MASTER THESIS

CIRCULAR ECONOMY INDICATORS FOR AGRICULTURAL SUPPLY CHAINS: A SYSTEMATIC LITERATURE REVIEW

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Abstract

The depletion of resources and the downgrading of the environment, driven by globalization and consumerism phenomena, is worldwide pushing the interest on the Circular Economy (CE) concept. CE has gained momentum both among scholars and practitioners as it represents a promising strategy for supporting sustainable, restorative, and regenerative agriculture. However, no established indicators exists to assist the transition of supply chains to a higher degree of circularity; also, most of the literature on CE indicators has focused on other industries and products and not specifically in the agricultural sector. Through a Systematic Literature Review, this paper examines the current state-of-the-art of literature for CE in agricultural supply chains, as well as the decision support tools and the related indicators employed for assessing CE performance. Firstly, this paper analyses the different available definitions for CE in an agricultural context and provides a complete and commonly accepted definition. Secondly, using the framework for sustainability adoption, it is identified that current literature is positioned at the Stage 2: Persuasion. Lastly, a breakdown of the indicators found is provided, where they are defined and later discussed depending in their scope and limitations. This paper recognizes that testing of a recognized set of indicators must be done in order to create assessments that allows comparison between productive areas, regions, and countries, considering that most available indicators focus on specific processes.

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1 Introduction

The circular economy (CE) is perceived as a sustainable economic system where linear economic growth is no longer dependent on the extraction of finite natural resources, instead relying on reduction and recirculation of supplies (Corona et al., 2019). Modern agriculture is facing crucial challenges in the attempt to supply a balanced diet for a growing population while considering the planetary boundaries (Hercher-Pasteur et al., 2021).) CE is a growing topic, especially in the European Union and China, that promotes the responsible and cyclical use of resources in a production context (Moraga et al., 2019). CE goes against the current economic growth that is based on a linear production model that has been proven to not be feasible in a planet with finite resources and a limited capacity to absorb waste (Suárez-Eiroa et al., 2019). CE is not a new concept; however, it wasn't until the last decade that an increase in interest can be observed from private businesses, governments, international organizations and civil initiatives. CE concepts and their applications are more commonly found in the design of cradle-to-cradle products and by using material recycling techniques, but, they fail to incorporate a holistic and systematic approach to an entire sector (Geissdoerfer et al., 2017). In the CE paradigm, every economic activity should maximize ecosystem functions and human well-being (Calzolari et al., 2022). In order to achieve this holistic approach, it is paramount that academia and their research has a "united front" that allows the other societal organizations to implement cohesive and practical approaches.

Due to the benefits of circular supply chains, companies have increasingly been placing more emphasis on achieving sustainable production, by shifting from simple mitigation actions to focus on prevention of environmental damage or even get involved in regenerative production practices (Calzolari et al., 2022). This trend has also been apparent in the academic literature focused on the applications of circular economy principles in an agricultural system (Rincón-Moreno et al., 2021; Velasco-Muñoz et al., 2021). Different assessment tools have been proposed such as life cycle analysis, systems thinking and indicators that support the involved stakeholders to measure their desired targets (e.g. economic, environmental and social) (Morseletto, 2020b).

It is worth noting that existing reviews of CE indicators show that there is no agreement among researchers and practitioners on which CE frameworks and indicators should be used for the different sectors and sustainability pillars (Potting & Hanemaaijer, 2018). In their research, Kirchherr et al. (2017) concluded, after analyzing 114 CE definitions, that CE definitions vary considerably and there is a risk of the concept eventually collapsing due to a conceptual deadlock. Therefore, it can be deducted that there is no consensus on a set of indicators that should measure desirable levels of circularity and establish improvement paths for agricultural production systems.

In order to manage this risk, Velasco-Muñoz et al. (2021) investigated the current CE literature in order to create a CE framework that adapts to the particularities of the agricultural sector. Nevertheless, one of the conclusions of their research is that there is no standardized framework, nor clear definition of the concept, principles, and strategies or practical implications in this context. Consequently, the scope of existing indicators for CE in agriculture is limited, and there is an urgent need to develop new, more comprehensive indicators.

To address these relevant research gaps, the aim of this study is to provide an overview of the existing research and research gaps associated with the adaptation of CE principles in an agricultural production system. This will be done by answering this main research question:

What is the current state of literature on circular economy indicators in agricultural supply chains?

The study is based on a systematic and critical approach. The literature is reviewed through a systematic database search with a pre-selected set of keywords.

The following sections will provide a detailed description of the PRISMA methodology, study area and data collection approaches; present the results, discussion of the findings and their implications; and conclude with recommendations.

2 Research Background

A need for attention and cooperation between stakeholders in the supply chain to create tangible impact in terms of innovation for CE plays a crucial role in the current time (Silvestri et al., 2022). These innovations are key for supporting the transition towards CE (Calzolari et al., 2022). In a circular supply chain, stakeholders cooperate to deliver goods and services to customers, but also provide feedback loops that allow for methods of production to be self-sufficient and for materials to be used multiple times. Products are designed to last longer and to flow through multiple use phases while materials are recovered and recycled. In the circular supply chains spectrum an important role is played by how products are designed, the output that is created and the end-use possibilities of the product or system. (Wastling et al., 2018). As for the role of companies or stakeholders, in this context, is to provide services and performances, rather than just products (Tukker, 2015). As a result, each product and by-products is considered an asset whose value is preserved for as long as possible with the goal of displacing the demand for new products (Rosa & Terzi, 2021). This is expected to keep consumptions levels within the current planetary boundaries. Therefore, according to Calzolari et al. (2022) a circular supply chain should be able to:

- Coordinate forward and reverse logistics supporting the creating of value from circular and product-as-service business model
- Reduce waste streams, by systematically restoring technical materials and regenerating biological materials
- Limit the throughput flow of societal systems to a level that nature tolerates, and utilize ecosystem cycles in economic cycles by representing their natural production rates

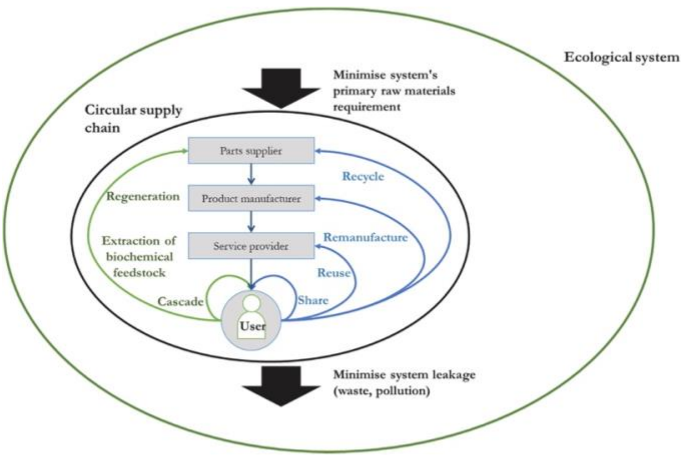


Figure 1 Circular Supply Chain as parts of the Ecological system (Calzolari et al., 2022)

In the context of circular supply chains and agriculture, according to the UN, circular agriculture focuses on using minimal amounts of external inputs to regenerate soils and minimize the impact on the environment (Batlles-delaFuente et al., 2022). It guarantees a reduction in land use as well as limiting the use of chemical fertilizers and the production of waste in order to reduce global emissions and ensure that production stays within the planetary boundaries (Schröder et al., 2020). Circular agriculture seeks to close the life cycle of products, services, waste, water and energy in order to seek better use and reduction of the ecological impact (Batlles-delaFuente et al., 2022).

2.1 Strategies for adopting CE in agricultural models

There are four main strategies found in literature that group the goal that a circular supply chain must contain. The main CE strategies are derived from the CE principles and represent different alternatives for developing circular models (Rivera et al., 2020). These strategies are: i) narrowing resource loops, ii) slowing resource loops, iii) closing resource loops, and iv) regenerating resource flows (Velasco-Muñoz et al., 2021).

