H2020 MSCA-ITN-2018

ReTraCE Project

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

D1.5

Measuring circularity in supply chains:

From theoretical assumptions to practical experiences

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

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Contributors: Andrew Brint, Tommaso Calzolari, Andrea Genovese, Ben Lowe, Ben Purvis, Azar MahmoumGonbadi

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General purpose and objectives of the report

Adequate measurement approaches are key to ensure the success and sustainability of the implementation of Circular Economy (CE) initiatives in industrial practices. It is therefore important to rely upon models and decision support tools to compare and assess the performances of production systems using a wide range of sustainability indicators. This requires to employ different metrics assessing all sustainability dimensions across the supply chain.

The ReTraCE project aims to progress understanding of how the transition towards a CE can be successfully realised in the European context, not only through innovative and sustainable business models, but also through the transformation of the current structure of supply chains. The proposed approach within the ReTraCE project is multi-disciplinary, drawing upon different work packages that will significantly advance the CE paradigm from an economic, environmental and social standpoint. This report is part of the Work Package 1 (WP1: Circular Production and Consumption Systems) of the ReTraCE project, which focuses on Supply Chain Management (SCM) aspects within the CE paradigm.

Previous analysis on circular economy indicators for supply chains shows that there is not a univocal approach to measure the circular economy and that literature and practice make different choices in terms of metrics selection. This was also the main contribution of D1.1 ("Measuring the transition towards circular supply chains: insights from academic literature and industrial practice", detailed in chapter 2) which is a first step and precursor of this deliverable.

If D1.1 has examined the literature to better understand the state of the art of circular economy indicators for supply chains, D1.5 aims to do some steps further. The literature review presented in D1.1 is further extended in Chapter 1, where methodological assumptions behind current indicators' systems are discussed to a greater detail[1]. Specifically, this Chapter details an important aspect that is often overlooked and not explicitly addressed when discussing indicators' systems: the underlying *value* assumptions. Moving from these premises, Chapter 2[2] goes on to discuss the *value* assumptions which underpin plausible future configurations of a Circular Economy. It is postulated that, within the broad umbrella of the Circular Economy, alternative and contrasting future configurations might exist; each of these might be characterised by a different conceptualisation of value, and, in turn, place emphasis on specific sustainability dimensions. Chapter 3 turns to the practice, and presents the results of an industrial secondment, where two leading CE indicators promoted by established think tanks are applied to the assessment of the operations of an industrial organisation, drawing some useful implications on the appropriateness of these indicators. Finally, Chapter 4 builds on the theoretical premises from Chapters 1 and 2, and on the practical implications drawn from Chapter 3 in order to build a potential dashboard of CE indicators at a supply chain level through a participatory approach. This exercise allows the identification of risks and traps related to the usage of indicators for the measurement towards a CE, also verifying in practice some of the theoretical premises from Chapters 1 and 2, and providing some concluding guidelines and remarks.

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[1] A journal paper version of this chapter is available in the following publication: Calzolari, T., Genovese, A., & Brint, A. (2022). Circular Economy indicators for supply chains: A systematic literature review. *Environmental and Sustainability Indicators*, *13*, 100160.
[2] A journal paper version of this paper is available in the following publication: Lowe, B. H., & Genovese, A. (2022). What theories of value (could) underpin our circular futures?. *Ecological Economics*, *195*, 107382.

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CHAPTER 1
Circular Economy Indicators for Supply Chains: A Systematic Literature Review

Tommaso Calzolari, Andrea Genovese, Andrew Brint

Abstract: Recently, the Circular Economy paradigm has emerged as an alternative to linear and unsustainable production and consumption systems. In order to implement Circular Economy practices and evaluate their effects, organisations need adequate measurement tools. These tools should extend beyond the single firm boundary and consider the complexity of supply chains, material flows, and environmental and social impacts. However, no established indicator exists to assist the transition of supply chains to a higher degree of circularity; also, most of the literature on Circular Economy indicators has focused on the firm rather than on the supply chain as the level of analysis. Through a Systematic Literature Review, this chapter examines decision support tools, and related indicators, employed for assessing the performance of Circular Supply Chains in the academic literature. In parallel, a content analysis and a template technique are employed to evaluate how Multi National Enterprises measure the effect of the adoption of Circular Economy practices in their reports. Results are synthesised in two composite indicators, which aggregate the most commonly employed metrics. Findings show that both academic literature and industrial practice show a scarce consideration of social and circularity measurements, rather focusing on classical environmental impacts and economic ones. In the academic literature, the economic dimension is prevalent; practitioners seem to evaluate and communicate more often the environmental impacts of already adopted Circular Economy practices. Also, different indicators' categories (monetary, biophysical, composite indicators) are recognised, according to their choices in terms of selection and aggregation of different metrics and to the contribution they can bring to the transition from linear to circular supply chains.

Keywords: Circular Economy, Indicators, Systematic Literature Review, Supply Chains, Performance Measurement, Sustainability Assessment

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1 Introduction

Since the first industrial revolution, supply chains have operated according to a linear paradigm, based on the extraction and unsustainable use of natural resources. This has caused irreversible ecological damage, as half of the total greenhouse gas emissions and more than 90% of biodiversity and water losses are related to resource extraction and processing (Bressanelli et al., 2019; Kazemi et al., 2019; European Commission, 2020). The Circular Economy (CE) concept was developed to reverse unsustainable patterns of development and create long-term prosperity (Fitch-Roy et al., 2020). In the CE paradigm, every economic activity should maximise ecosystem functions and human well-being (Murray et al., 2017). As such, the frontiers of environmental sustainability are pushed forward, and products are transformed in such a way that there are workable relationships between ecological systems, economic growth and human well-being. A higher circularity in the use of materials is supposed to provide organisations with a wide range of economic benefits; these include: reduced materials costs, greater value extraction from resources and greater resilience (Rosa et al., 2019), as well as a positive contribution to environment and society as a whole (Chiappetta Jabbour et al., 2019; WBCSD, 2019).

Because of the benefits of circular supply chains (CSCs), companies have recently been placing more emphasis on achieving sustainable production, by shifting from simple mitigation actions to a focus on prevention of environmental damage, based on whole lifecycle assessment and integrated environmental strategies and management systems (Zhu et al., 2011; Larsen et al., 2018). This trend has also become apparent in the academic literature focused on supply chain management (SCM) where many scholars have analysed how to close the loop of products and materials (Govindan & Bouzon, 2018; Lahane et al., 2020). Within the Industrial Ecology (IE) (Helander et al., 2019), Green and Sustainable Supply Chain Management (GSCM and SSCM) (Genovese et al., 2017) and Closed-Loop Supply Chain Management (CLSCM) streams of literature (Rezaei et al., 2019), decision support tools (DSTs) for designing and assessing CSCs have been proposed (Bressanelli et al., 2019; Kazemi et al., 2019). These DSTs employ several CE indicators to measure the adoption of CE practices towards desired targets (e.g. economic, environmental and social) (Morseletto, 2020).

However, existing reviews of CE indicators show that there is no agreement among researchers and practitioners on what metrics should be selected for the different sustainability pillar and on how to deal with trade-offs (Sassanelli et al., 2019; Saidani et al., 2019; Vinante et al., 2021). There is no consensus on a set of indicators that should measure desirable levels of circularity and establish improvement pathways for production and consumption systems (Vinante et al., 2021). However, these reviews (Saidani et al., 2019; Sassanelli et al., 2019; Vinante et al., 2021) focus on indicators and tools at the firm level rather than including existing knowledge and research gaps at the supply chain level.

To fill this gap, this study reviews CE indicators at a supply chain level developed and employed in the academic literature and in the industrial practice. This will allow the identification of a subset of frequently employed metrics across all the sustainability pillars and the proposal of two prototypes of indicators. These two indicators select and aggregate the most frequently mentioned metrics in the academic literature and in industrial practice. The review also questions the reductionist nature of the different approaches employed for measuring the performance of supply chains from a CE perspective. It then proposes a research agenda aimed at overcoming the limitations of the current literature.

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The remainder of this chapter is arranged as follows. The next section introduces the research background, defining CSCs and the different approaches that decision support systems can adopt, along with the general sustainability measurement debate. In Section 3, the method utilised to tackle the research questions is illustrated. Firstly, a systematic literature review (SLR) explores DSTs in the context of decision making in CSCs. Secondly, content analysis is used to reveal the CE Indicators in a general sample of Corporate Sustainability (CS) Reports from Multi National Enterprises (MNEs). Section 4 shows the results of both analyses, the most frequent metrics in DSTs for CSCs, the type of decision supported, and the type of sustainability dimension considered. Indicator systems are classified in to three groups on the basis of their underlying assumptions; a taxonomy of CE indicators for MNEs is also presented. In Section 5, results are discussed and a research agenda is proposed for supporting the development of CE indicators for supply chains.

2 Research background

Supply chains and inter-firm relationships have a crucial role in supporting the transition towards a CE (EMAF, 2015; Fischer & Pascucci, 2017; Herczeg et al., 2018). In CSCs (Figure 1), companies cooperate not only to deliver goods and services to customers, but also to provide feedback loops that allow for methods of production to be self-sustaining and for materials to be used multiple times (Bocken et al., 2013; den Hollander et al., 2017; Webster, 2017). Products are designed to last longer and to flow through multiple use phases (Bovea & Pérez-Belis, 2018; Sassanelli et al., 2020); materials are recovered and recycled many times (Go et al., 2015; Wahab et al., 2018). A very important role is played by how products and business models are designed (Bocken et al., 2016, 2017; Pigosso & McAloone, 2017; Lüdeke-Freund et al., 2019; Centobelli et al., 2020), with companies providing services and *performances*, rather than just products (Tukker, 2015; Prendeville & Bocken, 2017; Sassanelli et al., 2019). The result is that each product is considered as an asset, whose value is to be preserved for as long as possible in an attempt to displace (at least partially) the demand for new products and primary materials (Zink & Geyer, 2017; Rocca et al., 2021). This is expected to help keep consumption levels inside the earth's boundaries (Rockström et al., 2009). A CSC should be able to:

- Coordinate forward and reverse logistics supporting the creation of value from circular business models and products as a service (Batista et al., 2018; Ebikake et al., 2018);
- Reduce (ideally, to zero) the waste streams it produces by systematically restoring technical materials and regenerating biological materials (Farooque et al., 2019);
- Limit the throughput flow of societal systems to a level that nature tolerates, and utilises ecosystem cycles in economic cycles by respecting their natural reproduction rates (Korhonen et al., 2018).

The Literature is currently exploring enablers of CSCs. Digital technologies (Acerbi & Taisch, 2020; Chiappetta Jabbour et al., 2020; Acerbi et al., 2021) the integration with supply chain partners (Herczeg et al., 2018; Bressanelli et al., 2019; Elia et al., 2020), as well as collaboration with external partners (Cricelli et al., 2021) seem to play a key role in supporting organisations to adopt CE practices.

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2.1 Measuring sustainability in circular supply chains

Decision-makers need tools to evaluate the adoption of CE practices, and operationalise profitable, efficient, circular and sustainable supply chains. Decision support tools employ many CE indicators to account for a variety of impacts across boundaries between firms (Maestrini et al., 2017), concerning every dimension of sustainability (i.e. economic, environmental and social) (Figure 2). CE indicators are formed by single or multiple metrics, which can be defined as the "finest level of granularity for assessment means" (Vinante et al., 2021).

CE assessment metrics, indicators, methods and methodologies at the firm level have been extensively reviewed (Elia et al., 2017; Saidani et al., 2019; Sassanelli, Rosa, et al., 2019; Vinante et al., 2021). These papers confirm there is a lack of agreement on what needs to be measured, of standard methods of measurement and even of shared terminology and conceptualisation of the CE. For this reason they try to categorise indicators into frameworks and taxonomies to integrate current performance assessment methods of firms' functions with CE principles.

Figure 1. *Circular Supply Chain as part of the Ecological system (adapted from Bloemhof-Ruwaard, 2015)*

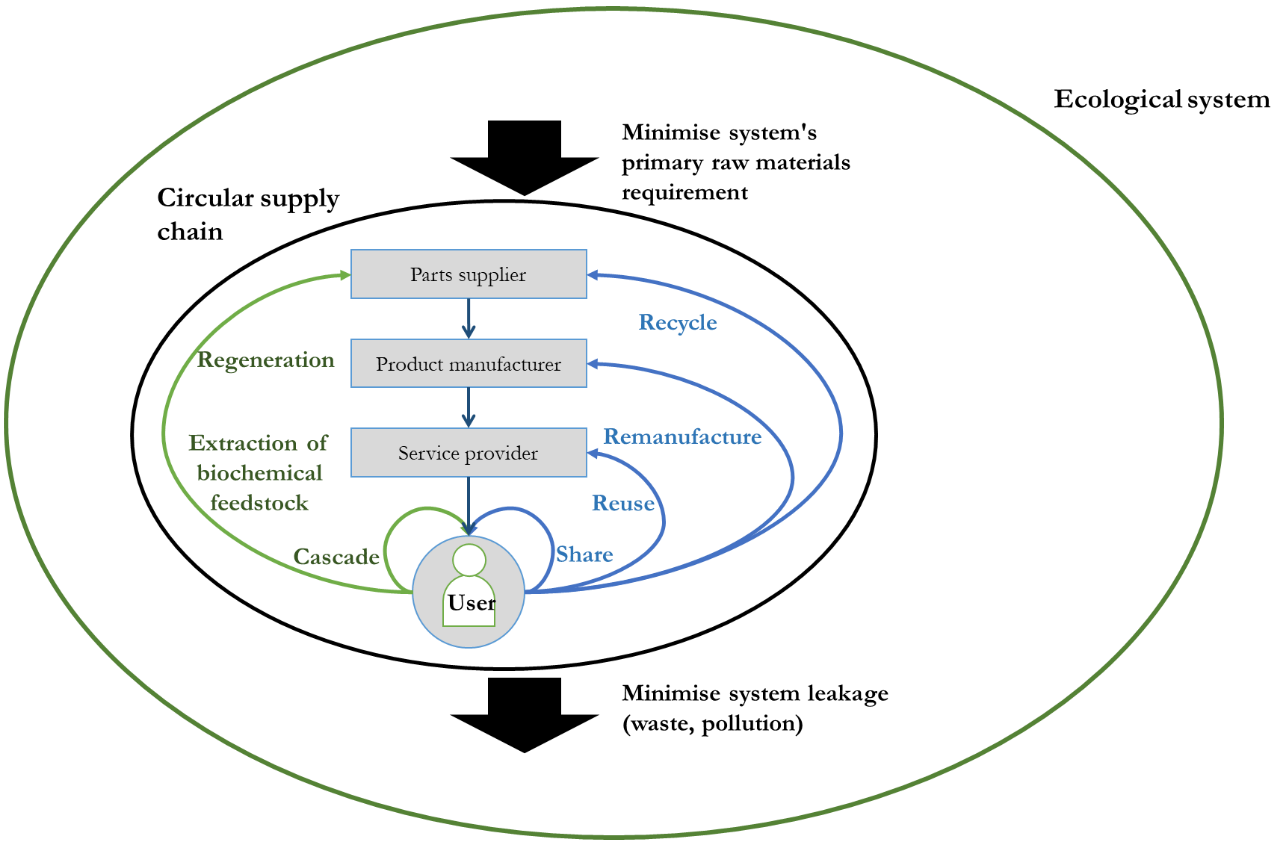

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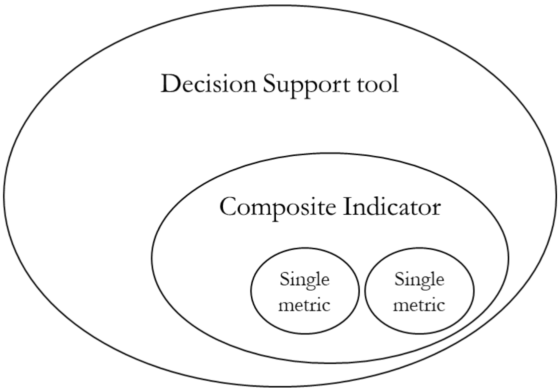
Figure 2. Decision support tools, Indicators and metrics



In SCM literature, some distinct research streams have developed tools to measure the adoption of CE practices with a supply chains level of anal ysis. The GSCM and SSCM literature (Brandenburg et al., 2014) is considered to offer insights about a crucial unit of action for implementing CE (Liu et al., 2018). Existing decision support tools (DSTs) incorporate a triple bottom line (TBL) approach and life-cycle perspective in the evaluation of impacts for complex and global supply chains (Acquaye et al., 2017; Genovese, et al., 2017a). Indeed, in the GSCM and SSCM literature, the evaluation of environmental impacts makes extensive use of established methods found in environmental science (e.g. *LCA, Life-Cycle Costing*). Some variants of these methods (e.g. *hybrid LCA, Multi Regional I/O Frameworks*) are also able to rigorously assess the environmental performance of complex and global supply chains (Acquaye et al., 2017; Genovese, et al., 2017a). Thanks to these methods, it is possible to determine supply chain *hotspots* (in terms of environmental impacts) using relevant key performance indicators (KPIs), thus identifying areas to be prioritised for action.

At the micro level of a single organisation, CE interventions support the design of reverse supply chains, recycling, reusing or remanufacturing end-of-life produ2cts. CLSCs should take back products from customers and return them to the original manufacturer for the recovery of added value by reusing the whole product or part of it (Rubio et al., 2008). RL and CLSCM research streams have firstly concentrated on the evaluation of the economic viability of the adoption of CE practices, and have only recently moved towards integrated multi-dimensional impact assessments (Kazemi et al., 2019). Apart from very recent attempts (Walker et al., 2021), no review of CE indicators with a supply chain perspective had been performed.

The literature on CE indicators for supply chains is very fragmented (Figure 3). It is quite clear that a standard way to support decisions and keep track of the transition of supply chains to higher levels of circularity has not been defined. There is no clarity of what should be measured nor of the criteria that should be employed to select metrics, as well as objectives of DSTs. Many CE indicators, metrics or set of metrics have been used. Many DSTs employ economic metrics (e.g. costs, revenues, net present value) or environmental ones (emissions, energy, waste, resources consumed, resources recovered), and even social ones (jobs created by the CSC).

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Figure 3. *Decision support tools and CE indicators in the CSCM literature*

CE indicators used and developed across research streams			
Industrial Ecology	**Green and Sustainable Supply Chain Management**	**Closed-Loop Supply Chain Management**	**CE indicators at the firm level**
design an interchange of resources and waste streams within clusters of firms	integrate environmental and social concerns into organisations. Green Supply Chains are an important building block towards CE	take back products from customers to the manufacturer for the recovery of added value	Sometimes have a value chain perspective

2.2 Understanding the choices behind DSTs for sustainability

DSTs for CSCs can be considered a subset of general sustainability tools (Gasparatos et al., 2008; Gasparatos, 2010; Gasparatos & Scolobig, 2012). When building DSTs, researchers and industrial practitioners have to choose how to systematically select among different metrics (Gasparatos & Scolobig, 2012) and whether to aggregate subsets of metrics into composite indicators. These choices are not just technical ones, but also constitute an important decision, in terms of value perception and worldview assumptions. Analysing general sustainability tools, Gasparatos & Scolobig (2012) recognised three categories of tools (Figure 4), according to their underlying perspectives and conceptions of value:

- *Monetary tools* evaluate sustainability phenomena based on the market evaluation of projects. Environmental impacts are generally transformed into costs. These tools are linked to a *neoclassical* conception of value, which is related to a deeply anthropocentric view. Cost-Benefit Analysis is a classical example of this category (Gasparatos & Scolobig, 2012).
- *Biophysical tools* focus on inflows and outflows of energy, materials and waste within a system. Usually, coefficients and algebraic rules are used to collapse the behaviour of a very complex system into a common unit of measurement, like in the case of EMergy accounting (Odum, 1996; Brown, 2018). This category also includes Life Cycle Assessment (LCA), which explores environmental impacts across a product's life stages. The type of value consideration of these tools is eco-centric – highlighting interconnections between economic activities and the environment (Daly & Farley, 2011).
- *Composite indicators* usually aggregate identified subsets of variables into synthetic measures. A complex system's performance is subdivided into measurable pillars and sub-pillars, where more indicators capture different variables. These sub-indicators can be either normalised in a single index, or can be presented singularly as part of multi-criteria assessment tools. These tools are more flexible in terms of value considerations, which depend on specific weighting and normalisation assumptions (Martinez-Alier et al., 1998).

No previous review has classified DSTs and associated indicators for CSCs by investigating their underlying assumptions, as per the Gasparatos (2012) framework. In general, the current literature on DSTs for CSCs contributes to knowledge at a very practical stage, investigating specific decisions without questioning world-views and assumptions (Korhonen, et al., 2018; Kirchherr & van Santen, 2019).

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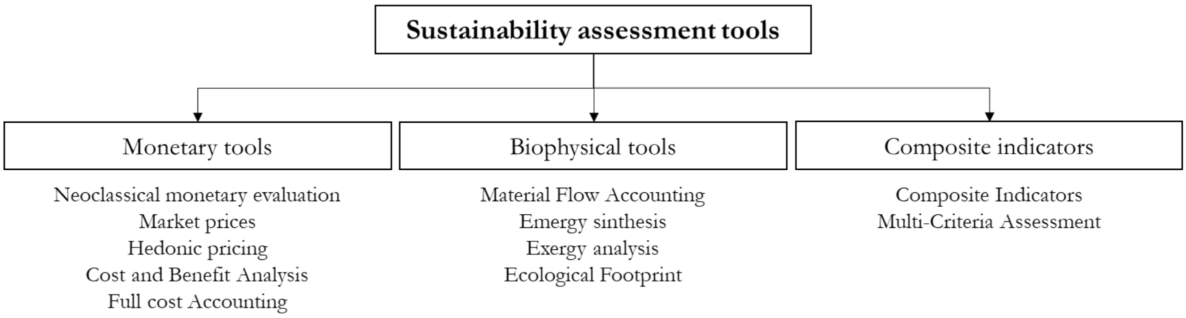
Figure 4. *Three classes of sustainability assessment tools (adapted from Gasparatos, 2012)*



2.3 Research gaps and Research questions

The CE literature lacks an overview of the standard indicators and DSTs to evaluate the transition towards a CE in supply chains. Available CE assessment metrics, indicators, methods and methodologies in the academic literature were mapped at the firm level (Elia et al., 2017; Saidani et al., 2019; Sassanelli et al., 2019; Vinante et al., 2021) and only recently at the supply chain level (Walker, Vermeulen, et al., 2021). Existing CSC DSTs have employed different methods and used different criteria to select the metrics, and deal with trade-off decisions. On the basis of the identified gaps, the research questions that will be addressed in this study can be summarised as follows:

- RQ1: What are the current CE indicators in the context of the CSC literature and in industrial practice?
- RQ2: Can a subset of the most commonly employed metrics in both the academic literature and industrial practice be identified and compared?

3 Research method

In order to address the research questions, CE indicators were reviewed both in the academic literature and from industrial practice, with two parallel analyses (Figure 5, top part). A Systematic Literature Review was employed in order to identify the key scholarly contributions in the topic of CE indicators at a supply chain level. In parallel, a representative sample of organisations was reviewed to identify how industrial organisations keep track of the impact of the adoption of CE practices. The top-50 European Multi-National-Enterprises from the Global Fortune 500 list were identified as a representative sample. Results of these two analyses were then synthesised to identify subsets of commonly employed indicators, and also build two synthetic composite indicators that are analysed in the discussion section (Figure 5, bottom part).

Academic literature and industrial reports have different nature and scope. DSTs in the literature support decisions on the adoption of new CE practices, adopting most often an *ex-ante* perspective. Corporate Sustainability reports tend to evaluate CE practices that have already been adopted by the company, taking an *ex-post* view. The comparison of the two bodies of knowledge will also allow checking the correspondence between adopted indicators across different contexts and perspectives.

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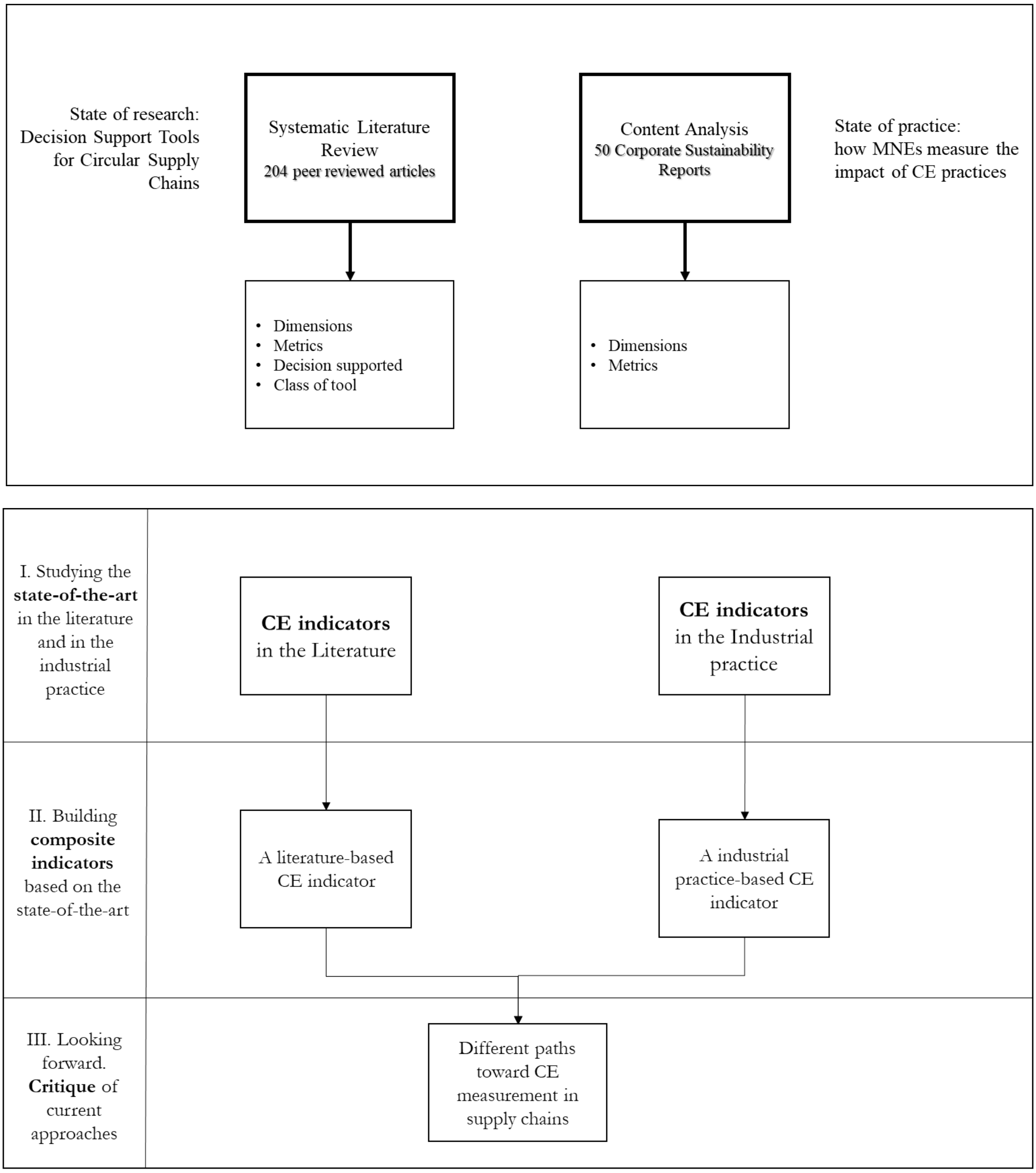
Figure 5. *Research methods diagram. Review of the literature and of the industrial practice protocol (top); approach followed for the derivation of literature and practice-based composite indicators (bottom)*



3.1 Systematic review of the literature – CE indicators for supply chains

To date, no SLR has been carried out in the topic of CE indicators at a supply chain level. Through a scientific, replicable and transparent process the SLR method identifies the key contributions that are relevant to a particular research question (Denyer & Tranfield, 2009). In this case, the objective was to assess the state of the art of the measurement approaches that have already been developed for assessing the transition towards the CE at the supply chain level. As suggested by Maestrini et al. (2017), the review included four main phases (Maestrini et al., 2017): (i) source identification, (ii)

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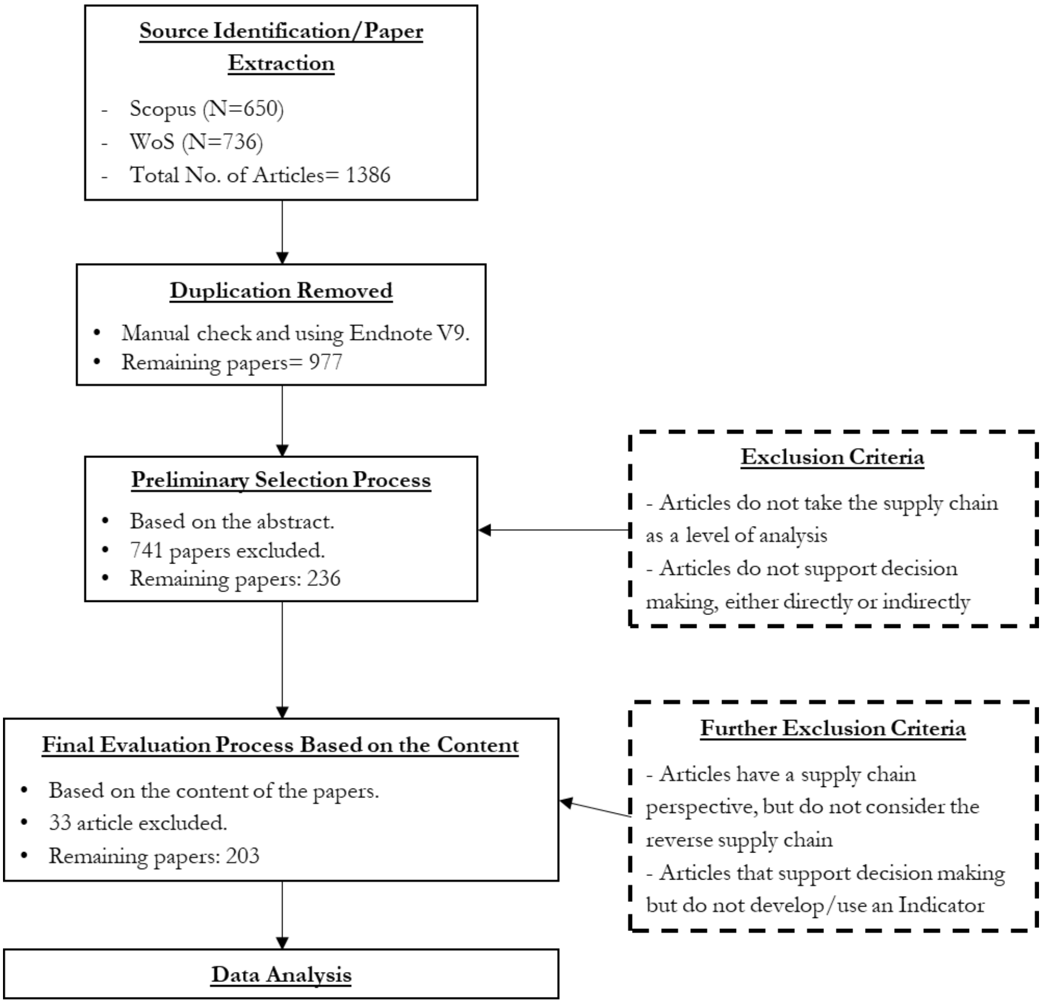
source selection, (iii) source evaluation, and (iv) data analysis (Figure 6). These four phases are illustrated in the following sub-sections.

