Resources, Conservation & Recycling 176 (2022) 105916

Contents lists available at ScienceDirect

Resources, Conservation & Recycling

journal homepage: www.elsevier.com/locate/resconrec

Full length article

Evaluating the transition to the circular economy in the agri-food sector: Selection of indicators

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ARTICLE INFO

Keywords:
Circular economy
Agri-food
Supply chain
Closed-loop
Multi-level indicators

ABSTRACT

The agri-food sector is one of the key sectors where the action is needed to ensure the transition to a more sustainable development model in line with the principles of the circular economy (CE). The use of indicators to monitor progress and areas for action is a key element in the shift of companies, regions, and countries toward a circular model.

This study aims to create a dashboard that can be used at various spatial levels to guide the agri-food sector toward a CE and sustainable development. Starting with the relevant literature, we identified 102 indicators classified according to three areas of sustainability (environmental, economic and social) and spatial dimensions (macro-meso-micro) within 8 scopes.

The dashboard provides a toolbox for directing decision-making processes and strategies through the targeted use of indicators with respect to the context in which the CE is applied.

In addition, the dashboard allows us to highlight missing aspects related to (1) new indicators not covered by the tool; (2) new scopes not yet explored in the literature; and (3) the need to adopt cross-sectional indicators. For this last aspect, the analysis revealed only 17 such indicators.

A future step is to define the most suitable configurations among the indicators in which CE is generated, starting from the test of the indicators at the micro level to validate their applicability and consider the impacts they may have at the macro or *meso* levels.

1. Introduction

The application of circular economy (CE) principles in the agri-food sector appears to be an important and, above all, necessary change to transform society and face future challenges (European Commission, 2020a). The key to making production systems, communities, and cities more circular (Caputo et al., 2020; Gravagnuolo et al., 2019; Paiho et al., 2020) is the conversion to an economic system focused on saving and recovering resources.

The agri-food value chain has many aspects to invest in to make production more sustainable and circular, and resource recovery is one of the most relevant aspects, where it is possible to act through a *closed-loop supply chain* (CLSC) (Kyriakopoulos et al., 2019) or externally through an exchange of resources between activities considered complementary (e.g., in agriculture or animal husbandry) (Jouan et al., 2020). The exchange between different sectors or production processes follows the logic of industrial symbiosis (Chertow, 2007), allowing the recovery and valorization of agricultural or animal residues to generate energy, fertilizers, and fibers to be shared with other production activities (Abuyuan et al., 1999; Özyurt and Realff, 2001), encouraging the inclusion of more companies in the system and favoring the closing of the loop (Alfaro and Miller, 2014). The recovery of *food waste* is one of the most important elements in which to compete (Alfiero et al., 2019), and it is necessary for the transition of the sector, whose proper management not only leads to a decrease in environmental pressure but also generates an advantage in economic terms (preservation of value) and social terms (job opportunities and empowerment of stakeholders) (Santagata et al., 2020).

The sector also needs innovation in the packaging of products that play a key role in reducing food waste (Chen et al., 2020) and on the consumption side. Here, the proposal of new foods and diets aimed at increasing the sustainability and resilience of systems, understood as the ability of an ecological system to resist and recover from a change of

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https://doi.org/10.1016/j.resconrec.2021.105916
Received 17 April 2021; Received in revised form 3 September 2021; Accepted 5 September 2021

A1- Abbreviations

Abbreviation	
AS	Areas of sustainability
CE	Circular Economy
COM	Cost of manufacture
CLSC	Closed Loop Supply Chain
DEA	Data Envelopment Analysis
ECESP	European Circular Economy Platform
EEIOA	Environmentally Extended Input-Output Analysis
EEIM	Integrated economic-environmental models
EPIs	Environmental Performance Indicator
GHG	Greenhouse Gas Emissions
ICEPS	Italian Circular Economy Stakeholder Platform
LCA	Life Cycle Assessment
LCC	Life Cycle Costing
LCEA	Life Cycle Energy Assessment
MAGNET	Modular Applied GeNeral Equilibrium Modeling Tool
MFA	Material Flow Analysis
MFR	Minimum Feedstock Requirement
MRIO	Multiregional Input-Output
MSP	Minimum Selling Price
NCF	Nutritional cost footprint
NIF	National Indicator Framework
NPV	Net Present Value
PI	Profitability indicator
SDGs	Sustainable Development Goals
SD	Spatial Dimension

A2- Definitions

~	Definition
Scope	Application function of the indicators derived by Cluster
Spatial Dimension	It consider the macro, *meso* and micro levels for the application of CE, with respect to the definition of Kirchherr et al. (2017).
Areas of Sustainability	They are the economic, social or environmental areas in which CE is applied, with respect to the definition of Kirchherr et al. (2017).

state while maintaining a function above a socially acceptable level (Oliver et al., 2015), is increasingly being studied by the scientific community (Lu and Halog, 2020; Zarbà et al., 2020).

However, as in all sectors, change requires a shared and homogeneous way of measuring it (Saidani et al., 2019). This gap is very evident in the agri-food sector, where there is no harmonized system of indicators, and it is necessary to create specific indicators to measure circularity (Aznar-sánchez et al., 2020).

