ghisellini et al., 2019b)	Construction (F)	Building Materials (General)	QCA
*(*Liu et al., 2020a*)*	Construction (F)	Building Materials (Steel)	EMA
*(*Liu et al., 2020b*)*	Construction (F)	Building Materials (Steel)	LCA

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1. Introduction

"The whole is greater than the sum of its parts" - Aristotle

CE is a paradigm where the elimination of waste will foster sustainable development in the economic, social, and environmental dimensions (Ellen MacArthur Foundation, 2012; Webster, 2017). The concepts of CE are now actively being adopted in the EU and form a cornerstone for achieving the EC's goal of making Europe a climate neutral continent by 2050 (European Commission, 2015; 2019; 2020).

Work Package 2 and its members have already studied the need for measuring CE processes and suggested suitable methodologies, such as EMA and LCA (Coleman et al., 2020; Oliveira et al., 2021b). Furthermore, Work Package 2 has performed a range of studies at the micro level (Ncube et al., 2021d) and at both the meso and macro levels (van Langen et al., 2021a) into the effects of CE policies and implementations by governments and/or firms.

To identify promising material streams for transitioning to the CE, governments and researchers typically rely on MFA (Elgie et al., 2021; Gao et al., 2021; Mayer et al., 2019; Wiedenhofer et al., 2019). Indeed, while MFA can successfully identify the major material and waste streams, it does not provide a lot of information about the possibilities of a material stream to become more circular. This report will highlight the methodologies and indicators used by Work Package 2 to identify the circularity promise of material streams in different industries. Previous studies performed within this Work Package highlighted the need for using proper measurement methods (Oliveira et al., 2021b) and indicators (Patil et al., n.d.; van Langen et al., 2021b) for better aligning the different stakeholders involved in CE implementation (van Langen et al., 2021c). In Deliverable 2.3, the advice was given to develop a research method for the synthesis of sustainability indicators (van Langen et al., 2021a), which this deliverable now aims to achieve.

Based on these premises, the rest of this deliverable is organised as follows: first is given an elaboration on the methodology used to make this report. After that, the results are presented for each studied industry, highlighting the different methods used and which of their indicators can best help to identify material streams. Finally, a discussion section and conclusion are provided.

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2. Methodology

This report uses mixed methods synthesis for identifying material streams best suited for a transition to the CE, which is a novel approach, to the best of our knowledge. Most research into material stream identification that consider multiple streams uses MFA (Elgie et al., 2021; Gao et al., 2021; Mayer et al., 2019; Wiedenhofer et al., 2019).

The process of implementing CE practices generally falls in the category of *complex interventions* (i.e., the need to consider a wide range of complexity dimensions, as defined by Petticrew et al., 2013). According to Petticrew et al. (2013), complex interventions require multiple methods in order to assess the different aspects related to them. While a systematic literature review can summarise and synthesise their findings, these do not necessarily provide a synthesis of results (Petticrew et al., 2013). In particular, Petticrew et al. (2013) provide three options for a review of complex interventions: quantitative synthesis, qualitative synthesis, and mixed-method evidence synthesis. As we use a collection of studies from our work package that contains both quantitative and qualitative research, it follows to use mixed-method synthesis, an approach that allows to synthesise quantitative and qualitative studies. Typically, this happens in a narrative summary where the results from different studies reinforce, contradict, or supplement each other. Considering that all studies aim to answer the same research question for this deliverable purpose (identifying material streams), the Integrated Design framework is chosen, where quantitative and qualitative studies are taken together in a newly synthesised qualitative analysis (Sandelowski et al., 2006). The studies assessed in this deliverable often rely on LCA or EMA, two methods, extensively described in ReTraCE deliverable 2.1,which are useful for environmental assessments and for identifying waste and potential materials streams for a CE (Coleman et al., 2020; Oliveira et al., 2021b). In a nutshell, LCA can be used to assess the environmental impact of different circular scenarios as well as the benefits of utilising material streams and diverging them from landfills. EMA allows for something similar and in particular to identify the embedded energy of by-products that go to waste.

Mixed method synthesis is performed for four different industries that are studied by Work Package 2 (NACE Rev. 2 codes in brackets): Agriculture, Forestry and Fishing (A), Manufacturing (C), Water Supply, Sewerage, Waste Management and Remediation Activities (E), and Construction (F). Within each of these industries a mixed methods synthesis is performed to see if this method can be used to find promising material streams for the transition to CE. For each assessed study in an industry, the used indicators and results are put together in a narrative summary, and an attempt is made to characterise materials streams to a further extent with respect to what is already done in the individual papers.

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3. Results

3.1 Agriculture, Forestry and Fishing

In Table 1 we presented seven studies that cover the agricultural, forestry and fishing industry. In this section, a narrative analysis of their results is given, in order to identify material streams that are suitable for the transition to CE. In Table 2 the indicators used by each study are presented.

Table 2, Overview of studies performed in the agricultural, forestry and fishing industry with their used methods and indicators.

Study:	(Ghisellini et al., 2019a)	**Method:**	QCA
Indicator:	Terrain type	Unit:	%
Indicator:	Utilised Agricultural Area	Unit:	hectares
Indicator:	Relative utilised agricultural area to total area	Unit:	%
Indicator:	Relative sector size to total economy	Unit:	%
Indicator:	Size of agricultural compartments relative to total sector size	Unit:	%
Indicator:	Availability of agricultural by-products	Unit:	tons/year
Indicator:	Cultivation area of agricultural products	Unit:	hectares
Indicator:	Average produce of by-product	Unit:	tons/hectare
Indicator:	Relative size of dry matter	Unit:	%
Indicator:	Quantity of by-products	Unit:	tons
Indicator:	Quantity of dry matter	Unit:	tons
Indicator:	Total special waste per sector	Unit:	tons/year
Indicator:	Share of (agricultural) waste undergoing recovery and disposal per food industry	Unit:	%
Study:	(Ncube et al., 2021c)	**Method:**	LCA
Indicator:	Global warming potential	Unit:	kg CO_2 eq
Indicator:	Fine particulate matter formation potential	Unit:	kg PM2.5 eq
Indicator:	Terrestrial acidification potential	Unit:	kg SO_2 eq
Indicator:	Freshwater eutrophication potential	Unit:	kg P eq
Indicator:	Marine eutrophication potential	Unit:	kg N eq
Indicator:	Human carcinogenic toxicity potential	Unit:	kg 1,4-DCB
Indicator:	Mineral resource scarcity potential	Unit:	kg Cu eq
Indicator:	Fossil resource scarcity potential	Unit:	kg oil eq
Indicator:	Water consumption potential	Unit:	m^3
Study:	(Ncube et al., 2020)	**Method:**	LCA
Indicator:	Global warming potential	Unit:	kg CO_2 eq
Indicator:	Terrestrial ecotoxicity	Unit:	kg 1,4-DCB
Indicator:	Freshwater ecotoxicity	Unit:	kg 1,4-DCB
Indicator:	Marine ecotoxicity	Unit:	kg 1,4-DCB
Indicator:	Human carcinogenic toxicity	Unit:	kg 1,4-DCB
Indicator:	Human non carcinogenic toxicity	Unit:	kg 1,4-DCB
Indicator:	Freshwater eutrophication	Unit:	kg P eq
Indicator:	Land use	Unit:	m2a crop eq
Indicator:	Fossil resource scarcity potential	Unit:	kg oil eq
Study:	(Ncube et al., 2021a)	**Method:**	LCA
Indicator:	Global warming potential	Unit:	kg CO_2 eq
Indicator:	Ozone depletion	Unit:	kg CFC-11 eq
Indicator:	Smog	Unit:	m2a crop eq
Indicator:	Acidification potential	Unit:	kg SO_2 eq
Indicator:	Eutrophication potential	Unit:	kg N eq
Indicator:	Carcinogenics	Unit:	CTUh
Indicator:	Non carcinogenics	Unit:	CTUh
Indicator:	Respiratory effects	Unit:	kg PM2.5 eq
Indicator:	Ecotoxicity	Unit:	CTUe