Figure 6*. Papers Search and Evaluation Process*



3.1.1 Source Identification

The source identification phase was conducted using the SCOPUS and Web of Science peer-reviewed academic databases. The use of two sources in parallel increased the rigor of the selection process (Denyer & Tranfield, 2009). Keywords were chosen to maximize the number of articles to be included in the analysis. Therefore, the IE, CLSCM and RL literature streams were included, as they have contributed to the origins of a CE discourse in the supply chain management literature (Batista et al., 2018; Sehnem et al., 2019). The following string of keywords was used:

(('Circular Economy' OR 'Circular' OR 'Closed-loop' OR 'Reverse' OR 'Industrial Ecology' OR 'Industrial Symbiosis') AND 'Supply Chain*' AND ('indicator*' OR 'measur*' OR 'assess*' OR 'index*' OR 'metric*'))

A manual cross-checking process was conducted in order to eliminate duplicated results. At least two of the research team members executed the overall process in parallel and independently, as suggested by Maestrini et al. (2017). Table 1 provides the results of the search protocols.

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Table 1. *Articles Searching Protocols*

Database	Search field	Language	Subject Area	Document Types	Total	Total Both	Duplicate	Remaining
Scopus	Article title, Abstract, Keywords	English	No restrictions	Article; Review	650	1386	409	977
WOS	Topic				736			

3.1.2 Source Selection

Once the subset of potentially relevant articles was identified, a first selection process was performed on the abstracts. To delineate the boundaries of the analysis the following inclusion/exclusion criteria were applied:

- Only articles in English language have been *included.*
- Only peer-reviewed papers were included; book chapters and conference papers have been *excluded.*
- Publications which did not develop or employ indicators or measurement systems have been *excluded.*
- Publications that considered the circular dimension of SCs (at least as a potential state) were *included.* If the focus was only on the forward element of a supply chain, articles were *excluded.*
- Studies were classified on the basis of the specific implementation levels that can be recognised in the CE literature (Ghisellini et al., 2016; Korhonen et al., 2018): the micro level, involving CE strategies at the product and firm level, thus involving an intra-organisational decision-making process; the meso level, including supply chains and, in some contexts, also related to Eco-Industrial Parks and Industrial Symbiosis systems (Masi et al., 2017); the macro level, including CE development in regions and nations (Ghisellini et al., 2016; Kirchherr et al., 2017). Based on this classification:
    - Papers defining indicators to assess CE at the macro level were *excluded* from the analysis.
    - Papers developing indicators and measurement approaches at the meso level were *included* in this SLR. Papers that did not consider the SCs as the level of analysis have been *excluded.*
    - Papers defining specific indicators to measure CE initiatives at the micro perspective of the single organization, were evaluated in detail. A decision was made on the basis of the explicit consideration given to the role played by supply chains (EMAF, 2015; De Angelis et al., 2018). Just studies assuming an inter-organizational perspective for the employed indicators were *included.*

This scanning process resulted in a large reduction in the number of papers (from 977 to 236). Also, this phase was handled separately and autonomously by at least two team members. Regular team meetings were held throughout this phase and the following ones, to compare the choices adopted and to ensure that the process was rigorous. Inter-reliability was satisfied by considering the number of disagreements over the number of papers classified; all the disagreements were

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examined one by one to come to a collective consensus. Articles that could not easily be excluded with the highest degree of certainty, were included to be further analysed and read in the source evaluation phase.

3.1.3 Source Evaluation

The resulting 236 articles were evaluated and classified from a relevance point of view in relation to the criteria described in Table 2. In particular:

- Studies developing an indicator/multiple indicators in order to explicitly evaluate the performance of CSCs were *included*.
- Studies employing an indicator/multiple indicators for CSCs in the context of wider Decision-Making models and problems were *included*.
- Studies contributing to the CE literature without developing any indicator were *excluded*.

Another 33 articles were excluded, because they did not develop or use any indicator; thus, 203 articles were shortlisted for the purpose of the analysis. Again for this process, at least two team members operated independently, assigning each paper to each category according to the four criteria as suggested by Maestrini et al. (2017).

Table 2*. Criteria for Selecting Articles*

Criteria	**Number of Studies**	**Relevance**
Studies developing an indicator/multiple indicators in order to explicitly evaluate the performance of CSCs	63	Included
Studies employing an indicator/multiple indicators for CSCs in the context of wider Decision-Making models and problems	140	Included
Studies contributing to the CE literature without developing any indicator	33	Excluded

3.1.4 Data Analysis

Finally, a critical analysis of the 203 shortlisted articles was performed, with the aim of summarising the relevant findings and highlighting the messages. Existing models were surveyed, on the basis of the research method employed, the types of decision supported, the sustainability dimension considered and the indicators employed. Single metrics were tracked, in order to understand the most popular ones. DSTs that employed multiple metrics were also classified according to normalisation and/or aggregation approaches. An overview of the classification dimensions is provided in Table 3.

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***Table 3**. Indicators Classification Dimensions*

Classification Dimension	Example
Authors	Taskhiri, MS; Jeswani, H; Geldermann, J; Azapagic, A
Title	Optimising cascaded utilisation of wood resources considering economic and environmental aspects
Year	2019
Source	Computers & Chemical Engineering
Decision type	Strategic
Detailed Decision	Circular Supply Chain Network Design - Compare alternative scenario
Modelling approach	Mathematical programming method
Research Method	Optimisation (& Life Cycle Assessment)
Detailed Research Method	Mixed Integers Linear Programming
TBL Dimensions considered	Economic & Environmental
Economic metrics	Circular Supply Chain Cost
Environmental metrics	• Global Warming Potential (GWP); • abiotic depletion potential of resources (ADP); • acidification potential (AP); • eutrophication potential (EP); • freshwater aquatic ecotoxicity potential (FAETP); • human toxicity potential (HTP); • marine aquatic ecotoxicity potential (MAETP); • ozone depletion potential (ODP); • photochemical ozone creation potential (POCP); • terrestrial ecotoxicity potential (TETP)
Social metrics	-
Single/Multiple/Composite indicator	Multiple indicators
Weighting Method	Pareto efficient frontier – indicators are kept separate
Class of Sustainability DST	Indicators, Multi-criteria

3.2 Review of CE indicators in the industrial practice

This part of the study identifies the homogenous metrics that are reported by companies when they evaluate the adoption of CE practices. The amount of data that organisations make public has been enhanced because of the greater accountability and transparency demanded for MNEs (Hahn & Kühnen, 2013) by a set of stakeholders (e.g. employee, customers, suppliers, pressure groups, investors, regulators). Also the quality of data, regarding their economic social, and environmental impacts and actions, has been enhanced and follows more and more standardised guidelines (e.g.

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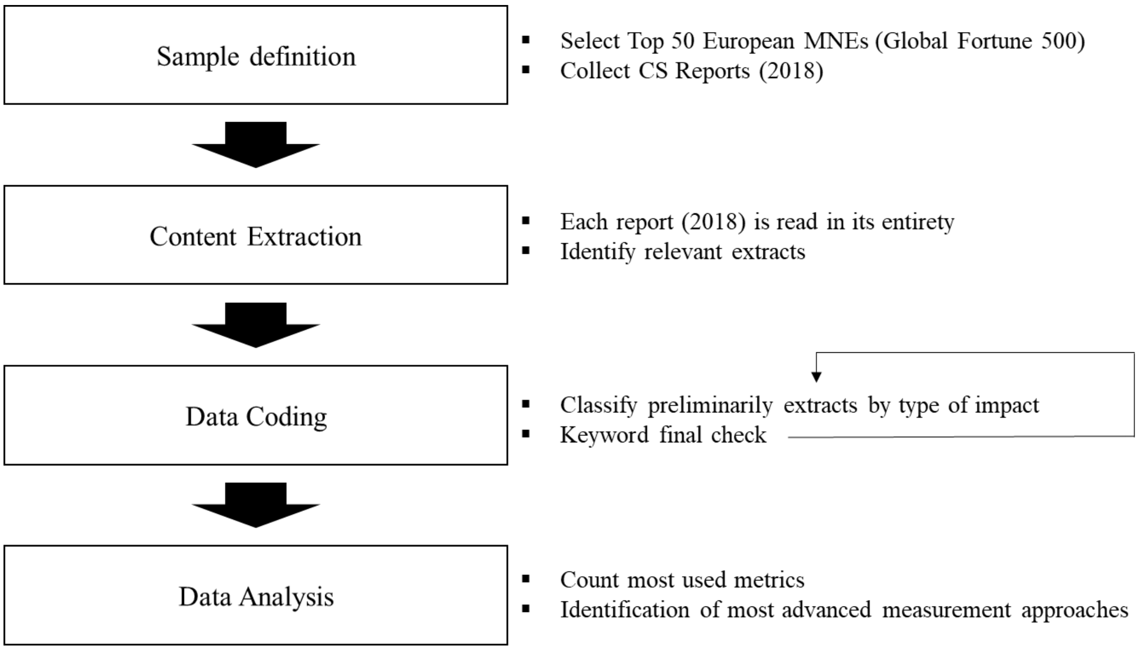
Global Reporting Initiative[3]). Corporate Sustainability reports represent an ideal platform for evaluating the adoption of CE practices and for identifying KPIs in industry. These reports can be seen as the most direct statement concerning sustainability practices (and, more specifically, CE practices) adopted by a firm (Stewart & Niero, 2018).

This review consisted of four main phases: (i) sample definition, (ii) content extraction, (iii) data coding and (iv) data analysis (see Figure 7). The Global Fortune 500 list[4] (2019 edition) was used to select the sample – which includes the Top-50 companies in the list from the European Economic Area[5] (EEA). A template analysis technique (King & Brooks, 2018) was used to analyse the reports content to identify KPIs related to sustainability and CE practices. During the data extraction phase reports were read in their entirety. The body of text of interest for the research questions was identified, extracted, collected through the NVivo software package, and then organised using an Excel spreadsheet. A keyword-based final check made sure that all the relevant text had been captured from all the reports. Keywords were related to the type of impact category (e.g. emissions, waste, and energy). Such a procedure was aimed at achieving the maximum level of replicability of the analysis.

Figure 7*. Content Analysis flowchart. CS reports: Corporate Sustainability Reports.*



4 Results

In this section, the main results from the analysis of the article sample are reported. The first part focus on the SLR. The following sub-section discusses indicators from the industry and the final sub-section proposes two CE indicators.

[3] https://www.globalreporting.org/
[4] https://fortune.com/global500/
[5] EEA includes EU countries and also Iceland, Liechtenstein, and Norway. The list of companies was compiled on the 1st of January 2019; it reflects, then, EU membership at that date.

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The sample analysed includes 203 papers from 99 different sources. Journals belong to different research areas, as CE topic has an inter-disciplinary nature. Three out of the four most represented journals belong to the Environmental Science literature (Table 4). An emerging interest comes from Industrial Engineering literature (e.g. International Journal of Production Economics; International Journal of Production Research) and from Decision Science and Operational Research disciplines. Publications range from 2002 to 2019 and there has been a sustained growth starting from 2015 (Figure 8).

Most of the publications support decisions at a strategic level (Figure 9), and more precisely related to the *design of CSCs*. Design decisions include locating and sizing facilities (e.g. industrial plants, distribution centres, collection centres, recycling centres disposal centres), selecting technologies and transportation modes. Capacities need to be allocated among different facilities in the forward and in the reverse supply chain. Some publications support tactical decisions, linked with the *planning of CSCs*. This means deciding how to size the production lots, manage inventory, and coordinate with other supply chain partners. Some papers include elements of both strategic and tactical planning. A significant group of articles does not support directly any specific decision (Unspecified), rather aims at *measuring the performance of CSC Networks*. These papers develop and use indicators to map and evaluate specific CSC processes, or to compare alternatives CSC configurations. Their focus is more on the ex-post measurement rather than on supporting specific decisions directly. For this reason they were distinguished from tools directly supporting planning decisions.

Table 4. *Top 10 Journals that show the highest number of papers*

Source	**Number of publications**
Journal of Cleaner Production	25
International Journal of Production Economics	16
Sustainability (Switzerland)	10
Resources, Conservation and Recycling	9
International Journal of Production Research	8
Computers and Industrial Engineering	7
Applied Mathematical Modelling	6
Science of the Total Environment	4
European Journal of Operational Research	4

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Figure 8. *Increase in annual publications since 2015*

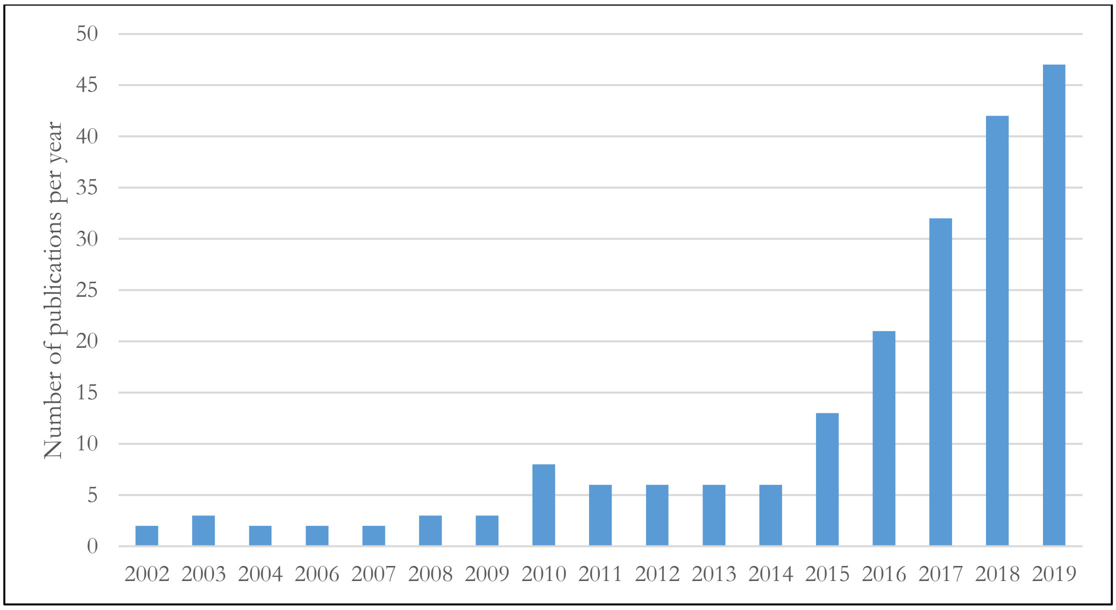
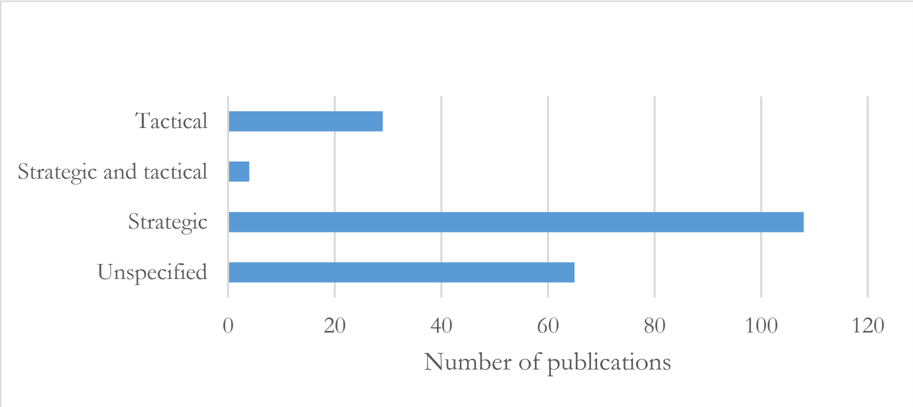


Figure 9. *Type of decision supported*



The majority of the publications employ methods from the Operational Research tradition, namely Mathematical Programming and Simulation (Figure 10). Optimisation models (such as Mixed Integer Linear Programming) can employ either single or multi-objective functions decision variables. Some articles employ analytical models; these tools are either Multi Criteria Decision Making (MCDM) method based or Environmental Science approaches. Among these LCA is the most common, followed by Input/Output and Material Flow Analysis models. Other tools employ a mix of these methods (like LCA and Ecological Network Analysis) or cost-based models (Material Flow Cost Analysis or Life Cycle Costing). The distribution in terms of modelling approaches represents the main difference with previous reviews on CE indicators at the firm level (Sassanelli et al., 2019; Vinante et al., 2021). These reviews have not included CLSCM and RL research streams, which makes a frequent use of Operational Research methods. However, this figure is aligned with the only review that focus on sustainability assessment at the supply chain level (Walker, Vermeulen, et al., 2021).

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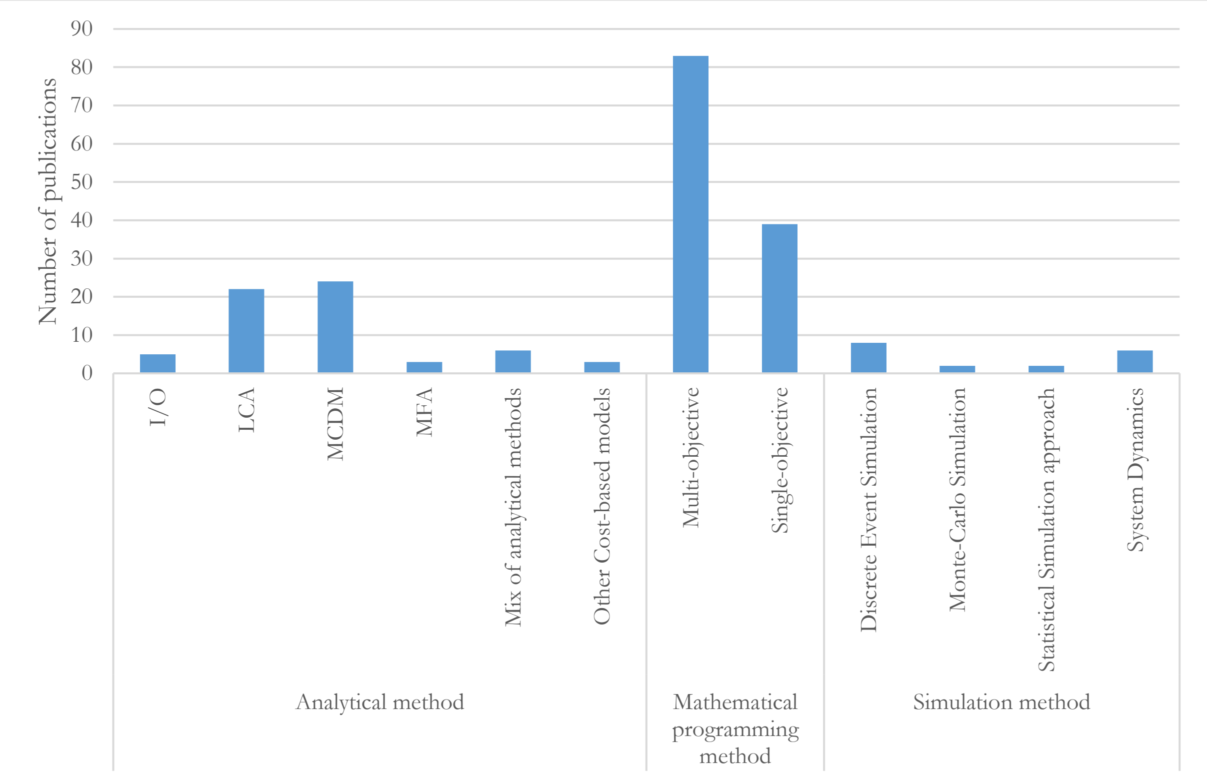
Figure 10. *Modelling approaches following Seuring classification (2014). ENA: Ecological Network Analysis; I/O: input /output models; LCA: Life Cycle Assessment; MCDM: Multi Criteria Decision Making models; MFA: Material Flow Analysis.*



4.1 Metrics and Dimensions

In line with RQ1, the articles reviewed were classified according to the sustainability dimensions they consider and the single metrics they select. The TBL approach is a central concept in sustainability studies, where performance standards need to be achieved across environmental, economic and social dimensions. Following the inclusion of environmental and social issues in the public agenda, SCM scholars have gradually incorporated adequate indicators in their models (Seuring & Mueller, 2008).

Only 15% of the 203 papers integrate the three dimensions simultaneously (Figure 11). The great majority of the papers (82%) do not consider social indicators, favouring the economic and the environmental dimensions. An interesting result is that 34% of the papers do not consider, in an explicit manner, environmental issues. Many of these 34% incorporate reverse logistics considerations, which (as explained in Section 2.1), were at first mainly based on economic aspects. This result highlights some differences in the choices between firm and supply chain level DSTs. Firm level DSTs seem to incorporate more often environmental considerations (Sassanelli et al., 2019).

Half of the articles in the sample adopt a single-dimension perspective, mainly favouring the economic (32%) and the environmental (18%) dimensions. Nevertheless, looking at how the consideration of sustainability dimensions has evolved over time, it can be seen that an increasing number of studies account for at least two dimensions (Figure 12). Individual dimensions and employed indicators are discussed in detail in the following subsections (Table 5).

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Figure 11*. Dimensions considered by the existing models and tools in the literature*

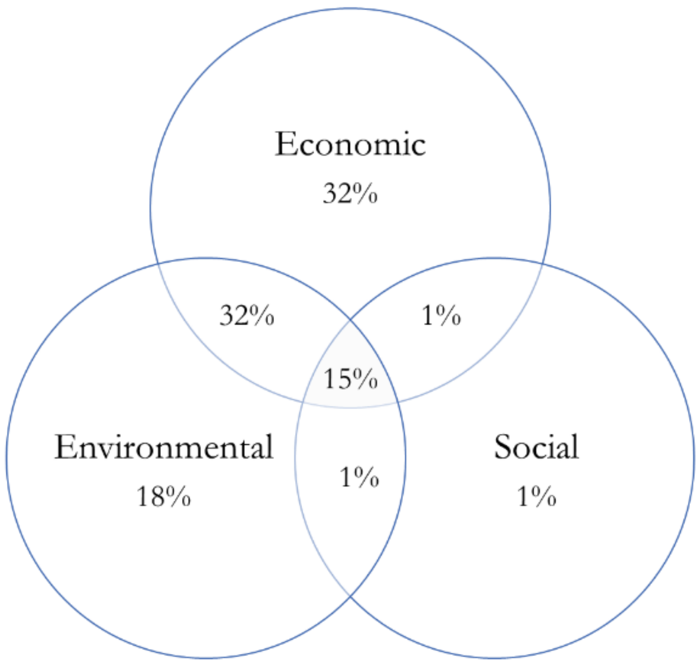

Figure 12*. Interactions between the different methods considering sustainability dimensions and scale of interest.*

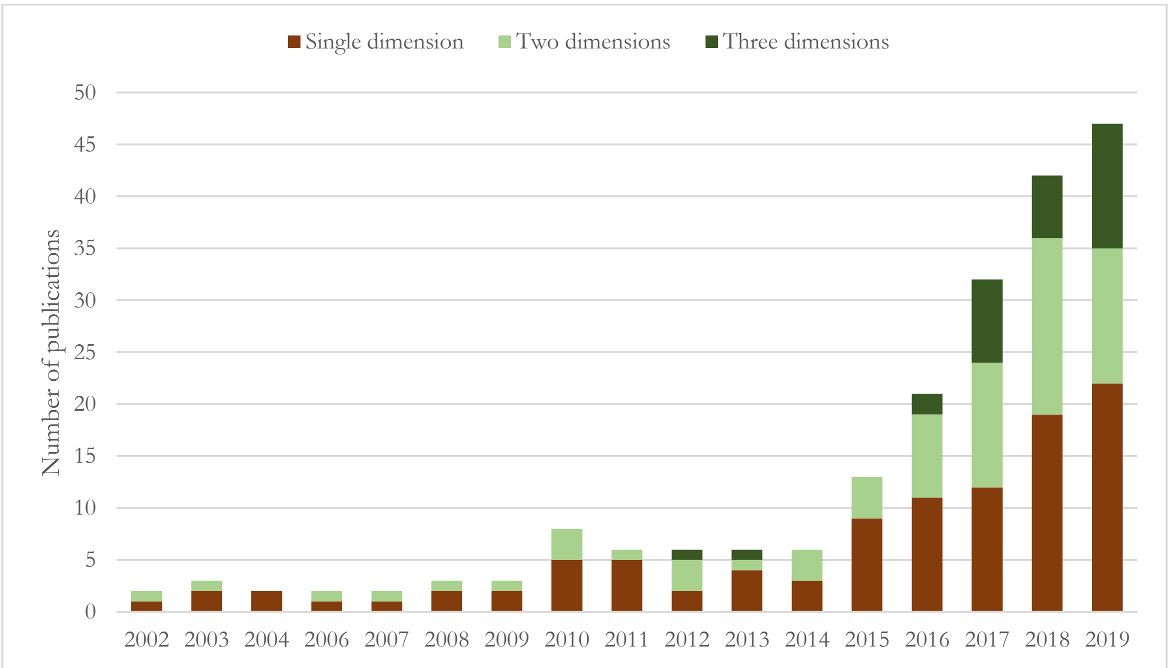

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Table 5. *The most commonly employed metrics*

TBL Dimension	Category	Metrics	Description	Occurrences	%
Economic	Costs	• Operational costs • Facility location costs • Transportation cost • Reverse supply chain cost	Cost-based indicators, both at a company and at a supply chain level	112	55%
	Profits	• Total CSC profits • Profits from recovery activities including remanufacturing, recycling and disposal	Profit-based indicators, both at a company and at a supply chain level	50	25%
	Time	• Time responsiveness of the network • Delivery reliability of suppliers	Time responsiveness-based indicators, both at a company and at a supply chain level	18	9%
	Quality	• Reliability of supply • Quality level of the production • Quality of the returns	Quality-based indicators, both at a company and at a supply chain level	14	7%
	Risk	• Financial risk • Value at risk • Conditional value at risk • Variability index • Downside risk	Risk-based indicators associated to uncertainty (e.g. of demand, collection)	12	6%
	Profitability	• Net Present Value • Return on Equity • Return on Assets	Profitability-based indexes, measuring	9	4%
Environmental	Emission equivalent	• Climate Change • Greenhouse gases • Global Warming Potential	CO2 eq. emissions associated with supply chain	90	44%
	Waste	• Waste Landfilled • Recycled waste	Residual waste produced and landfilled or recovered by supply chain activities	35	17%

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		• Recovered waste • Recyclability and ease of disassembly			
	Energy usage	• Energy use • Cumulative energy demand • Renewable energy use • Energy self-sufficiency	Energy-based indicators associated with supply chain	32	16%
	Virgin resources usage	• Abiotic depletion of resource • Mineral, fossil & renewable resource depletion	Virgin resource use associated with supply chain material consumption	26	13%
	Water	• Water depletion • Water emissions • Water use	Water used or contaminated	26	13%
	Air emissions	• Particulate Matter • Respiratory inorganics	Other air emissions associated with supply chain	22	11%
	Acidification	• Terrestrial acidification • Marine acidification	Acidification potential associated with supply chain processes	19	9%
Social	CSC jobs created	• Number of fixed and variable jobs • Number of drivers hired for transportation	Employment opportunities provided by the CSC	15	7%
	Organisational H&S compliance	• Compliance with the ILO guidelines	Measures of compliance to H&S Guidelines for the jobs created in the CSC	7	4%
	Quality of work	• Work damages • number of accidents, lost • Employee turnover	Measures of quality of the jobs created	7	3%
	Training	• Average hours of training • Training on skills for employability	Indicators of the training provided to workers	4	2%
	Expenditure on Benefits for employees	• Food • Transportation • Pension	Indicators of benefits provided to the workers	4	2%

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	Customer environmental awareness	• Enlightening customers to return end of used product • Customer incentives for recovery from discarded product	Indicators of environmental awareness of the customers	3	1%
	Social cost of waste	• Penalty cost of disposal	Social cost of waste produced. Sum of disposal cost and of the cost for the recycler	2	1%

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4.1.1 *Economic indicators*

80% of the studies employ economic indicators, with a clear prevalence of cost-based measures (Table 5). Notable examples include cost of production, transportation cost, facility location cost (Özceylan & Paksoy, 2013; Shankar et al., 2018; Ponte et al., 2020). These considerations are very common in CSC Network Design Optimisation models. Indicators related to the time responsiveness of the CSC and to the quality of the products are less common (Kazancoglu et al., 2018; Liao et al., 2020). Some CE indicators can be noticed across the different categories of measures. Notable examples are the cost of the reverse supply chain, the profits associated with recovery activities (Baptista et al., 2019; Jin et al., 2019), including remanufacturing (Abdi et al., 2019), recycling and disposal (Li et al., 2019), and the quality of the recovered products after the end of their life (Jeihoonian et al., 2017).