2.1.1 Narrowing

Narrowing resource loops is related to improving efficiencies in terms of nutrients, costs, materials, labor, energy and capital (Moraga et al., 2019). Associated externalities such as: GHC emissions, polluted water and/or toxic substances are also included in this strategy. Narrowing resource loops involves eco-efficient solutions that reduce resource intensity and the environmental impacts per unit of product or service (Mendoza et al., 2017). This strategy is based on the notion of earth as an economic system in which the environment and the economy are linked in a circular relationship (Velasco-Muñoz et al., 2021). Following this notion, material flows intend to improve efficiency while eliminating resource leakages (Kristensen et al., 2016).

2.1.2 Slowing

Agri-food products have the characteristics that they are irreversibly altered with their use, which does not allow them to be used for the same purpose or repaired to expand their useful life (Mhatre et al., 2021). Therefore, the slow resource strategy is a set of measures to extend the life of products within the agri-food system. The slowing strategy aims to keep nutrients in the food chain so they can be utilized for human consumption for as long as possible (Velasco-

Muñoz et al., 2021). Although it is not possible to extend the life of resources for consumption on multiple occasions, there are other ways to extend the life of agricultural products. The main way to decelerate these loops in food production is to prevent them from being thrown away before being eaten as food (Aznar-Sánchez et al., 2020).

2.1.3 Closing

The closing of resource loops is typically regarded as resource cascading (Aznar-Sánchez et al., 2020). The premise in this cascading use of resources is that the reused materials satisfy the necessary technical and functional requirements in the new value chain, the marginal costs of doing so are lower than using virgin resources (Brennan et al., 2015).

2.1.4 Regeneration

A regeneration strategy is comprised of all actions aimed at preserving and enhancing natural capital. In other words, agricultural practices that include: agroforestry, rotational grazing, agroecology and permaculture (Jose, 2009; Torreiro et al., 2020). The regeneration strategy is closely linked to biological resources since it intends to return those resources to the earth as a form of nutrients at the end of their life cycle. Restoration in the CE literature is associated primarily with a need to restore to natural capital (Morseletto, 2020a).

2.2 Measuring sustainability in agricultural circular supply chains

In order to apply the strategies of CE, decision-makers need tools to evaluate the adoption of CE practices, while continuing to manage profitable, efficient, circular and sustainable supply chains. Decision support tools employ many CE indicators in order to account for a variety of impacts across the different sustainability dimensions (Calzolari et al., 2022).

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).

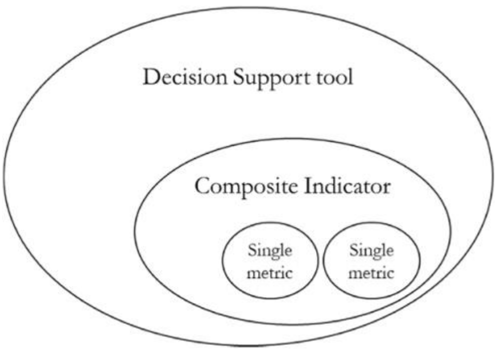


Figure 2 Decision support tools, Indicators and metrics (Calzolari et al., 2022)

According to Åkerman (2016) CE indicators can be categorized in a 5-level grouping system based on a sustainability standpoint, which include: (1) technical characteristics – where focus is placed on assessing a set of technical criteria including energy consumption, and/or use of materials, etc.; (2) environmental aspects – focuses on environmental issues such as health of the ecosystem and humans; (3) economic opportunities – where economic and financial performance is measured; (4) social aspects – where the objective is the analysis of welfare-related variables (Velasco-Muñoz et al., 2021).

In CE assessment metrics, indicators and methods at the firm level have been extensively reviewed (Batlles-delaFuente et al., 2022; Calzolari et al., 2022; Johansen et al., 2022; Rincón-Moreno et al., 2021) while other implementation levels have gotten less academic attention such as the meso level (business network) and macro level (society). However, the mentioned studies jointly agree that there is a lack of agreement on what needs to be measured, on standard methods of measurement and even on shared terminology and conceptualization of CE in an agricultural context.

In supply chain management literature, research streams have developed tools to measure the adoption of CE practices with a supply chain level analysis (Brandenburg et al., 2014). These literature offers insights about a crucial unit of action for implementing CE and decision support tools. These decisions tools are characterized for incorporating a tripe bottom line approach (social, environmental and financial) and life-cycle approaches for the impact evaluations of global supply chains. Continuing on this context, the evaluation of environmental impacts makes extensive use of established methods found in environmental science, such as: life cycle costing, hybrid life cycle analysis, multi-regional frameworks, etc. These methods make it possible to identify supply chain hotspots that allow decision-makers identify areas to be prioritized for action (Calzolari et al., 2022).

As for where a scientific consensus can be found, it is in the existence of three implementation levels of CE: micro level, meso level and macro level. The micro level refers to the implementation of CE systems in a company. The meso level refers to the interaction within the inter-firm network (a network that does not normally need to be within the 'park boundaries') and which may lead to industrial symbiosis. The macro level refers to the implementation of CE systems in the society as a whole, i.e. cities, regions, nations and the international community (Calzolari et al., 2022; Corona et al., 2019; Harris et al., 2021).

2.3 Research gaps and research questions

There isn't a set structure for this situation, nor are there any clear definitions of the concept, principles, or practical applications. As a result, the range of current indicators for CE in agriculture is constrained, and it is important to create new, more thorough indicators. Special attention needs to be directed in making the methodology practical and easy to apply to non-expert stakeholders. Most of the indicators currently in use are indicators for measuring efficiency improvements in the linear economy that have been converted to the CE and a new set of specific indicators has yet to be developed to quantify circularity in agriculture. As a result, the available indicators provide partial information on agricultural models' levels of circularity, which can misguide sustainability-oriented decision-making processes.

The CE literature lacks an overview of the standard indicators to evaluate the transition towards a CE in supply chains. On the basis of the identified gaps, the research questions that will be addressed in this study can be summarised as follows:

Main research question

What is the current state of literature on circular economy indicators in agricultural supply chains?

Sub-question 1

Can a general definition of CE for agricultural supply chains be identified within the literature?

Sub-question 2

In what stage of the innovation process is CE for agricultural supply chains research positioned?

Sub-question 3

What are the current CE indicators in the context of the agriculture circularity literature?

3 Methodology

The methodology used in this study is based on traditional methods for conducting systematic and critical reviews. A systematic review is often used in medical science and is, for example, conducted in alignment with the requirements of the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) Statement. PRISMA is an evidence-based minimum set of items for reporting in systematic reviews and meta-analysis (Moher et al., 2009). This method includes a 27-point checklist and a template for flow information through the review. By following the PRISMA method three major steps are considered: (1) Identification, (2) Screening and (3) Included. These steps allows transparent, comparable and replicable results that, with a methodological approach that includes strict inclusion and exclusion criteria, provide meaningful outcomes while reducing bias (Moher et al., 2009). In this case the PRSIMA method is used to assess the state of the art of literature concerning CE indicators in the agricultural field.

Inspired by this approach, the literature in this study is managed through a structured database search using pre-selected search words. To collect all relevant literature two electronic databases were used taking into consideration that they are peer-reviewed academic databases. These databases are Web of Science and Scopus. They both provide with a trustworthy search engine that allows an effective search of the relevant academic articles. Furthermore, they provide the users with the option to export to excel, which facilitates the coding of the combined results of the two database searches.

The papers from these searches were then screened for duplicates and irrelevance. The keywords used to retrieve are made up by the following three inclusion criteria: (1) “circular economy”, (2) “agriculture”, and (3) “indicator*”. These keywords were inserted in each of the databases with an AND condition between each of the inclusion criteria, which allows the connection of the different groups. The asterisk behind one of the inclusion criteria is known as a wildcard which allows the search output to include different word endings. The search is limited to the title, abstract and keywords, where the inclusion criteria (in their different combinations) were be included.

Furthermore, a time period between January 2001 and July 2022 was selected. This goes in accordance with the approximate timeframe in which the circular economy has gain momentum for scientific publications and public discussion. This momentum can be observed in the graph below which includes CE related publications from the SCOPUS database. From 2001 to 2021an increase of publications can be observed where 2015 marks the most significant and constant increase to the end of 2021. It is important to mention that no articles were found using the pre-selected keywords from before 2016, which entails, that the articles selected for this study are only from 2016 onwards.