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Indicator:	Fossil fuel depletion	Unit:	MJ surplus
Study:	(Santagata et al., 2021)	**Method:**	i-Tree and LCA
Indicator:	Tree over Pervious area	Unit:	km^2
Indicator:	Impervious non-plantable area	Unit:	km^2
Indicator:	Agricultural land area	Unit:	km^2
Indicator:	Impervious partially plantable area	Unit:	km^2
Indicator:	Shrubs/bushes area	Unit:	km^2
Indicator:	Grass/herbaceous cover area	Unit:	km^2
Indicator:	Tree over Impervious area	Unit:	km^2
Indicator:	Pervious non-plantable area	Unit:	km^2
Indicator:	Water area	Unit:	km^2
Indicator:	Other area	Unit:	km^2
Indicator:	Carbon Monixede absorbed	Unit:	CO
Indicator:	Nitrogen dioxide absorbed	Unit:	NO_2
Indicator:	Ozone absorbed	Unit:	O_3
Indicator:	Particulate matter PM10 absorbed	Unit:	PM10
Indicator:	Particulate matter PM2.5 absorbed	Unit:	PM2.5
Indicator:	Sulfuric Dioxide	Unit:	SO_2
Indicator:	Annual carbon sequestration	Unit:	kiloton/year
Indicator:	Lifetime carbon storage	Unit:	kiloton
Indicator:	Hydrological benefit	Unit:	Megaliters
Indicator:	Carbon sequestration	Unit:	USD/year
Indicator:	Air pollution removal	Unit:	USD/year
Indicator:	Hydrological benefit	Unit:	USD/year
Indicator:	Global warming potential	Unit:	kg CO_2 eq
Indicator:	Fine particulate matter formation potential	Unit:	kg PM2.5 eq
Indicator:	Terrestrial acidification potential	Unit:	kg SO_2 eq
Study:	(Santagata et al., 2020)	**Method:**	LCA and EMA
Indicator:	Climate change potential	Unit:	kg CO_2 eq
Indicator:	Stratospheric ozone depletion potential	Unit:	kg CFC11 eq
Indicator:	Ionising radiation potential	Unit:	kBq Co-60 eq
Indicator:	Ozone formation, Human health potential	Unit:	kg NO_x eq
Indicator:	Fine particulate matter formation potential	Unit:	kg PM2.5 eq
Indicator:	Ozone formation, Terrestrial ecosystems potential	Unit:	kg NO_x eq
Indicator:	Terrestrial acidification potential	Unit:	kg SO_2 eq
Indicator:	Freshwater eutrophication potential	Unit:	kg P eq
Indicator:	Marine eutrophication potential	Unit:	kg N eq
Indicator:	Terrestrial ecotoxicity potential	Unit:	kg 1,4-DCB
Indicator:	Freshwater ecotoxicity potential	Unit:	kg 1,4-DCB
Indicator:	Marine ecotoxicity potential	Unit:	kg 1,4-DCB
Indicator:	Human carcinogenic toxicity potential	Unit:	kg 1,4-DCB
Indicator:	Human non-carcinogenic toxicity potential	Unit:	kg 1,4-DCB
Indicator:	Land use potential	Unit:	m^2a crop eq
Indicator:	Mineral resource scarcity potential	Unit:	kg Cu eq
Indicator:	Fossil resource scarcity potential	Unit:	kg oil eq
Indicator:	Water consumption potential	Unit:	m^3
Indicator:	Emergy related to incineration, industrial composting and anaerobic digestion	Unit:	U
Indicator:	Emergy related to anaerobic digestion	Unit:	U
Study:	(Tiegam et al., 2021)	**Method:**	Literature Review
Indicator:	Biogas production	Unit:	Megawatt
Indicator:	Available residues for biogas production	Unit:	tons
Indicator:	Digesters	Unit:	Amount
Indicator:	Primary sources of energy mix	Unit:	%
Indicator:	Use of energy mix	Unit:	%
Indicator:	CO_2 pollution per sector	Unit:	Gg
Indicator:	CH_4 pollution per sector	Unit:	Gg
Indicator:	N_2O pollution per sector	Unit:	Gg
Indicator:	Total pollution per sector in CO_2 equivalent	Unit:	Gg

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Indicator:	Potential in biomass residues	Unit:	ton
Study:	(Oliveira et al., 2021a)	**Method:**	**LCA and EMA**
Indicator:	Climate change potential	Unit:	kg CO_2 eq
Indicator:	Stratospheric ozone depletion potential	Unit:	kg CFC11 eq
Indicator:	Ionising radiation potential	Unit:	kBq Co-60 eq
Indicator:	Ozone formation, Human health potential	Unit:	kg NO_x eq
Indicator:	Fine particulate matter formation potential	Unit:	kg PM2.5 eq
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Indicator:	Human carcinogenic toxicity potential	Unit:	kg 1,4-DCB
Indicator:	Human non-carcinogenic toxicity potential	Unit:	kg 1,4-DCB
Indicator:	Land use potential	Unit:	m^2a crop eq
Indicator:	Mineral resource scarcity potential	Unit:	kg Cu eq
Indicator:	Fossil resource scarcity potential	Unit:	kg oil eq
Indicator:	Water consumption potential	Unit:	m^3
Indicator:	Total Emergy	Unit:	sej
Indicator:	Unit Emergy Value	Unit:	sej/J
Indicator:	Percentage of Renewability	Unit:	%
Indicator:	Emergy Yield Ratio	Unit:	ratio
Indicator:	Environmental Loading Ratio	Unit:	ratio
Indicator:	Environmental Sustainability Index	Unit:	ratio

The overview in Table 2 shows a diverse set of indicators used in the different studies performed. There tends to be some overlap between LCA studies, but they all cover different material streams within the industry. While the literature review by Tiegam et al. (2021) and the QCA by Ghisellini et al. (2019) provide more of an overview of the entire sector, mostly connected to a specific region, the LCA studies complement them by showing the impact of possible interventions in the sector. In a study on improving the circularity of wineries, several by–product flows were identified, namely grape seed oil, calcium tartrate, bioethanol, exhausted flour, and yeast cells (Ncube et al., 2021c). An overview of the studied system is provided in Figure 1. By utilising the by-products, a lower environmental impact of the production system can be achieved according to the results of LCA. A similar study that applied LCA on different scenarios for using the by-products in olive oil production was performed, as showcased in Figure 2 (Ncube et al., 2020). By-products identified in olive oil production are pruning, pomace, olive seeds, wastewater, and waste cooking oil. By recovering and using the energy of these by-products, the LCA study showed that these material streams can lower the environmental impact of olive oil production. Two other studies looked into Sorrento's Lemon production system using LCA (Borzelli, 2021; Portarapillo, 2021), as shown in Figure 3. Again, LCA helped identify the environmental benefits of using by-products and limiting waste. A study on deriving biogas from organic waste at an AD plant, using LCA, was performed (Ncube et al., 2021a), as shown in Figure 4. In this case, using organic waste offers large environmental and economic opportunities when fossil fuels are replaced by electricity generation and heat

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production. In a different study on a dairy production system, using both LCA and EMA, whey and manure were identified as useful by-products that can help optimise the environmental quality of the entire system by reusing them as inputs on other parts of the production process (Oliveira et al., 2021a), as is shown in Figure 5.