4.1.2 *Environmental indicators*

Most of the studies that consider the environmental dimension utilise indicators based on Global Warming Potential and Greenhouse Gas Emissions (Tsoulfas et al., 2002; Low et al., 2016; Chavez & Sharma, 2018; Rezaei et al., 2019; Taleizadeh et al., 2019). Emission equivalent (such as CO_2-eq) metrics are three times more likely to be employed than any other category of environmental indicators, which seems to confirm that SCM literature has an established carbon-centric point of view (Genovese et al., 2017).

Fewer studies select indicators related to the residual waste that is incinerated or landfilled (17%), or on waste recovered thanks to CSC feedback loops (Rachaniotis et al., 2010; Jayant et al., 2014; Gusmerotti et al., 2019). Other commonly utilised indicators focus on use of energy across supply chains (Genovese et al., 2017). Cumulative energy demand (CED) considers the energy consumed throughout the product lifecycle, including the energy consumed during the extraction, manufacturing and disposal of the raw and auxiliary materials (Govindan et al., 2016; Sgarbossa & Russo, 2017; B. Liu et al., 2018). Only 13% of the articles measure the quantity of virgin resources (e.g. minerals, fossil fuels, renewable resources) that are depleted throughout the supply chain (Rao, 2014; Daaboul et al., 2016; Hazen et al., 2017).

In total, 77 different environmental indicators are employed. This denotes the lack of an agreed standard for measuring the environmental performance of CSCs, or the transition of supply chains towards CSC configurations. Many studies use traditional LCA frameworks, in this way taking into account a wide variety of impacts across the whole product supply chain.

Another relevant gap is the absence of explicit metrics regarding process or material 'circularity'. Only a very small minority of papers employ specific indicators to measure the proportion of waste and by-products reincorporated in the supply chain (Wei et al., 2014; Gilbert et al., 2017; Jeihoonian et al., 2017; Al-Aomar & Alshraideh, 2019).

4.1.3 *Social indicators*

Only 18% of the sample consider the social dimension within the definition of the objectives (Darbari et al., 2019; Taleizadeh et al., 2019). It can be observed that there is no agreement on the

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stakeholders to be involved. Some measurement approaches only consider employees, whilst others consider customers and as well as suppliers, organisations or communities (see Table 5).

The most common indicator (which appears in 7% of the papers included in the sample) is represented by the employment opportunities generated within the supply chain (i.e. the total number of jobs created by the CSC). Whilst not common, some metrics representing the 'quality' of the jobs created are also considered: 3% of these indicators mention aspects such as the presence of decent work conditions (Rahimi & Ghezavati, 2018; Hajiaghaei-Keshteli & Fathollahi Fard, 2019), 2% of employee training opportunities (Govindan et al., 2016) and other benefits for workers.

A less common indicator (which appears in just 1% of the papers considered) measures customers' environmental awareness, related to their willingness to return used products at the end of their life (Govindan et al., 2016; Gusmerotti et al., 2019). Another notable indicator describes the social cost of waste (1%), defined as a penalty cost assigned to companies for disposal of materials throughout the supply chain.

4.1.4 A classification of existing measurement approaches

In this section articles are classified by looking at the work of Gasparatos and Scolobig (2012) on general sustainability assessment tools, characterising existing measurement approaches on the basis of the underlying conceptual assumptions. Three DST classes could be identified (Table 6). Each class of tools shows a good degree of similarity in terms of DST objective, research method adopted, sustainability dimension considered, and metrics selected. Each class also reflects very similar assumptions of value. The three classes of CSC DSTs can be defined as follows:

1. *CSC Monetary tools (88 papers)* support decisions by looking mainly at the economic viability of CSCs. As a consequence, within these tools the economic dimension is prevalent. 63 out of 88 DSTs do not consider at all environmental and social metrics. The other 25 consider multiple dimensions and convert environmental and social impacts in monetary terms to become part of a general cost function. Usually, they employ simplified environmental indicators, mainly based on carbon emissions which are translated into carbon cost. Only 4 out of 88 tools select indicators related to the circularity of material flows or to waste creation at the different stages of the supply chain. 79 out of 88 use mathematical programming or simulation approaches. This class encompasses articles that have an acceptance of *neoclassical* value assumptions.
2. *CSC Biophysical tools (29 papers)*: This class collects mainly tools from the environmental sciences and other tools that analytically represent systems. Articles have the objective of quantifying flows and stocks of materials within the supply chain system and calculating the environmental impacts associated with those flows. The methods employed are mainly LCA, Material Flow Analysis (MFA), hybrid LCA, and I/O methods. The type of decision supported is mainly at the strategic level (e.g. comparing different products, processes and CSCs); chosen metrics are purely environmental. They are usually not aggregated or normalised into composite indicators. The type of value consideration of these tools is *eco-centric*: production and consumption systems are evaluated on how much resources they are

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consuming, how much waste they produce and how much and how they affect natural systems.

3. *CSC Composite and multicriteria indicators (86 papers)*: these tools consider multiple dimensions at the same time; just 9 over 86 focus on one dimension only. Their objective is to combine performances offered by alternative solutions across different criteria, assisting decision-makers in selecting the best course of action according to their preferences. MCDM and multi-objective mathematical programming approaches are the most common methods. Within these approaches, a first group of papers (38) normalise and combine all the different aspects into a single indicator. These DSTs weight and aggregate more metrics into a *composite indicator*. A second group of studies (48) do not perform normalisation and weighting operations, rather they keep separate aspects that might not be comparable, doing sensitivity analysis and showing alternative solutions (*multicriteria indicators*). Decision-makers are left with a qualitative evaluation of the different profiles of dominant and dominated solution. Also *multicriteria tools* consider simplified environmental indicators and often normalise different environmental metrics into an environmental index, which is considered a proxy of all the environmental impact. Value considerations within these models are complex.

4.2 CE indicators from industry practitioners

Also this section contributes to answering RQ 1, highlighting CE indicators in the industrial practice[6]. Indicators of the economic impact of CE practices adoption vary according to the industrial sector and to the type of practice. 'Revenues from remanufactured products' is a common indicator among the manufacturing companies that built an infrastructure to recover end of life parts to be sold in the secondary markets (*Renault, FCA, PSA, Volkswagen, Daimler, and BMW*). In the financial sector, economic indicators refer mostly to the 'green' investments associated with CE activities or with the promotion of renewable energy or resource efficiency solutions. Most of the environmental KPIs which are employed are efficiency indicators (Table 7), comparing a measure of polluting activities (for instance, carbon emissions) to the total production output. It must be highlighted that the usage of such indicators for measuring the success of CE practices is problematic. Figures could be manipulated to obtain better results, for example just by increasing production volumes (for instance, through productivity improvements), rather than by implementing practices which can promote a more efficient usage of resources. Social impacts associated with CE practices are included only in 3 organisations and refer to the employment opportunities provided by the CSC. Just one company, the Italian Energy Utility provider *Enel*, develops a measurement system to assess the level of circularity of its solutions and products. Enel *X Circular Economy Score*[7] evaluates five CE key dimensions (commitment by suppliers to CE principles; the presence of reusable elements which can increase the life-cycle of the product; the resource efficiency; the reuse of materials; and the support offered to suppliers) and circular business models (inter alia: product as a service; sharing platforms; product life cycle extension).

[6] The following results refer to the analysis of the Corporate Sustainability reports of the Top-50 companies from the European Economic Area (EEA), according to the Global Fortune 500 list (2019 edition).

[7] Enel X Circular Economy Score

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Table 6. *Objectives, methodological approaches, and metrics of different classes of articles in the literature*

Type of tools	Objective	Methodological approach	Economic metrics	Environmental metrics	Social metrics	Aggregation Technique	Value	Examples
CSC Monetary tools	Evaluate the economic viability of CSCs	Mathematical programming; Simulation	Cost-based	Emission based	CSC jobs created	choose an efficient solution on the Pareto frontier	Neoclassical economics Utility-based; anthropocentric	(Baptista et al., 2019; Polo et al., 2019)
CSC Biophysical tools	Evaluate CSCs impact on Nature	LCA; MFA; I/O Analysis; Hybrid I/O LCA	No	mainly standard LCA based metrics / material, waste flows	No	do not aggregate; aggregate per type of impact (Recipe, Eco-indicator 99)	Eco-centric	(Prosman & Sacchi, 2016; Hoehn et al., 2019)
CSC Composite and Multicriteria indicators	Combine multiple performances	MCDM; Mathematical programming	Cost-based	Emission based	CSC jobs created	normalise all the metrics into one composite indicators; identify many dominant and dominated solutions on an efficient Pareto frontier	Flexible	(Chavez & Sharma, 2018; Darbari et al., 2019)

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***Table 7**. Commonly used economic, environmental and social KPIs for European MNEs*

Dimension	Category	Examples	Description	Adopting Companies
Economic	Revenues	• Revenues from remanufactured products • Revenues from 'green products'	Revenues associated with CSC activities	3/50
	Investments	• Capital invested in sustainable solutions • Capital dis-invested from carbon intensive assets	Investments associated with CSC activities	15/50
Environmental	Emissions equivalent	• CO2eq per functional unit • Absolute CO2-eq	CO_2 eq. emissions associated with the supply chain	44/50
	Energy Usage	• Energy intensity • Cumulative energy use • Energy from renewable sources	Energy-based indicators associated with the supply chain	44/50
	Water	• Water used • Wastewater production • Discharges to water	Water used or contaminated	42/50
	Waste	• Waste sent to landfill • Waste recovered	Residual waste produced or recovered by supply chain activities	36/50
Social	Social Impacts associated with CSC	• 'Green' jobs created	Employment opportunities provided by the CSC	4/50
CE	Overall Circularity	• CE Score • Parts Collected and Remanufactured	Indicators of environmental awareness of the customers	3/50

4.3 Developing CE indicators for supply chains from the state-of-the-art

This final section addresses RQ 2. The results of the reviews of the academic and of industrial practitioners' literature are used to identify appropriate subsets of KPIs from the three dimensions of sustainability (i.e. economic, environment and social). KPIs are then normalised though MCDM method into two distinct CE composite indicators. These two prototypes could form the basis of DSTs that could be used to keep track of the effectiveness of CE interventions in CSCs; to focus on the trade-offs between different sustainability dimensions; and to account for benefits, impacts and preferences of different decision-makers and stakeholders.

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4.3.1 *A literature-based CE composite indicator for supply chain*

The first multi-objective composite indicator is based on the results of the literature review. This Literature-based CE index (L-CEI) aims to synthesise the models and tools already developed in the literature. The steps for the definition of this indicator are presented below:

- The weights of the three components representing the sustainability dimensions have been determined on the basis of their relative frequencies (as reported in Table 8). For instance, the weight of the economic dimension is 0.49 as this represents the normalised frequency of articles accounting for economic factors (with respect to a normalisation factor that is the sum of the percentage of articles reporting of each dimension).
- The subset of indicators considered for each dimension has been determined by considering the most popular metrics in the subset of papers selected in the review. The three most popular metrics have been selected for each dimension. Weights have been determined in a similar manner to what has been done for dimensions, considering normalised relative frequencies (Table 9).

Table 8. *Calculation of the normalised weights for the dimensions*

Dimension	Occurrences (%)	Normalised dimension weight
Economic	80%	0.49
Environmental	66%	0.40
Social	18%	0.11

Table 9. *Calculation of the normalised weights for the economic indicators*

Indicartor	% articles	Normalised indicator weight
CSC Cost	52%	0.31
CSC Profit	22%	0.13
Time Responsiveness	8%	0.05

Figure 13 shows L-CEI and its components and the weights. The economic dimension dominates, and accounts for around half of the total weight. The metrics are mainly cost-based and profit-based measures. A small portion (0.05) is given by a parameter representing the Time Responsiveness, which measures the time taken by the supply chain to move materials and components in the forward and the reverse supply chain.

Among the environmental metrics prominence is given to the CO_2-eq. emissions parameter. The 'Energy use' and 'Virgin Resource use' metrics have a similar and limited importance (0.08 and 0.07), and account for how intensively the supply chain makes use of energy and of primary resources. The Social component just accounts for 11% of the weight; within this dimension, selected metrics include the employment opportunities of the reverse supply chain 'CSC Jobs created' (0.05), and some measures of the quality of jobs, such as compliance to Health & Safety standards and 'Quality of work'. This last measure usually includes the number of accidents that cause workers' injuries across supply chain activities.

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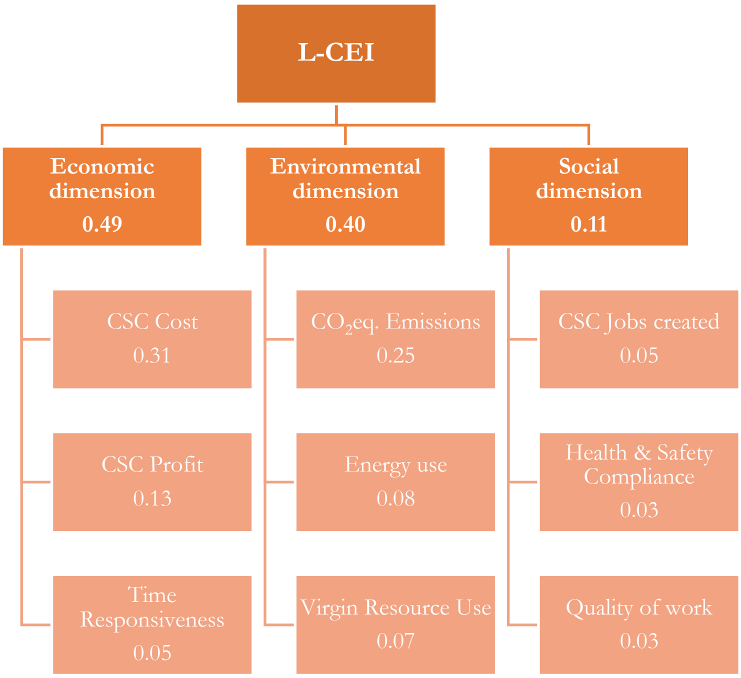
Figure 13. *A literature-based CE indicator*



4.3.2 An industry-based CE composite indicator for supply chain

The second prototype, the Industry-based CE index (I-CEI), is based on the results of the previously presented review of the industrial practice (Section 4.2). The steps for the definition of this indicator are presented below:

- The weights of the three components representing the sustainability dimensions have been determined on the basis of the relative frequencies, in analogy with the calculations shown for L-CEI.
- The subset of indicators considered for each dimension has been determined by considering the most popular metrics in the sample of organisations. The three most popular metrics have been selected for each dimension. The relative weights inside each dimension have been chosen on the basis of the relative frequencies, in analogy with the calculations shown for L-CEI.

The environmental component is dominant (Figure 14), and accounts for more than half of the total weight. The most important metrics are mainly carbon-based and energy-based measures, not differing from the ones which can be found in the sustainable supply chain management literature, with no specific emphasis on circularity issues. A large portion (0.21) is also given by a parameter representing the consumption of water. Among the economic indicators considerable importance is given investments to support the transition towards a more CE, both through sustainable investments (0.15) and through disinvesting from polluting and carbon intensive solutions (CIS) (0.09). Revenues from "green" products refers to the sale of sustainable or remanufactured products and services. The Social dimension has a slightly lower weight than in the L-CEI (0.06) and includes a single indicator (the amount of 'green jobs' created).

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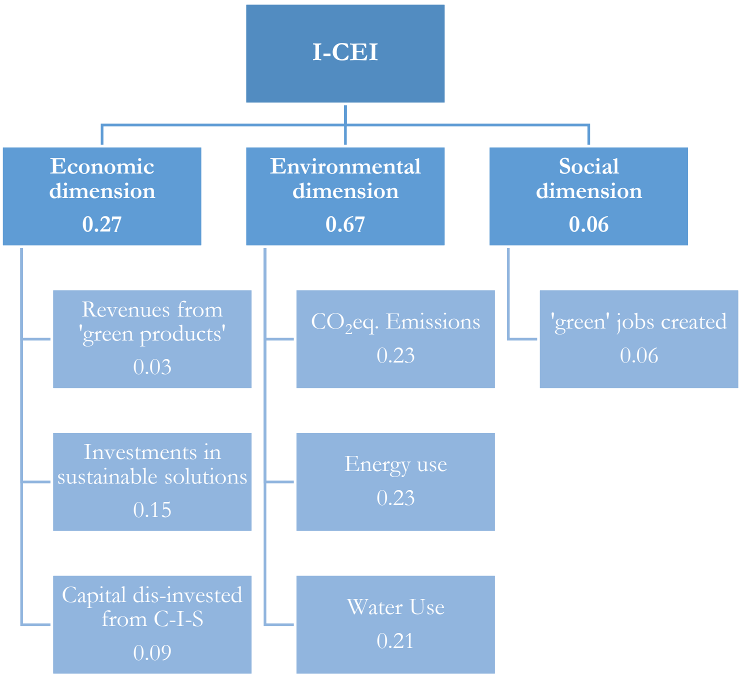
Figure 14. *An industry-based CE indicator. CIS: Carbon Intensive Solutions.*



5 Discussion

The objective of the discussion section is to critique what existing DSTs in the context of CSCM are measuring. The first subsection compares the academic and the industrial literature. Then, a critical discussion highlights how DSTs and CE indicators are always affected by reductionism. The advantages and the disadvantages of different approaches to multidimensional decision making are discussed, together with some research avenues and new research ideas that could be looked at to contribute to future research on DSTs for CSCs.

5.1 Comparing CE indicators in the literature and the practice

The first aspect that emerges is that DSTs in the literature and Corporate Sustainability reports place emphasis on different aspects and metrics. L-CEI, which represent the most common metrics selected in DSTs in the literature, seems to over-represent measures that depend on the economic cost. On the other side practitioners measure more often positive environmental effects of CE practices, focusing on the energy consumption of the supply chain, and on its dependence on carbon intensive sources. Also, they integrate more often circularity metrics which make a mass balances between inputs and outputs in the production system (Walker, Vermeulen, et al., 2021).

A possible explanation of these differences might have to do with the different scope of sustainability reporting and DSTs. DSTs most of the times look at the implementation of new CE practices, which require evaluating economic aspects and to define a business case for the organisation and the supply chain. Differently, Corporate Sustainability reports perform a consumptive evaluation of already implemented CE practices (usually referring to the previous financial year). Despite the lack of standard reporting approaches (Opferkuch et al., 2021), CE is considered a framework expected to reduce organisations' impact on the environment and the stakeholders are requiring this type of evidence in reports (Howard et al., 2019).

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Both the indexes (L-CEI and I-CEI) show that existing frameworks and selected metrics struggle to fully capture the adherence of supply chains to the CE paradigm. Materials circularity indicators are included only in rare cases and environmental aspects are often restricted to very simplified indicators, usually based on the cumulative carbon emissions of the supply chain. This choice might derive from knowledge that is consolidated in SSCM discipline: the operationalisation of reverse logistics feedback loops require the activation of facilities (such as processing and disassembling centres, along with remanufacturing plants) and, possibly additional transportation flows (Helander et al., 2019). All these activities employ resources, energy, and cause emissions in the environment and could give rise to rebound effects (promoting, overall, higher resources consumption rates) (Zink & Geyer, 2017). However, in a CE, supply chains should work in a radically different way and try to consider alternative strategies to reduce waste streams.

I-CEI economic metrics are mainly representative of revenue flows related to 'circular' products. This can be explained as, at the moment Industrial Organisations are not adopting CE practices across the whole supply chain, but just in some niches. As such, the current indicators are not designed to measure the performance of a whole CSC, but just some parts of it. Some of the possible metabolisms, where products and materials are used multiple times, are not measured. Rather, DSTs concentrate on a few metabolisms related to recycling, where the products and the waste of linear productions consumption systems are recovered and down-cycled. Measuring multiple feedback loops and metabolisms would tell something more about how much methods of production are self-sustaining and less dependent on primary materials, as well as how much primary production has been displaced with the adoption of CE-related practices.

Both the indexes similarly have a low consideration of social indicators, which confirms previous literature claims (Walker et al., 2021b).

5.2 Reductionism in Decision Support Tools for Circular Supply Chains

The results section 4.3 shows that DSTs systematically select some metrics and ignore others. These choices are not just technical, but also constitute an important decision, in terms of value perception and worldview assumptions.

DSTs in the CSCM domain need to be simple and easy to use, as decision makers need to understand and support the resulting decisions to design and transform existing supply chains. Simplification concerns many aspects that have already been mentioned (selection of metrics, and their aggregation) and some others, like the temporal horizon, considered the type and number of objectives or actors included in the decision. A single indicator is often chosen as a proxy of all environmental (or social) impacts. As a consequence, DSTs have a reductionist interpretation of what to measure to support decisions, and as a consequence of what sustainability is and on what a CSC should be.

A second aspect of reductionism in the academic literature of CE indicators concerns how DSTs deal with trade-offs among different variables. Most of the time, models accept some increase of negative impacts if that allows some type of benefit. This is quite a strong assumption, as variables belonging to different sustainability dimensions have complex relations and dependencies, which cannot be easily described by some linear parameters. *Composite indicators* represent an extreme case

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aggregating metrics from different dimensions into a single unit-less number. *Monetary tools* transform many variables in to monetary terms, even natural or social ones. Also *Biophysical tools* are not exempt from doing some approximations: CO_2-eq., which is the most commonly used indicator, is a linear combination of different greenhouse gases and their global warming potential. Non-compensatory *multi-criteria* approaches can provide a solution to this; their main advantage is that, by avoiding simplistic aggregations, they are less affected by a reductionist perspective (Martinez-Alier et al., 1998). However, also these approaches might not be free from problems: sometimes a single indicator is used as a proxy of all the possible indicators within one sustainability dimension; in other cases composite indicators are created for each sustainability dimension as linear combinations of some selected metrics. This could lead to the same problems highlighted for composite indicators (e.g. loss of meaning) as the metrics considered might have a complex relationship (e.g. CO_2-eq and land use).

5.3 Different paths towards CE measurement in supply chains

DSTs are not always transparent and open on value assumptions behind the models. Both the conceptual choices (e.g. what metric to select and what to ignore) and the methodological ones (whether to aggregate or normalise or not and with what weights) behind each DST are never neutral or objective. They are inspired by embedded worldviews, which are linked to a certain idea of value. These underlying value assumption have an impact on guiding decisions towards different paths of adoption of the CE in supply chains. The recent debate on the CE acknowledges different circular futures are possible (planned circularity, circular modernism, bottom-up sufficiency, peer-to-peer circularity) (Bauwens et al., 2020). The way the transition towards the CE is measured will impact the type of future and the type of supply chains. In fact, indicators act as value-articulating institutions, enforcing a very specific worldview and set of values, which should at least be acknowledged (Gasparatos & Scolobig, 2012).

The classification according to Gasparatos' framework (Section 4.1.4) groups DSTs according to similar value assumptions. The following paragraphs explore these differences, along with the advantages, the disadvantages of each class of tools (Table 10). Different paths towards CE measurement in supply chains are recognised, according to what desired outcome of change can be measured by the tools.

Monetary DSTs for CSCs adopt a neoclassical perspective of value and do not challenge the assumptions and the "rules of the game" in today's free market economies (even without mentioning it openly). In free-market economies actors are driven by economic benefits and companies are profit maximisers (Martinez-Alier et al., 1998); what is right or wrong is decided by subjective preferences and an anthropocentric valuation system that focus on utility functions and consumer preferences in a market setting (Martinez-Alier et al., 1998). Also, Nature or environmental impacts are monetised and included in market transactions. Markets have a key role in guiding the transition towards CSCs.

These DSTs usually provide whole-supply chain visibility of the processes and materials involved in the manufacturing process, as well as different actors' preferences and utility functions. As such they are able to present the different economic incentives for each CSC actor involved in the value

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creation process. These models estimate how much it costs to set up reverse channels to recover end of life products and how much additional revenues (or avoided investments) different CE practices can help to generate. Modelling CE benefits and negative impacts across more dimensions and more supply chain stages could show under which condition establishing a CSC is profitable.

As such successful CSCs are systems that use recycling and other CE strategies to increase the efficiency they have in using materials, are able to create economic value for their customers through the adoption of some CE practice, are able to use reverse logistics to recover "linear" products at the end of their life, and thus consume less resources and produce less waste. As these DSTs come mainly from an engineering background, they consider a CSC as a system that should work efficiently, without considering the socioeconomic context in which they operate (Zink & Geyer, 2017). This view usually implies reductionist views of sustainability and of the CE. These supply chains might use materials more efficiently or not (this is not often measured). The risk of a rebound effect and of market barriers to the operationalisation of CE practices is usually not part of the models. Desirable CSCs do not necessarily produce less products, but more products with less inputs per product.

Biophysical DSTs incorporate an *eco-centric* perspective of value. Monetary incentives and supply chain actors' preferences and utility functions are usually not part of these models. What is right or wrong to produce is decided by the cost and the impact of production. Production and consumption systems are considered in close relationship with Nature, as an active and integrative part of it. They measure the flows between economic systems and natural ones and look at how much resources are consumed, how much waste is created, how much emissions and environmental impacts are caused.

These tools are able to compare different products and configurations of reverse supply chain along with value retention strategies. Alternatives are compared according to the environmental cost of their production and to how heavily they depend on Nature. As such, the amount of primary resources a CSC uses for the production of goods should be minimised. Successful CSCs are systems that are able to decouple production from consumption of resources in absolute terms. Biophysical tools can provide an accurate estimation of environmental impacts thanks to a life-cycle perspective. This can help CSC decision-making processes to move away from the mainstream perspective of accounting just for the economic cost of production of goods and services. But they can also provide insights on how to measure and visualise the CE potential related to regenerative and restorative flows of resources in supply chains, in order to re-use material flows and waste as a resource according to an Industrial Ecology view.

Composite and multicriteria indicators have not a pre-defined conception of value. It depends on the weights chosen. It can be more eco-centric or more anthropocentric. Also, in SCM environments, composite indicators are rather common, both among researchers and practitioners. CSCs provide an ideal theoretical and practical context in which these methods could support decision-making. In this complex context, a wide range of stakeholders inside and outside the supply chain may be interested in evaluating the performance of the CSC using an established and standard model. *Composite indicators* approaches can combine strengths from the previous approaches. The main

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advantage provided by composite indicators is the ability to summarise complex, multi-dimensional realities for supporting decision-makers. Such methods are particularly effective in contexts in which multiple stakeholders are involved. However, normalisation and aggregation might cause loss of details and meaning (Martinez-Alier et al., 1998).