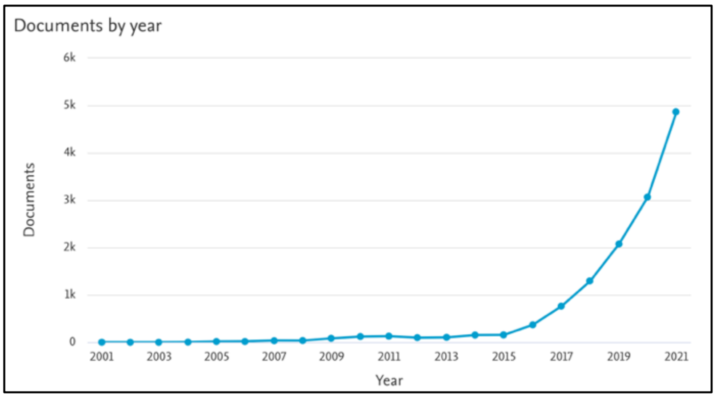
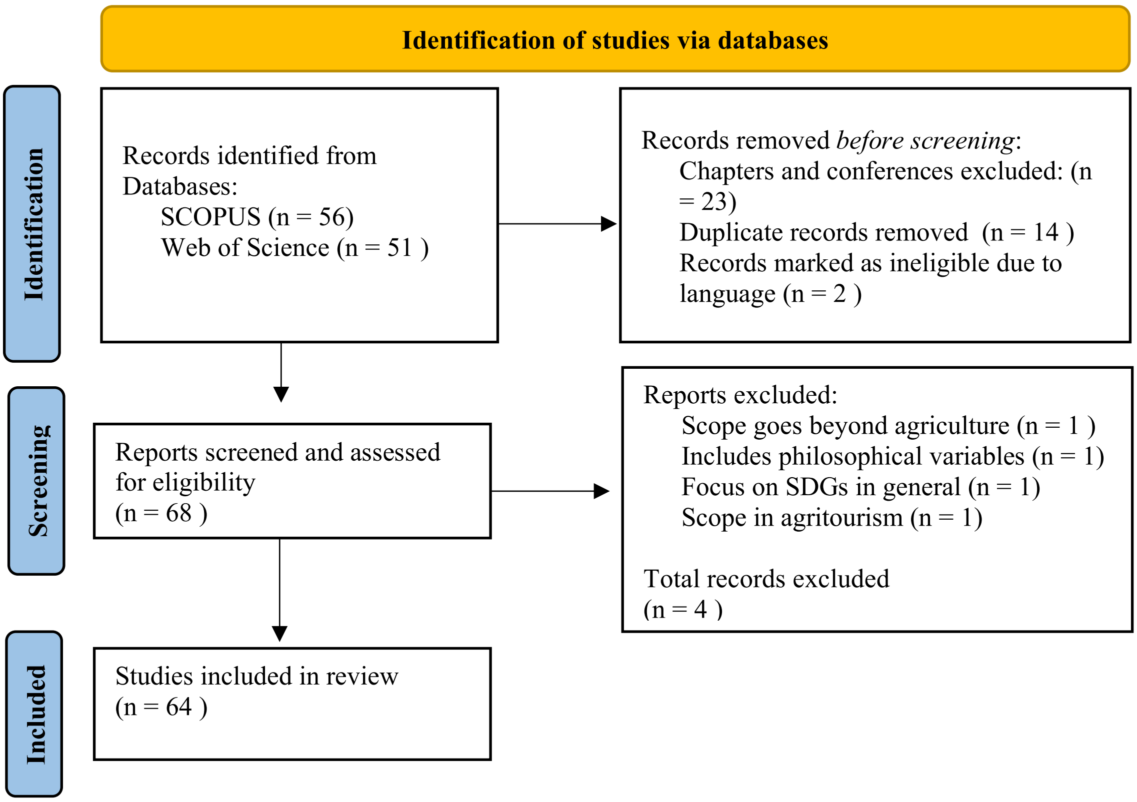


Figure 3 Published articles in Scopus with Circular Economy as keyword from 2001 to 2021

The results were retrieved from the databases using an excel document as base to export the results. These two downloads were then consolidated to make one excel database that contains the same columns and information from each paper. The columns included the following categories: Authors, Title, Year, Abstract, Author Keywords, Language, Document Type and Source. Having the articles organized in this matter facilitates further analysis of the papers.

Then, the papers were checked for duplicates and irrelevance. The figure below shows the PRISMA 2020 flow diagram for systematic literature review which includes searches of databases.



The inclusion and exclusion criteria can be divided in two parts. First, general criteria using the filter function in excel was applied to the consolidated database. To delineate the boundaries of the analysis the following inclusion/exclusion criteria were applied:

- Only articles in English have been included.
- Only peer-reviewed papers were included; book chapters and conference papers have been excluded.
- Publications which did not develop, employ indicators or measurements systems have been excluded

The second part of the inclusion and exclusion criteria involves the screening of each article based on the abstract, and in some cases a more thorough screen of the article itself. In this screening part, the scope, methodology and variables included were assessed. After the screening four articles were excluded due to: (1) scope goes beyond agriculture, (2) includes philosophical variables, (3) main focus on SDGs and (4) industry being studied was agritourism and not specifically agriculture. Going through the identification and screening parts reduced the number of articles from 107 to 64 articles, which were left to code and analyze.

The resulting 64 articles were evaluated and categorized from a content point of view in relation to the criteria described in the list below.

1. Article is a literature review of state of the art of a specific scope
2. Article proposes and/or conducts an assessment to a specific scenario
3. Articles proposes a set of CE indicators that can be applied to the agricultural sector
4. Article measures and proposes an activity for nutrient uptake and/or recovery
5. Article does not fall under any of the previous categories

The objective was to develop an understanding of where the focus of CE literature in the agricultural context in the chosen time frame is. First, describing the data as year of publication, research methodology and industry, including the scope of the research was specifically noted. The articles were examined thoroughly, and their findings classified along with the set criteria and categories. Industries where research focused were identified as well as processes in the value chain. Furthermore, the main definitions used for CE in agriculture were identified and argued as well of the identified indicators that researchers propose.

Using the aid of the Conceptual Framework for Sustainability Adoption proposed by So et al. (2012), this study attempts to show in which stage is CE for agriculture research positioned in the framework. Since applying CE principles in the agricultural sector requires a change of the current production model, a process of adaptation is required. In addition to the framework, So et al. (2012) emphasizes that supply chain members need to be supported throughout the decision process of sustainability adoption. He divides this decision process in five stages: (1) knowledge, (2) persuasion, (3) decision, (4) implementation, and (5) confirmation. Since CE in agriculture can be considered a new topic in research, there is an interest to find out where in these stages is the majority of literature focused on. Hence, as a tool for further analysis, the papers that have been chosen for this study were evaluated and assigned to one of the decision process stages.

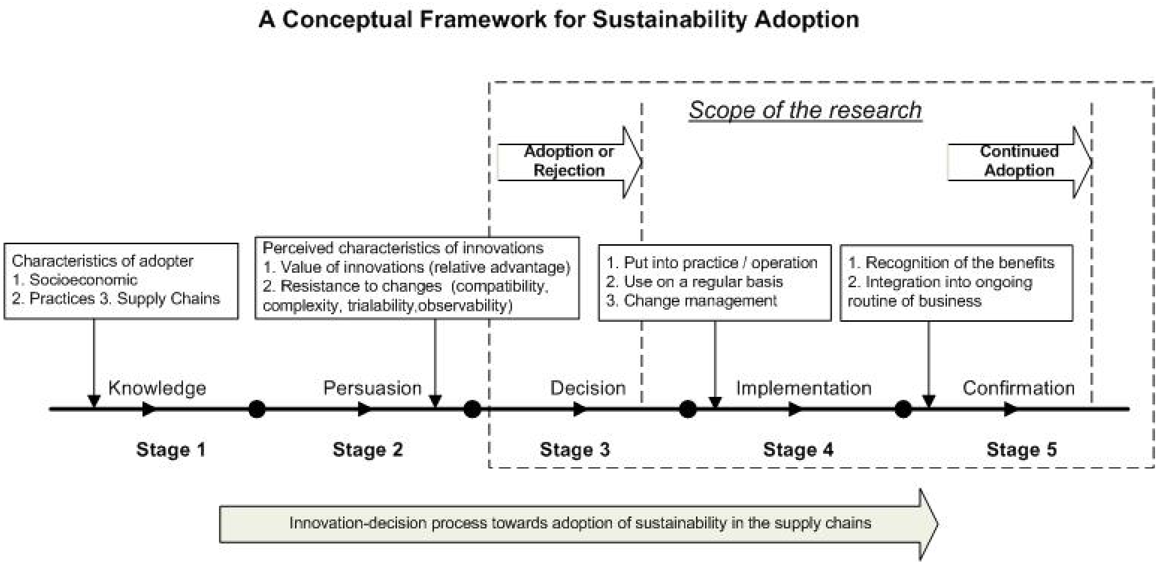


Figure 4 Conceptual Framework for Sustainability Adoption (So et al., 2012)

4 Results and Discussion

In this section, the main results with their respective discussion from the analysis of the articles sample are reported. The first part focuses on the systematic literature review. The following sub-sections discusses the indicators found from the literature and the final sub-section argues the most commonly employed metrics in the academic literature.