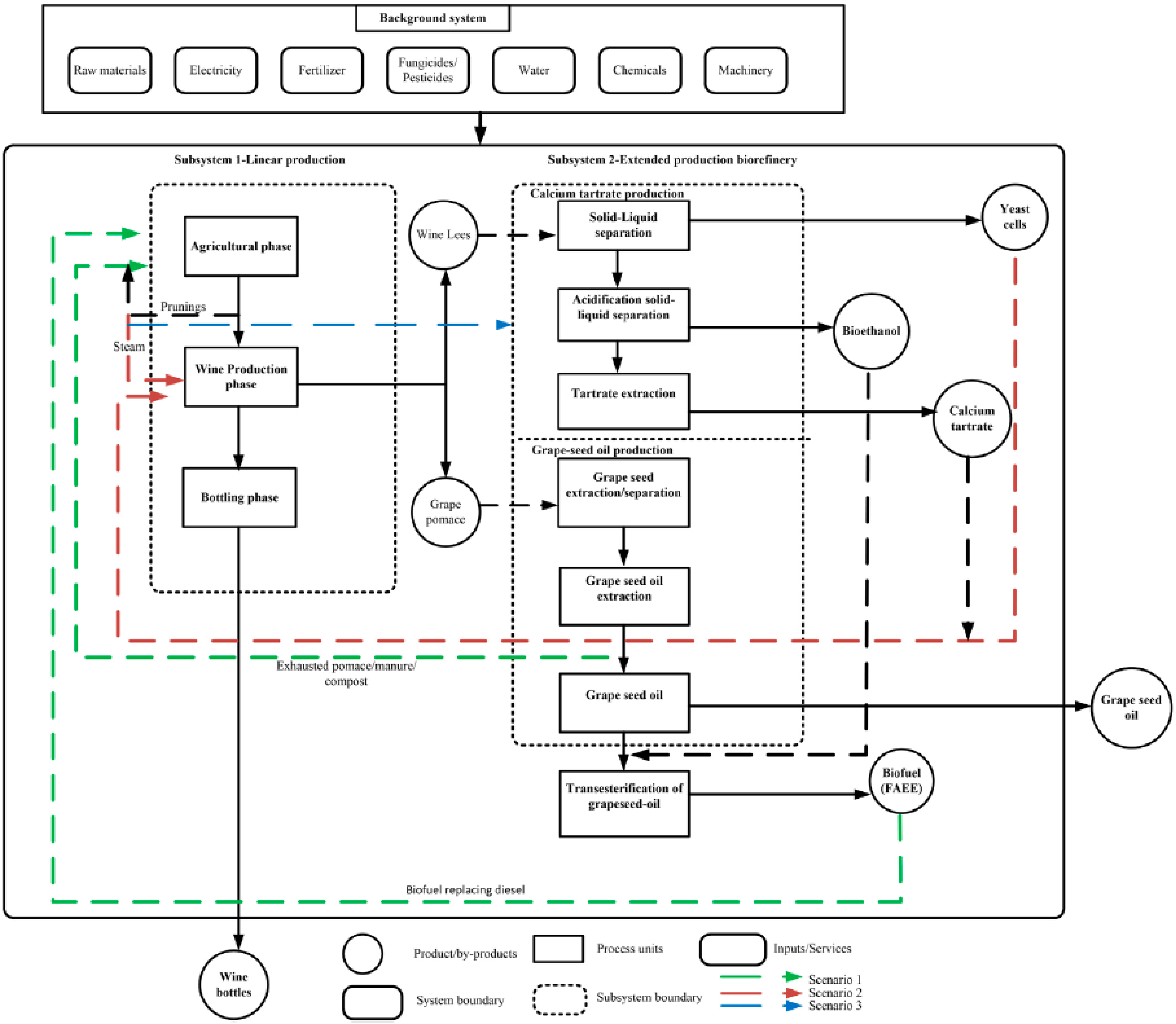

Figure 1. Process flow chart and investigated system boundary of a winery production system (Ncube et al., 2021c).

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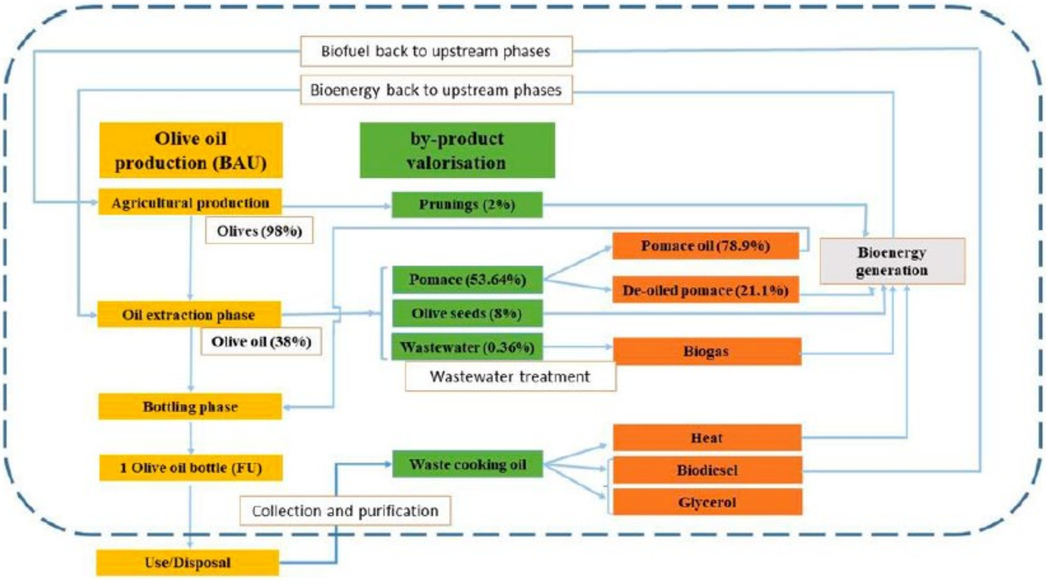

Figure 2. Process flow chart of olive oil production (Ncube et al., 2020).