Table 10. *Advantages and Disadvantages of different classes of articles in the literature*

Type of tools	Advantages	Disadvantages	CSC desired evolution
CSC Monetary tools	Detailed evaluation of: flows among SC stages; actors' utility functions	Unable to highlight the systemic impacts of CSC on the environment and society	CSC are able to close the loop; focus on efficiency
CSC Biophysical tools	can determine with precision the negative environmental impact of the CSC Can measure the CE potential related to regenerative flows of resources	Unable to measure and visualise the CE potential related to regenerative flows of resources; Not always able to take into account the environmental impact associated with circular flows	CSC that consume less resources and work in symbiosis with the Nature
CSC Composite and multicriteria indicators	useful to consider and integrate multiple stakeholders' perspective	the outcome of the analysis might depend exclusively on technical decisions (weights)	Flexible; it depends on involved decision-makers, weighting and normalising procedures

In general, the main worldviews in supply chain management might have a role in influencing the type of transition towards the CE (Nieuwenhuis et al., 2019). Values assumptions affect how the tools are designed and as a consequence also the prescription of the analysis (Saltelli et al., 2020). The majority of the DSTs for CSCs (even without stating it openly) adopt a neoclassical perspective of value and do not challenge the assumptions and the rules of the game in today's free market economies (Korhonen, Nuur, et al., 2018). By doing so models enforce and promote this worldview. This is a key point: they might be measuring the wrong things and be supporting an evolution of our production and consumption systems that is not the one required by Science and International Agreements. For example, not all the types of CE practice are part of the models, with a clear prevalence of end of life recycling over more innovative supply chain configurations that include radical changes in the use phase, ownership of products. The outcome could be production systems that are circular, make use of a lot of recycled materials flows, but consume a lot of resources and energy to produce the wrong products in the wrong quantities.

For these reasons, it is important to discuss what value there is in a CE. Incorporating other worldviews means making a reflection on consumerism, on the desirability of the growth paradigm and on the effectiveness of free market settings for some goods. This discussion is part of a wider political discussion, which includes the need to update GDP as a measure, integrating it with some other metrics and perspective. It includes a reflection on the role of firms and of other institutions to deliver more sustainable production and consumption systems.

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5.4 Contribution to theory and practice

This study contributes to theory by reviewing already developed CE indicators at the supply chain level, which were not reviewed until very recently (Walker et al., 2021). Previously CE indicators and metrics were reviewed only at the single firm level of analysis and no SLR had focused on CE indicators at the supply chain level. This review confirms some of the results and considers many papers that were not included in previous literature reviews (Sassanelli, et al., 2019; Vinante et al., 2021). By identifying indicators and extracting metrics from decision support tools this paper connects streams of literature (or topics) that seems to be disconnected, e.g. SCM literature focusing on CLSCs, and CE literature.

A second theoretical contribution of this paper consists on reflecting critically on the choices behind tools definition and indicators selection. This literature identifies the value assumptions behind the choices that characterise the creation of tools and indicators, as suggested in sustainability science literature (Gasparatos & Scolobig, 2012). DSTs supporting CSC decision making will determine how the transition towards the CE in production and consumption systems will happen and define the type of CE economy our societies will achieve. By recognising the different paths of evolution of supply chains from a linear configuration to a circular one, this paper aims to contribute to this discussion.

This paper contributes to practice by putting together all the CE indicators that have been developed and included in existing DSTs for supply chains. Two first prototypes are proposed to summarise existing knowledge for practitioners.

6 Conclusions

This chapter aims to investigate CE indicators in the context of CSCM literature as well as those found in company Corporate Sustainability reports and represents a first step towards the development of decision support tools for designing and evaluating CSCs. Two CE indicators prototypes are proposed with the objective of summarising the most frequent choices in current models in the academic and practitioners' literature.

The analysis reveals that current indicators in the literature focus mostly on measuring the negative environmental impacts of CSCs and not incorporate almost any metrics to evaluate the economic and environmental potential behind the circulation of resources. The most frequently employed metrics are carbon emissions, the use of energy and economic cost. DSTs in the literature evaluate economic aspects more frequently than Corporate Sustainability reports, which measure more often environmental aspects. Both the literature and the industrial practice show a simplified and superficial consideration of social implications in measuring the transition towards the CE in supply chains.

The chapter also argues that the approaches in the CSCM literature have a reductionist interpretation of sustainability aspects. Single metrics are selected to represent whole sustainability dimensions, arbitrary weights are chosen, strong assumptions are made, such as that environmental and social impacts can be converted into monetary terms. The 3 different classes of tools identified reflect very different assumptions and worldviews and as such can drive different pathways of evolution of supply chains from a linear configuration to a circular one. CSC Monetary tools focus

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on improving the economic efficiency of production and consumption networks through the adoption of CE practices; CSC Biophysical tools aims at developing CSC that consume less resources and work in symbiosis with the Nature; CSC composite indicators path is uncertain and depends on involved decision-makers, weighting and normalising procedures.

Future research in SCM should clearly state value assumptions of the models and challenge the prevalent configurations and beliefs to explore how the CE can deeply transform production and consumption systems.

6.1 Limitations and future directions

A first limitation could arise from the different scope of practitioners' and academic literatures, which might make it problematic the comparison. The former deals with reporting consumptive results for stakeholders; the latter with the creation of tools that most of the times are used both to support decisions in the design phase and to evaluate existing production and consumption networks. For this reason, more research is needed to confirm these findings.

A better CE indicator could be built through a more comprehensive and structured application of MCDM methods and involvement of stakeholders and experts from a variety of backgrounds (academia, industry, NGOs, national and local government). These actors could rigorously choose a subset of representative indicators as well as the relative weights. Selected CE Indicators might also be kept separate in order to avoid the disadvantages of composite indicators. The use of Principal Component Analysis (PCA) could also help to identify a subset of indicators that are independent of one another and develop a more robust and effective index. Secondary datasets could be utilised for this purpose, such as Ecoinvent (2018)[8], a life cycle inventory database that associates detailed environmental impact indicators across all the phases of the life of a product; essentially, such database provides a big repository of Bill of Materials for specific products and processes, along with associated environmental impacts and estimates of resource consumptions.

[8] Ecoinvent is one of the world's leading life cycle inventory database. Available at: https//www.ecoinvent.org/

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CHAPTER 2
What theories of value (could) underpin our circular futures?

Benjamin H. Lowe, Andrea Genovese

Abstract: The transition to a circular economy is often presented as a straightforward, neutral and apolitical process, characterised by an implicit techno-optimistic and eco-modernist stance. However, in their recent paper on 'circular futures', Bauwens et al. (2020) illustrate that the circular economy is best understood as an umbrella term that might come to define very contrasting visions of sustainable development. Despite this, there continues to be a lack of discussion about the basic assumptions regarding social and economic structures on which the circular economy should be based, with research predominantly focusing on technical and practical questions. Therefore, in this conceptual chapter, we assess the *a priori* compatibility of different plausible configurations of the circular economy with the principal theories of value found in mainstream and heterodox economics. We argue that these futures are themselves value articulating institutions that implicitly adhere to a theory of value even if this is not recognised. Moreover, given that theories of value go to the heart of how economies and societies function and reproduce themselves, we argue that circular economy research should recognise the importance of value and acknowledge how value theory might enable or contradict the visions of sustainable development articulated.

Keywords: circular economy; classical political economy; ecological pricing; Sraffian economics; subjective preference value; sustainability transitions.

"The economist, like everyone else, must concern himself [sic] with the ultimate aims of man." Alfred Marshall

Abbreviations: Abstract Socially Necessary Labour Time, ASNLT; Circular economy, CE; Deliberative Monetary Valuation, DMV; Input-Output, I-O; Steady State Economy, SSE; Total Economic Value, TEV; Value Articulating Institutions, VAI.

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1 Introduction

According to its proponents, the circular economy (CE) describes "an economic system that is based on business models which replace the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes" (Kirchherr et al., 2017, pp.224-5). The core idea is that, rather than discarding products that can be potentially reused/recycled, they should be re-employed in a cascade of subsequent or feedback uses. Also, CE goes beyond the traditional waste prevention, reduction and recycling objectives and aims to inspire technological, organisational and social innovation and design across and within value chains (Andersen, 2007; Genovese et al., 2017). The CE is seen as a new paradigm that can square the circle of economy-society-nature interactions (Ellen MacArthur Foundation, 2012).

While the underlying theoretical foundation of the CE concept has been debated for some time and is rooted in a wide array of academic disciplines and fields (see, for example, Boulding, 1966; Daly, 1974a; Georgescu-Roegen, 1977; Pearce and Turner, 1990; Frosch and Gallopoulos, 1989), it has only recently broken through into public discourse. Despite the abundance of literature on the CE that is starting to appear (Schöggl et al. 2020), competing ideological views are framing the debate, ultimately producing different approaches to the transition towards a CE (Genovese and Pansera, 2021).

According to Korhonen et al. (2018), the CE might be defined as an essentially contested concept. Gallie (1956) postulated that a concept becomes essentially contested if there is agreement on the means and goals but disagreements on its definition, underpinning cornerstones and units of analysis. As such, the translation of the CE concept into practical initiatives might produce diverse outcomes: this is already apparent when looking at the plurality of pathways adopted in the transition towards a CE by different national and supra-national institutions. For instance, while the European Commission has promoted a wide array of directives and flagship initiatives aimed at fostering a bottom-up transition towards the CE, the People's Republic of China has adopted a top-down approach by putting CE at the heart of its recent five-year plans as a national development strategy (McDowall et al., 2017). Starting from these already diverging implementations of CE initiatives, Bauwens et al. (2020) argue that a CE can be organised in contrasting ways according to variations in the innovations deployed and the configuration of the governance regimes adopted. As such, multiple 'circular futures' might be plausible.

Despite the name, much of the CE literature lacks any grounding in economic theory and economic logics: as Bauwens et al. (2020, p.1-2) argue, many current approaches to CE are conceptually underdeveloped and "overlook the fundamental systemic changes needed". CE proponents have tended to look at the engineering and technical implications of the concept while not addressing the economic dimension and the central socio-economic implications of changes to production and consumption practices (Zink and Geyer, 2017). This is all the more surprising, as Llorente-González and Vence (2020, p.2) recognise, given that present economic structures resulting from "two centuries of development driven by continuous accumulation sustained on a linear logic" clearly impose limitations and constraints on the transition to the CE. Therefore, if

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the transition to a CE requires a paradigm shift, solid economic foundations must be explored and developed.

Within this context, a dimension that has surprisingly been overlooked in the current CE debate is that of *value*. How we define and account for what is *valuable* reflects a worldview about how economic and environmental systems as a whole are orchestrated, interact and reproduce themselves. Whilst the idea of value may seem natural and therefore immutable, there are multiple conceptions regarding where value stems from and the institutions through which it should be articulated, and these conceptions (or theories of value) have profound practical implications (Farber et al., 2002; Pirgmaier, 2021).[9]

The central aim of this chapter is to assess the *a priori* compatibility of the different plausible configurations of the CE with the principal theories of value found in mainstream and heterodox economics. After all, theories of value have formed the theoretical core of several major schools of economic thought; disagreements over theories of value still cause tensions between schools of economic thought, and, as such, might play an important role in shaping CE futures (Cole et al., 1991; Patterson, 1998). In addition, though, this chapter will also argue that 'circular futures' portrayed in the literature are themselves *value articulating institutions* (VAIs) (Jacobs, 1997; Vatn, 2005, 2009) that, at least implicitly, adhere to a theory of value even if this is not understood or recognised.[10] Therefore, openly calling attention to the issue of value in the context of a CE, and in particular concerning the multiple plausible 'circular futures', is a fundamental task to be considered and one that should form the *sine qua non* of future CE-related research.

To this end, this chapter goes on to develop a series of 'scorecards' for different plausible circular futures: these scorecards map how the underlying assumptions of circular futures enmesh with the underlying assumptions of theories of value, and in so doing, we hope this furthers rigorous assessment of the impacts and requirements of a transition to circularity.

An examination of the academic literature produced only two papers published in international peer-reviewed journals that discuss CE and theories of value (Kopnina, 2014; Doussoulin, 2019)[11]. In particular, Doussoulin (2019) appears to provide the only attempt to characterise the mechanisms of the CE in terms of a specific theory of value; however, this study does not acknowledge the plurality of circular futures introduced by Bauwens et al. (2020) and developed in what follows. Therefore, this chapter is aiming to fill a clear research gap by providing the first attempt to link the CE discourse and theories of value.

The paper proceeds as follows. In the next section, we illustrate plausible circular futures and consider how these futures can act as VAIs. Then, in Section 3, we briefly examine the principal theories of value found in mainstream and heterodox economics. Following this, in Section 4, we

[9] In this paper, "theory/theories of value" and "value theory" are used interchangeably.
[10] Vatn (2009, p.2208) suggests that value articulating institutions - "meaningful rule structures facilitating value articulation" - define, amongst other things, who should participate, how they are supposed to participate, what counts as data, how information is conveyed and how conclusions are reached.
[11] The following search string was employed in the academic search engine Scopus (TITLE-ABS-KEY ("circular economy") AND TITLE-ABS-KEY ("theory of value" OR "value theory" OR "values theory")) AND (LIMIT-TO (DOCTYPE , "ar")).

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bring these two elements together and discuss which theories of value might be most compatible with different visions of circularity and introduce the value scorecards which provide a visual depiction of this. Section 5 discusses the implications of these scorecards and how an awareness of value theory can help us articulate ambitious visions of a CE that move beyond dominant value narratives. Finally, Section 6 provides some concluding remarks and elaborates on future research avenues.

2 Plausible circular futures

While there is common agreement that the transition towards a CE could foster more sustainable futures, there is a lack of discussion about how a truly circular economic system should be organised. Most of the current literature on CE fails to openly acknowledge this, presenting the transition towards a CE as a straightforward, neutral and apolitical process, implicitly characterised by a techno-optimistic and eco-modernist stance (Genovese and Pansera, 2021). According to Korhonen et al. (2018), most CE work is conducted at the practical and technical levels, looking at material and energy flows in production-consumption systems. Emphasis is placed on metrics, tools and instruments; however, the basic assumptions concerning societal structures, production relationships, economic structure and underlying world-views which should be embedded in a CE are largely overlooked or unclear (Zink and Geyer, 2017; Friant et al., 2020).

Genovese and Pansera (2021) openly acknowledge this issue, stating that, given the prevalent apolitical nature of the CE discourse, the transition could become an ideological battleground, which could lead to different, and contrasting, future scenarios, ranging from a technocratic and authoritarian solution to a bottom-up and community-based one, mainly depending on which technological solutions are adopted. Developing this argument further, thanks to a thought experiment, Bauwens et al. (2020) propose four different plausible scenarios for a circular future. According to them, the future configuration of a CE depends on two "key drivers of change": the nature of technologies deployed (high-tech or low-tech innovations) and the governance regime (centralised or decentralised). Based on these two dimensions, they identify, according to a two-by-two matrix, four plausible (but not mutually exclusive) scenarios ("circular modernism", "planned circularity", "bottom-up sufficiency", and "peer-to-peer circularity"), reinforcing the key concept that a CE could be organised in very contrasting ways.

The *circular modernism* scenario described by Bauwens et al. (2020) is the dominant conception of what currently constitutes the CE narrative. This scenario is reflective of an eco-modernist approach (Grunwald, 2018; Genovese and Pansera, 2020) in that technological innovation and market forces are viewed as being able to decouple resource use and carbon emissions from human development. As such, the scenario is compatible with the concept of 'green growth' given that it does not significantly call into question the high consumption and growth-orientated focus of western capitalist societies and the business models that they are based on (Smulders et al., 2014; Hickel and Kallis, 2020).

In a *planned circularity* scenario, the transition towards a CE is centrally piloted by the government through strong coercive measures. Governments develop command-and-control regulations (based on taxation, bans on certain materials, direct economic intervention and mandatory right-

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to-repair initiatives) to force state-owned and private businesses to engage in CE-inspired strategies. The way in which the Chinese have embraced CE illustrates this state-led approach through the adoption of CE as a national strategy in the framework of 5-year plans. Yet, this approach can also be characterised by eco-modernist assumptions, which identify economic growth as the ultimate aim of the economic system (Genovese and Pansera, 2021).

In a *bottom-up sufficiency* scenario, small-scale CE solutions are implemented at the local level; production mainly aims to satisfy the community's immediate needs, thus challenging surplus production and the principle of servicing export markets. The focus here is on a more radical interpretation of CE, which is critical of the eco-efficiency agenda and is based on several tenets from the degrowth literature (Hobson and Lynch, 2016; Schröder et al., 2019; Bauwens, 2021). The ultimate aim is not to boost resource productivity but rather dramatically reduce resource consumption and the extraction of virgin raw materials (Bimpizas-Pinis et al., 2021), while encouraging democratic participation and community-driven deliberation. Business models emphasise durability, repairability and "and a non-consumerist approach to marketing and sales"; the emphasis is on higher R strategies such as refuse, reduce and reuse; supply chains are shorter, and companies are smaller and less reliant on economies of scale (Bauwens, 2020, p.5).

In a *peer-to-peer circularity* scenario, the focus is on technologies (such as blockchain, 3D printing and internet platforms) enabling collaborative consumption. Given its reliance on servitisation, this scenario could be seen as related to the narratives of the "sharing economy" (Martin, 2016). Organisations and individuals shift their focus from *products* to *access to resources* through arrangements that could also be beneficial from an ecological point of view, thanks to higher asset utilisation.

While the above-mentioned contributions have had the merit to characterise CE as an umbrella term, which includes different narratives and conceptualisations, and is open to different future implementations, the debate on the topic is still fairly limited, with some key dimensions not having been considered thus far when describing future CE scenarios (Genovese and Pansera, 2021; Pansera et al., 2021).

For instance, the role of social relations of production[12] in shaping different visions of the CE has been neglected. The result of this has been the development of a CE discourse that does not question the underlying assumptions of capitalist economies, despite the inherent contradictions between the overarching objectives of the latter and the implications of an ambitious CE agenda (Bimpizas-Pinis et al., 2021; Genovese and Pansera, 2021). An example of this is the conflict between the emphasis on economic growth of the mainstream CE discourse and the problematic nature of this concept within the original formulations of CE (Hickel and Kallis, 2020). It is clear that different circular futures could arise in societies that are characterised by different types of social relations of production and different models of ownership and control of the means of production (Genovese and Pansera, 2021; Pansera et al., 2021).

[12] Social relations of production of a society give that society its fundamental character and make it, for example, a capitalist rather than some other kind of society.

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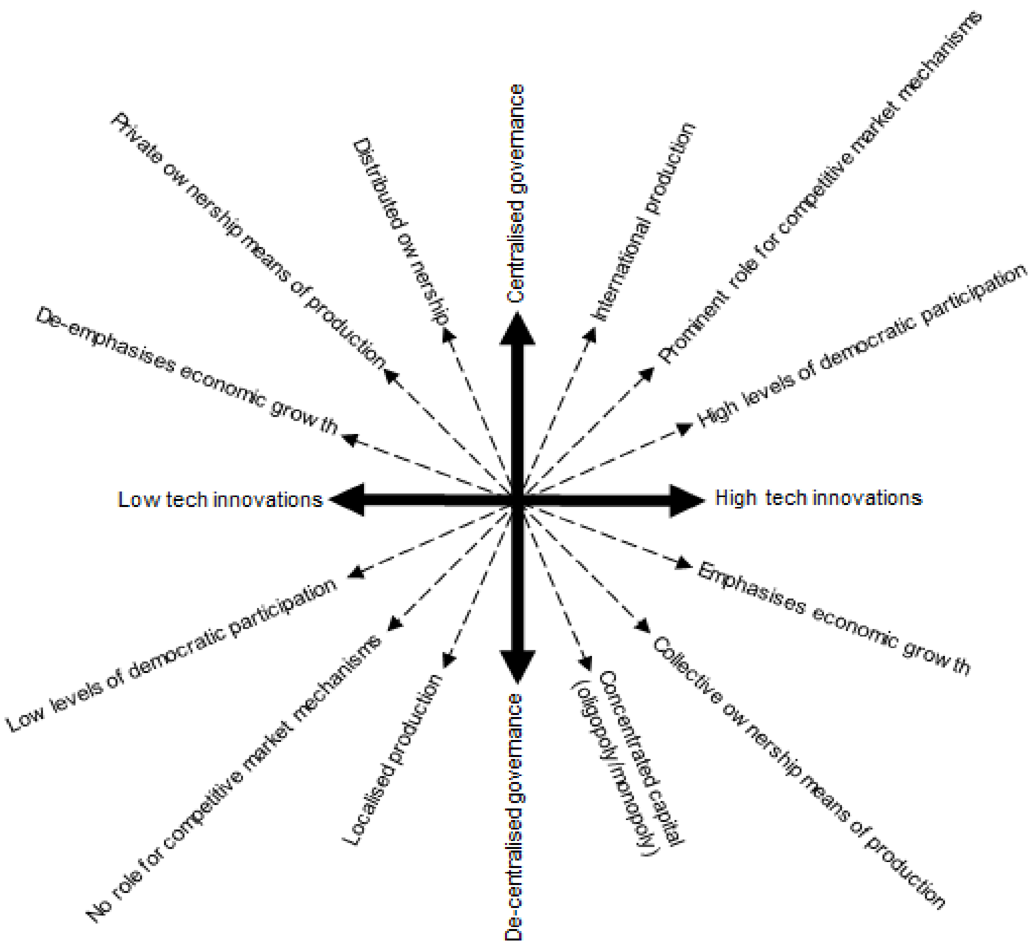
Similarly, while the current literature acknowledges the role of different types of economic actors in the transition towards a CE, not much is said about how such a transition could shape capital concentration and centralisation. While there are arguments in favour of a bottom-up transition, which could favour lower levels of capital concentration and centralisation (such as, for instance, the emergence of democratically run SMEs, labour-managed firms and workers' cooperatives), the technological requirements for the implementation of CE practices on a wide scale could also foster the emergence of oligopolistic structures and high degrees of concentration and centralisation of capital (Genovese and Pansera, 2021).

Building on the two key drivers of change suggested by Bauwens et al. (2020), Figure 1 summarises several additional dimensions that we suggest could, in combination, demarcate further circular scenarios. In addition to social relations of production and capital concentration, these include the desirability of economic growth, levels of democratic participation, the emphasis on competitive markets as vehicles for delivering allocative efficiency, and location of production and supply chains (local vs global). No doubt other dimensions could be added to this.

***Figure 1**. Dimensions of plausible circular futures (adapted from Bauwens et al., 2020). The two key drivers of change proposed by Bauwens et al. (2020) are represented on the vertical and horizontal axes by solid lines; the additional dimensions suggested here are represented by dashed lines emerging from the origin. Dimensions are shown as polarities as a way of highlighting the spectra that could define plausible circular futures.*



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2.1 Circular futures as Value Articulating Institutions

As conceptualised by Gasparatos (2010), different sustainability conceptualisations make different (explicit or implicit) assumptions regarding what is important to measure and how to measure it. These assumptions are structured sets of rules and typifications which, at the same time, constitute embedded value judgments. As a result, the outcome of such conceptualisations is far from being value-free and neutral.

In this sense, Gasparatos and Scolobig (2012) invoke the concept of Value Articulating Institutions in relation to sustainability conceptualisations. According to the seminal definition provided by Vatn (2005, p. 211), VAI define: (a) "who and in which capacity, i.e. in which role" should be considered during the decision-making process and (b) "what is considered relevant data and how data is to be handled".

In this sense, it can be argued that circular futures, as conceptualised by Bauwens et al. (2020), clearly meet the definition of VAI. Looking at the two main dimensions that these authors introduce to conceptualise and classify circular futures, the first one, governance regime, is clearly concerned with defining "who shall participate and on the basis of which capacity, in which role" when it comes to shaping the future implementation of CE policies and practices. Bauwens et al. (2020) recognise the existence of a continuum of governance solutions, spanning from a centralised one (where decision making is in the hands of national governments and large corporations) to a decentralised one (where community-based decision making is promoted).

On the other hand, the technology dimension is concerned with the types of solutions being adopted, distinguishing between a techno-optimistic perspective (in which the main societal goal is to maintain a growth-orientated consumer economy, through competitive market mechanisms, decoupled from environmental degradation) and a techno-sceptic one (emphasising the need to move away from resource-intensive, consumerist lifestyles and adapt to a resource descent pathway through the adoption of "low-tech" innovations). As further specified by Bauwens et al. (2020), this also clearly dictates the types of data that are needed to realise such transitions, the types of technologies that are needed to handle this data (with specific reference to artificial intelligence and big data techniques as opposed to more community-based and convivial types of decision-making processes) and the underpinning rationality of this process (based on individual versus socially constructed approaches).

3 Theories of value

Having reflected on different plausible circular futures, the theories of value that will be covered here are now introduced. These theories are illustrated in Figure 2; they have been selected because they represent the principal currents of thought in mainstream and heterodox economics (see Dobb, 1973; Patterson, 1998; Farber et al., 2002). The distinction between *receiver* theories of value and *donor* theories of value referred to by Odum (1996) and Gasparatos and Scolobig (2012) has been adopted. Broadly, donor theories account for the objective resources utilised to produce an item or service; receiver theories link value to human demand. Elsewhere this dichotomy is also sometimes referred to as *cost of production* versus *subjective preference* (Patterson, 1998, 2002; Gasparatos, 2010). However, the donor/receiver categorisation is slightly more useful for two

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reasons: (a) receiver values include additional approaches beyond the utilitarianism conjured up by the reference to subjective preferences, and (b) cost of production can imply a financial or monetary aspect that does not apply to all of the approaches in this category.

Whilst Figure 2 provides a sense of how the various theories *broadly* relate to one another and thus provides a guide to the reader, it masks profound differences in terms of the purpose and ambition of the different theories, which are beyond the scope of this paper. For instance, some theories exist to explain market prices, others focus on social relations, and others still examine social-ecological interdependencies. Moreover, some theories are descriptive, and some seek to be transformative.

These variations are also reflected in the understanding of *value* that the theories address. The traditional focus of value theory in economics has been on seeking an invariant unit to explain the source of *exchange value*, be that labour time, marginal utility or energy flows (Farber et al., 2002).[13] In other words, theories of value have sought to address "how...things with very different qualities – shoes and teapots – are made commensurable in 'free and equal' market exchange" (Pirgmaier, 2021, p.1). However, some contemporary approaches have sought to commensurate different units through an understanding of biophysical interdependencies without reference to market exchange: for example, Patterson's (2002) notion of *contributory value* (explained in what follows). In addition, other approaches focus more on *use value* (the satisfaction provided by the physical features of an item). Therefore, whilst we provide a brief overview of the key features and implications of each of the theories, this has been tailored so that it is relevant to the discussion in what follows; more comprehensive guides to the historical and philosophical foundations of the theories are provided by Dobb (1973), Patterson (1998), Farber et al. (2002), Martins (2013, 2016) and Pirgmaier (2021).

3.1 Receiver theories of value

The receiver theories of value covered here are neoclassical marginal utility theory, deliberative approaches to valuation and the Non-reductionist ecological economics associated with Nicholas Georgescu-Roegen and Herman Daly.

3.1.1 Neoclassical theory of value

The Neoclassical approach based on marginal utility theory has provided the canonical conception of value since the 'Marshallian Scissors' demand and supply diagram appeared at the end of the 19th century. From this perspective, exchange value emerges at the intersection of marginal benefit

[13] As Pirgmaier (2021, p.1) states, this may sound simple but "it remains one of the biggest controversies in the history of economic thought."

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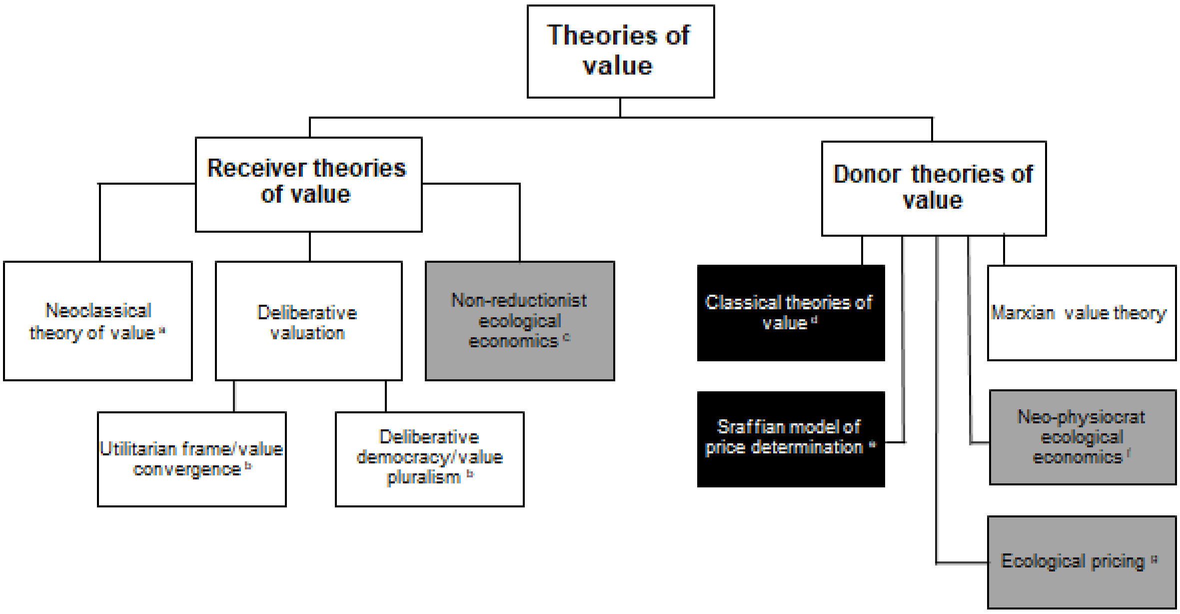
demand) and marginal cost (supply) curves and is thus determined by utility (subjective individual preferences) and cost of production (scarcity).[14,15]

***Figure 2**. Typology of theories of value. The theories of value in black boxes have been grouped together because they adopt a similar circular conception of the economy that revolves around a socio-economic process of continuous reproduction (Martins, 2016). The theories of value in grey boxes link value, in varying ways, to energy inputs. However, the tradition of economic thought advanced by Non-reductionist ecological economics ultimately understands value as 'enjoyment of life' (Daly, 1981). As such, even though low-entropy matter-energy is seen as the basis for 'enjoyment of life', the Non-reductionist ecological economics approach has been grouped alongside receiver theories of value. [a] For example, see Champ et al. (2003). [b] For a discussion of deliberative approaches, see Lo and Spash (2013). [c] For example, Georgescu-Roegen (1971) and Daly (1996). Following Hornborg (2014), we have labelled the approach of Georgescu-Roegen and Daly "Non-reductionist ecological economics". [d] Classical theories are understood here as including contributions from the French Physiocrats and the English classical tradition. For an overview, see Dobb (1973). [e] Sraffa (1960). [f] For example, Costanza (1980). Following Hornborg (2014), we have labelled the approach of Costanza "Neo-physiocrat ecological economics". [g] Patterson (1998, 2002, 2008).*



The model of consumer behaviour that underpins this approach assumes, on *a priori* grounds, that *homo economicus* exhibits clear, stable, fully rational and exogenously given preferences, which exist independently of the preferences of others. Furthermore, preferences, in general, are also subject to the principle of non-satiation (greater consumption leads to greater utility); individuals, therefore, are utility maximisers (and cost minimisers) and best characterised as calculating egoists

[14] The supply side of this equation is also understood subjectively: in Marshall's view, the real cost of production was defined by notions such as "efforts", "sacrifices" and "abstinence" (Bharadwaj, 1978).
[15] It is important to note that while the term "neoclassical" was first used by Thorstein Veblen to designate Alfred Marshall's principles of demand and supply, the term "neoclassical" was later used to designate an even more subjective theory of value than Marshall intended after Lionel Robbins criticised the idea of interpersonal comparisons of utility.