The sample analyzed includes 64 papers from 24 different sources. Journals belong to different research areas, as CE in agriculture has an inter-disciplinary nature. From the topmost represented journals, they all belong to the Environmental Science literature as seen in Table 1.

Journal Name	WoS	Scopus	**Number of Publications**
Sustainability (Switzerland)	7	5	**12**
Journal of Cleaner Production	5	3	**11**
Science of the total enviroment	1	2	**8**
Resources, Conservation and Recycling	6	5	**7**
Journal of Environmental Management	2	5	**3**

Table 1 Top 5 Journals that exhibit the highest number of papers

Publications range from 2016 to July 2022. It can be observed from Figure 5 that there has been a sustained growth on peered reviewed publications throughout the years studied. This data goes in accordance with what can be found in Figure 3 where the number of publications in relation with CE considerably also increases around the year 2015. Nevertheless, this data slightly differs to the study conducted by Sassanelli et al. (2019) where the journal that concentrated the most publication was Journal of Cleaner Production while Sustainability (Switzerland) was not taken into account. It is noteworthy to mention that the time period currently being studied is from 2001 to 2022; but only articles published from 2016 onwards fulfilled the search criteria for this study.

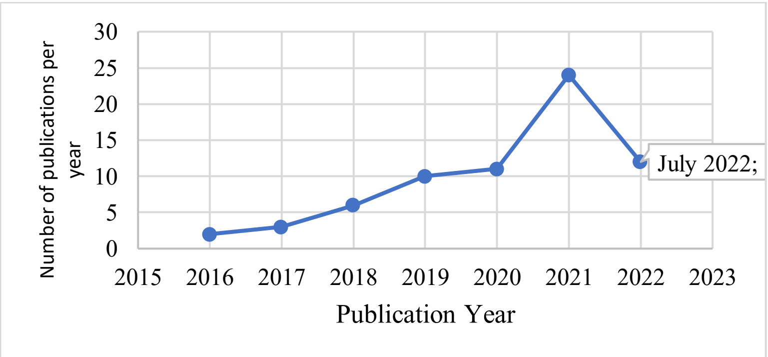


Figure 5 Historical series of published papers

The majority of the papers analyzed in this study fall into the category of "Assessments of CE for a specific scenario" as shown in Figure 6, with a total of 21 articles falling into this category. These assessments vary from country, agri-food systems, viability, production systems case studies. The second group with the most publications is the one related to research around nutrient management in a circular production system. These articles include research regarding different extraction or preservation methods of macronutrients required in an agricultural production system, where nitrogen is the most prominent nutrient studied. The third category with most articles is "Reviews" where the criterion in this category is based on the nature of the article in terms of literatures reviews, policies analysis and CE world trends. The "unspecified" category makes a reference to the articles that include variables that have no practicality approach or do not study indicators as mathematical science for sustainability and production. Lastly, the category of "indicators" takes into account the articles that study the mathematical modeling behind the CE indicators, their characteristics over time and how they can be applied in a specific scenario.

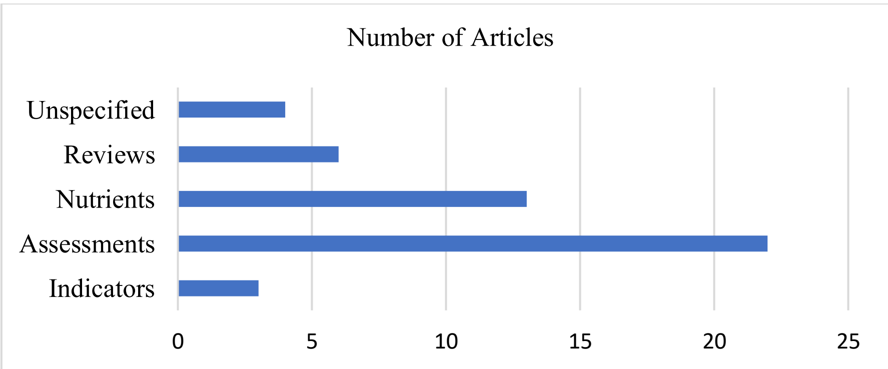


Figure 6 Type of category being studied

The majority of the publications employ methods from the analytical model approach, namely Life Cycle Analysis (LCA) and Systematic Literature Review (SLR) which both hold the most repeated approaches within the analyzed articles. Following by the category of Material Flow Analysis (MFA) with seven articles falling into this approach. Under the analytical methods category a considerable amount of articles falls under the Mix of Analytical Methods category, which means that, the articles employ a mix of these methods (LCA, Ecological Network Analysis and Energy Systems Analysis) or cost-based models (like Materials Flow Cost Analysis or Input/Output Cost Analysis). Two of the articles employ mathematical programming models, one of which uses a multi-objective function and the other a single-objective function.

When evaluating the effects of circular economy in agricultural production systems, as seen in Figure 7, different approaches are typically used. One of them, the LCA has been recognized by researchers as a robust, scientifically based tool which can measure and evaluate products and business models coming from circular economy (Chen & Huang, 2019; Padilla-Rivera et al., 2021)

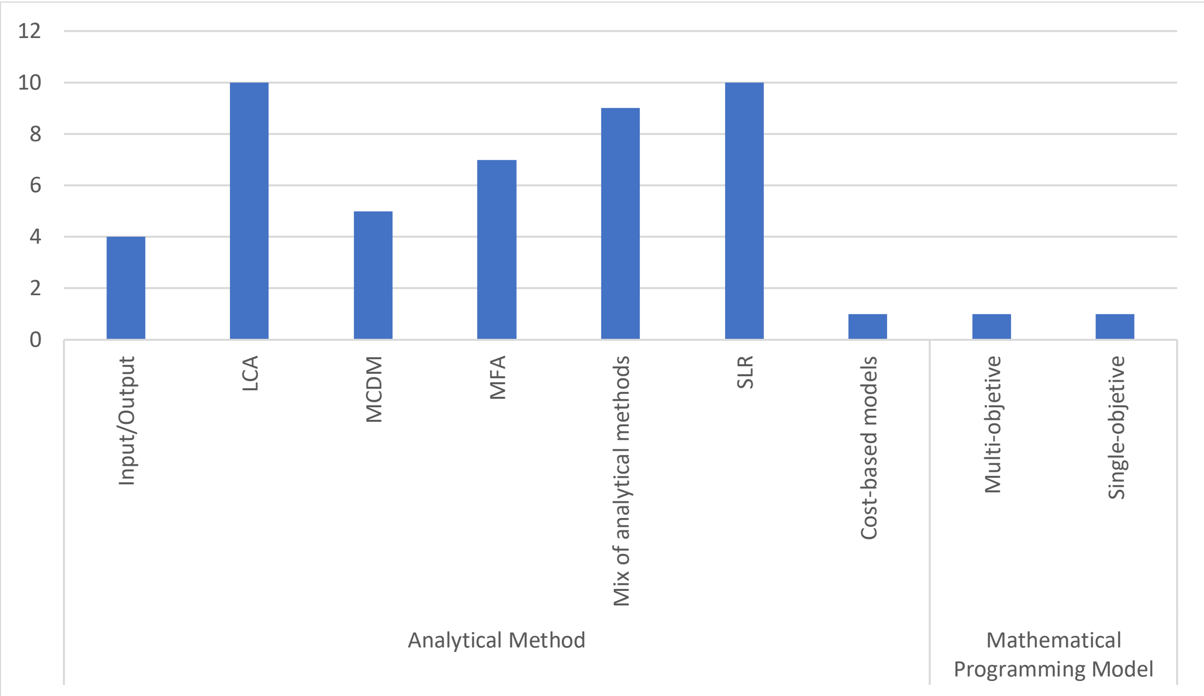


Figure 7 Modeling approaches following classification rom (Brandenburg et al., 2014). LCA: Life Cycle Analysis; MCDM: Multi-Criteria Decision-Making models; MFA: Material Flow Analysis; SLR: Systematic Literature Review.