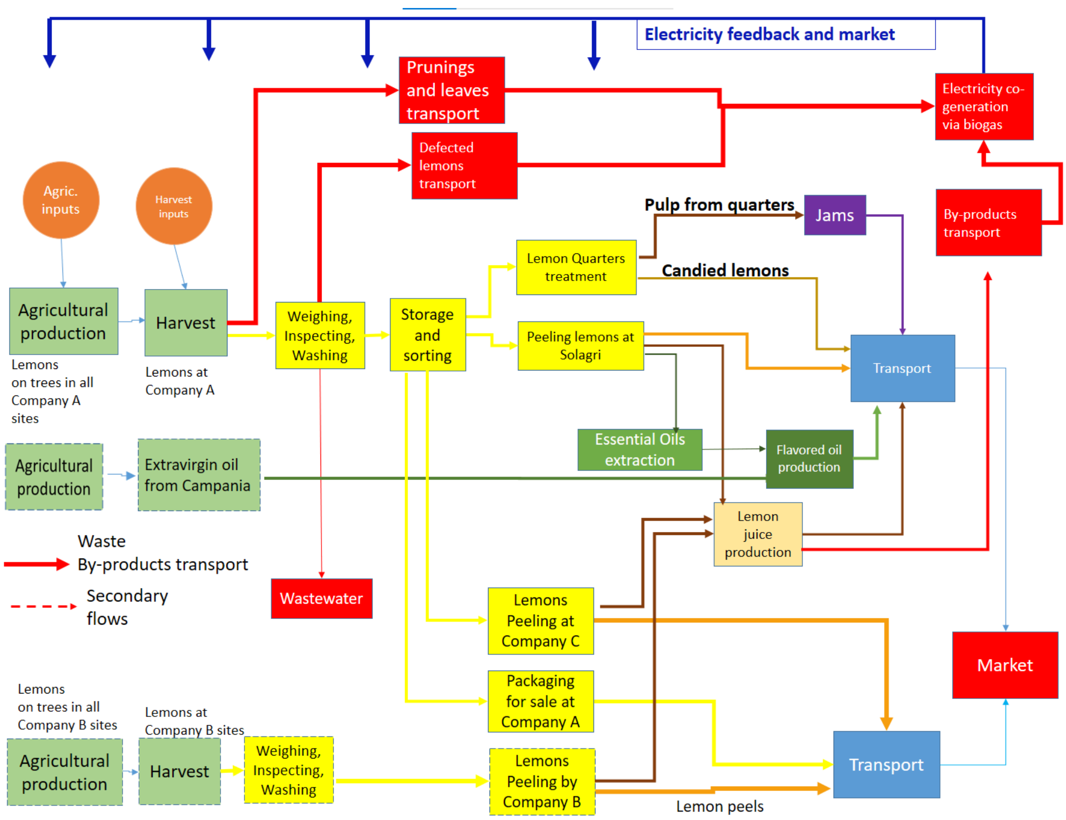

Figure 3. Process flow chart of Sorrento's lemon production (Borzelli, 2021; Portarapillo, 2021).

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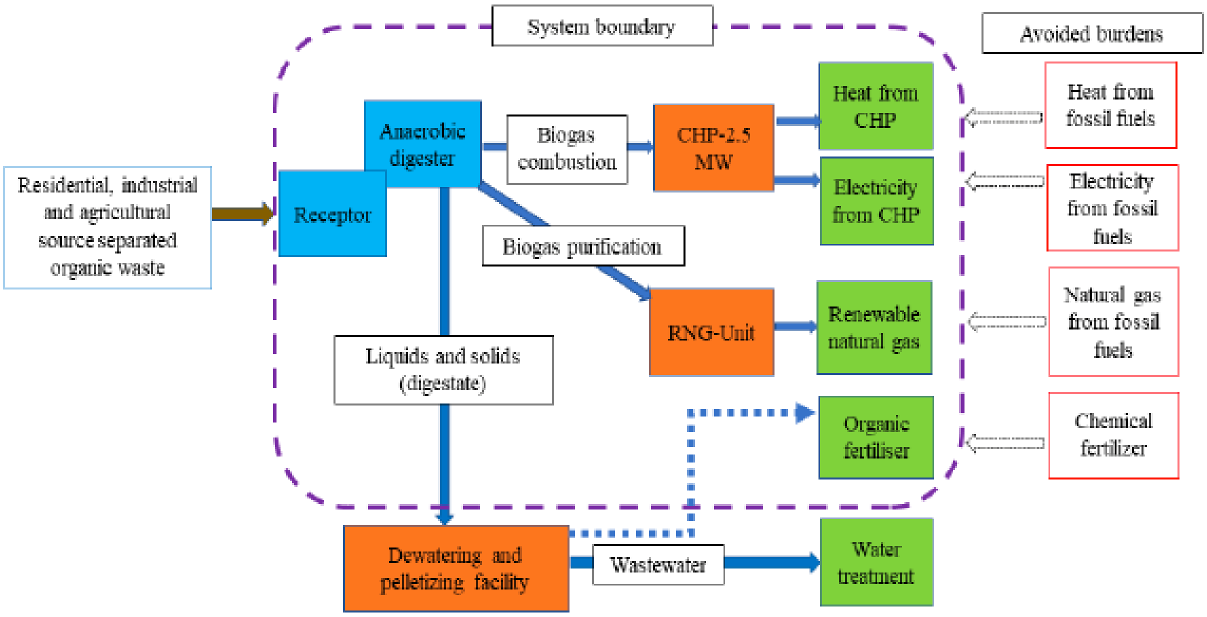

Figure 4. Graphical abstract from LCA study on utilising biogas from organic waste at an AD plant (Ncube et al., 2021a).

One example of where the studies complement each other is the work by Santagata et al. (2021), which considers the impact of covering Naples' urban land with trees, and the study by Ghisellini et al. (2019), which analyses, amongst other things, the land use in Campania and Naples. About one third of agricultural land within the Metropolitan City of Naples is used for olive trees, apple trees, pear trees, peach trees, and citrus trees (5795 hectares in total), with the remaining two thirds (10128 hectares) being used for other crops (Ghisellini et al., 2019a). Land where fruit trees are grown absorbs a significant amount of particulate matter from the air and provides several hydrological benefits, which are important for cities (Santagata et al., 2021). It follows that with the smart allocation of land, assigning agricultural land in or near urban areas for orchards, while moving other crops further from cities, significant gains can be made, and this is an interesting avenue for further studies.

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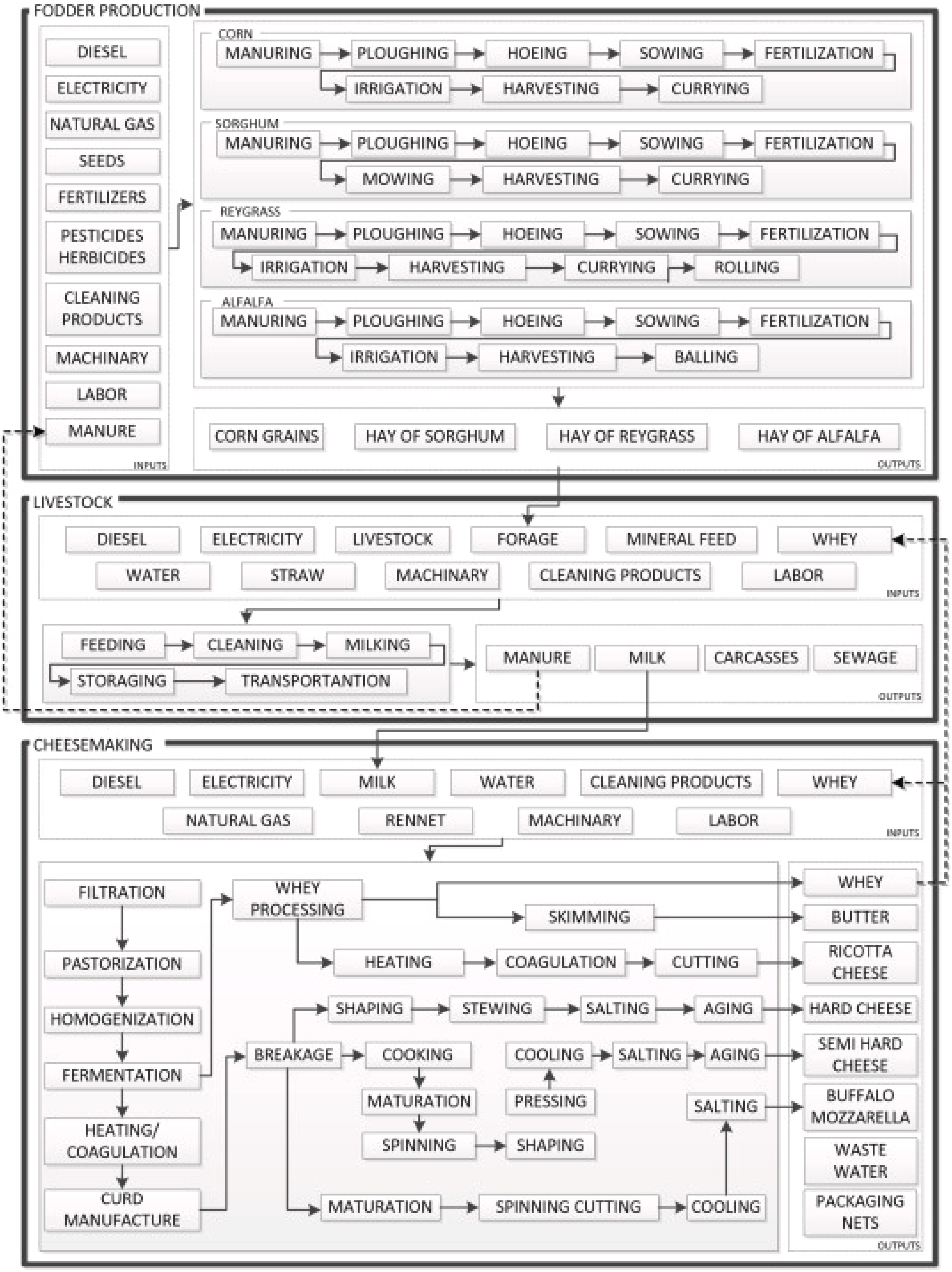