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who view the world predominantly through an instrumental and anthropocentric lens and act in light of perfect knowledge.[16]

When revealed through market exchange, preferences are expressed using money as the monistic numeraire, which is seen as a universal measure via which different values are made fully commensurable. According to this approach, the "fundamental economic 'problem' consists of optimally satisfying preferences" (consumers in this parlance are *sovereign*); this is achieved via competitive market mechanisms, which in turn deliver Pareto optimality (Farber et al., 2002, p.380). Where there are impediments to this functioning, such as public goods and externalities, non-market costs and benefits need to be internalised (and atomised) to ensure markets operate efficiently. When price signals reflect social benefit, this furthers what Spash (2013, p.356) refers to as the "strong and implicit ideology" behind the neoclassical approach, namely the potential for free markets to further democratic and free societies, as well as problem-solving technology.

In terms of key implications here, the principle of non-satiation, in conjunction with a focus on *relative* scarcity, suggests that so long as the *total* stock of capital is unchanged, infinite substitution between forms of capital (natural and man-made) is not ethically problematic and it does not compromise intergenerational equity and the desirability of infinite economic growth. Indeed, preferences and utility levels tomorrow are not seen as being influenced by preferences and utility levels today (Norton et al.,1998): individuals have a positive (high) time preference with consumption now preferred over consumption in the future as utility is discounted at an increasing rate the further into the future it occurs. Given the assumed stability of preferences, at its essence, this approach views the world as working "largely deterministically, moving from one equilibrium to another in relatively stable fashion, and [responding] to changes in constraints in a predictable fashion" (Farber et al., 2002, p.380).

3.1.2 Deliberative (monetary) valuation

Deliberative monetary valuation (DMV) was first developed in response to limitations with traditional stated preference methods used to elicit non-market values for the environment (Lo and Spash, 2013). Specifically, public participation based on small group discussions occurs before the value elicitation exercise to aid learning and *individual* preference formation and overcome cognitive limitations to stating preferences. Drawing on a utilitarian framing, these approaches produce values that converge on a single metric and are the product of instrumental rationality and orthodox economic logic (e.g. see Urama and Hodge, 2006; Alvarez-Farizo et al., 2007). Lo and Spash (2013) refer to these approaches as *preference economisation* DMV.

An alternative approach to DMV appeals to the theory of deliberative democracy and is often rooted in Habermas's discourse ethics (Habermas, 1984) and Dryzek's theory of discursive

[16] In the Total Economic Value (TEV) conceptual taxonomy proposed by Pearce and Turner (1990), an individual's utility function can reflect a range of motivations including the value of knowing that environmental attributes continue to exist (existence value) and are available for others to use now (altruistic value) and in the future (bequest value). Therefore, TEV can include limited altruistic and intrinsic motivations as well.

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democracy (Dryzek, 1990). The focus of this approach is to engender a form of collective preferences, which are borne out of social or communicative rationality (Vatn, 2009). Individuals within these groups are viewed as citizens or stakeholders rather than utility maximisers, and the group-based nature of decision making is seen as encouraging consensus and compromise. What is more, this approach fosters the integration of non-utilitarian ethics (rights-based thinking), non-economic motives (e.g. social norms and procedural and distributional fairness) and plural values based on incommensurable or lexicographic preferences (Sagoff, 1998; Howarth and Wilson, 2006; Spash, 2008; Lo and Spash, 2013). Lo and Spash (2013) refer to these approaches as *preference moralisation* DMV. However, in this context, they are referred to simply as *deliberative valuation* to distinguish them from the neoclassical-based DMV.

3.1.3 Non-reductionist ecological economics

The Non-reductionist ecological economics of Georgescu-Roegen and Daly does not articulate a theory of value *per se* but rather presents a vision of a Steady-State Economy (SSE) which frames a particular conception of value.[17] An SSE adheres to the laws of thermodynamics (i.e. the throughput of low-entropy matter-energy) and the impossibility of complete recycling and has three central features: sustainable scale, just distribution and efficient allocation (Daly, 1974a; Georgescu-Roegen, 1979; Daly, 1992; Farley and Washington, 2018).

Sustainable scale refers to the imposition of ecological boundaries on the economic system that reflect the *absolute* scarcity of resources, thus ensuring that future generations are considered. A sustainable scale is to be implemented by adopting depletion quotas and birth licences to ensure constant stocks of people and artefacts (sustained by low throughput of matter-energy). A just distribution suggests limiting disparities in the distribution of income and wealth (and reductions to monopoly power): such a distribution is to be effected via distributive limits, including minimum and maximum incomes. Finally, as Farley and Washington (2018, p.443) recently clarified, an efficient allocation is defined as one which achieves "the greatest amount of useful services for the lowest ecological cost, as measured by throughput". Once scale and distribution have been addressed, efficiency is achieved via market mechanisms. However, Daly emphasises that this is "market with a *small m*, a limited tool for rationing resources, communicating information, and exchanging goods and services" (Daly, 2016, p.27, emphasis added; see also Kunkel, 2018). Where there are market failures and public goods, allocation is to be achieved via participatory democratic processes (Farley and Washington, 2018).

The reference to participatory processes points towards a cooperative understanding of human behaviour: humans are "capable of both altruism and egoism" (Farley and Washington, 2018, p.445) and best viewed "as persons-in-community, heavily influenced by their cultural milieu" (Daly and Cobb Jr., 1994 *cited in* Farley and Washington, 2018, p.445). Within this context, value is understood as enjoyment of life or psychic utility (Daly, 1981), hence why this approach has

[17] Following Burkett (2003), Hornborg (2014, p.16) distinguishes two biophysical schools of thought that adhere to the laws of thermodynamics: the "Non-reductionist" ecological economics of Georgescu-Rogen (1971) and Daly (1996) and the Neo-Physiocrat" ecological economics of Costanza (1980) covered in Section 3.2.4.

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been classified as a receiver theory of value. Indeed, the ultimate goal of the economy is to satisfy needs ("basic psychological requirements") rather than just 'wants' (Farley and Washington, 2018, p.443).[18] However, low-entropy is seen as the basis for value, even if this is not a sufficient condition in its own right (Georgescu-Roegen, 1979). Moreover, the conception of value associated with an SSE is best understood in *use value* terms given that the focus of such an economy is simple commodity exchange, i.e. reproduction and qualitative development as opposed to growth and accumulation (Kunkel, 2018, p.97).

3.2 Donor theories of value

The donor theories of value covered here include those emanating from the classical tradition, Marxian value theory, Sraffa's neo-Ricardian model of price determination, Neo-physiocrat ecological economics and ecological pricing.

3.2.1 Classical theories of value

For classical theorists, value stemmed from objective inputs – in particular land and labour time – required to produce a commodity (Patterson, 1998). This was part of a fundamentally different view of the economy, not as a "one-way avenue that leads from 'Factors of Production' to 'Consumption Goods'", as Sraffa (1960, p.93) described neoclassical economics, but as a "circular process of reproduction that takes place within limits set by natural constraints" (Martins, 2016, p.33).

The Physiocratic school, led by Francois Quesnay (1694-1774), made an early contribution in this direction (Patterson, 1998) by theorising an economy of interdependent sectors, characterised by a circular flow of commodities. Natural resources (specifically, 'land') were seen as the sole source of all values; primary production from the agricultural sector was seen as the only source of a surplus, deriving its wealth directly from the land. The Physiocrats also employed land as a value numeraire, even if they did not construct a formal theory of value.

Adam Smith (1723-1790) showed that a "surplus originated from production in general and not from agricultural production alone" (Garegnani, 1984, p.293). Smith argued that a pure labour theory of value could be valid for pre-capitalist economies. However, the fundamental characteristic of capitalist economies is the interplay of different social classes that contribute to production. For this reason, with specific reference to capitalist economies, Smith proposed a cost of production theory of value, which explains the long-run exchange value of a commodity as the sum of wages, profits and rents required to produce it (Screpanti and Zamagni, 2005; Pirgmeier, 2021).

David Ricardo (1772-1823) noted a circularity in Smith's reasoning, as it seeks to explain prices by prices of land, labour and means of production. Also, he stated that profits are a residual income

[18] This approach distinguishes between *absolute* and *relative* wants; unlike the neoclassical approach, only relative wants are infinite. However, relative wants cannot be universally satisfied via growth (Daly, 1992).

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that remains after wages have been paid. Ricardo argued for a labour embodied theory of value also for capitalist economies, i.e. the concrete labour contained in commodities, thus rejecting the view that exchange value is governed by supply and demand.

Despite disagreements, both Ricardo and Smith concur with an explanation of exchange value at a level that underpins the fluctuations of supply and demand (Pirgmaier, 2021). Furthermore, in the classical conception, the reproduction, allocation and use of the social surplus (defined as that "part of production which is not necessary for the reproduction of the existing economic system" – Martins, 2013, p.227) are the key theoretical constructs (Garegnani, 1984; Kurz, 2003; Cesaratto, 2020). Where the social surplus is used for "productive activities, the economy flourishes…[whereas when it is used for] gross luxuries, the economy and society enter into a stage of decadence" (Martins, 2016, p.36).

The classical focus on the social surplus was in stark contrast to the neoclassical preoccupation with scarcity and the optimal allocation of scarce resources. For classical theorists, scarcity was not universal to all forms of capital but instead a special case that applied to land and natural resources because they are not reproducible (Martins, 2016). In addition to giving greater prominence to the limited nature of natural resources, the effect of this divergence had additional implications. In the classical conception, manufactured capital can always be reproduced, and therefore prices are influenced by (or gravitate towards) the cost of production (Martins, 2016); by contrast, in the neoclassical approach, scarcity is the general case, and thus price is determined by recourse to demand and supply schedules (which in turn influences the cost of production).

Within the process of circular reproduction, human agents are not seen as utility maximisers but "creatures of habit whose utility level gets adapted to a given social situation, and…a given (customary) standard of living" (Martins, 2013, p.227). According to Martins (2016, p.36), this flows from an Aristotelian conception of happiness which suggests that human beings "become satisfied…with a finite number of basic commodities". Accordingly, economic growth becomes one "possibility amongst others" of improving living standards, including through distribution (taxes on rents and luxuries) so long as this does not impact the process of reproduction (Martins, 2013, p.229). The reference to a customary standard of living was understood as being more than that needed for physical survival, given that this was "essential for the reproduction of the economy and society" (Ibid, p.228).

Also, a distinctive characteristic of classical economists is that they took the socio-economic system as they found it, stratified in social classes – workers, landowners and capitalists (Kurz and Salvadori, 1998); therefore, they saw human agents as part of a social class, in a context where distribution is made according to social class, and social class springs from a given division of labour. As such, drawing on Heidegger's phenomenology, Martins (2016, p.37) suggests that classical theories of value are compatible with an ontological perspective that views the "human agent...as a Being-in-the-World, which means, amongst other things, being part of a broader whole".

3.2.2 Marxian value theory

Marx argued that value in a capitalist society is explained through abstract socially necessary labour time (ASNLT).

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"The value of any commodity – and this is also of the commodities which capital consists of – is determined not by the necessary labour-time that it itself contains, but by the socially necessary labour-time required for its reproduction" (Marx, 1990, Vol. 3: 238).

Rather than referring to 'labour' as a generic activity or social practice, 'socially necessary' labour identifies the average amount of labour time required to produce certain commodities within a given set of technological development conditions. As such, ASNLT is an average value that acknowledges the key role played by technological development, knowledge and skills in shaping value (Reuten, 2018). Also, abstract labour is labour that produces products with 'value' in the sense of universal exchangeability. Essentially, in the act of exchange, different kinds of individual labour become homogenised. If abstract labour represents the qualitative aspect of value, this can be quantified and measured through 'labour time' (Banaji, 1979). In other words, how much time it takes on average to produce a given commodity provides an explanation of the exchange value of that commodity. While inheriting the classical view of a socio-economic system stratified in social classes, Marx clarified that such stratification, and its power imbalances, are inherently embedded in capitalist production relationships. Wages received by workers provide them with purchasing power; this allows their reproduction. However, the difference between the ASNLT required for workers' reproduction and the labour-power expended in the capitalist process of production represents the very essence of capitalist exploitation.

Hence, while still offering an anthropocentric perspective and a commensurable view of value (based on a donor perspective and on physical inputs), compared to other classical theories of value, the major innovation in Marx's theory of value lies in the fact that abstract labour is a historical fact, specific to capitalism, as generalised wage-labour did not exist in previous societies (Smith, 2018; Pirgmaier, 2021). As such, the Marxian ToV provides a radical critique of capitalist value and valuation.

3.2.3 Sraffa model of price determination

Sraffa's neo-Ricardian model of price determination revived the classical circular (and reproductive) conception of the economy following the intervening neoclassical revolution (Sraffa, 1960).[19] In this macro-based model, exchange values are established by Input-Output (I-O) modelling and the solutions to a series of simultaneous linear equations which represent the circular flow of physical commodities in the economy, any one of which can be used as the numeraire.[20] As Farber et al. (2002, p.377) state, the Sraffian system "established conditions under which exchange ratios between commodities can be determined based on their use in production; i.e. a set of commodity prices that would exhaust the total product". The key point here is that socio-technical conditions of production, or alternatively, the costs of production of commodity

[19] Martins (2013) suggests that the Sraffa model is the first stage in the revival of the classical surplus theory; the second stage being the capabilities approach of Sen (1999) and Nussbaum (2000). The latter is relevant to determining the basic capabilities necessary to achieve human well-being and thus what remains can be understood as a social surplus.

[20] Although Sraffa made use of a *standard commodity* - "which is a mixed commodity, made up of the basic commodities necessary for the reproduction of the economy in a certain proportion" - to express exchange value (Martins, 2016, p.35).

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inputs, determine exchange value and not reference to demand and supply schedules representing individuals' preferences (Judson, 1989).

Martinez-Alier (1995, p.78) argues that the underlying "political objective" of the Sraffian system is ultimately to show that the distribution between wages and profits "determines, from the supply side, the 'prices of production', together with the technical specificities of the production". As a result, the value of the capital stock is said to depend "on the results of distributional conflict between wage workers and capital owners" (Ibid, p.79).

3.2.4 Neo-physiocrat ecological economics

Neo-physiocrat ecological economics assumes that value has a biophysical basis in the energy used to produce goods and services. This mirrors both the Physiocratic school, who believed that land constituted the ultimate source of value, and the Ricardian embodied labour theory of value, which identified labour as the primary factor of production. Drawing on the physics of thermodynamics, at least at the global level, 'free' or 'available' energy from the sun is seen as the primary input into the system that explains production costs and therefore the value that humans assign to goods and services in the process of exchange.[21] Such an 'energy theory of value' was proposed by Costanza (1980, 1981a, 1981b) and Costanza and Herendeen (1984), who utilised I-O analysis to investigate the relationship between embodied energy (direct and indirect energy consumption) and market exchange values.[22,23]

As Burkett (2003, p.151) points out, Neo-physiocrats take a distinctly positive view of free markets and their function in providing "adequate measures of the true resource costs of production". From this perspective, environmental problems emerge because "markets for natural wealth are missing, incomplete, or imperfect. Apparently, if nature's use value were properly reduced to embodied energy and then properly measured by money, environmental problems would be automatically corrected" (Ibid, p.152).

3.2.5 Ecological pricing

The ecological pricing models developed by Patterson (1998, 2002, 2008) can be seen as a variation on the Neo-physiocrat approach. In a similar way to the work of Costanza, ecological pricing draws on I-O modelling and simultaneous equations to map biophysical interdependencies in the reference ecosystem. However, these interdependencies are inferred from energy *and* mass flows,

[21] Farber et al. (2002, p.382) suggest free energy has the following special characteristics which satisfy the criteria for a "primary" input: "Energy is ubiquitous. It is a property of all of the commodities produced in economic and ecological systems. While other commodities can provide alternative sources for the energy required to drive systems, the essential property of energy cannot be substituted for."

[22] Using an 87-sector I-O model of the United States economy for 1963, 1967 and 1973, Costanza (1980, 1981a, 1981b) and Costanza and Herendeen (1984) found a strong correlation (R2 = 0.85 - 0.98) between embodied energy and the market determined dollar value of sector output. The validity of this empirical finding has been questioned, for example, by Daly (1981).

[23] Hornborg (2014) suggested that Odum (1996) also forms part of Neo-physiocrat ecological economics. However, we disagree with this: Odum clearly described his EMERGY approach as a theory of "environmental value" not an economic theory of value. If anything, EMERGY is most similar to ecological pricing introduced in the next section; however, Odum did not describe EMERGY as a 'pricing procedure.'

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and the resulting shadow prices are termed 'contributory values'. Contributory value reflects the backward and forward linkages between 'ecological entities' or 'compartments' and the contribution that they make to the existence of one another – "for example, plankton provides contributory value to a fish species, as it is a source of food for fish" (Patterson, 2008, p.143).

Unlike embodied-energy theories, there is no suggestion that contributory values will explain, and be adequately reflected in, market prices: as Patterson (2002, p.470) argues, whilst ecological prices "are important in defining market prices, they are by no means the only factors". Indeed, the notion of contributory value does not require a human valuer given that it "can be defined in terms of the 'needs' of non-human species", and as such, it can "be considered to be a more biocentric valuation concept" (Patterson, 2008, p.143). In addition, ecological pricing is less reliant on using solar energy as the numeraire (any commodity in the system under analysis can assume this role) (Patterson, 1998), and it can be applied to levels below the biosphere (Patterson, 2008). These differences lead Patterson (1998) to label his approach a "biophysical theory of value".

4 Which theories of value for which circular future?

To examine the compatibility between the circular futures and theories of value introduced in the preceding sections, we drew on the dimensions that Vatn (2009, p.2211) suggests when considering VAIs.[24] These dimensions – supplemented by relevant additions from Gasparatos (2010) and Hornborg (2014) – were used to produce a template that was applied to the theories of value described in the previous section. Consisting of eight dimensions, the completed template (framework) reveals the key differences between the theories and the traditions of economic thought that underpin them (Table 1). Following this, the framework was then applied to each of the circular futures, i.e. for each of the eight dimensions in the framework, the theory of value that best matched that aspect of the circular future in question was selected.[25] The result is a 'scorecard' for each future that sets out how the "meta principles" that Bauwens et al. (2020, p.3) use to characterise each of their scenarios enmesh with the currents contained within value theory. This procedure is summarised in Figure 3.

It should be stressed that, just as Bauwens et al. (2020, p.2) recognise that their four futures are not mutually exclusive and represent "extreme cases of continuums", so too here some of the arguments presented may be reconciled across the different futures and particularly the hybrid scenarios that appear most likely. Also, where necessary (and where indicated), we have made some limited assumptions about the content of each future given that Bauwens et al. (2020) did not describe each one exhaustively.

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[24] The dimensions concerning *rationality* and *interaction of agents* were particularly relevant in this context.

[25] The matching process was conducted by both members of the research team independently. The resulting scorecards for each circular future were then compared. In the case of a disagreement, members of the research team tried to resolve these through a conversation. Whenever doubts still persisted, the opinion of an independent external subject expert was sought. It is worth noting that disagreements occurred in less than 5% of the matching cases; the involvement of an external expert was needed on just three occasions.

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Figure 3. *Stages in mapping values theories to circular future*

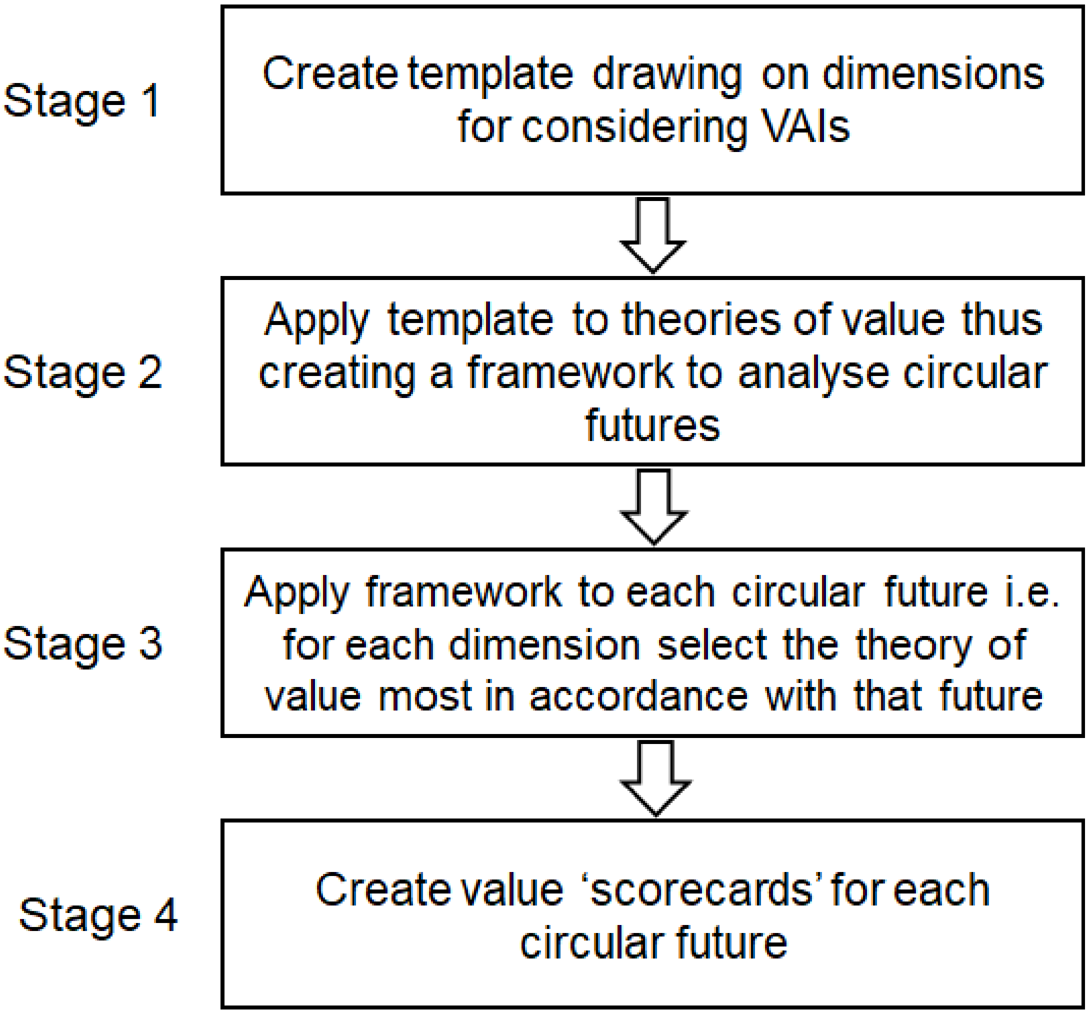

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Table 1. *Summary of main features of theories of value*

	Neoclassical theory of value	**Deliberative valuation**	**Non-reductionist ecological economics**	**Classical theories of value**	**Marxian value theory**	**Sraffa's model of price determination**	**Neo-physiocrat ecological economics**	**Ecological pricing**
Purpose	Description of and prescription for the status quo	Transformative	Transformative	Descriptive	Critique of capitalism - descriptive and transformative	Descriptive and transformative	Descriptive and weakly transformative	Transformative
Relevant groups (timeframe and geographical scale) [a]	Humans (present generation; disaggregated)	Humans representing themselves, their local communities, and potentially future generations	Humans (present and future generations) and non-humans	Social classes, landowners, farmers, owners of means of production and labourers	Social groups/classes, owners of the means of production and labourers	Social groups/classes, owners of the means of production and labourers	None. Focus is inputs of embodied energy	Ecological entities that contribute or receive value
Roles [a]	Individual consumer	Citizen or stakeholder representative	Persons in community; expert rule-setter (optimal scale) [f]	Human agent part of a "circular reproduction process that transcends the human individual" [h]	Participation mediated by power imbalances and social forces	Participation mediated by power imbalances and social forces	Participant is irrelevant	Participant is irrelevant
Value orientation of relevant stakeholders [b]	Egoistic, instrumental, anthropocentric	Altruistic, anthropocentric	Altruistic and egoistic; biocentric (optimal scale) [f]	Biocentric	Anthropocentric	Biocentric	Biocentric	Biocentric, intrinsic
Concept of value and rationality [b]	Receiver system of valuation; individual rationality (full); individual preferences	Receiver system of valuation; social rationality; social preferences; fair distribution [d]	Receiver system of valuation; individual rationality (bounded) and social rationality [f,g]	Donor system of valuation; cost of production	Donor system of valuation; cost of production	Donor system of valuation; cost of production	Donor system of valuation; cost of production	Donor system of valuation; cost of production

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Value dimensions [a]	Commensurable	Commensurable and incommensurable (but weakly comparable) [e]	Commensurable (market allocation); incommensurable (setting optimal scale and allocation to correct market failures via participatory democratic processes) [f]	Commensurable (e.g. Ricardo's labour theory); weakly comparable (Physiocratic school)	Commensurable	Commensurable	Commensurable	Commensurable
Form of communication and principle of participation [a]	Individual actions revealed via market exchange	Small group negotiations/ deliberation	Wants revealed through market exchange; allocation to address market failures via participatory democratic processes	Institutions and customs [i]	Power structures, class conflict	Distributional conflict between wage-workers and capital owners [k]	Not relevant	Not relevant
Why are there environmental problems? [c]	Environmental costs are insufficiently internalised in market prices	Environmental policy does not reflect non-economic motives and non-utilitarian ethics [e]	Economic value generation generates entropy	Inefficient use and distribution of the surplus [j]	The capitalist mode of production generates environmental destruction	Unclear	Natural values such as embodied energy are insufficiently internalised in market prices	Failure to account for the biophysical roles that species play in natural ecosystems

[a] Dimensions from Vatn (2009). [b] Dimensions adapted from Gasparatos (2010). [c] Dimension (and column entries) adapted from Hornborg (2014). [d] Regarding fair distribution, see Howarth and Wilson (2006). [e] See Lo and Spash (2013). [f] See Farley and Washington (2018). [g] Whilst this approach equates value with 'enjoyment of life', ultimately enjoyment of life is viewed as having an ecological basis. [h] Martins (2016, p.34). [i] Martins (2013) discusses the role of institutions and customs in setting the subsistence wage. [j] See Martins (2016). [k] See Martinez-Alier (1995, p.78/9)

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4.1 Circular modernism and value theory - sustaining growth

Of the four futures Bauwens et al. (2020) put forward, the circular modernist future has the most evident association with a single theory of value, in this case, marginal utility theory. This is perhaps not surprising given that circular modernism essentially reflects the status quo in many capitalist countries whereby competitive market forces, technological progress and the macroeconomics of growth – all as we have seen hallmarks of marginal utility theory – go unquestioned. In this scenario, individuals are unbridled consumers without reference to a wider community or incentive system other than themselves. As such, transformations are supply-side focused and based on conventional business models which, as Bauwens et al. (2020 p.7) suggest, are "still largely compatible with the linear economy". The role of government is focused on setting minimum standards (for example, regarding eco-efficiency) and, we might surmise, correcting market failures and promoting value monism by extending the reach of individual preferences to cover environmental *goods* and *services* for which markets do not exist (Buchmann-Duck and Beazley, 2020).[26]

Table 2 presents the scorecard for circular modernism reflecting the preponderance of the neoclassical approach. In addition to marginal utility theory, though, Marxian value theory's *positive* (i.e. descriptive) function also particularly resonates in this context. Whilst Bauwens et al. (2020) do not explicitly describe circular modernism in terms of social forces and the exploitation of labour, nonetheless, Marxian value theory provides a radical critique of the capitalist market provisioning that underlies circular modernism (relevant groups, roles, forms of communication etc.) and in so doing provides the foundation for transition pathways towards more ambitious circular futures. Given its common emphasis on class struggle and distributional conflict, the Sraffian model could also be relevant here (Judson, 1998).