The distribution in terms of modelling approaches represents the main difference with previous reviews on CE indicators research. A similar comparison was done by Calzolari et al. (2022) but in their results the category of Mathematical Models contained the majority of articles, contradicting the results of this paper. In a similar research conducted by Sassanelli et al. (2019) they discovered that the majority of literature focused on case studies followed by analytical and theoretical assessments accordingly. The scope of the before mentioned studies is on CE in supply chains in general, while this paper's scope is on agricultural supply chains which means that current research on CE indicators on agriculture is positioned at the early stages of sustainability adoption framework. This is by making the assumption that research using analytical methods translates to the Stage 2.

4.1 State-of-the-Art of CE in Agriculture

As previously mentioned in this paper, CE has gained momentum within the scientific community which can be observed lately among the papers being published on the topic. Through systematic literature reviews, Morales et al. (2021) and Calzolari et al. (2022) also identified this trend by concluding that there is indeed a sustained growth in the number of papers published starting from 2011. Calzolari et al. (2022) further argues that most of the publications support decisions at a strategic level. These strategic decisions entail e.g., selecting technologies, transportation modes, locations of industrial plants, etc. They also identified that the majority of publications employ methods from the Operational Research tradition, such as mathematical programming and simulation. Additionally, the second biggest group of articles employ analytical methods such as life cycle analysis, multi criteria decision making methods, among other cost-based models.

When it comes to the metrics and dimensions identified in the articles reviewed, the majority of the papers do not consider social indicators, hence, there is a preference for the economic and environmental dimensions when it comes to research. When looking at CE specifically in the agricultural sector and government policy, in their research Yuille et al. (2022) identified ambiguity in key terms and proposals such as: the use of inappropriate indicators and the lack of a systematic approach to key sustainability objectivates. This ambiguity of key terms was further confirmed by the studied conducted by Batlles-delaFuente et al. (2022), Rukundo et al. (2021), Abad-Segura et al. (2021) and Velasco-Muñoz et al. (2021). Table 3 shows the different definitions found in the sample papers for CE applied of the agricultural sector. This table attempts to show the main definition found and which authors support each definition.

Definition	Sources that support each definition
A circular economy is an economic system designed with the intention that maximum use is extracted from resources and minimum waste is generated for disposal	- (Salomone et al., 2020) - (Ghisellini et al., 2016) - (Corona et al., 2019)
A systems solution framework that tackles global challenges like climate change, biodiversity loss, waste, and pollution. It is based on three principles, driven by design: eliminate waste and pollution, circulate products and materials (at their highest value), and regenerate nature	- (Ellen-MacArthur-Foundation, 2021) - (Heshmati, 2016) - (Schroeder et al., 2019) - (Bonviu, 2014)
An economic system in which production and consumption are based on the reusability of products and their parts, the recyclability of materials and the sustainable extraction of any other resources required. This assumes the recovering ability of natural resources, minimising value destruction and	- (Potting & Hanemaaijer, 2018) - Supported by the Dutch Government by PBL Netherlands Environmental Assessment Agency

optimum value creation in every link of the production and consumption chain.	
Circular Economy is a sustainable development initiative with the objective of reducing the societal production-consumption systems' linear material and energy throughput flows by applying materials cycles, renewable and cascade-type energy flows to the linear system.	- (Korhonen et al., 2018) - (Ellen-MacArthur-Foundation, 2021)
An economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations	- (Kirchherr et al., 2017) - (Hobson, 2016) - (Ellen-MacArthur-Foundation, 2021)
The set of activities designed to not only ensure economic, environmental and social sustainability in agriculture through practices that pursue the efficient, effective use of resources in all phases of the value chain, but also guarantee the regeneration of and biodiversity in agro-ecosystems and the surrounding ecosystems	- (Velasco-Muñoz et al., 2021) - (Hobson, 2016) - (Jurgilevich et al., 2016)
A regenerative system in which resource input and waste, emission, and energy leakage are minimised by slowing, closing, and narrowing material and energy loops. This can be achieved through long-lasting design, maintenance, repair, reuse, remanufacturing, refurbishing, and recycling	- (Geissdoerfer et al., 2017) - (Geissdoerfer et al., 2020)

Table 2 CE Definitions Found in Literature

Kirchherr et al. (2017) argued that the CE concept has not reached a mainstream consensus yet. This can also be interpreted from Table 2 where the most prevalent definitions are mentioned and the authors that argue for them or use them in their research are indicated in the right column. Utilizing Table 2, three main theoretical approaches can be identified: i) minimizing inputs of raw materials and outputs of waste ii) keeping resource value as long as possible within the system, and iii) reintegrating products into the system when they reach the end-of-life (Suárez-Eiroa et al., 2019).

In line with RQ1, the different definitions for CE in agriculture were extracted and compared with each other. Following Kirchherr et al. (2017) of CE not reaching a mainstream consensus, this paper identified the most commonly recognized definition as the one provided Velasco-Muñoz et al. (2021) which is considerably similar to the one provided by the Ellen McArthur Foundation in terms of the elements that the definition includes. This definition is as follows:

The set of activities designed to ensure economic, environmental and social sustainability in agriculture through practices that pursue the efficient, effective use of resources in all phases of the value chain while guaranteeing the regeneration and biodiversity in agro-ecosystems and the surrounding ecosystems (Velasco-Muñoz et al., 2021).

In their research Velasco-Muñoz et al. (2021) further identified the main three principles of CE and proceeded to evaluate their application in an agricultural production system. They concluded that the most relevant principles correspond to the ones proposed by Prieto-Sandoval et al. (2018) in combination with the research conducted by the Ellen MacArthur Foundation in 2015. In their research they selected each of the principles and made a link to agriculture. These principles are: 1) design out waste and pollution, 2) keeping products and materials in use and 3) regenerating natural systems.

Figure 8 shows how the CE definition has been adapted to the CE applied for the agricultural sector

CE in supply chain research		CE in agricultural supply chain
Minimizing inputs of raw materials and outputs of waste	→	Design out waste and pollution
Keeping resource value as long as possible within the system	→	Keeping products and materials in use
Integrating products into the system when they reach the end-of-life	→	Regenerating natural systems

Figure 8 Relationship between generalized CE and CE in an agricultural supply chain

By adapting these principles to agriculture Velasco-Muñoz et al. (2021) provides a circular model for agriculture that allows to pursue system-wide efficiency and the elimination of unwanted externalities. These systems should be able to maximize the value of the resources at all stages of the supply chain while enhancing natural capital through the use of renewable resources. This adaptation continues to go hand-in-hand with the proposed theoretical approaches that researches have defined for CE in supply chain management.

4.2 CE assessments in agricultural production systems

The assessments in these articles have importance regarding the methodologies that each of them uses as well as the justification for their chosen scenario. Nevertheless, the following section focuses on the fact that the reviewed papers follow an assessment methodology.