Figure 5. Overview of the studied dairy production system, with circular patterns highlighted by dashed arrows (Oliveira et al., 2021a).

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The LCA studies into upgrading wineries to biorefineries (Ncube et al., 2020) and valorising the co-products of olive oil production (Ncube et al., 2020), combined with the study by Ghisellini et al. (2019) into the main agricultural compartments in Campania and Naples and the total of by-products they each produce, can be used to inform decision makers on which interventions will give the greatest benefit. For example, the vine grape industry produces 195,616.7 tons of by-products in the Campania region annually, while the olive tree sector produces 94,651.1 tons annually in the same region (Ghisellini et al., 2019a). From this data, it seems logical that the regional government should focus on the vine grape industry, however, from the LCAs it follows that much of the environmental impact of the wine making is outside the agricultural phase, while for olive oil production 93% is produced by the agricultural phase, indicating it might be better to focus on circularising the olive oil material stream first within the agricultural sector.

While the study by Ncube et al. (2021a) focused on improving biogas refineries and the study by Tiegam et al. (2021) focused more on providing an overview of the biogas industry in Africa and China, the two studies on biogas complement each other. There is a lot of potential for more biogas refineries in Africa (Tiegam et al., 2021), but building the sector is not without its pollution. Different approaches to refining clearly have different environmental impacts, and some industries (such as steel and electricity) can benefit more from it than others (Ncube et al., 2021a). By combining studies on the most environmentally friendly options for biogas refineries and studies on which areas have the most potential (by-)products to use for biogas refineries, policy makers can make more informed decisions on funding new refineries.

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3.2 Manufacturing

Manufacturing research within Work Package 2 has mainly focused on the EEE industry, specifically on issues regarding WEEE/e-waste. An overview of identified methods and indicators is given in Table 3.

Table 3. Overview of studies performed in the manufacturing industry with their used methods and indicators.

Study:	(Ghisellini et al., 2019d)	**Method:**	QCA
Indicator:	Total collection rate of WEEE as percentage of EEE put to market in the three preceding years	Unit:	%
Indicator:	Amount of WEEE collected per capita	Unit:	kg
Indicator:	Materials recovered per ton of WEEE	Unit:	kg or m³
Indicator:	Energy recovered per ton of WEEE	Unit:	kWh or MJ
Indicator:	Total annual collected WEEE	Unit:	tons/year
Indicator:	Annual collected WEEE per product category	Unit:	tons/year
Indicator:	Annual collected WEEE per product category as percentage of total collected WEEE	Unit:	%
Indicator:	Share of WEEE categories per region	Unit:	%
Indicator:	Annual collected WEEE per capita	Unit:	kg
Indicator:	Change in annual collected WEEE per capita between years	Unit:	%
Study:	(Georgantzis Garcia & van Langen, 2021)	**Method:**	Literature Review, Statistical Analysis and Taxonomy Building
Indicator:	Household EEE put to market per capita in the EU	Unit:	kg
Indicator:	Household WEEE collected per capita in the EU	Unit:	kg
Indicator:	Percentage of household WEEE collected relative to the amount of household EEE put to market in the same year in the EU	Unit:	%
Indicator:	Household WEEE per capita that remains uncollected in the EU	Unit:	kg
Indicator:	Household EEE put to market per capita globally	Unit:	kg
Indicator:	Household WEEE collected per capita globally	Unit:	kg
Indicator:	Percentage of household WEEE collected relative to the amount of household EEE put to market in the same year globally	Unit:	%
Indicator:	Household WEEE per capita that remains uncollected globally	Unit:	kg
Indicator:	Taxonomy of EEE categories based on characteristics, physical, functional and symbolic, that predispose consumers to some behaviours	Unit:	size
Study:	(Bruno et al., 2021)	**Method:**	Case Study
Indicator:	Percentage of served population by WEEE collection centres	Unit:	%
Indicator:	Total number of WEEE collection centres per unit population	Unit:	ratio
Indicator:	Distance from user to nearest WEEE collection centre	Unit:	km
Indicator:	Average distance from users to nearest WEEE collection centre	Unit:	km
Indicator:	Maximum distance from users to nearest WEEE collection centre	Unit:	km
Indicator:	Fraction of users in a population that is under a specified distance to their nearest WEEE collection centre	Unit:	km

The amount of WEEE collected in Naples, as a percentage of EEE put to market in previous years is about 40% in 2018, slightly under the EU and the Italian average (Georgantzis Garcia & van Langen, 2021; Ghisellini et al., 2019d). Yet the average distance to collection centres in Napoli is, at 1.53 kilometres, one of the lowest in Italy, as shown in Figure 6 (Bruno et al., 2021). Taken together, this indicates that, despite the available infrastructure, Naples is underperforming in WEEE collection. As infrastructure is normally one of the more expensive aspects of WEEE collection, it stands to reason that Naples has a good potential for increasing the

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WEEE collection rate. However, from 2017 to 2018, the amount of WEEE collected per capita lowered in Naples and is the lowest in the entire Campania region, as shown in Table 4. This makes WEEE in Naples a promising material stream to study further, to assess why Naples is underperforming despite its good collection centre infrastructure and to design interventions that can increase the WEEE collection rate.