Finally, dimensions within Non-reductionist ecological economics are also relevant (albeit to a lesser degree) given that the economic system imagined by this approach is based on limited market allocation within ecological and distributive limits. As such, there is a common focus on the communicative and commensurating role of market mechanisms and a receiver system of value centred on the individual (albeit influenced by a cultural context).

4.2 Planned circularity and value theory - CE by command

The planned circularity future presents a scenario where governments impose strong coercive measures in favour of the transition towards a CE; in this situation, the role of the 'invisible hand' is supplanted to varying degrees by top-down planning and coordination. Therefore, in general, donor theories of value which do not focus on human participants and instead have a biocentric value orientation and commensurable value dimensions are particularly applicable in this context.

[26] This omission arises because of public good characteristics and externalities and means that environmental goods and services often have no price, even though they clearly provide substantial benefit.

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More specifically, a planned circularity future might take the shape of a 'command economy' (similar to the ones which have existed in the 20th-century), in which competitive market mechanisms play no role in the allocation of resources. Within these contexts, central planners attempted to construct inventories for natural resources, also depicting their interactions with production systems through *stock-flow* models. For instance, in the former Soviet Union, inventories recorded stocks of natural resources in physical units; in an attempt to enhance commensurability, stocks were then also recalculated into "comparable physical units" by taking into account differences in quality, concentration and other characteristics. Prominent examples of this were provided by stocks of fuels (which were inventoried in equivalent energy units) and attempts to assess the *embodied metal* content of infrastructures and equipment of the whole Soviet economy (Zusman, 1976). As stated by Thornton (1978) and Sathre and Grdzelishvili (2006), such approaches were not able to measure value, due to limited progress, at the time, in non-market valuation methods.

Therefore, for circular futures based on a 'command economy' framework, theories of value where allocation is based solely on physical calculations and where there is not a sympathetic view of competitive market mechanisms, such as Patterson's ecological pricing approach, may be most applicable. In general, within all types of planned circularity scenarios, appropriately modified Input-Output approaches (Leontief, 1986), which can show the connections of the economic system in its entirety, could also be relevant to coordinating material flows. The usefulness of an Input-Output framework within a planned economy was documented by Lange (1978), as also discussed by Lopes and Neder (2017).

Table 2. *Circular modernism and theories of value*

Question	Neo-classical	Deliberative valuation	Non-reductionist	Classical	Marxian	Sraffa	Neo-physiocrats	Ecological pricing
Purpose	✓✓				✓✓		✓	
Relevant groups	✓✓			✓✓	✓✓	✓✓		
Roles	✓✓		✓		✓✓	✓✓		
Value orientation of stakeholders	✓✓				✓✓			
Concept of value and rationality	✓✓		✓					
Value dimensions	✓✓	✓✓	✓	✓	✓✓	✓✓	✓✓	✓✓
Communication and participation	✓✓		✓		✓✓	✓✓		
Why are there environmental problems?	✓✓				✓✓		✓	
SCORE out of 16	16	2	4	3	14	8	4	2

Legend: ✓✓ = highly consistent; ✓ = consistent

However, planning may also be driven by a specific recognition of the incommensurability of different values and/or the entropic nature of energy and mass flows and thus the need to impose

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ecological limits for the economy to operate within (Daly, 1992). Therefore, dimensions within deliberative valuation and non-reductionist ecological economics, respectively, are also potentially relevant.

Where planning still involves a role for competitive market mechanisms (such as in contemporary China and Vietnam, or 20th-century examples of 'market socialism', such as Yugoslavia), then Sraffa's model of price determination would also be a compatible approach. As Patterson (1998) points out, whilst inputs and outputs are denominated in physical terms in the Sraffa model, this approach is nonetheless based on the circular flow of exchange value (which is subjective and reminiscent of neoclassical economics) and the production of surplus wealth (i.e. a system of accumulation). Table 3 presents the scorecard for Planned Circularity.

***Table 3**. Planned circularity and theories of value*

Question	Neo-classical	Deliberative valuation	Non-reductionist	Classical	Marxian	Sraffa	Neo-physiocrats	Ecological pricing
Purpose			✓✓			✓✓		✓✓
Relevant groups							✓✓	✓✓
Roles			✓				✓✓	✓✓
Value orientation of stakeholders			✓	✓✓		✓✓	✓✓	✓✓
Concept of value and rationality				✓✓	✓✓	✓✓	✓✓	✓✓
Value dimensions	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓	✓✓
Communication and participation			✓				✓✓	✓✓
Why are there environmental problems?		✓✓	✓✓		✓✓		✓✓	✓✓
SCORE out of 16	2	4	9	6	6	8	14	16

Legend: ✓✓ = highly consistent; ✓ = consistent.

4.3 Bottom-up sufficiency and value theory – embracing degrowth

In a bottom-up sufficiency scenario, the focus is on localised production to "[satisfy] needs rather than...[promote] wants" (Bauwens et al., 2020, p.6); a significant reduction in consumption and the extraction of virgin raw materials is foreseen. This scenario also takes a less optimistic view on the potential for technology to deliver the transition towards a CE, perhaps in part out of a recognition of the rebound effect and the scope for efficiency gains to ultimately give rise to demand increases (Zink and Geyer, 2017). As a result, it is conceivable that this scenario is more likely to focus on resilience and ecological integrity rather than cost-based notions of efficiency (Bimpizas-Pinis et al., 2021). Therefore, the fallibility of individual preferences is likely to be highlighted, along with an understanding of the environment, not as operating in a deterministic and stable fashion, but as characterised by critical thresholds and tipping points (Lenton et al. 2008).

Related to this point, a focus on resilience also presupposes a long-term perspective whereby a certain stock of natural resources (and the assimilative capacity of the environment) is maintained in its entirety across generations, thus safeguarding intergenerational equity. This is based on the

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understanding that needs tomorrow can be influenced by needs today (reversing neoclassical logic) and therefore that a low time preference is more appropriate; this is consistent with the explicit focus on future generations of non-reductionist ecological economics. It may also be consistent with ecological pricing, which takes account of the 'needs' of non-humans and does not require the presence of a human valuer.

In a context where economic growth is no longer privileged, theories of value that impose overall limits on the size of the economy and economic growth (such as non-reductionist ecological economics) may be the most compatible. Indeed, this scenario would likely recognise that low-entropy matter-energy is the ultimate input of, and constraint on, production (Georgescu-Roegen, 1973, pp. 53-54, 58); so, this implies that the economy will have to adjust to a "steady state" to ensure its own reproducibility (Daly, 1974b).

The de-emphasis of economic growth in this scenario is coupled with "political and economic relocalization [sic] through the decentralization [sic] of decision making…[thus creating] the conditions for direct participation and control in the decision-making process" (Bauwens et al., 2020, p.8). Individuals are "active citizens" within a civil society that promotes the transition and not "mere consumers or users" (Ibid, p.6). The concept of value most in keeping with a focus on participation and social rationality would appear to be deliberative valuation, with its emphasis on deliberative decision making, civic preferences (including fair distribution) and diverse (and incommensurable) values that go beyond economic considerations (Howarth and Wilson, 2006). As explained in Section 3, within these approaches, individuals are seen as citizens or stakeholders rather than utility maximisers, with group-based processes encouraging consensus and compromise for achieving procedural and distributional fairness. The classical conception of the human agent as part of a "circular reproduction process that transcends the human individual" may also be better aligned with futures based on bottom-up decision making (Martins, 2016, p.34). Table 4 presents the scorecard for Bottom-up Sufficiency.

***Table 4**. Bottom-up sufficiency and theories of value*

Question	**Neo-classical**	**Deliberative valuation**	**Non-reductionist**	**Classical**	**Mar xian**	**Sraffa**	**Neo-physiocrats**	**Ecological pricing**
Purpose		✓✓	✓✓			✓✓	✓	✓✓
Relevant groups		✓✓	✓✓					
Roles		✓✓	✓✓	✓✓				
Value orientation of stakeholders		✓✓	✓	✓✓		✓✓	✓✓	✓✓
Concept of value and rationality		✓✓	✓					
Value dimensions		✓✓	✓✓					

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Communication and participation		✓✓	✓✓					
Why are there environmental problems?		✓✓	✓✓		✓✓			✓✓
SCORE out of 16	0	16	14	4	2	4	3	6

Legend: ✓✓ = highly consistent; ✓ = consistent.

4.4 Peer-to-peer circularity and value theory – a sharing economy?

Suggesting which theories of value might be compatible with peer-to-peer circularity is not straightforward; this scenario falls somewhere between circular modernism and bottom-up sufficiency, and the compatibility of different value theories is dependent on the assumptions made, in particular, regarding ownership of the technology and servitised platforms that are the focus here. On the one hand, if the sharing economy envisaged in this scenario is powered by platforms that are community-owned and which promote truly collaborative consumption, then peer-to-peer circularity may evidence reduced consumption in the shift towards *performance* rather than *ownership*, and individuals as *users*, not *consumers*. Therefore, revisiting the arguments made in the context of bottom-up sufficiency, the theories of value most relevant here may include those that do not accept the primacy of surplus value creation and perpetual economic growth. Therefore, Non-reductionist ecological economics and ecological pricing are both relevant. Similarly, the localisation and decentralisation themes evident in bottom-up sufficiency are also evident to some degree in peer-to-peer circularity as new distributed production technology leads to the "democratization [sic] of manufacturing and the empowerment of consumers" (Bauwens et al., 2020, p.8). Therefore, again, deliberative valuation is also potentially relevant.

However, if peer-to-peer circularity is characterised by 'platform capitalism' (Srnicek, 2017), whereby the servitised platforms are owned by growth-driven organisations (as Bauwens et al., (2020, p.8) put it, if "sharing economy initiatives…[are] co-opted by large corporates'), and if the focus is on the technology itself rather than the service it provides, then this future could also be consistent with a status quo scenario focused on competitive market mechanisms and thus the neoclassical theory of value.

Given these divergent conceptions of a future characterised by peer-to-peer circularity, Table 5 reflects both the extent and tentative nature of the potential associations with the various theories of value.

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Table 5. *Peer-to-peer circularity and theories of value*

Question	**Neo-classical**	**Deliberative valuation**	**Non-reductionist**	**Classical**	**Marxian**	**Sraffa**	**Neo-physiocrats**	**Ecological pricing**
Purpose	✓	✓	✓		✓	✓	✓	✓
Relevant groups	✓	✓	✓	✓	✓	✓		
Roles	✓	✓	✓	✓	✓	✓		
Value orientation of stakeholders	✓	✓	✓	✓	✓	✓	✓	✓
Concept of value and rationality	✓	✓	✓					
Value dimensions	✓	✓	✓	✓	✓	✓	✓	✓
Communication and participation	✓	✓	✓		✓	✓		
Why are there environmental problems?	✓	✓	✓		✓		✓	✓
SCORE out of 16	8	8	8	4	7	6	4	4

Legend: ✓✓ = highly consistent; ✓ = consistent.

5 Discussion

Figure 4 summarises the analysis that has been undertaken here, which suggests that different circular futures are compatible with different theories of value and vice versa. In the case of circular modernism, marginal utility theory and Marxian value theory were most relevant (depending on whether the aim was to substantiate the status quo or decipher and surmount it); for planned circularity, it was donor theories of value that utilise objective inputs, and for bottom-up sufficiency, it was deliberative valuation and Non-reductionist ecological economics reflecting the de-emphasis on economic growth and the added emphasis placed on democratic participation. In the case of peer-to-peer circularity, it depended heavily on the assumptions regarding the nature of servitised platforms. This level of variation resonates with our conception of circular futures as VAIs.

Given that our analysis was predicated on the four futures proposed by Bauwens et al. (2020), concepts of value have by necessity been reduced to a second-order issue, i.e. one of fitting theory to predefined scenarios. In this context, one of the implications here for any forthcoming research into CE futures or imaginaries is that the underpinning theories of value need to be both fully explicit and consistent with the future being portrayed. One example suffices to illustrate this: in Bauwens et al. (2020, p.5), the notion of economic efficiency that is used to judge each of the four futures is only briefly defined as the "degree to which a scenario allocates resources to produce the highest possible welfare while minimizing [sic] costs". Now, the reference to allocative efficiency,

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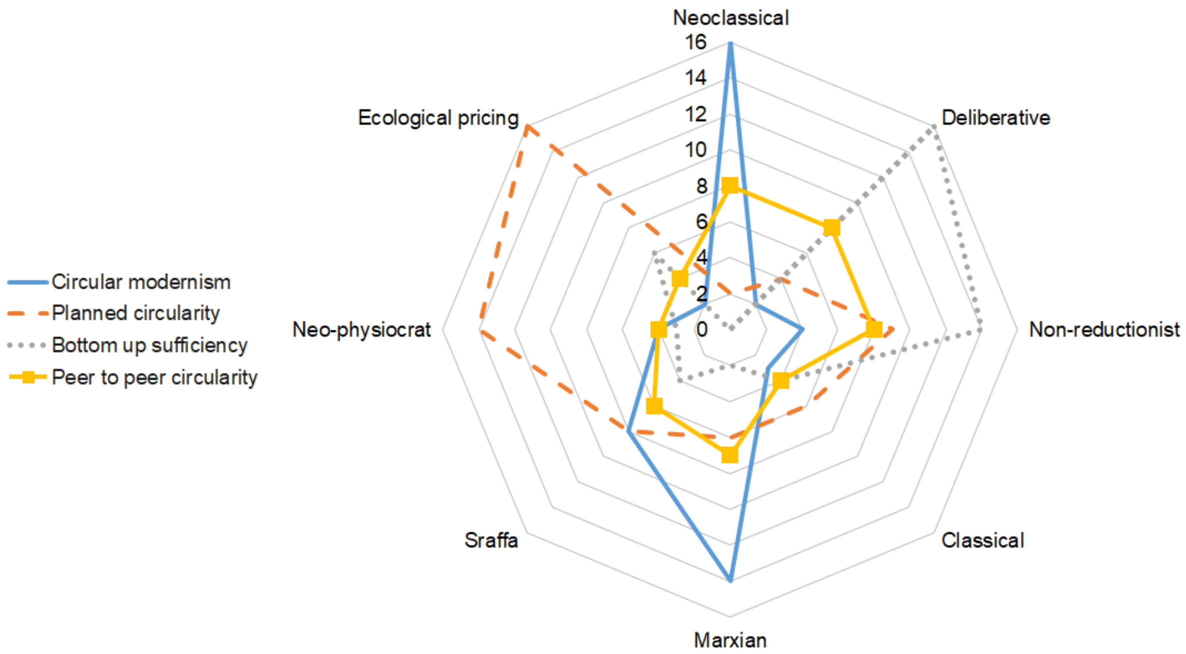
in combination with the reference to welfare, *could* be indicative of a neoclassical theory of value. However, as we have seen, this would be contradictory to those futures, for example, embracing sufficiency and de-growth that are unlikely to view efficiency in terms of monetary costs. The guide that this paper offers as to the compatibility (or otherwise) of the different circular futures and theories of value is not meant to be exhaustive though; we have sought only to provide an outline that suggests broad areas of confluence. Moreover, as Bauwens et al. (2020) recognise, circular futures are not likely to fit neatly into one of the four options they provide; they will probably be hybrid scenarios, which will come to be defined by the multiple dimensions discussed. As such, the arguments advanced here will need to be revisited and expanded as these futures are further refined in different contexts and different historical phases.

Figure 4. *Summary of theories of value relevant to each circular future. The scores assigned to each future (0-16) reflect the analysis presented in Tables 2-5.*



However, the relevance of value theory to circular futures is not just about consistent foundations: drawing on a critical political economy perspective can enable future-orientated research to question the fundamental assumptions that underlie our current economic systems. These assumptions include not just where value comes from and how it is articulated and reproduced, but also what we mean, for instance, by cognate concepts such as 'efficiency', equitable distribution and human nature itself. Indeed, rather than acting as a second-order issue, theories of value can also shape (and constrain) the futures that we articulate and imagine, given that they inform our awareness of what is important, how we should act and the policies that we prescribe for achieving social-ecological transformations. For instance, the consequences of following the eight different theories screened here range from 'getting the prices right' for atomised ecosystem *goods* and *services* and focusing eco-efficiency, to recognising the ecological connections that exist in nature as a

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whole, independent of a human valuer; from highlighting capital's exploitative appropriation of natural conditions (Burkett, 2003), to adhering to the laws of thermodynamics and striving for a post-material lifestyle.

In addition, though, given the power of theory to prescribe and proscribe our behaviour, it becomes crucial to expose theories that inhibit transitions to just and sustainable futures. Therefore, recognising that marginal utility theory has fuelled what Daly referred to as *growthmania* and thus provided the very rationale for a CE that is more than a mere cipher, then the theories of value we have highlighted provide guidance and inspiration for the transition to alternative futures that go beyond the limited horizons of circular modernism. In so doing, these theories can help fully define the "true north" that Bauwens et al. (2020, p.11) suggest their four futures provide and "steer society away from less desirable scenarios". As a result, we would argue that far from viewing theories of value as a dusty relic at the back of the drawer, the new and emerging concept of the CE should recognise the value of value theory not just in helping to fully articulate the futures that we aspire to design, but also thereby persuading people that these futures are worth striving for.

Nonetheless, any discussion of theory at the current moment in history when we are in the midst of a pressing environmental emergency risks the charge of engaging in ephemera rather than consequential, practical action. In this context, perhaps what the current research also indicates is that whilst theory is not transhistorical (i.e. it is borne of a particular moment in time), we are already in possession of a great cannon of value theory that can inspire action towards a wide range of (what some might consider) positive futures that we can already envisage. Therefore, perhaps more theory and theoretical evolution is not immediately necessary; perhaps we need to be working from a recognition that elements of different scenarios and how we achieve them may be compatible with multiple aspects of the existing theoretical toolkit. As a result, the future may be best defined not by value monism, but increasingly by a practical realisation that we can draw on multidimensional values (with multiple numeraires), and thereby incorporate different stakeholder perspectives and encourage methodological pluralism in the shift to an ambitious circular future (Lockwood, 1997; Martinez-Alier et al. 1998).

6 Conclusion

The transition to a CE is often assumed to be both free of challenges and controversies, and synonymous with an eco-modernist and techno-optimistic perspective which is, accordingly, advanced in technical and apolitical terms. However, as compellingly described by Bauwens et al. (2020), the CE is best understood as an umbrella term that might come to define contrasting visions of sustainable development. These visions (or futures) will likely have very different social and economic foundations, but this has often been neglected in the CE research conducted to date, and this includes how theories of value might contradict or enable these scenarios. Therefore, this conceptual paper has sought to articulate the potential congruence between the principal theories of value in mainstream and heterodox economics – the neoclassical approach based marginal utility theory, theories of value emanating from the classical tradition, Sraffa's Neo-

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Ricardian model of price determination, and theories of value based to varying degrees on energy flows – and different visions of the CE.

We hope that the brief outline presented prompts further inquiry into competing conceptions of a circular future and a recognition that circular futures are themselves VAIs that implicitly adhere to a conception of value even if this is not explicitly acknowledged. However, we suggest that this inquiry should commence from an understanding of value theory given that this goes to the heart of how societies evaluate trade-offs between environmental, social and economic goals, and thus has the potential to question the very foundations of the societies we wish to create.

The conceptual developments included in this paper suggest multiple avenues for further research. First of all, efforts could be devoted to combining some of the most promising theories of value presented in this paper, in order to develop multi-criteria and multi-dimensional approaches, which could be even more suitable for assessing and guiding the transition towards ambitious circular futures. Also, the wide implementation of CE initiatives in different contexts offers an opportunity to test future developments in the field of value theory through empirical studies directed towards analysing policy options. This would be aligned to the recommendation provided by Patterson (1998), regarding the need to relate theories of value to practical applications.

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CHAPTER 3

Circular Economy indicators promoted by think thanks – A case study from material processing industry

Tommaso Calzolari, Azar MahmoumGonbadi, Andrea Genovese

Abstract: Think tanks are building and promoting indicators for companies to guide and standardise how they measure their progress towards the circular economy. The purpose of this report is to introduce two of these tools, Circular Transition Indicators and Circulytics, and to apply them in the context of a company in the material processing industry. The case study informs decision makers that are interested in using these indicators and explores the practical challenges that they might meet. Some of the challenges might be commonly shared by material producers, because these indicators are mostly designed for final products manufacturers. Also, the report warns on how these indicators suffer from the same limitations mentioned in Chapter 1. As they select metrics discretionally, they might forget about some important aspects of the circular economy. Also, the aggregation they do with different metrics in a composite indicator, might cause a loss of meaning.

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1 Introduction

In accordance to the need for CE indicators in industrial practice, in the last years some of the most important think tanks that are championing the implementation of CE strategies have proposed some solutions to standardise how companies assess their degree of circularity (Table 1). These indicators select metrics like the amount of recycled inputs, the amount of end of life products that are recovered, reused or remanufactured (Helander et al., 2019; Saidani et al., 2019). Companies can use these self-assessment tools to guide the innovation process of their supply chain and create a more circular and sustainable business model.

***Table 1**. Main CE indicators in the grey literature. Adapted from Lindgren et al. (2021) and from Circle Economy, (2021b)*

CE indicator	Developers	Year	Type	Objective	Scope
C2C	Cradle to Cradle Institute	2014	Quantitative	Evaluates physical flows and social fairness	Product/Process
Material Circularity Indicator (MCI)	Ellen Macarthur Foundation	2015	Quantitative	Evaluates the physical flows and materials utility	Product/Process
Circle Assessment	Circle Economy	2017	Quantitative	Evaluates several aspects of circularity	Process/Process
Circelligence	Boston Consulting Group	2020	Qualitative/ Quantitative	Evaluates several aspects of circularity	Process
Circular Transition Indicators (CTI)	World Business Council for Sustainable Development	2020	Quantitative	Evaluates physical flows and material productivity	Product/Process
Circulytics	Ellen Macarthur Foundation	2020	Qualitative/ Quantitative	Evaluates enablers and outcomes of circularity	Process

Developed metrics vary in their purpose, objective, scope, type and audience. The main purposes are the following:

- To create awareness in their company and extended supply chain;
- To assess and compare potential solutions and build business cases;
- To validate and share results;
- To include circularity measures in company reporting

Two different scopes to measure the circularity can be recognised (Roos Lindgreen et al., 2021):

- Product-focussed CE indicators: Which measure CE properties of a product, its utility-lifetime (extension), its reusability, its recyclability and the actual amount of end of life products that are not lost. This would therefore help to develop more circular products and enhance the overall circularity degree of the company (as a system that produces many products).
- Process-focussed CE indicators: Which compare the material and components inflows and outflows and take the whole company, or industrial site as a level of analysis. It analyses the key processes that would enable substantial circularity enhancement in the industry.

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A recent report of the Dutch cooperative Circle Economy has classified the most relevant CE tools in the industry according to two dimensions: how widely available and how easily accessible they are (Circle Economy, 2021b). The first dimension measures the extent to which tools are freely available (e.g., to what extent resources and methodological notes are easily accessible online); the second one how easy it is for an organisation to apply this tool to its operations without needing a third party support. According to these dimensions, the two most relevant indicators are represented by the Circular Transition Indicators (developed by WBCSD supported by KPMG, 2020) and Circulytics (by Ellen MacArthur Foundation, 2020) (as highlighted in grey in Table 1). The advantage of these two tools is that they are freely available (resources, methodological notes are easily accessible online) and provide a feasible application without needing any third party support. Both the tools provide some premium service; the professional edition of CTI, for instance, equips companies with a more user-friendly experience with the platform (evaluating more products simultaneously, better integration with excel, dedicated support from the developers' team).

In the next sub-chapter two of the most prominent indicators, namely CTI and Circulytics, are described in the detail and then applied in a real world case study in the material processing industry. After this, some possible scenarios to highlight the differences and the tensions among them.

2 Methodological notes

2.1 Circular Transition Indicators

According to the Circularity Gap Report (Circle Economy, 2021), the global economy is only 9% circular today. The Circular Transition Indicators (CTI) was developed in 2020 by the WBCSD, with the support of KPMG. It has the goal of raising awareness, setting a baseline and identifying opportunities (WBCSD, 2020).

CTI is a self-assessment framework for organisations (Figure 1) that mainly looks at physical material flows across the company to determine its ability and ambition to transition to a CE by minimising resource extraction and waste material. It does so by focusing on three circularity aspects: to what degree company is closing products and material loops, to what degree it is optimising material flows and to what degree it is creating value from their resources. It is accessible through an online platform (available at this link) and requires companies to follow a seven-step framework to estimate and input relevant information classified into three modules (Closing the Loop module, Optimising the Loop and Value the Loop). During this process, companies are required to select the indicators from a menu. For each step, the platform helps identifying the relevant sources and facilitating the collection of data. This might require to connect with supply chain partners, which the most labour-intensive part of the process. Finally, it also provides support in interpreting the results and inspiring concrete actions in the decision making process. These include the establishment of SMART targets to monitor progress on relevant aspects.

The final dashboard shows a set of indicators that provides insights into overall resource use optimisation and the link between the company's circular material flows and its business performance. In this way, it creates awareness and prioritises certain actions. The algorithms behind the calculation of the indicators are open and transparently shared.

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2.2 Circulytics

Circulytics was developed by the Ellen MacArthur Foundation (2020). Although some of its final goals are similar (raising awareness, establishing a baseline, identifying opportunities) it is has a broader scope then CTI. This indicator does not only evaluate the CE performance of products and material flows (CE outcomes), but aspects that might support their future improvement (CE enablers). As such, it wants to highlight CE opportunities, but also the related organisational requirements.

Enablers include strategy and planning, innovation, people and skills, systems, process and infrastructure and external engagement. These aspects (themes) were selected because the academic literature has highlighted their importance, and companies can leverage on them to improve their CE performance. However, this link is generic and supporting studies are not mentioned explicitly.

The outcome indicators provide a snapshot of an organisation's circular economy performance, covering relevant outcomes in material flows, services design, physical assets, water flows, energy, and finance (themes). Each theme is measured through some pre-defined questions, which is transformed in a quantitative indicator. By answering all the questionnaire each theme gets a score, which is a weighted average of the single indicators. Outcome indicators as well as weights vary according to the sector of the company. Given the broad range of information that all themes required, the data collection process might take even 2 months. After data are charged on the platform, results are benchmarked on an industry level.

3 Assessing circularity with existing tools

This section presents the results of the two assessments and reflect on the current level of circularity of the production process of a case company (in the following, generically referred to as Company X) according to Circulytics and to CTI. It also elaborates on the recommendations provided by the tools in order to increase circularity.

Figure 1 shows a very simplified scheme of the production process with the most relevant inflows of raw materials and outflows of final materials and by-products. The production process is very energy intensive and makes use of some secondary material as an input, which comes from end of life products that are recovered.

The following data were used to include the main inflows and outflows, as reported in Tables 2 and 3. Table 2 characterises the inflows, their weight and their inherent degree of circularity (whether they are coming from virgin or from non-virgin sources). Table 3 describes the outflows, their recovery potential and the actual recovery at the end of the product's life. Data is representative of the typical process for a given material X at the production plant, which was provided in order to test the tools; data is normalised for one unit of output.