Using the conceptual framework for sustainability adoption that was previously presented, the papers that fall under the "assessment of CE for a specific scenario" category can be located in Stage 2. Stage 2 in the framework is related to the perceived characteristics of sustainability that lead the its use (So et al., 2012). If the assumption is made that there is a societal interest in changing from a linear economy to a circular economy and such transition is deemed as an innovation, then it can be argued that the transition to a CE agricultural production system is in Stage 2: Persuasion. In their research So et al. (2012) claim that resistance to change in sustainability implementation can be reduced by having information transparency. By having the majority of the articles fall into Stage 2, it being characterized for conducting an assessment on a practical case of CE, it can be implied that practices are being put into place and their effectiveness is being measured.

By using the framework showed in Figure 9, it is possible to hypothesis the current stage where CE currently is in the adoption process within supply chains. This hypothesis, if correct, can help researchers and further interested parties to continue moving forward in the innovation-decision process. Following this logic, this paper argues that CE for agricultural supply chains is in Stage 2 since current research focuses on a trial basis and conclude if the practices are viable or not. Even if the majority of the papers can be placed in Stage 2, the papers falling under the "Indicators" category can be assigned to Stage 3, where theory is put into practice and new production practices are being adopted.

4.3 Application of circular economy indicators in the agricultural sector

Velasco-Muñoz et al. (2021) in their research adjusted the general CE framework to the agricultural sector's specifics. Likewise, Rukundo et al. (2021) published a similar paper where they developed a holistic approach for designing indicators to asses a micro production system in agriculture. Both studies were published the same year. They were later followed by the publication of Batlles-delaFuente et al. (2022) that, through a systematic literature review, assessed the current literature body concerning CE research's timeline. The three studies confirmed the same hypothesis that the CE framework had not yet been comprehensively adapted to the field of agriculture. Yet, only the paper of Velasco-Muñoz et al. (2021), actually reviewed each of the indicators present in the CE general framework and adapted them to an agricultural setting. While their papers can be considered the most recent research matching the criteria chosen for this study, they did not look into the academic validity that each indicator has received from other authors. This gap is addressed by Table 5 where a recompilation of indicators identified by the study of Velasco-Muñoz et al. (2021) combined with the indicators further found from selected group of papers for this study.

	Indicator	Definition	Supporting Authors
1	Circular carbon element within the system	Based on the carbon emissions and the carbon fixation per land used	(Lim et al., 2019)
2	Energy index	Energy used to make products or services; expressed as the solar joules per joule	(Liu et al., 2018)
3	Return on investment	Profit from the investment made	(Matrapazi & Zabaniotou, 2020)
4	Pay-out time	Time required to recover an initial investment	(Matrapazi & Zabaniotou, 2020)
5	Indicator of circular economy efficiency for the bio-fertilizer	Percentage of bio-fertilizer produced relative to the amount of raw materials used	(Molina-Moreno et al., 2017) (Oishi et al., 2021)
6	Overall greenhouse gas balance	The CO2 equivalents emitted per unit product, and the quantity of unit product present in each step	(Moreno et al., 2020)
7	Net present value	The difference between the present values of cash inflows and outflows over time	(Moreno et al., 2020)
8	Internal rate of return	A discount rate that sets the net present value of all cash flows equal to zero in a discounted cash flow analysis	(Moreno et al., 2020)
9	Effective cation exchange capacity	A soil's capacity to retain and release positive ions	(Mosquera-Losada et al., 2019)
10	Species richness	Species richness of a soil fertilized with bio-waste	(Mosquera-Losada et al., 2019)
11	City circularity	Phosphorous potentially reused or reusable within the boundary of the city	(Papangelou et al., 2020) (Tadesse et al., 2019)
12	Food circularity	Phosphorous potentially reused or reusable in agriculture, both within the city and outside the system boundary	(Papangelou et al., 2020) (Tortorella et al., 2020)
13	Weak circularity	Phosphorous potentially reused or reusable anywhere	(Papangelou et al., 2020)
14	Energy accounting method	Obtained by multiplying all inflows by an environmental cost factor to convert raw resource inflows into corresponding energy values	(Santagata et al., 2020) (Di Maio et al., 2017)
15	Partial nitrogen balance	Difference in farmer-managed N inputs and N outputs	(Tadesse et al., 2019) (Moretti et al., 2020)
16	Performance indicator for circular economy	Based on productivity, energy use, the quantity of inputs, ecological impact and technological levels and socio-economic factors	(Tadesse et al., 2019)

17	Crop – livestock ratio	The relative allocation of nitrogen to crop and livestock compartments	(Tadesse et al., 2019)
18	Nitrogen recycling index	The proportion of total nitrogen that is recycled	(Tadesse et al., 2019) (Aso, 2022) (Moretti et al., 2020)
19	Nitrogen use efficiency	The ratio between the harvested N output and managed N inputs	(Tadesse et al., 2019) (Aso, 2022) (Borchert et al., 2021) (Moretti et al., 2020)
20	Net farm income	Gross margin minus the farm's fixed costs	(Tadesse et al., 2019)
21	Water quality	Amount of pollutants entering waterways	(Zabaniotou et al., 2015) (Mihai & Minea, 2021) (Nika et al., 2020)
22	Land use and land-use changes related to bioenergy feedstock production	Total land area for bioenergy feedstock production compared to total national area, agricultural land, and managed forest land	(Zabaniotou, 2018)
23	Change in unpaid time spent by women and children collecting biomass	Average number of unpaid hours woman and children spend collecting biomass	(Zabaniotou, 2018)
24	Allocation and tenure of land for new bioenergy production	Percentage of land – both total and by land-use type – used for new bioenergy production	(Zabaniotou, 2018)
25	Soil quality	Percentage of land with maintained or improved soil quality relative to total land	(Zabaniotou, 2018) (Mosquera-Losada et al., 2019)
26	Biological diversity in the landscape	Nationally recognized areas of high biodiversity value converted to bioenergy production	(Zabaniotou, 2018)
27	Import dependency	Measure of country's dependence on imported phosphorus (P)	(Zoboli et al., 2016)
28	Avoided carbon emissions for bioenergy systems	Savings from energy substitution by renewable energy, measure in tones of CO2 equivalent	(Zoboli et al., 2016)
29	Emissions to water bodies	Amount of phosphorus emitted in bodies of water	(Zoboli et al., 2016) (Nika et al., 2020) (Tortorella et al., 2020)
30	Consumption fossil-P fertilizers	Total consumption of fossil-P fertilizers	(Zoboli et al., 2016) (Hristova et al., 2021)

Table 3 List of CE Indicators for Agriculture

Table 5 shows which are the indicators that are found the most in the selected literature. First, the majority of the indicators are only supported by the authors that proposed them, which can still be considered valid as they were all presented in peer reviewed journals. From this group two themes that stand out from this table are "Water" and "Nitrogen". This can be observed from indicators number 15, 18 and 19 where each indicator is supported by at least three authors. In this paper when referred to supported it means that the author has explicitly endorsed the indicator formula in their own research. Next, indicators number 21 and 29 make reference to water quality in terms of measuring the pollutants that enter waterways surrounding agricultural production systems. These indicators also show a considerable number of authors that support them, which suggests that water quality and the measurement of nutrient flows exiting the production system holds importance in the selected literature. Lastly, the remaining indicators that hold support from more than one author are number 25 and 30 which focus on soil quality in terms of macro nutrients and phosphorus (P) fertilizers. This shows the importance that academics have shown to the role of soil in a circular supply chain for agricultural production systems.

In section 4 of this paper, it was mentioned how CE indicators can be categorized in a 4-level grouping system, which are: technical, environmental, economic and social. All these categories can be covered by the different identified indicators except the social group, where only indicator number 23 can be assigned. This goes in accordance with the results of Batlles-delaFuente et al. (2022) where they found only 8% representation of social indicators within their CE research. Likewise, Calzolari et al. (2022) results also coincide with this observation as they found that the majority of papers they analyzed (82%) do not consider social indicators in their assessments and/or metrics.

Table 4 shows how the indicators are sorted depending on the CE principle they fall under in relation to their 4-level categorization.

4.3.1 Design waste and pollution principle

Design waste and pollution in this paper was defined as all practices aimed at optimizing the use of resources (Section 4.1). This strategy shares similar models to the one found in a linear production system, which can give an explanation of why it is the principle that contains the majority of indicators. Compared to the other principles, the more documents and indicators related to this dimension can be found in the selected literature. Since traditional indicators related to efficiency are technical, logically this type of indicator is the most common within this dimension. Examples of this are CE efficiency indicator for bio-fertilizer produced relative to the amount of raw materials used (Molina-Moreno et al., 2017), or the nitrogen use efficiency indicators, which is measured as the ratio between the system's N inputs and outputs (Tadesse et al., 2019).