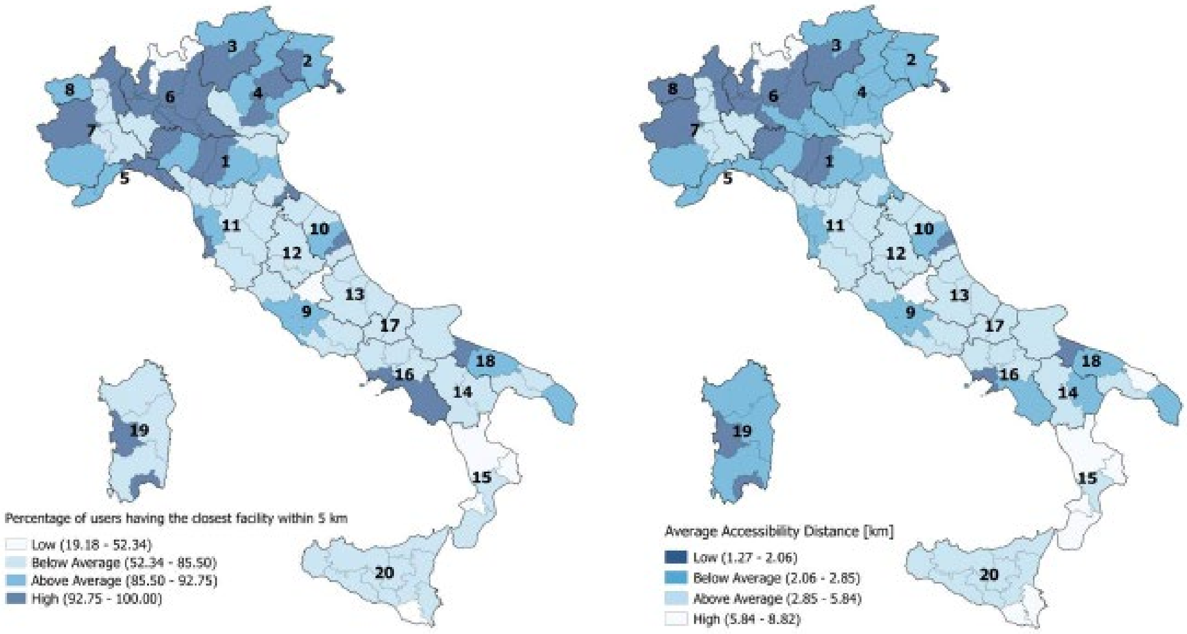

Figure 6, Percentage of users with a WEEE collection centre within 5 kilometres, and the average distance for users to their nearest WEEE collection centre per region in Italy (Bruno et al., 2021).

Table 4, WEEE collected per capita in Italy and selected regions in 2018, adapted from Ghisellini et al., (2019d)

Region	**WEEE Collection per Capita in 2018** (kg)	**Change from 2017 to 2018** (%)
Avellino	3.19	5.11%
Benevento	3.02	17.19%
Caserta	5.42	7.06%
Naples	*2.24*	*-1.33%*
Salerno	2.38	3.94%
Campania Region	2.96	3.29%
Southern Italy and Islands	3.54	5.55%
Italy	5.14	4.84%

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3.3 Water Supply; Sewerage, Waste Management and Remediation Activities (E)

Table 5 provides the indicators on the different studies in the Water Supply, Sewerage, Waste Management and Remediation Activities industry. The studies complement each other by looking at the quantity of wastewater and potential uses of that wastewater.

Table 5, Overview of studies performed in the water supply, sewerage, waste management and remediation activities industry with their used methods and indicators.

Study:	(Ghisellini et al., 2019c)	**Method:**	QCA
Indicator:	City population	Unit:	amount
Indicator:	Parameters of non-compliance	Unit:	substances
Indicator:	Average waterflow	Unit:	m^3/hour
Indicator:	Maximum water flow	Unit:	m^3/hour
Indicator:	BOD5	Unit:	kg/day
Indicator:	Nitrogen	Unit:	kg/hour
Indicator:	Wastewater treated	Unit:	m^3/year
Indicator:	Dry sludge production	Unit:	kg/year
Indicator:	Potential nitrogen recovery	Unit:	kg/year
Indicator:	Potential biogas (as syngas) recovery	Unit:	Nm^3/year
Indicator:	Distribution of re-used urban sledge to different sectors	Unit:	%
Indicator:	Companies active in water collection, treatment, and provision	Unit:	amount
Indicator:	Companies active in sewage management	Unit:	amount
Indicator:	Total quantities of wastewater	Unit:	m^3/year
Study:	(Catone et al., 2021)	**Method:**	Literature Review
Indicator:	Lipid content of wastewater	Unit:	%
Indicator:	Biomass concentration of wastewater	Unit:	g/L
Indicator:	Biomethane yields	Unit:	L/g
Indicator:	H_2 production yields	Unit:	kg H ha^{-1} d^{-1}
Indicator:	N and P absorption	Unit:	%
Indicator:	Caloric value of biomass	Unit:	kcal g^{-1}
Indicator:	Urban treated wastewater	Unit:	L/a
Indicator:	Biomass productivity	Unit:	ton/L_{tot}
Indicator:	Lipids productivity	Unit:	ton/L_{tot}
Study:	(Colella et al., 2021)	**Method:**	QCA and Literature Review
Indicator:	Regional availability of ground and surface water	Unit:	%
Indicator:	Interregional water imports and exports	Unit:	Mm^3/year
Indicator:	Total water availability	Unit:	Mm^3/year
Indicator:	Volume of water withdrawn	Unit:	Mm^3/year
Indicator:	Annual per capita water withdrawal	Unit:	m^3/year
Indicator:	Water consumption per capita	Unit:	m^3/year
Indicator:	Amount of treated wastewater per municipality	Unit:	Mm^3/year
Indicator:	Water consumption per sector	Unit:	%
Indicator:	(Potential) material gains from wastewater treatment	Unit:	kg or ton

Catone et al. (2021) studied the potential of growing microalgae in urban wastewater, focussing on the species that can best be used and obtainable bio-based products from this process. The Chlorella and Scenedesmus species of microalgae were found most useful to create biofuels such as biodiesel and biogas from urban wastewater. Furthermore, algae fed on urban wastewater can produce fertilizers, biochar, bioplastics, animal

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feeds, and molecules for the pharmaceutical and cosmetic industries. By using wastewater, the eutrophication by wastewater that typically occurs in ecosystems can be avoided. The papers by Colella et al. (2021) and Ghisellini et al. (2019c) both look at wastewater quantities in the Campania region while the paper of Catone et al. (2021) looks at its potential for producing biofuels and other products using microalgae. The studies on wastewater quantities use several different metrics and can be well combined to get a better overview of the wastewater in the Campania region. Combining these studies can give an estimation of retrievable lipid and the amounts of eutrophication that can be avoided by creating microalgae plants in the Campania region. i.e., the Campania region produces about 635 million m^3 of wastewater each year, of which 456 m^3 (72%) goes through the two largest wastewater plants, which, with a found biomass concentration of ~1.3g/L when using Scenedesmus algae to treat the wastewater could mean a potential of 825500 metric ton of biomass that could be produced annually in these two plants alone.

3.4 Construction (F)

Table 6 provides the indicators on the different studies in the construction industry.

Table 6. Overview of studies performed in the construction industry with their used methods and indicators.