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Figure 1*. Material x production process*

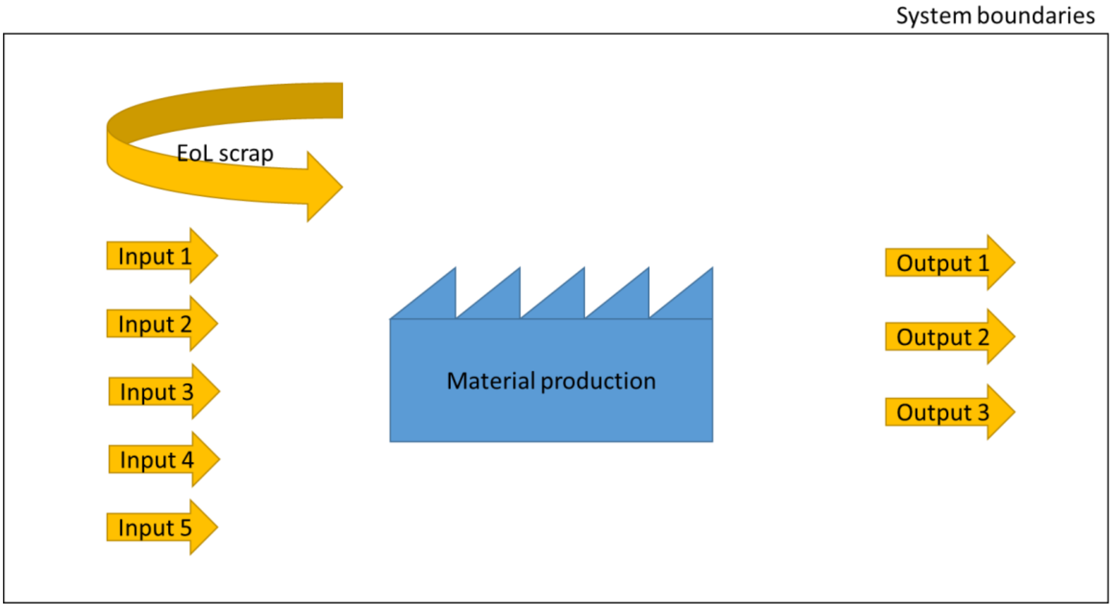

Table 2*. Process inflows (normalised per 1 unit of output)*

	Total weight (Tt)	**Non-virgin renewable**	**Non-virgin Non-renewable**	**Virgin renewable**	**Virgin Non-renewable**
Input 1	1.1		8% (external material x scrap)		92%
Input 2	0.167				100%
Input 3	0.5				100%
Input 4	0.133				100%
Input 5	0.005				

Table 3. *Process outflows*

	Total weight (T)	**Recovery potential (%)**	**Actual recovery**
Output 1	1	100%	95% [Recycling (85%) Reuse (5%) Remanufacturing (5%) Disposal (5%)]
Output 2 (byproduct)	2	0%	Nutrient absorption in the biosphere - linear outflow
Output 3 (byproduct)	0.183	100%	Recycled in the cement industry (80%)

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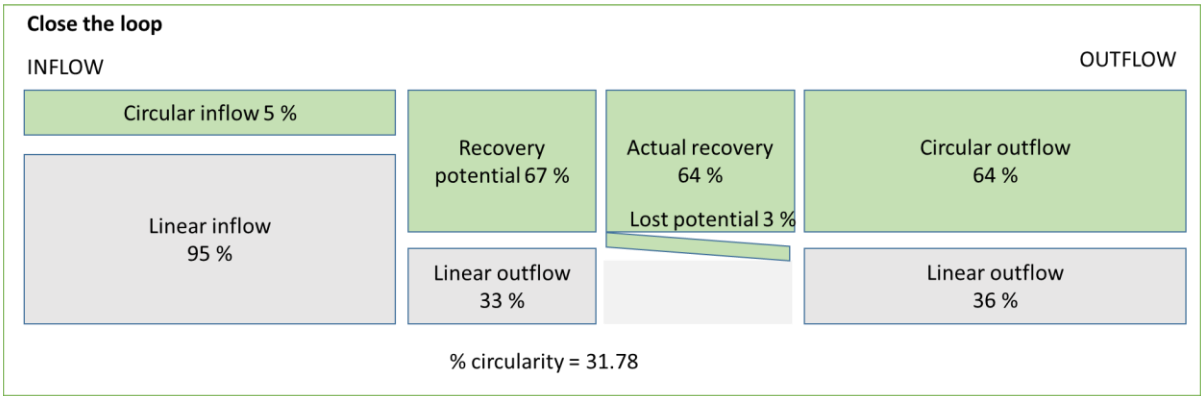
3.1 CTI assessment

In order to critically assess the CTI tool, the online platform is used (available at [this link]). In this report (in order to protect the confidentiality of Company X) we are including only the results relative to the Closing the Loop module, not those relative to Optimising the Loop and Value the Loop.

Figure 4. *CTI results (Close the loop module)*



The most important outcome of the assessment is a simplified Sankey diagram which represents the material flows (Figure 4). A single value weighs the degree of circularity of inflows and outflows (31.78%).

This comes from a weighted average of a very low circular inflow (5%) and a very high circular outflow (67%). The lost potential is just 3% and reflects the 5% of the total mass of outflows that ends up in disposal or energy recovery. All the material outflows of material production have the potential to be recycled (excluding Output 2, which is a gas). A very big part of end of life material is recovered or designed to have a long useful life and be to be reused. The actual recovery rate is very high, with Recycling being the most common recovery strategy (85%), followed by Reuse (5%) and Remanufacturing (5%). Output 3, which is a by-product of the production of the material, can be recycled by another industry through an *open loop* (the actual recovery rate is 80%, according to the website of a relevant industrial association).

The total linear outflow is 36% of the mass of all the outflows and it includes mostly the CO_2 emissions (33%), the material that is lost at the end of products life (2.97%) for different reasons (it cannot be disassembled, it is lost in the reverse logistics, end up in landfill and it is not recovered), and Output 3, that is not recovered (0.043%).

Because of most of the outflows of the Material production being recovered, the improvement possibilities in terms of outflow circularity seems to be very limited. In fact, one of the main contributions of this tool is the identification of material outflows that have some potential of being recovered, which are currently lost. It seems that the main lever to improve the circularity is to decrease the input of Non-virgin Non-renewable inputs, substituting input 1 with recycled input. This can be achieved, for example, by substituting some of the existing production technologies, which make use of recycled inputs at higher percentages.

A paradox of this tool could be that an increased material efficiency, that reduces by-products that are currently recycled (for example, output 3), could have a negative effect on CTI. Also, there is

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no consideration of the lifetime of products and no distinction between reuse and recycling in the calculation of this input (even though WBCSD is working at an improved version of the tool that should integrate this aspect). Finally, there are no considerations about the quality of the recycling process. The tool distinguishes between recycled and not recycled outflows, without giving the possibility to identify how the recycling process can become more efficient, for example by employing less virgin inputs to dilute low quality or contaminated materials in secondary production.

3.2 Circulytics assessment

To calculate the Company's Circulytics score, we used the methodological notes on EMF website. We created an excel worksheet with some realistic weightings for an energy intensive industrial process[27]. Because of the type of industry (energy intensive, with very substantial material flows), some of the themes are not considered (Services and Finance). The final score is a composite indicator that aggregates the single indicators that correspond to each question. We dedicated 3 sessions 3 hours sessions with two company managers to answer all the questions and we had 2 one-hour meetings with 2 other specialists in the company (Appendix). Final scores are transformed into letters, from A to E (Ellen Macarthur Foundation, 2020), as shown in Table 3 below.

Enablers and Outcomes both scored 57%, which corresponds to a letter score of B-. The highest score among the enablers themes is related to the innovation phase, as the company develops some considerations about circularity in the design phase. In particular, they think about extending product life-time, facilitating reuse and recycling. The lowest score is in operations. This reflects the challenges the company has in sharing information with its supply chain.

In terms of outcomes, we registered a very high score in water circularity and quite high score in Products and Materials, which is also the most relevant theme. The Products and Materials score contributes to the 70% to the Outcomes score. The score on energy is quite low and reflects the limited possibilities of an industry that needs a lot of heat to transition towards renewable sources of energy.

To conclude, some insights were drawn on how the score guides the innovation process. In line with CTI also this method analyses inputs and outputs with a mass-based perspective characterising inflows and outflows as percentages of the total mass. As such, the considerations on possible paradoxes of the previous subchapter on the case of increased material efficiency held true. A positive point of Circulytics is that, differently from CTI) reuse is rewarded more than recycling. Another interesting aspect is the possibility of measuring the impact of the implementation of product-as-a-service business models.

[27] The report provides some examples of weightings in different sectors according to some characteristics (energy intensity and relevance of material flows).

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Table 3. *Circulytics results*

Overall	**57%**		**B-**
Enablers	**weights**	**57%**	**B-**
Strategy and planning	30%	58%	B-
Innovation	20%	75%	B
People & skills	15%	45%	C
Operations	15%	33%	D
External engagement	20%	63%	B-
Outcomes	**weights**	**57%**	**B-**
Products and Materials	70%	61%	B-
Services	0%	N/A	N/A
PPE assets	10%	50%	C
Water	10%	88%	A-

4 Building future scenarios for the material x industry - Process vs Product

Future scenarios were defined through discussion with managers. They describe different possible paths towards the CE in the industry. We distinguished between scenarios from a process perspective (Scenario 1 and 2) and a product one (Scenario 3). We measured the sensitivity of the composite indicators to small changes to specific indicators that characterise a scenario (the detail is included in Appendix).

Process-scenarios come from the perspective of a material producer which is at very much upstream in the supply chain. Usually these companies have limited or no control on the product's life span as they often do not produce the end-user product. The focus lies on the material properties of the intermediate product and the recycling process.

The Product-scenario focuses on a particular final product the company sells to final consumers (as opposed to most of the other intermediate products that are sold across many industries). Scenario 2 studies the product business and the implications of product lifetime extension through reuse.

4.1 Scenario 1 - Purer materials for open-loop recycling optimisation

The secondary material that feeds into the recycling process needs to be diluted with some virgin material input. This is because the scrap, which might be of various qualities, could contain some compounds/additives that was added to improve material's properties or could be contaminated by other materials (e.g. impurities, rust). These substances (compounds and impurities) might no longer required in materials' second life.

Many experts advocate that in a Circular Economy technical materials should be as pure as possible to allow a smooth and efficient recycling process which makes less use of virgin materials to dilute

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secondary materials. This scenario envisions a future where the reliance of compounds is reduced to optimise secondary production of the material. Recycling happens in a similar way to the baseline scenario, with no segregation; however, the efficiency of recycling is improved because the material produced for different applications is purer. Products are designed with no particular emphasis on lifecycle extension, as having shorter product lives can increase the availability of end of life scrap.

This scenario also has some drawbacks. The material produced for many industrial sectors would be heavier (and less energy efficient) and have worse material properties. Lower grade applications also mean facing some commercial risks, which could bring job loss and decreased production. Another drawback is the environmental impact of more frequent recycling processes.

This scenario is the least probable. Today, the market drives new material grades. There are good reasons behind the use of chemical compounds. For example, they improve material resistance to stress or its durability.

***Table 4**. Characterisation of Scenario 1*

Key dimension	**Detail**	**Implications**	**Advantages**	**Disadvantages**
Product design	Design for optimising open-loop recycling for disassembly (for shorter life)	(Material maker perspective) purer materials • less use of compounds • less use of coatings	Improved recyclability • Less dilution • Less contamination	Rebound effect Worst properties per material per input • Heavier products • More material required for same functionality
Reverse supply chain	EoL reverse flows are not segregated (similar to today's recycling)	Material producers would produce at least the same Volumes and potentially more but being more circular in material use (displacement)	Recycling infrastructure is already in place, but higher capacity is required	Commercial Risk • Of decreased production • Less skilled jobs Regulation would be required Risk of Rebound effect

4.2 Scenario 2 - Closed loop recycling with EoL materials segregation

Another way of dealing with the downcycling of materials that are rich in chemical compounds consists in making sure that the compounds are not lost in secondary production. This could happen if materials with similar composition and grades are recycled with a closed-loop perspective. Better collection of end of life material and segregation of materials of different grades

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are fundamental activities to allow end of life materials to be used in similar applications. These can include take-back schemes with customers.

The advantage of this approach is the lower dilution grade required with virgin material in secondary production, less dependence on virgin compounds and less by-products produced from oxidation of compounds. Another change in this scenario concerns the 50% of chemical compound recovered throughout secondary production.

Table 5. *Characterisation of Scenario 2*

Key dimension	Detail	Implications	Advantages	Disadvantages
Product design	Design for closed-loop recycling for disassembly for segregating different material grades for recovering chemical compounds	(Material maker perspective) material grades are demand driven (like in Scenario 0) Same use of compounds Compounds are recycled and not lost	Improved • recyclability of compounds • functionality of materials (thanks to the closed loop recovery)	Impact of more transportation Rebound effect Check list
Reverse supply chain	Materials/scrap take-back schemes with customers Better collection/ segregation/ control of where that material is coming from	You are closing loops on products or materials – making the same grade again Not only that but some other materials	Same competitiveness in markets More efficient and specialised recycling processes	Recycling infrastructure to be built - reverse channel to be operationalised Regulation would be required Risk of Rebound effect

4.3 Comparing process-based scenarios.

Appendix A highlights the data we have assigned to each scenario. Both scenarios refer to the same amount of material production as an output (and are normalised on that quantity). In both cases, the input coming from scrap is doubled (from 0.1 to 0.2 units) and substitutes some primary inputs. However, Scenario 1 uses less scrap and more primary material input (e.g. 0.095 units in Scenario 1; 0.1 units in Scenario 2). The difference lies in the need, in Scenario 1 (purer materials), for an additional input of virgin material to produce materials with the same quality and properties that it would have using compounds.

The same change is studied in both the tools. The results are not very significant. As the great majority of all the outflows are already recovered in the baseline Scenario (see section 3) the

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improvement possibilities in terms of outflow circularity seems to be very limited. Also, this reflects the inability of the tool to take into account the quality of the recycling process.

Table 6. *Process scenario comparison*

	CTI	Circulytics
Baseline case	31.78%	57%
Scenario 1	34.68% **(+2.9%)**	58% **(+1%)**
Scenario 2	34.77% **(+2.99%)**	58% **(+1%)**

4.4 Scenario 3 – Product X lifetime extension through reuse

This Scenario concentrates on product X, which is sold to another industry with an open loop perspective. Data were taken from an industry report, which also included a bill of material of product and the actual recovery rate at the end of their life.

In Table 7 we compared a baseline Scenario, which refers to the current situation, to Scenario 3. In Scenario 3 we increased the percentage of end of life products that go through Reuse from 10% to 25%, with a reduction of recycling from 89% to 74%. The circularity metrics show a very small improvement, which is less than 2%. CTI does not really distinguish among recovery options, the improvement reflects the greater recovery potential of reuse (100% of the product can be reused), over recycling (just 75% of it can be recycled, as there are some economic barriers to the diffusion of technologies to recycle some of the other materials it is made of).

Table 7. *Characterisation of Scenario 3*

Key dimension	**Detail**	**Implications**	**Advantages**	**Disadvantages**
Product design	Design products, components for reuse For remanufacturing	(Material maker perspective) Either thicker material Or use of Coatings	Less products needed to satisfy the same functionality to last more time Protected from rust	Does this affect profitability? Energy efficiency of heavier products Higher dilution required during recycling
Reverse supply chain	Different ways to make it more reusable Reuse - Resell Remanufacturing	Material producers would produce at least the same Volume but being more circular in material use (displacement)	Jobs on collection – remanufacturing – certification bodies reuse	Commercial Risk • decreased production from cannibalisation • jobs loss primary material production

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Table 8. *Product scenario comparison*

	CTI	Circulytics
Baseline case	40.99%	62%
Scenario 3 Product	42.68% **(+1.69)**	64% **(+2%)**

5 Conclusions

This report has been aimed to get an understanding of the dominant circularity tools which are available to industrial organisations in order to describe their operations and get insights about potential improvements. The case study from the materials industry seems to reveal that both the tools which have been analysed are designed for manufacturers who want to identify possible material inflows that are not coming from secondary sources and material outflows that are not yet recovered. In the case of the material industry, the amount of the non-virgin inflows depends often on technology or on pricing mechanisms and on the availability of secondary materials. Also, most of the outflows are already recovered because they have a high market value.

Looking at the process scenarios, we have reflected on what is important to measure from a materialmaker perspective. A very important aspect has to do with materials efficiency in the recycling process. Three possible more circular pathways were compared. The two tools seem to bring no real value added in comparing the scenarios. This calls for a selection of better metrics that have to do with dilution rate - quality of recycling process - saved chemical compounds and greater functionality from lifetime extension. An ideal circular economy indicator for the material production sector should be able to track a real improvement according to these aspects of circularity.

The analysed tools incorporate a mass-based perspective. As such, they try to incentivise quantitative improvements in the circular use of resources. They give insights to organisations that have many inputs and outputs and complex products about how to prioritise their actions. The reality in the material industry seems to be quite different and adopting a mass-based approach might not be optimal. Some elements (e.g. chemical compounds) which are present in small quantities might be critical for their contribution for different circular scenarios.

The best strategy for a material processing company could include both open-loop and closed-loop recycling scenarios. Lower grade and purer applications could be pushed to follow a certain open-loop pathway and specific applications with higher grades could flow in a closed loop one. Having a supply chain perspective is paramount to recognise the best strategies for each different application. Regulatory and normative stances have also a very important role to inspire responsible innovation of products in a perspective of relying less on virgin materials. Material producers could be in a privileged position to oversee the additives that the market is asking for as a result of innovation processes (more complex and high-performance materials) and evaluate qualitatively until what point it is appropriate to innovate at the expense of the efficiency of recycling.

Also, the analysed tools seem to provide a very reductionist view of the transition to a CE. Social implications are completely disregarderd; the evaluation of environmental performance seems to

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be extremely simplistic, based on mass balances. This further reinforces the findings from Chapter 1, and highlights the need for more sophisticated measurement tools if a transition towards more ambitious circular futures needs to be pursued, as discussed in Chapter 2.

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Appendix A

Scenario 1 - open loop recycling

Process inflows

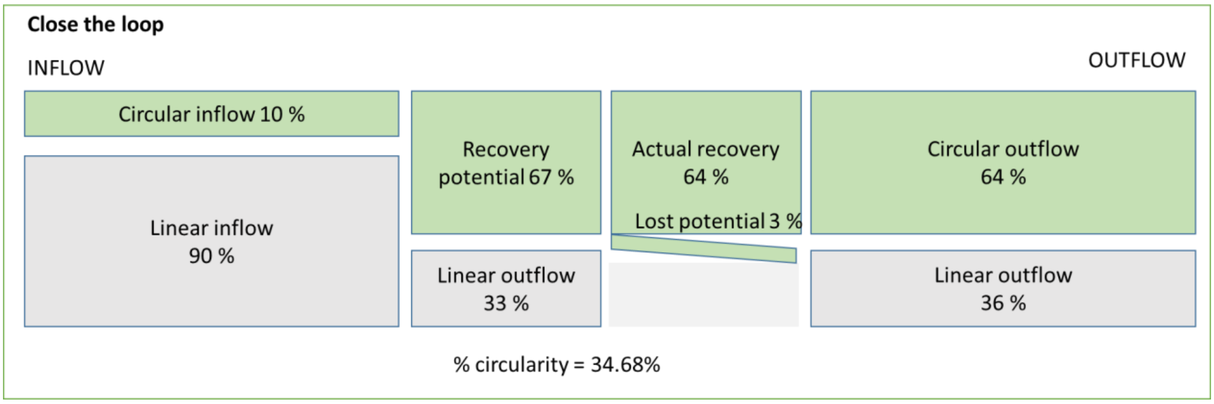
(variation on Scenario 0)	Total weight (T)	Material source type
Input 1 (-0.095,+0.066)	1.04	Virgin Non-renewable
Input 1b (0.1)	0.20	Non-virgin Non-renewable
Input 2	0.13	Virgin Non-renewable
Input 3	0.17	Virgin Non-renewable
Input 4 (-100)	0.48	Virgin Non-renewable

Process outflows

	Total weight	Recovery potential (%)	Actual recovery
Output 1	1	100%	95% [Recycling (85%) Reuse (5%) Remanufacturing (5%) Disposal (5%)]
Output 2 (-0.017)	0.31	0%	Nutrient absorption through biodegradation
Output 3 (-0.017)	0.17	100%	Recycle

The circular inputs doubles

Circularity goes up to 34.68%



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Scenario 2 - closed-loop recycling

Process inflows

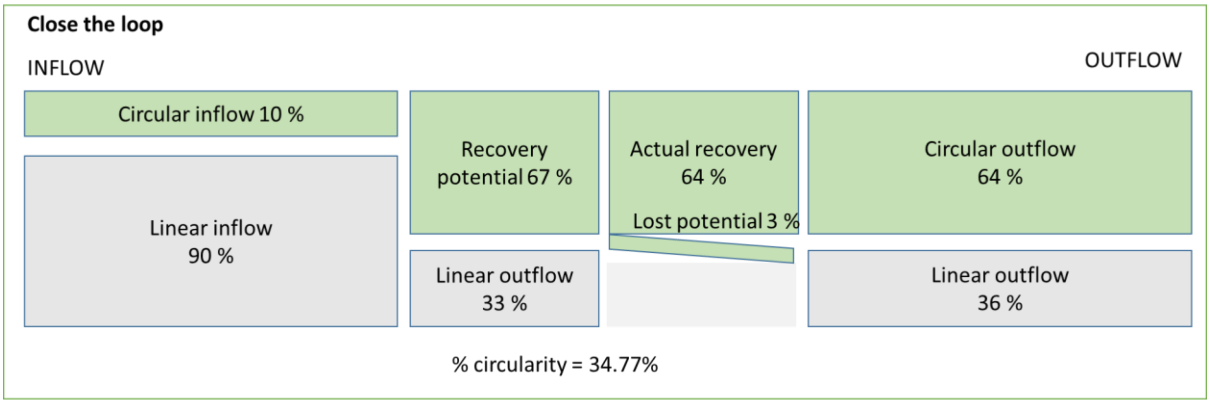
(variation on Scenario 0)	Total weight (T)	Material source type
Input 1 (-600)	1	Virgin Non-renewable
Input 1b (+600)	0.2	Non-virgin Non-renewable
Input 2	0.13	Virgin Non-renewable
Input 3	0.17	Virgin Non-renewable
Input 4 (-100)	0.48	Virgin Non-renewable
Input 5	0.005	Virgin Non-renewable (50%) Non-virgin Non-renewable (50%)

Process outflows

	Total weight	Recovery potential (%)	Actual recovery
Output 1	1	100%	95% [Recycling (85%) Reuse (5%) Remanufacturing (5%) Disposal (5%)]
Output 2 (-0.05)	0.283	0%	Nutrient absorption through biodegradation
Output 3 (-0.05)	0.13	100%	Recycle

The circular inputs doubles

Circularity goes up to 34.77%



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Scenario for a product perspective

Scenario 3 - Life extension through reuse

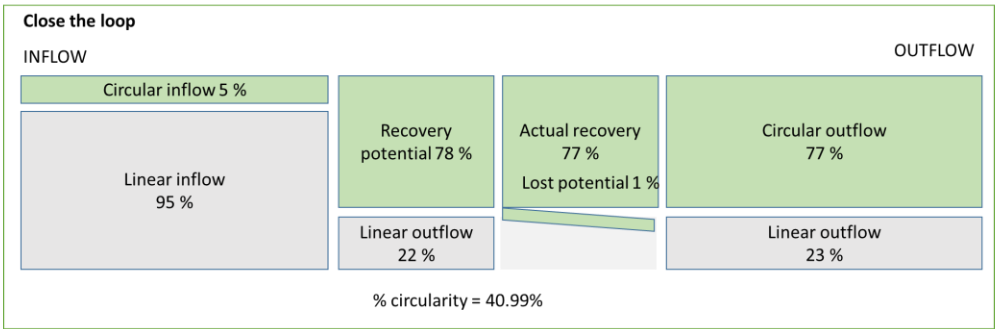
Process inflows

	Total weight (T)	Material source type
Input 6	0.759	Virgin Non-renewable (93%) Non-virgin Non-renewable (7%)
Input 6	0.005	Virgin Non-renewable
Input 7	0.25	Virgin Non-renewable

Process outflows

	Total weight	Recovery potential (%)	Actual recovery
Product - Scenario 0	1	70% for recycling 100% for reuse	Recycling (89%) Reuse (10%) Disposal (1%)
Product - Scenario 3	1	70% for recycling 100% for reuse	Recycling (74%) Reuse (25%) Disposal (1%)

CTI - Scenario 0 - product



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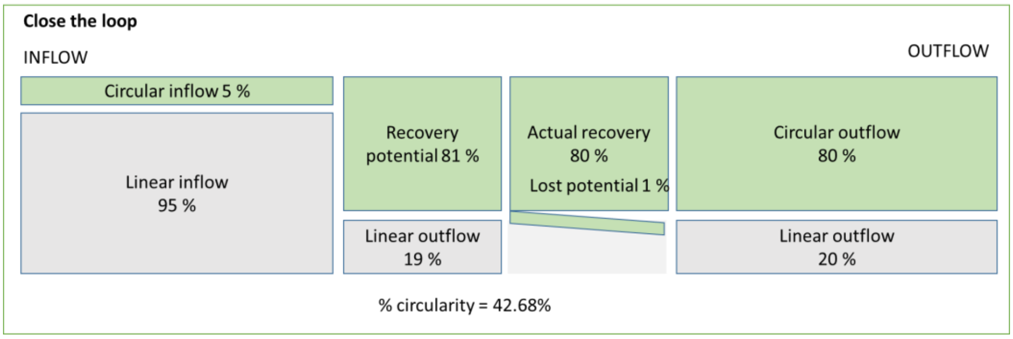
CTI - Scenario 3 - product reuse

Reuse from 10% to 25%

CTI up to 42.68%



It goes up because reuse recovery potential is 100% against the 70 % of the recycling

Circulytics

No change in inputs

Change the actual recovery - less recycling and more reuse (from 10% to 25%)

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CHAPTER 4
A participatory exercise for the establishment of an indicators' dashboard to evaluate supply chains and the transition towards a just Circular Economy

Ben Purvis, Andrea Genovese, Tommaso Calzolari

Abstract: Following up on the systematic literature review focused on CE indicators for supply chains reported in Chapter 1 (and published in *Environmental and Sustainability Indicators* by Calzolari et al., 2022), this work aimed at investigating the challenges related to the construction of an indicators' dashboard for the measurement of Circular Economy performance in supply chains. Results emerging from a participatory exercise, along with lessons learned, are reported.

Keywords: Circular Economy, Indicators, Supply Chains

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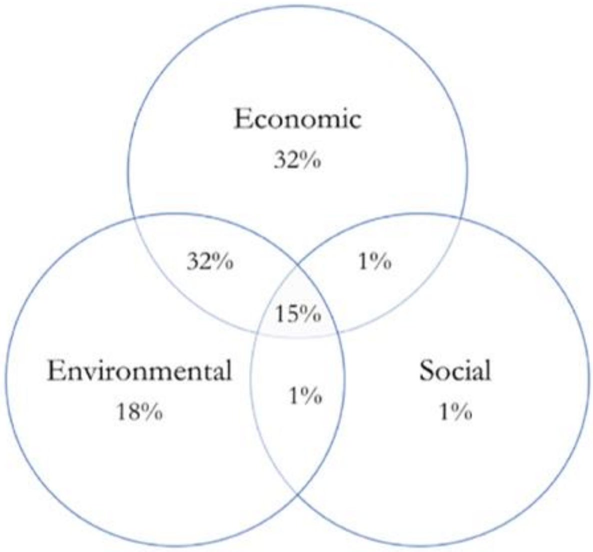
1 Introduction

In Chapter 1 of this report, after being systematically collated and analysed, prior work within the literature related to circular supply chains was analysed. In particular, papers dealing with the development of performance evaluation methods were assessed on their coverage of economic, environmental, and social dimensions, and the most commonly used metrics within each of these categories were collected. This allowed a first appraisal of feasible approaches for the measurement of the progress of supply chains towards a Circular Economy (CE). Figure 1 shows, as has been noted elsewhere in the literature, that, when evaluating performance, CE studies examined focused primarily on economic and environmental dimensions with relatively little attention given to social dimensions; only 18% of studies included any social dimension, compared to coverage of 80% and 66% for environmental and economic dimensions respectively. This is also something common in the grey literature, as demonstrated in Chapter 3, where the most widespread CE indicators have been reviewed; these indicators show no coverage of the social dimension.

Figure 1. *Dimensional coverage; reproduced from Calzolari et al, 2022*



Even where social dimensions are present, they are often simplistic, focusing on quantitative rather than qualitative aspects, and are relatively far from elements of social justice and distributional conflicts, with the most popular social metrics relating to jobs created, and Health & Safety compliance.

Calzolari et al. (2022) compiled a list of the most commonly employed metrics, which is reproduced below in Table 1, where the frequency of occurrence across the 203 analysed papers is also recorded. This results in 6 of each economic and social categories, and 7 environmental categories. From the occurrences column, the variability of coverage may be seen, with cost and greenhouse gas (GHG) indicators being particularly common across all studies.

Following the identification of the most common indicator categories within the literature, Calzolari et. (2022) al created a dummy composite index, which compiles the 3 most frequent metrics for economy, society, and environment (Figure 2). This is intended to illustrate the

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priorities that are present within the literature for CE metrics for supply chains. It is thus presented for illustrative purposes, rather than as something recommended for use in practice. The numbers (weightings) presented in the diagram indicate the relative popularity of each dimension and sub category within the literature. This more clearly shows the dominance of nominally economic and environmental indicators, and in particular those relating to cost and GHG emissions.