	Technical	Environmental	Economic	Social
Design out waste and pollution	• Nitrogen index • Nitrogen efficiency • Circularity indicators components • Self-sufficiency index • Waste output index • Nitrogen balance • Renewable energy production • Energy index • Crop-livestock ratio • Weak circularity • Food circularity • City circularity	• Land use and land use change related to bioenergy feedstock production • Emissions to water bodies • Avoiding emissions in bioenergy systems • Overall greenhouse gas balance • Carbon balance	• Net farm value • Internal rate of return • Value-based indicator • Return of investment • Pay-out time	• Change in the unpaid time women and children spend collecting biomass • The allocation and tenure of land for new energy production
Keeping products and materials in use	• Resource export index • Food and feed autonomy • Logistics • Efficiency of agricultural food circular economy • Circular carbon element within the system • Indicator of circular economic efficiency for bio-fertilizers • Partial nitrogen balance • Performance indicator for circular agriculture • Import dependency		• Net farm income	
Regenerating natural systems	• Consumption of fossil-p fertilizers	• Soil quality • Effective cation exchange capacity • Biological diversity in the landscape		

Table 4 Classification of indicators based on CE based on grouping proposed by (Åkerman, 2016).

These indicators provide partial information on the circular agricultural supply chain's performance and overall sustainability. While one strategy may control pollutant emissions with high success it can also increase the amount of waste (e.g. decreasing the circularity of the agricultural process). Therefore, other indicators should be prioritized that measure a wider range of aspects to avoid burden-shifting and rebound effects.

4.3.2 Keeping products and materials in use principle

Keeping products and materials in use involves all operations aimed at reusing agricultural materials, but for different applications than what they were originally designed to do. Thus, this strategy follows the resource cascading approach (as mentioned in section 4.1).

The indicators belonging to this principle intend to measure processes that use different agricultural residues for bioenergy production. An example of this is the indicator of nitrogen balance proposed by Fernandez-Mena et al. (2020), where nitrogen is measured by considering the alternative to recycle it. Using these sort of indicators help to contribute to minimize pollution and the recovery of ecosystems (Velasco-Muñoz et al., 2021).

Indicators for recycling are helpful for determining how nutrients are moving through farms as a result of on-farm recycling. When assessing circular models, these indicators' informational capacity is constrained. These statistics do not take into account other factors, such as the usage of electricity or other renewable resources, or how the farm's outputs are used outside of the farm. To get over the farm boundary restriction, Cobo et al. (2018) suggests a different indicator, which is defined as the percentage of component *i* that increases its lifespan by performing a service in the upstream processes. This indicator is used to accurately quantify the entire principle as well as the recovery of nutrients from urban organic waste for application in corn crops, but also to use precise measurements throughout the principle.

Organic waste and sewage from urban origins have proven to be a source of nutrients that can be recycled and used in agriculture (Velasco-Muñoz et al., 2021). These indicators can be used to estimate the potential for utilizing valuable resources that currently provide a management challenge and a health concern, and they are particularly relevant when taking into account the trend of increasing population in metropolitan areas. These indicators' main drawback is their inability to be generalized to other agricultural contexts, such as those with different management techniques, crops, or climatic circumstances. Only three examples—renewable energy production, mixed crop-livestock systems, and the use of urban wastes in agriculture—were found in the evaluated literature, despite the fact that there are many alternatives to the cascade use of biological resources. Indicators related to the production of materials for other sectors, such as construction, compostable materials, or other biomaterials, were not found.

4.3.3 Regenerating natural systems principle

The regenerating natural system principle is related to the actions aimed at preserving and enhancing natural capital. Only 4 indicators were found in the papers reviews that are related to regenerating practices.

The soil quality indicators measures the soil's quality through its capacity to retain and release positive ions given its content in clays and organic matter (Mosquera-Losada et al., 2019). The species richness indicator uses similar calculations such as the cation-exchange capacity. These indicators must be calculated using primary data, which could be a drawback. These indicators also have a narrow emphasis since they provide only fragmentary data, and leave out important characteristics like the availability or condition of water resources and air quality. In their study, Zabaniotou (2018) includes an indicator to measure biodiversity (biological diversity) which also falls under the environmental category with the soil quality indicator. This biological diversity indicator measures the biodiversity value converted to bioenergy production. The biodiversity index differs principally in its reliance on secondary data, whereas the soil quality indicator depends on primary information for calculation. Because the soil indicator is used to compare different practices, it is more suitable in transitory situations. The biodiversity indicator is based on national protection information, which is highly generic (Mosquera-Losada et al., 2019; Zabaniotou et al., 2015; Zoboli et al., 2016).

It is important to mention that it is a trend within the papers analyzed not include social indicators or to conclude that there is a lack of available social indicators. Different authors argue that the social dimension of CE is virtually inexistent. Nevertheless, Padilla-Rivera et al. (2021) through the research formulated social circular indicators in relation to their relevance to increase sustainability. In their research they validated twelve social indicators that can be applied to CE.

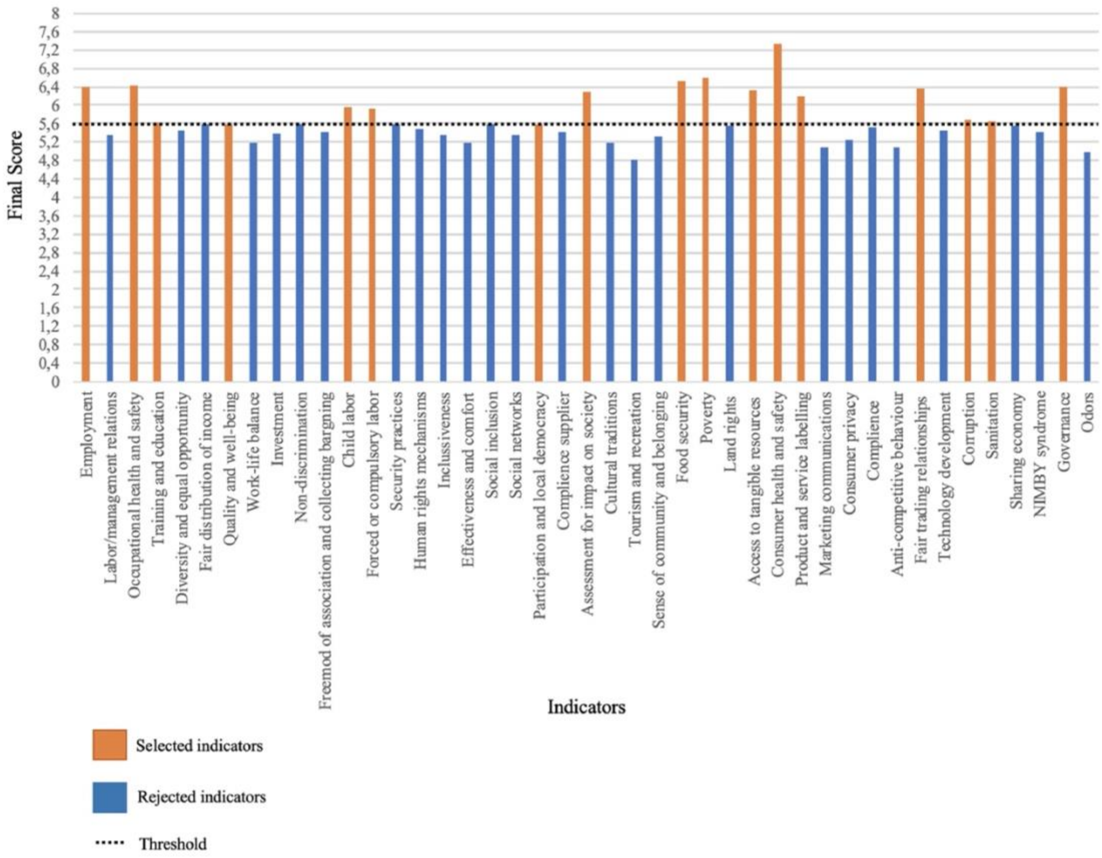


Figure 9 Selected indicators for social circular economy based on (Padilla-Rivera et al., 2021)

Instead of arguing that there are no available indicators researchers should proceed and test the ones identified by Padilla-Rivera et al. (2021) in an agricultural context. This way research can continue to move forward which will eventually achieve a commonly accepted set of CE indicators for an agricultural production system.