Study:	(Ghisellini et al., 2019b)	**Method:**	QCA
Indicator:	Waste generation by economic activity	Unit:	%
Indicator:	Recycling rates	Unit:	%
Indicator:	Distribution of land use	Unit:	%
Indicator:	Buildings per economic use	Unit:	amount
Indicator:	Buildings per construction type	Unit:	amount
Indicator:	Buildings per height category	Unit:	amount
Indicator:	Material intensity of (reinforced) concrete and steel	Unit:	kg/m^2
Indicator:	(Reinforced) concrete and steel per building type	Unit:	kg
Indicator:	Total of (reinforced) concrete and steel	Unit:	kg
Indicator:	Total production of C&DW (split for hazardous and non-hazardous material)	Unit:	kg
Indicator:	Special waste produced per classification	Unit:	ton/year
Indicator:	Composition of special waste that undergoes recycling or recovery treatments	Unit:	%
Indicator:	Number of waste treatment plants	Unit:	amount
Indicator:	Number of companies in the construction sector, split per legal form	Unit:	amount
Indicator:	Number of workers in the construction sector, split per company size	Unit:	amount
Study:	(Ncube et al., 2021c)	**Method:**	LCA
Indicator:	Global warming potential	Unit:	kg CO_2 eq
Indicator:	Fine particulate matter formation potential	Unit:	kg PM2.5 eq
Indicator:	Land use	Unit:	m2a crop eq
Indicator:	Land use	Unit:	m2a crop eq
Indicator:	Water consumption potential	Unit:	m^3
Study:	(Cristiano et al., 2021)	**Method:**	QCA, i-Tree and SWOT
Indicator:	Buildings per economic use	Unit:	amount
Indicator:	Buildings per construction type	Unit:	amount
Indicator:	Buildings per height category	Unit:	amount
Indicator:	Material fractions of annual C&DW production	Unit:	%

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Indicator:	Annual C&DW production	Unit:	ton/year
Study:	(Liu et al., 2020a)	**Method:**	EMA
Indicator:	Production of steel making steps	Unit:	ton/year and %
Indicator:	Emergy benefit ratio	Unit:	EBR
Indicator:	Emergy yield ratio	Unit:	EYR
Indicator:	Environmental loading ratio	Unit:	ELR
Indicator:	Emergy sustainability index	Unit:	ESI
Indicator:	Renewable fraction of emergy used	Unit:	%R
Indicator:	Product emergy money ratio	Unit:	sej/$
Indicator:	Empower density	Unit:	sej/(m^2*yr)
Indicator:	Renewable empower density	Unit:	RED
Indicator:	Embodied land	Unit:	m$_2$
Indicator:	UEV values of iron and steel making processes	Unit:	sej/t
Study:	(Liu et al., 2020b)	**Method:**	LCA
Indicator:	Agricultural land occupation	Unit:	m2*a*t^{-1}
Indicator:	Climate Change	Unit:	kg CO_2 eq*t^{-1}
Indicator:	Fossil depletion	Unit:	kg oil eq*t^{-1}
Indicator:	Freshwater ecotoxicity	Unit:	kg 1,4-DB eq*t^{-1}
Indicator:	Freshwater eutrophication	Unit:	kg P eq*t^{-1}
Indicator:	Human toxicity	Unit:	kg 1,4-DB eq*t^{-1}
Indicator:	Ionising radiation	Unit:	kg U_{235} eq*t^{-1}
Indicator:	Marine ecotoxicity	Unit:	kg 1,4-DB eq*t^{-1}
Indicator:	Marine eutrophication	Unit:	kg N eq*t^{-1}
Indicator:	Metal depletion	Unit:	kg Fe eq*t^{-1}
Indicator:	Natural land transformation	Unit:	m$_2$*t^{-1}
Indicator:	Ozone depletion	Unit:	kg CFC-11 eq*t^{-1}
Indicator:	Particulate matter formation	Unit:	kg PM10 eq*t^{-1}
Indicator:	Photochemical oxidant formation	Unit:	kg NMVOC*t^{-1}
Indicator:	Terrestrial acidification	Unit:	kg SO_2 eq*t^{-1}
Indicator:	Terrestrial ecotoxicity	Unit:	kg 1,4-DB eq*t^{-1}
Indicator:	Urban land occupation	Unit:	m^2*a*t^{-1}
Indicator:	Water depletion	Unit:	m^3*t^{-1}

A study investigated replacing clay with fly ash, an environmentally damaging by-product of brick manufacturing, in the brick production process, is proposed by Ncube et al. (2021c). An overview of the process is provided in Figure 7 (Ncube et al., 2021c). LCA showed that replacing clay with fly ash significantly reduces environmental damage by the industry by both reducing the disposal of waste and the amount of clay required in the production process. Clay pit expansion will be reduced leading to a lower loss of topsoil, which also increases food security. Another study investigated construction and demolition waste in the Metropolitan City of Naples showing a lack of demand for recycled products (Cristiano et al., 2021). By combining i-Tree analysis and SWOT analysis it was found that the amount of construction and demolition waste was underestimated, with 903,000 tons of non-hazardous waste produced annually. Moreover, two studies have been performed on the iron and steel industry in China, one utilising EMA and the other utilising LCA (Liu et al., 2020a; Liu et al., 2020b). An overview of the iron and steel making process is given in Figure 8. They found that recycling steel provides significant environmental performance improvements in both EMA analysis and LCA. Furthermore, it helps in reducing reliance on foreign imports which could be disrupted.

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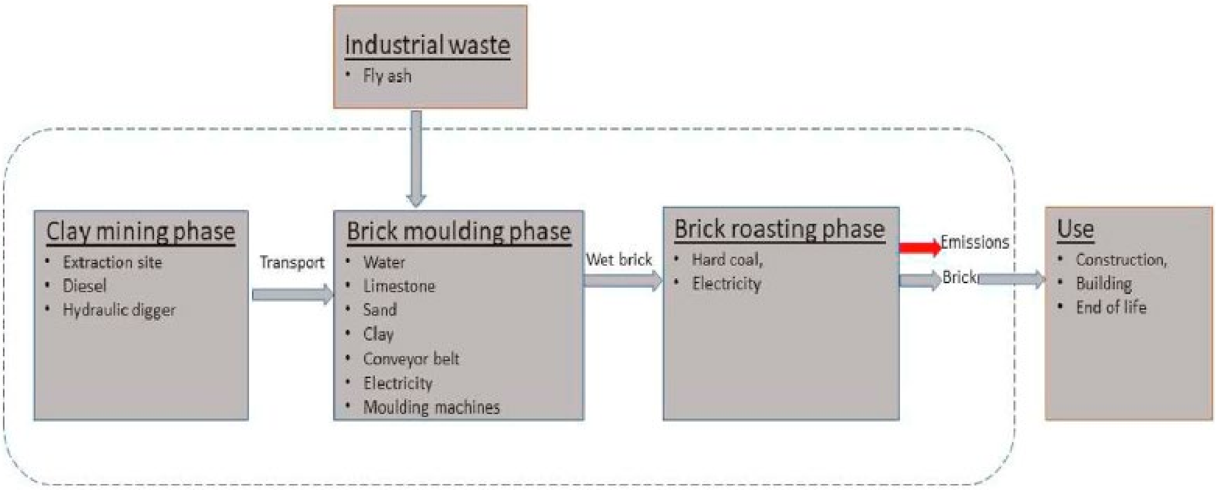

Figure 7, Brick manufacturing production system (Ncube et al., 2021c).