Table 1. *Most common identified indicator categories across the academic literature. Reproduced from Calzolari et al, 2022*

	Energy usage	• Energy use • Cumulative energy demand • Renewable energy use • Energy self-sufficiency	Energy-based indicators associated with supply chain	32	16%
	Virgin resources usage	• Abiotic depletion of resource • Mineral, fossil & renewable resource depletion	Virgin resource use associated with supply chain material consumption	26	13%
	Water	• Water depletion • Water emissions • Water use	Water used or contaminated	26	13%
	Air emissions	• Particulate Matter • Respiratory inorganics	Other air emissions associated with supply chain	22	11%
	Acidification	• Terrestrial acidification • Marine acidification	Acidification potential associated with supply chain processes	19	9%
Social	CSC jobs created	• Number of fixed and variable jobs • Number of drivers hired for transportation	Employment opportunities provided by the CSC	15	7%
	Organisational H&S compliance	• Compliance with the ILO guidelines	Measures of compliance to H&S Guidelines for the jobs created in the CSC	7	4%
	Quality of work	• Work damages • number of accidents, lost • Employee turnover	Measures of quality of the jobs created	7	3%
	Training	• Average hours of training • Training on skills for employability	Indicators of the training provided to workers	4	2%
	Expenditure on Benefits for employees	• Food • Transportation • Pension	Indicators of benefits provided to the workers	4	2%
	Customer environmental awareness	• Enlightening customers to return end of used product • Customer incentives for recovery from discarded product	Indicators of environmental awareness of the customers	3	1%
	Social cost of waste	• Penalties and costs for disposal	Social cost of waste produced. Sum of disposal cost and of the cost for the recycler	2	1%

Calzolari et al. (2022) systematic literature review, also included in Chapter 1 of this report, concludes that the current approaches within the literature are not adequate for analysing the whole circular supply chain. Calzolari et al. (2022) observe that most studies focus only on recycling or similar imperatives, with a lack of attention given to social dimensions. In this way existing approaches based upon CE metrics are not adequate for the structural change required for a just transition. Whilst this limitation is noted in terms of the coverage of identified metrics, it is also important to note the problems of reductionism that are inherent in metric based approaches as a whole (Gasparatos et al., 2008), and the problematic assumptions in terms of *value*, as discussed both in Chapter 1 and 2. We should be careful about how we handle such simplifications, particularly in relation to trade-offs, rebound effects, and the breadth of the domain scope. A further element to consider is the depoliticisation within indicator frameworks (and the fact that their value assumptions are often not clearly discussed), and the danger in stripping out context, coherence, political nuance, and normative considerations in favour of a list of popular metrics. These challenges are revisited in Section 5 of this report.

2 Expert survey

In May and June 2022, members of this research group circulated a questionnaire survey across the ReTraCE and consortium mailing list, also targeting members of the JUST2CE sister project. Overall this elicited 35 usable responses. The survey questions were designed to explore how the

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‘just circular economy’ is understood across the consortium, and build on Calzolari et al’s (2022) analysis of CE supply chain indicators, employing a Delphi-like technique to investigate consensus across the consortium. The preliminary analysis of these findings were presented at joint ReTraCE/JUST2CE workshop held in Thessaloniki (Greece). The survey design and results are detailed below under each individual question.

Q1 - *What is your understanding of the term ‘A Just Circular Economy’?*

We judged it necessary to build a picture of whether there was a shared understanding of a just CE across the consortium. This question thus took long form text responses which we coded thematically (Braun & Clarke, 2006) in Nvivo. The Word Cloud presented in Figure 3 displays recurrent terms used across the written responses. Quotes are reported below. Many participants mentioned the dimensions of environment, economy, and society unprompted, as well as responses mentioning products, materials, and resources. Some quotes are reported below:

“*An alternative economic model, focused on sufficiency, harmony with nature and social justice*”

“*A circular economy that goes beyond economic growth but takes into consideration the environmental and societal aspects so growth is realised across all spheres*”

“*A discursive strategy attempting to critique, amend or subvert the modalities by which powerful actors and institutions such as the EU and state governments seek to govern populations and the environment*”

“*A regenerative arrangement of the human social metabolism, in which each person is expected to contribute according to their means and capacities and is provided according to their needs*”

Figure 3. *Wordcloud of responses to Q1 relating to how members of the JUST2CE understand a just circular economy*

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The most recurrent themes across the written responses for this question related to social justice, the need for participation, environmental sustainability and justice, R-imperatives, and a focus on primary production. Other frequent themes included holism, i.e. thinking of the interconnectedness of human and ecological systems, equality and equity, fairness, and sufficiency.

Key divergences in the written responses related to the nature of the concept, whether it represented an alternate economic system or model, a construct or tool used to shape narratives in the present, or a set of practices that could be implemented. These understandings are not necessarily mutually exclusive, yet they illustrate the breadth of ways in which the term can be conceptualised and operationalised, also linking back to the plurality of CE futures and value implications discussed in Chapter 2. A second area where consortium members expressed a range of views relates to the economic growth orientation, whether shifting focus away from growth, explicitly denouncing it, or implicitly accepting that growth may be able to be decoupled from adverse environmental and social impacts. Thus, we find that even within our consortia where we might expect a more common understanding, we find a plurality of views. We can link this plurality of understandings to the nature of CE as an umbrella term which has grown to incorporate many different narratives, and thereby become something of an empty signifier (Genovese & Pansera, 2021).

Q2 - *What are your thoughts on the suitability of the dimensions 'People, Planet, Profit' as a framing device to be used by in a Decision Support Framework?*

Question 2 seeks opinion from the consortium on the framing of 'people, planet, profit' (PPP) for use in the indicator dashboard. There are two matters for consideration here, first is the broader conceptualised three dimensions or pillars of sustainability (environmental, social, economic), and then their presentation under the labels presented as a 'Triple Bottom Line' (Elkington, 1997). The broader tripartite framing is something of a default in the CE literature, both orthodox, and critical. This does not mean we should accept it uncritically, but it forms the most logical starting point. Some quotes are reported below:

"*I am wary that this framing is reductive and is too close to the original bottom line approach. I recognise that these elements may be relevant and comprensible to stakeholders though*"

"*Profit is either a misleading definition or a wrong dimension to be considered*"

"*I believe that these three dimensions are easily understandable by everybody who is going to use the DSS since they coincide with the most extended manner of representing sustainability*"

"*I think these should not be considered separate categories, but in terms of their relationships. Frequently, the pursuit of Profit is obtained at the expense of People and Planet, two categories that are very much related. Justice is the main factor that explains how these categories can interact in a balanced way*"

"*I think this framing is not compatible with the CE view pursued by our projects*"

Responses to Q2 were variable; most participants were critical of the PPP framing though nevertheless many of these described it as a pragmatic choice or an adequate starting point. Responses questioned exactly what these open terms mean, and how the relationship between them could or should be considered. For example, several respondents explicitly noted that they

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felt these three elements should not be regarded as of equal importance. A particular source of concern was the profit dimension, and how it can be reconciled with elements of justice. Respondents also offered several alternative framings that should be considered instead, these encompassed drawing on the frameworks articulated in the work of the ReTraCE and JUST2CE projects:

- An overarching framework relating to concepts of justice (e.g. labour, gender, environment)
- Reframing profit in terms of resources or production
- Considering broader time, space, and inter-organisational dimensions.

Q3 - *Which of these categories do you think are relevant for assessing the contribution of an organisation and its supply chain to a just circular economy?*

The next series of questions under Q3 take the indicator categories identified through Calzolari et al. (2022) systematic review and ask participants whether they think they are relevant for our purposes in creating an indicator dashboard for the DSS. A written response box was provided to solicit further categories that respondents would add to each PPP dimension. We amended a number of the category names in order to provide descriptive detail; for example, 'risk' was updated to 'Supply chain risk or uncertainty (e.g. raw materials availability; reliance on critical materials)'. The following sections analyse each listed dimension individually.

Q3a - *People*

Of the dimensions presented, the selection of those deemed relevant by respondents was broad without strong agreement. No category was selected by all participants, with the most frequently picked category, **jobs created**, selected by 78% of respondents, followed by **customer environmental awareness** 76%, **social cost of waste** 76%, **quality of Work** 67%, **worker training** 64%, **H&S compliance** 61%, and **employee benefits** 61%.

Over half of participants provided write-in responses which were analysed for recurrent themes. Several of these were judged to relate to the already prompted categories of quality of work (n=6: 'modern slavery'; 'reliance on degraded overseas labour'; 'reducing unpaid work'; 'employee satisfaction'; 'use of child & migrant labour'; 'different working conditions in different countries'), and worker training (n=3: 'employee environmental awareness'; 'level of knowledge of work processes'; 'leadership training'). Four additional categories were identified relating to **worker participation** (n=7: 'worker participation in production management'; 'organisational structure'; 'internal practices of democracy'; 'participation of employees in decision making'; 'workers control'; 'participatory management process'; 'grade of interaction among the hierarchy within the organisation'), **gender & equalities** (n=6: 'gender equality issues'; 'inclusion of vulnerable groups'; 'gender distribution'; 'gender balance'; 'access of marginalised groups'; 'key dimensions e.g. age, and gender'), **stakeholder/customer/community participation** (n=7: 'wider stakeholder engagement'; 'implementation of participatory planning approaches'; 'inclusion of vulnerable groups'; 'modes of customer engagement and feedback'; 'participation of customers in decision making'; 'considering the "people"'; 'organisation has formal links with local stakeholders'), and **social/community benefits** (n=5: 'social/community benefits'; 'value of

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firm's production for society'; 'social and environmental conflicts on place'; 'share of workers/community in profits'; 'extent the organisation is reducing local and global inequalities').

Based on these results, we decided to present an updated list of people categories, combining the original most frequently observed categories from Calzolari et al, with the categories proposed in the survey responses. This resulted in the following list:

- Jobs created (JC): Jobs created across the supply chain
- Customer Environmental Awareness (CEA): e.g. information on disposal methods, incentives for recovery
- Social cost of waste (SCW): e.g. community impact, personal health impacts (combining the categories of Social cost of waste, and social/community benefits)
- Participatory planning (PP): e.g. worker participation in production management, involvement of key stakeholders and communities, participation in decision making (combining the worker & community participation write-in categories)
- Gender & equalities (G&E): e.g. gender balance, opportunities for marginalised groups
- Quality of work (QW): e.g. percentage of employees on open-ended contracts, unionisation rates

The social indicator categories identified by Calzolari et al. (2022) that were least popular with the survey participants were thus removed at this stage.

Q3b - *Planet*

The selection of categories in the planet dimensions among participants displayed a significant amount of agreement relative to the people dimension. All categories were selected with a high frequency: **waste produced** 100%, **GHG emissions** 97%, **energy usage** 94%, **air pollution** 91%, **water used or contaminated** 88%, **virgin resource usage** 82%, **acidification** 79%.

A fewer number of write-in responses were received, which were on the whole a lot more diverse and divergent. Notably, 'circularity' was mentioned by only one respondent. Themes that occured multiple times within the responses encompass: **global supply chain factors** (n=6: 'planetary boundaries'; 'outsourced impacts'; 'extraction from emerging economies'; 'unequal exchange of flows'; 'proximity of actors'; 'distance raw material and products need to travel to their destinations'), **land use aspects** (n=3: 'land use'; 'green area care'; 'regeneration'), and **displacement of primary production** (n=2).

Due to the high degree of perceived relevance of the planet categories from Calzolari et al, we decided to retain these six categories in our second list iteration. Additionally due to the divergence of the write-in categories suggested, none of these were taken forward. This resulted in the following list of planet indicator categories:

- Waste produced (WP): Waste produced across the supply chain
- GHG Emissions (GHG): Emissions produced by supply chain activities
- Energy Usage (EU): Energy usage across the supply chain
- Air pollution (AP): Air pollution produced by supply chain activities
- Water consumption (WC): Water used and contaminated across the supply chain
- Virgin resource usage (VRU): Virgin resource usage across the supply chain

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Q3c - *Profit*

For the profit dimension the selection of relevant categories displayed some agreement, though it appeared several of the presented categories were unpopular. The selection rate was as follows: **cost of production** 97%, **supply chain risks** 84%, **quality** 81%, **profits** 68%, **time responsiveness** 65%, **return on investment** 55%.

There were 11 write-in responses, with recurrent themes relate to **ethical and equitable investments,** and aspects of **profit distribution** (e.g. "who does the company invest in?"; "share of workers/community in profits"; "how is profit shared/distributed/invested?"; "profit distribution share between different countries").

We thus synthesised the following list of economic categories to bring forward. Note, due to the distribution of perceived relevance, it was difficult to justify a sixth category, and thus we opted to retain only 5 categories.

- Cost of Production (CP): Cost of production at company and supply chain level
- Supply chain risks (SCR): e.g raw materials availability, reliance on critical materials
- Products quality (PQ): e.g. defect rates of end products
- Equitable investments (EI): e.g. ethical investment practices (derived from write-in responses)
- Surplus distribution (SD): e.g. worker & community share in profit (derived from write-in responses)

3 Co-Production Workshop

At the joint ReTraCE/JUST2CE workshop (30th June - 1st July 2022), we decided to hold a discursive workshop in order to garner the consortium's views on the indicator categories selected from the survey results. In order to best capture the breadth of views across the consortium, and understand how members judged the importance and priorities of individual categories relating to the just transition to a CE, we decided to frame this workshop around an application of the Analytical Hierarchy Process (AHP).

AHP is a quantitative technique, commonly employed to structure and facilitate complex decision making processes (Saaty, 2008). It employs 'pairwise comparison matrices' which ask the participant to compare components and assign a numerical weighting to quantify their relative importance. Table 2 demonstrates an example pairwise comparison matrix used to compare the dimension of PPP. AHP employs the 'fundamental scale' designed by Thomas Saaty, which uses the integers 1 to 9 representing the prompts from '1 = equal importance' to '9 = extremely more important'. Reciprocal values are used to indicate that the column is more important than the row, whereas integers indicate that the element in the row is more important than the element in the column.

Table 2. *Example of a pair-wise comparison matrix*

	People	Planet	Profit
People	1		
Planet		1	
Profit			1

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The workshop began with a brief presentation of the survey outcomes and an introduction to AHP. Following this, the members present were split into groups (3 in person, and 1 online), and each group, aided by a facilitator, were presented with several tasks to work through relating to pairwise comparison matrices for the identified indicator categories. Participants were each given a worksheet which presented four pairwise comparison matrices, one as reproduced in Table 2 comparing PPP; and individual category matrices for each respective dimension using the categories selected following the survey analysis. Each worksheet contained a set of instructions detailing the process, the qualitative description of the numerical values, and the short descriptions of each identified category as outlined above in Section 3.

The participants were asked to fill in these matrices responding to the following prompts: which of the two elements is more important in the context of the transition towards a Just Circular Economy, and how strongly? Participants were asked to conduct this exercise individually, reflecting on their own perspectives. At this stage, the facilitators (each of whom had prior experience with using AHP) acted to answer any technical questions or difficulties with filling in these matrices. Individuals were given around 25 minutes to fill in the matrices (the online group ran for longer due to the inability to proceed with group activities in the online environment).

Following the individual matrix activities, the three face-to-face groups were asked to derive a collective group matrix based on their individual matrices. This was done by deliberation and group discussion as guided by the group's facilitator, and aided by consideration of each participant's individual matrices. Due to time constraints, this deliberative group process was only performed for the first matrix comparing PPP dimensions (Table 2). Each individual matrix was collected for further analysis, and the group facilitators were asked to make notes relating to how members of their group approached the tasks and where any disagreements and causes for concern arose. The workshop concluded with a discussion among all participants to garner member's views on these activities and techniques. The following sections outline some headline findings from this process.

3.1 Workshop findings - Quantitative: Consistency

Each participant's matrices were digitised and compiled within a master spreadsheet. Our first task was to check each matrix for 'consistency'. Consistency adjustment is a routine analysis within the AHP paradigm, whereby the matrices are checked for areas of logical inconsistency in assigning numerical values. Whilst we must be careful drawing conclusive conclusions from these quantitative checks, we consider within our analysis, consistency to represent a proxy for how much participants had difficulty comparing elements. Thus a high consistency represents easier choices within comparison, and a lower consistency represents a more difficult choice. Consistency is determined by computing the 'consistency index' of the matrix using the principal eigenvalue, and comparing this index to a random index (i.e. the index of a matrix filled in with a randomly assigned set of uniform values). Should the consistency index be much smaller than the random index, the matrix is judged to be suitably consistent. Usually the threshold of 0.1 is selected for this (Karapetrovic & Rosenbloom, 1999).

Overall, the consistency across all matrices was 72%, this represents a fairly good rate of consistency. Nevertheless, the presence of logical inconsistencies as a standard observation within the AHP process highlights some of the inherent challenges relating to comparing and weighting indicators. We should thus be cautious of uncritically centring multi criteria decision-making approaches within our DSS framework.

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Whilst 72% of the PPP matrices were consistent, the consistency of the other matrix typologies varied. In particular, the people matrices were the least consistent at only 60%, whilst the planet matrices scored highly at 88%. The profit matrices had a collective consistency rate of 68%. These lower levels of consistency can be linked to more difficulty in comparing elements and deciding which categories are most important. Interestingly, these scores align with the results of the survey, in which the people dimension observed the most disagreement over the importance of categories, whereas the planet element saw strong agreement. It is notable that a number of participants filled in their planet matrices in a manner indicating that they viewed all elements as equally important.

Following these consistency checks and the identification of inconsistent matrices, we used an algorithmic method to 'fix' the identified consistency matrices to allow for further standard analysis. Whilst the preferred approach for this involves a deliberative process between the decision maker and a facilitator, we did not have the time available for this. Instead, we used an online calculator (Goepel, 2018) to determine consistency of each element, before manually adjusting the most inconsistent element 1 point on the scale to improve consistency. This process was repeated until the overall consistency of the matrix met the 0.1 threshold. This algorithm is intended to maximise consistency whilst minimising the change to the matrices in terms of the judgements made, thus aiming to preserve the overall preference structure.

3.2 Workshop findings - Quantitative: Ranking of Elements

Once all the adjusted matrices met the consistency threshold, we were able to calculate the weightings of each element in each matrix. This is done by multiplying the scores in each row together and calculating the nth root, and then normalising this value to derive each weight (Render et al., 2017). Each weight is thus calculated as a percentage, with importance summing to 1. This provides a picture of how each participant has ranked each item in regards to its importance for inclusion in the DSS. By calculating these weights for each participant we are able to examine divergences and convergences across the consortium. Tables 3-6 display the headline weights of each element averaged over all consortium participants. We also display the standard deviation, and minimum and maximum individual values for comparison.

Table 3. *Weights of each people/planet/profit dimension averaged over all exercise participants*

	Mean	S.D.	Max	Min
People	43.78%	10%	63.70%	27.85%
Planet	45.46%	12%	66.31%	25.83%
Profit	10.75%	9%	33.33%	5.13%

An immediate observation here is that as a whole, participants judged people and planet to be roughly equivalent in importance, with profit being judged the least important dimension by some way. Apart from two participants that judged all these elements to be of equal importance, all other participants indicated profit to be the least important, often by a large amount (i.e. using a 9). Of the remaining filled in matrices, 7 participants judged People to be the most important element, 6 selected Planet, and 7 judged the two to be equally important. This shows that whilst the mean scores average out, this does not illustrate the broad spectrum of responses presented across participants of whom nearly 60% did not identify people and planet as equally important.

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It is interesting to compare these findings to Calzolari et al's (2022) summation of the frequency of each dimension's occurrence across the literature, whereby the economic/profit dimension is observed in 49% of studies and the social/people in only 11%. This emphasises that frequency of occurrence in the literature should not be considered as an expression of value judgement that the consortium might assent to.

The results of the individual category matrices (Tables 4-6) are more difficult to parse. The standard deviation remains high such that it is difficult to draw clear conclusions on preferences across the consortium. This, as the variation across individual matrices can be seen, shows that there is little agreement across the consortium as to which individual categories are most important. This mirrors the qualitative feedback gathered in the closing section and the observations from group facilitators.

Nevertheless, there are some observations that can be drawn from these results (though of course we must be careful of drawing inferences with such variance of results):

- The categories added following the survey stage (PP, G&E, EI, and SD) performed well within their respective categories. Notably, the Surplus Distribution (SD) and Equitable Investments (EI) topped the profit category. This again reveals the limitations of drawing directly from frequency of occurrence within the literature.
- The variance and deviation in the Planet dimension is notably lower, as can be seen by the lower standard deviation values and a more equal distribution of means.

We see consistency here with the results from the survey, where responses were more aligned in the choice of important planet indicators, whilst divergence was seen in the choice of important people indicators. This may be influenced by the permeation of environmental indicators, particularly GHG emissions, across popular discourse. The social dimension itself, on the other hand, is notably underconceptualised, and there are few so prominent indicators that have become the subject of global policy initiatives.

Table 4. *Weights of each people category averaged over all exercise participants*

People Categories	**Mean**	**S.D.**	**Max**	**Min**
Jobs created (JC)	13.10%	0.09	33.23%	2.61%
Social cost of waste (SCW)	21.60%	0.10	48.62%	3.23%
Customer Environmental Awareness (CEA)	10.01%	0.10	40.50%	2.04%
Participatory planning (PP)	18.65%	0.11	50.46%	4.18%
Gender & equalities (G&E)	18.20%	0.07	29.99%	5.24%
Quality of work (QW)	18.45%	0.10	40.33%	2.56%

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Table 5. *Weights of each planet category averaged over all exercise participants*

Planet Categories	Mean	S.D.	Max	Min
Waste produced (WP)	13.95%	0.06	25.52%	3.94%
GHG Emissions (GHG)	21.76%	0.09	39.50%	5.28%
Energy Usage (EU)	14.00%	0.06	26.71%	4.86%
Air pollution (AP)	16.41%	0.05	32.13%	5.93%
Water consumption (WC)	17.26%	0.04	25.00%	9.25%
Virgin resource usage (VRU)	16.62%	0.10	52.88%	2.56%

Table 6. *Weights of each profit category averaged over all exercise participants*

Profit Categories	Mean	S.D.	Max	Min
Cost of Production (CP)	11.38%	0.08	35.53%	2.42%
Supply chain risks (SCR)	17.90%	0.12	43.41%	3.74%
Products quality (PQ)	17.55%	0.13	56.54%	4.11%
Equitable investments (EI)	22.91%	0.13	46.92%	2.90%
Surplus distribution (SD)	30.26%	0.19	65.71%	6.99%

Using these calculated mean weightings we were able to develop a master list, Table 7, which ranks each category across the total participant list. This was done by factoring in the derived weights of the PPP dimensions, multiplying these by the weights of the individual indicator categories within these dimensions, and then normalising.

One immediate observation from the ranking shown in Table 7 is that all the economic categories scored lower than any other category. The social elements representing more quantitative metrics relating to the activities of firms, namely jobs created and customer environmental awareness also performed relatively poorly.

3.3 Workshop findings - Qualitative

The quantitative findings of the workshop go some way to illustrate the plurality of views across the consortium, and these may be contributed by the qualitative observations from the group facilitators and the final discussion held after the workshop activities.

Most participants found the task of filling in their individual matrices difficult. Part of this was technical and due to unfamiliarity of the technique, which may be one of the reasons that the first large matrix filled in (People) was on average more inconsistent than subsequent matrices. Yet the difficulty also related to the task itself and the challenge of comparing a diverse set of elements, and then translating thoughts into numerical terms. Referring back to the consistency of matrices, discussed above, it is notable that nearly all the matrices were inconsistent, even if most of them met the acceptability threshold.These difficulties relate to AHP as a method, and more broadly the epistemological issues relating to comparing qualitatively different items, something which has

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been critiqued in the academic literature in relation to indicator approaches (Gasparatos et al., 2008; Kaika, 2017; Turcu, 2013).

Participants articulated frustration at the relatively vague definitions given for each dimension and category, leaving each title somewhat arbitrary and up to divergent interpretation. This impacted the perceived ease with which participants approached the matrix exercises, and may have been one of the sources of inconsistent matrices. The difficulties this presented at an individual level were compounded in the group discussion section when participants discovered that members of the group had competing interpretations of several terms.

Table 7. *Weights of each individual category, normalised for dimensional weighting. People categories are indicated in red, planet in green, and profit in yellow.*

GHG Emissions (GHG)	0.098
Social cost of waste (SCW)	0.095
Participatory planning (PP)	0.082
Quality of work (QW)	0.081
Gender & equalities (G&E)	0.080
Water consumption (WC)	0.078
Virgin resource usage (VRU)	0.075
Air pollution (AP)	0.074
Energy Usage (EU)	0.063
Waste produced (WP)	0.063
Jobs created (JC)	0.058
Customer Environmental Awareness (CEA)	0.044
Surplus distribution (SD)	0.033
Equitable investments (EI)	0.025
Supply chain risks (SCR)	0.020
Products quality (PQ)	0.019
Cost of Production (CP)	0.013

One area where groups struggled to reach consensus on was whether planet was more important than people. The differing views here appeared to be as much epistemological and axiological, with participants raising the dependence of the social sphere on the ecological sphere. Others in opposition argued that the reason we want a healthy planet is for people, and thus the people dimension should be judged more important. Regardless of the individual values articulated, it was clear that there was broad consensus that people and planet are closely linked, and that both should be judged much more important than profit.

The discussion also circled back to some of the doubts articulated in the survey phase about the framing of PPP. In particular, several participants articulated their feeling that the profit title was not adequate due to its centering of profit generating economic activity at the expense of other modes of production.

One final area that emerged during the discussion was the baseline of comparison. Many of the participants were based in Northern European countries, and one participant raised the bias that this situatedness may introduce. Context is important for comparing elements, and part of this is

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the geopolitical context of where the decision maker is located. This is something that the process articulated in this report has not suitably accounted for, other than the observation that the literature reviewed possesses a large eurocentric bias. This issue is thus important for WP4 to consider within the design of the DSS, particularly as the JUST2CE project explicitly aims to embed decolonisation and issues of global justice within its frameworks.

4 Conclusions and next steps

We have outlined the systematic literature review of existing indicators, and shown several steps to gather feedback and consideration from members of the wider consortium on the suitability of common indicator categories, their framing, and how different categories of indicator can be compared. The results of these latter steps have demonstrated some of the difficulties inherent to an indicator approach, particularly in relation to the selection of important factors. Even across a consortium of like minded researchers with many shared values, despite broad agreement on several issues such as the prominence of profit oriented metrics, there are also many areas in which a consensus has been difficult to reach.

The difficulties that have arisen during the above described exercises allow us to draw some tentative conclusions that can inform the next steps towards the establishment of Decision Support Frameworks for the evaluation of the transition towards a CE in supply chains.

Firstly, the weighting of indicators in terms of relative importance, a technique which is routinely applied in indicator based approaches, is a highly subjective exercise. We have observed that even within the ReTraCE and JUST2CE consortia, where we might expect a broad alignment of values that there was a stark lack of agreement in terms of which elements to prioritise. Reading the max and min columns of Tables 3-6 shows starkly the variability of participant's views as to the importance of each category identified within the literature. It is only at a more abstract level when we discuss PPP that we see more consensus. Even here though, we have documented the disagreements relating to whether people or planet is the more important dimension. Whilst the approach of averaging over the consortium may smooth out these disagreements and leave us with a table of weights (Table 7), such an approach erases the underpinning values and theoretical frameworks relating to participant's justification of their prioritisation. We can argue too that even individual weights are largely arbitrary, and there is no reliable method for standardising each participant's understanding of what 'moderately more important' or 'extremely more important' may mean.

For these reasons, we argue against employing methods that weight or compare a range of different indicators using quantitative multipliers. The upside of weighting however is that it can often be employed to reduce the complexity of information presented to the user of the tool.

The second major conclusion that we have drawn from the work described in this report relates to the method of indicator selection. There are a range of views within the academic literature on how best to select indicators for a specified task. There is also important discourse on the epistemological drawbacks of metrics and indicator approaches, particularly relating to elements that are not easy to quantify (this is a common reason for neglect of social dimensions). In the work described we followed what is arguably the typical approach of indicator selection, by deriving a set of commonly used indicators from the literature and then using a deliberative process to refine this indicator set. Further typical refinements might relate to pragmatic choices based on

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data availability. An alternate approach entirely involves first developing a theoretical framework for the problem, and then selecting relevant themes of interest based upon theory, rather than arbitrary choices of popularity or expediency.

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Concluding remarks

Adequate measurement approaches are key to ensure the success and sustainability of the implementation of Circular Economy (CE) initiatives in industrial practices. It is therefore important to rely upon models and decision support tools to compare and assess the performances of production systems using a wide range of sustainability indicators. This requires to employ different metrics assessing all sustainability dimensions across the supply chain.

This report has highlighted, however, that the construction of systems of indicators aimed at measuring the circularity of production systems and supply chains is not a trivial task. Starting from a review of the literature (presented in Chapter 1), it has been shown how the current approaches (both in academic literature and in corporate practice) rely on a number of problematic assumptions, which are both of theoretical and practical relevance. Specifically, it has been shown (also through the case study presented in Chapter 3) that the most widespread approaches suffer from an intrinsic reductionism. The transition to a CE is viewed as a merely technocratic process, with a complete overlook of the social dimension and of the structural transformations induced by this paradigm change.

Also, Chapter 1 and 2 have debated the lack of a sound theoretical underpinning to most of the methodological proposals for measuring the transition towards a CE. The shift to a new mode of production and consumption might require also a deep redefinition of *value*; however, our measurement systems and indicators' dashboards seem very much aligned to a neoclassical theorisation of value, which might be incompatible with a transition to an ambitious circular future.

Methodological traps in the construction of CE indicator systems have been highlighted throughout the report, and, especially, in the participatory exercise which has been conducted in Chapter 4. The selection of indicators, their weighting and the intrinsic trade-offs represent very subjective processes, which might be influenced by competing worldviews and conceptualisations.

As such, this report has warned against *one-size-fits-all* approaches to CE measurement, and calls for the development of more sound theoretical foundations which should aim to define processes, methods and models for the definition of indicators and assessment systems. As highlighted in Chapter 2, future approaches to CE measurement may be best not characterised by monistic approaches, but increasingly by a practical realisation that we can draw on multidimensional approaches, and thereby incorporate different stakeholder perspectives and encourage methodological pluralism in the shift to an ambitious circular future.

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