4.4 Nutrient uptake and/or recovery

Part of CE in the agricultural context is to keep products and materials in use. In this context research was conducted on how to keep the different nutrients cycles within a production system. From the academic articles being analyzed, 13 of them have a scope concerning nutrient allocation, alternative sources of nutrients, uses of composting techniques in different contexts, extraction and recovery of nutrients, anaerobic digestions systems, etc. There is great importance on researching and measuring the different alternatives to nutrients uptake and recovery since today's mainstream agriculture depends heavily on synthetic fertilizers in order to feed our world's growing population. Additionally, the usage of fertilizers in modern agricultural practices is frequently wasteful. They endanger human health and cause irreparable damage to the environment when they enter soil and water systems. Both directly and indirectly, these issues raise health concerns. Harmful substances like nitrogen and phosphates, both of which have a severe impact on the quality of the air and water, are also present in artificial fertilizers. Because of this, ammonia is released, nitrogen runs off, and eutrophication occur, all of which are harmful to the ecosystem (Rodriguez et al., 2004; Tadesse et al., 2019).

An argument of why the second group with the most literature is “Nutrients uptake/and or recovery” can be due to the severity of improper fertilizer management and their unquestionable importance in an agricultural production system (Hossain et al., 2022). Researchers can greatly influence agricultural producers by testing and validating techniques and indicators which will provide them with alternatives that stay within the planetary boundaries. All 13 articles of this category study alternatives to artificial fertilizers. These alternatives range from bio-waste from urban sewage, nitrogen allocation from crops and livestock, compost and anaerobic digestion, mushroom waste, composting, pig farming waste and seaweed. From the 13 articles 6 give focus on nitrogen recovery and allocation, this goes in accordance with the indicators identified in Table 5 where these indicators showed the most supports from authors. This shows the importance of measuring the nutrient uptake and recovery.

The majority of these papers use a case study methodology to collect their data and show their results. These cases vary from pig production cases to geographical specific cases. Furthermore, a number of articles differ in technical level, as some have complex mathematical model and require expertise knowledge and skills to conduct the experiments. Others, on the other hand, use qualitative approaches and methodologies.

5 Conclusions

This research operated a systematic review of the existing literature aiming to understand which methods used so far can measure and assess the circular performance of an agricultural production system and practiced by researchers.

RQ1. Can a general definition of CE for agricultural production system be identified within the literature?

The analysis revels that they are multiple definitions for CE for an agricultural production system. The different definitions for CE in agriculture were extracted and compared with each other. The following definition is selected as it includes the three principles that a circular supply chain must have: (1) design out waste and pollution, (2) keep products and materials in use, and (3) regenerating natural systems.

> *The set of activities designed to ensure economic, environmental and social sustainability in agriculture through practices that pursue the efficient, effective use of resources in all phases of the value chain while guaranteeing the regeneration and biodiversity in agro-ecosystems and the surrounding ecosystems (Velasco-Muñoz et al., 2021).*

It is also argued that the gap on terminology for CE in an agricultural sector has been fulfilled by more than one author, as presented in Table 3. Research should focus on revising the application of CE indicators by testing their reliability and applicability. This will support decision makers to move forward to Stage 3 and continue to incorporate CE practices in their production systems.

RQ2. In what stage of the innovation process is CE for agricultural supply chains research positioned?

Using the conceptual framework, the Innovation-decision Process Towards Adoption of Sustainability in the Supply Chains that was previously presented, the papers that fall under the "assessment of CE for a specific scenario" category can be located in Stage 2. In the framework, this stage is related to the perceived characteristics of sustainability that lead to its use (So et al., 2012). If the assumption is made that there is a societal interest in changing from a linear economy to a circular economy and such transition is deemed as an innovation, then it can be argued that the transition to a CE agricultural production system is in Stage 2: Persuasion.

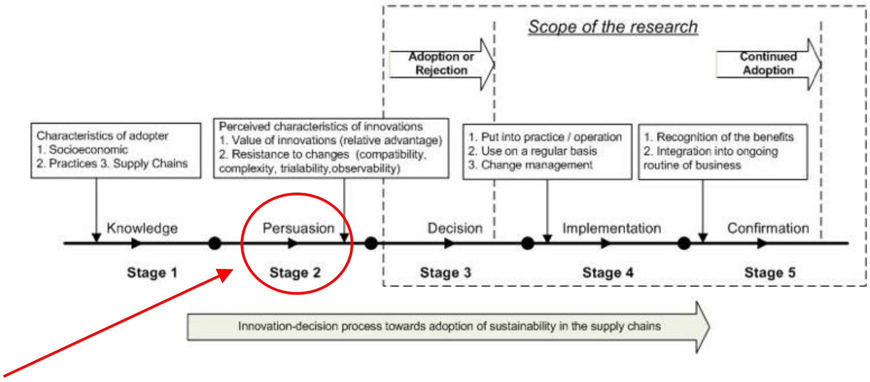


Figure 10 Conceptual Framework for Sustainability Adoption (adapted from So et al., 2012)

RQ3. What are the current CE indicators in the context of the agriculture circularity literature?

A set of 30 indicators were identified from literature which can be found in Table 5. From these, it was found that water and nitrogen related indicators are the most common but also the ones that are validated and supported by more than three authors. Furthermore, the majority of paper making reference to indicators do not include social markers and even conclude that there is a lack of available social markers.

5.1 Limitations and future research directions

While indicators were studied in depth and validated by multiple authors, there is still a question on the practicality of them. Just because multiple researchers have validated their mathematical model it does not automatically translate into practicality on the farm. Therefore, further research should be carried out where the methodology has a practical approach as its main objective. In doing so, validate the applicability and replicability of the findings.

Further testing of a recognized set of indicators must be done in order to create assessments that allow comparison between productive areas, regions, and countries, considering that most available indicators focus on specific processes.

When studying CE in agriculture, a reflection on the variety of activities and processes that occur within the agricultural sector must be considered due to the nature of the products (e.g. perishability). This gains relevance when taking into consideration the CE strategies of closing, narrowing, regenerating, and slowing since agri-food products have particular characteristics that make them unique if compared to other consumer goods.

Agricultural policies must be reviewed and reorganized in order to harmonize the definitions and implications of CE in agriculture. Public and private organizations should promote the creation of commercial and financial cases that show the possible economic benefits connected with the adoption of CE principles. This is especially important if these cases take into account the costs of negative externalities.

Lastly, further research in stage 3 of the innovation decision process is suggested in order to encourage CE general adaptation. Advancing to this stage entails that CE strategies will be put into practice which will create a pivotal moment for the agricultural industry where the strategies will be adopted or rejected. The adoption of these indicators and strategies will help society as a whole as it will promote an economic system that lives and thrives within the planetary boundaries and where CE in agriculture is the norm.

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7 Appendix

Appendix 1. Official statement of original thesis

Official statement of original thesis

By signing this statement, I hereby acknowledge the submitted thesis (hereafter mentioned as "product"), titled:

Circular Economy Indicators for Agricultural Supply Chains: A Systematic Literature Review

to be produced independently by me, without external help.

Wherever I paraphrase or cite literally, a reference to the original source (journal, book,
report, internet, etc.) is given.

By signing this statement, I explicitly declare that I am aware of the fraud sanctions as stated in the Education and Examination Regulations (EERs) of the SBE.

Place: Geldropseweg 139A, Eindhoven, The Netherlands

Date: 21 August 2022

First and last name: Ana Maria Duursma Cortés

Study programme: Msc Global Supply Chain Managment and Change

Course/skill: Final Msc Thesis

ID number: i6273068

Signature:

Appendix 2. Data of PRISMA model application

Please find the excel document in the link below:

Articles SCOPUS and Web of Science 2.0.xlsx