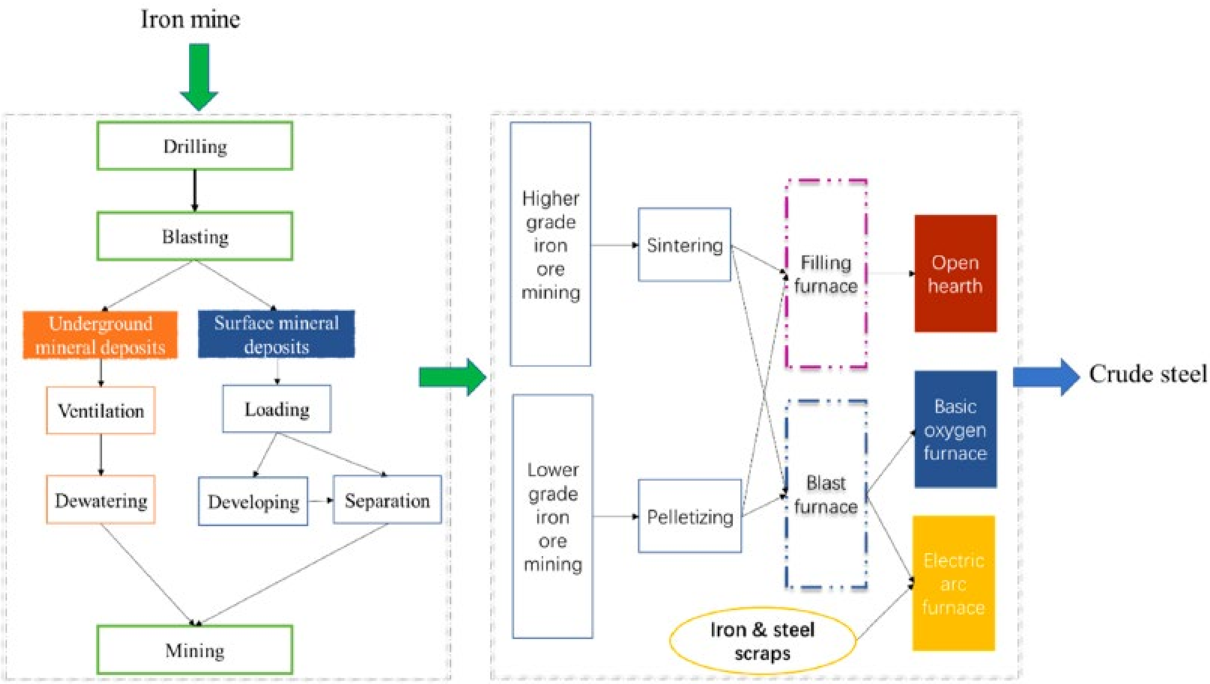

Figure 8, Flow chart of the iron and steel production system (Liu et al., 2020b).

While the studies on iron and steel production and the study on available iron and steel in construction and demolition waste covered different regions (Cristiano et al., 2021; Liu et al., 2020a; Liu et al., 2020b), they can still tell us some useful things. In Naples, 903,000 tons of non-hazardous waste is produced annually of which

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7% is iron and steel (63,210 tons). While Italy's mix of iron ore and steel imports is different than that of China, they are both reliant on the same major exporters, in fact Italy is entirely reliant on imports of iron ore as well as a large part of its steel needs. The studies on iron and steel production show that the electric arc furnace process for turning iron and steel scraps into crude steel provides a large environmental benefit over using virgin iron ore. It is thus advised that the city of Naples invests in this production process to better utilise the large amount of iron and steel waste in its construction industry, providing both environmental benefits and new jobs. Moreover, considering also that electric arc furnaces are flexible in how much scrap they handle, they are not reliant on a constant flow of material which is often an issue in using waste products as material inputs.

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4. Final remarks and lessons learned

The results show that both quantitative and qualitative studies into specific industries and material streams can be indeed combined, to synthesise new findings for identifying promising material streams in the transition to the CE. The approach of providing an overview of the used indicators for each study helps in identifying opportunities for synthesis that is useful for policy makers. Through the combination of multiple approaches, mixed methods synthesis represented a viable approach for deriving new insights based on existing studies. Especially studies that focus on the same region showed promise, as we did several times for the Campania region/city of Naples in this deliverable.

Within the sector of Agriculture, Forestry and Fishing, several novel findings were achieved, always exploiting the combination of qualitative and quantitative approaches; specifically, material streams were not only classified based on their suitability for the transition towards a CE, but also prioritised. Individual studies using methods such as LCA and/or EMA were already quite successful in identifying material streams on their own. In the manufacturing sector we learned, by combining studies, that the city of Naples has a rather good infrastructure for WEEE collection, but still severely underperforms in collection rates, indicating that there is a lot to be gained in this material stream without the need to invest in expensive infrastructure, but by investing in better organisation mechanisms of the system actors on the one hand and greater involvement and communication with citizens on the other. Synthesising the results of the available studies on the Water Supply; Sewerage, Waste Management and Remediation Activities sector shows that by investing in a microalgae biomass production process in only two wastewater plants in Naples can yield significant improvements in biomass production from wastewater and in avoiding eutrophication by wastewater, turning wastewater into an interesting material stream for the transition to a CE. In the construction sector the main lesson learned, by looking at the different available studies, is that by better utilising the stockpile of iron and steel in Naples' annual construction and demolition waste significant environmental benefits could be gained. However, the exact amount depends on the mix of iron and steel imports, specifically as to from which country they originate, this requires further study. A further benefit should be the reduction of dependence on imports of iron ore and steel. This study was limited in that within each sector only a limited number of studies was available, as selection was based on studies performed by our work package. In future studies, it is strongly suggested to cover a larger number of studies on the topic under analysis. This can improve both the quality and quantity of the findings. While this study covered several sectors, it was performed for testing if this methodology is useful for the study aim of material stream identification. It is then recommended that future studies focus on a single sector per study.

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While existing methods for material stream identification, such as LCA and EMA, are effective in achieving their goal, mixed method synthesis is found to be a good method to identify additional material streams that are important for the transition to a CE. It can present both newly found material streams and strengthen the results of the studies it synthesises. In this study, coherently with the aim to contribute to provide a new methodological approach for material stream identification in the perspective of the CE, the method was applied to four different sectors and provided valuable and interesting results in each of them.

4.1 Lessons learned

- Mixed method synthesis can help in material stream identification, bringing new insights to existing studies. They combine quantitative and qualitative aspects allowing to widen the knowledge in those cases in which the results from different studies reinforce, contradict, or supplement each other. While methods like LCA and EMA on their own are successful in identifying promising material streams for the transition to CE, more results are gained from combining quantitative and qualitative studies in a synthesis. In view of this, mixed method synthesis could aspire to become a novel methodology for material streams identification in the CE perspective.

- Studies focussing on the same sector within the same region are the best candidates for synthesis as they provide a set of homogeneous conditions that favour a linear interpretation of the phenomena that are analysed. If the sectors and regions differ, more variables become different, which makes it harder to accurately identify promising material streams.

- Results obtained through mixed method synthesis are typically based on 2-3 studies. This is for the same reason as with the previous point: Iif too many variables are different, it becomes harder to reach sound new findings and this does not support the policy makers' efforts.

- Besides identifying material streams, the used approach can help in prioritising material streams for policy makers. For example, a qualitative study about the effectiveness of an intervention to circularize a material stream could be combined with a quantitative study that showcases the size of said material stream in region. This can allow policy makers to better assess the impact of supporting certain interventions and not others.

- Starting with an overview of the methodologies and indicators used in each study is a good starting point to find topics on which papers can strengthen and/or complement each other. This gives a clear overview of what is measured in each study and can help to better analyse the results of an individual

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paper when you consider its relation to indicators used in other studies. Policy makers can benefit from this aspect.

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