This study, with a review of the literature, aims to identify indicators used in the agri-food sector to measure the circular economy and understand in what spatial dimensions (SD), macro-meso-micro, and areas of sustainability (AS) they are applied, according to the different scopes used. In this view, it is possible to diversify process, product and symbiotic change indicators from more general indicators related to the organization as a whole or to support policy makers. A shared, systemic, and multidimensional measurement method is at the core of the research direction, where the focus is to systematize the indicators with respect to their applications. The final result is to provide a dashboard, which is an operational tool for practitioners to support decision-making processes and strategies through a targeted use of indicators in the different contexts in which the CE is applied. The paper is organized as follows: Section 2 presents the background of the literature on which the authors based their assumptions; Section 3 explains the materials and methods used for the analysis. In the final sections, the data and results are presented and discussed. Some final remarks conclude the paper.

2. Theoretical background

The literature on agri-food proposes different types of indicators aimed at measuring the impacts of the sector in different AS (economic, social, environmental), which includes supply chains (e.g., fruit (Ingrao et al., 2015), the value chain, (e.g., supply chain (Sgarbossa and Russo, 2017; Younis et al., 2020)) and natural resources (e.g., water (Borsato et al., 2019; Lovarelli et al., 2018; Pellegrini et al., 2016)). This fragmentation appears to be in line with the literature on indicators of a CE (Kristensen and Mosgaard, 2020), where a shared way forward has not yet been found, an issue that is also present for the broader measurement of sustainable development (Staszkiewicz, 2019). To solve this gap at a national level, in Italy, the Italian Circular Economy Stakeholder Platform (ICEPS) network, based on the ECESP (the European Circular Economy Platform), has reviewed the methodologies and indicators present and applicable at the international level, also considering the good practices adopted in the country to promote and address the CE (ICESP, 2018). The areas assessed in the literature have as their boundary of analysis specific companies and sectors of the agri-food production of a country. There are residual studies on products and on their supply chains, particularly on packaging stages.

For companies and sectors, studies focus on assessing the adoption of circular practices in terms of investment (Ioannidou et al., 2020; Sgarbossa and Russo, 2017) and the optimization of existing structures (Cobo et al., 2018; Younis et al., 2020) of choices aimed at increasing the eco-efficiency of the value chain (Chaudron et al., 2019; Laso et al., 2018). Further research focuses on the method used by revising existing indicators (Ilija Djekic and Igor Tomasevic, 2018), by proposing new indicators (Vázquez-Rowe et al., 2020), or integrating them (Borsato et al., 2019).

Countries' agri-food production studies rank nations based on energy performance resulting from direct and indirect energy consumption (diesel and electricity) for agricultural practices (Ghisellini et al., 2016) to environmental and socioeconomic impacts of the *food supply chain* (Kucukvar et al., 2019) to drivers put in place for circular transition (Vasa et al., 2018) and possible implications of adopting circular actions (Philippidis et al., 2019). Country-specific works highlight the impacts of national agri-food supply chains on the environment and the economy by proposing recommendations to make the systems circular (Pagotto and Halog, 2016) and analyzing the economic, environmental and social challenges for the sustainable and inclusive transformation of the sector (Priyadarshini and Abhilash, 2020).

For products, a focus is placed on the packaging of agri-food. The main topic is the environmental and economic impacts of the choices made regarding the packaging material (Abejón et al., 2020; Barilla Center for Food and Nutrition, 2010) and format from an eco-design point of view (Del Borghi et al., 2018). However, the proposed LCA methodologies have been criticized for not being suitable for specific products, and some authors have focused on developing an indicator that can be used for different product categories (Šerešová and Kočí, 2020).

The CE is also analyzed in relation to its reference AS: economic, environmental and social. The environmental aspect appears to be the most present, and it is followed by various indicators capable of assessing economic performance and measures marginally social aspects. Regarding the methodologies adopted, in accordance with the above indications, we can assert that economic and environmental indicators reflect quantitative methods, while social aspects are considered through mostly qualitative assessments. Next, we present background information about the three AS within which the CE occurs.

2.1. Areas of sustainability

2.1.1. Environmental

To assess environmental aspects, there are multiple indicators. A review of the use of indicators in the agri-food sector (meat) reports three levels of *EPIs* (*Environmental Performance Indicators*) (Ilija Djekic and Igor Tomasevic, 2018). The first level consists of generic environmental indicators (water consumption, energy, wastewater, production activity-specific indices); the second is based on functional units (e.g., kg/of food) and is derived from the correlation of first-level EPIs, e.g., energy consumed for the production of a single unit (m3 of water/kg of food) (Djekić and Tomašević, 2017); the last provides information on different environmental footprints (ecological, water, carbon, etc.), e.g., (Herva et al., 2011)). These aspects can be calculated by adopting the LCA method (Ilija Djekic and Igor Tomasevic, 2018), which is one of the most widely used methods in the agri-food sector (e.g. Del Borghi et al., 2018; Ingrao et al., 2015; Laso et al., 2018), following a standardized system.

The primary role that resources management has in the CE is reflected in studies related to its use in the agri-food sector, where the energy used is a highly considered aspect followed by water resources. Further aspects of analysis concern waste, negative externalities (e.g., GHG) and models dedicated to their optimization.

Regarding energy, the LCA methodology is the most widely used. In detail, the product assessment (Abejón et al., 2020; Del Borghi et al., 2018; Šerešová and Kočí, 2020), the cumulative energy demand and consumption, Life Cycle Energy Assessment (LCEA) (Ghisellini et al., 2016) MFA (Material Flow Analysis), DEA (Data Envelopment Analysis) and EEIOA (Environmentally Extended Input-Output Analysis) (Kucukvar et al., 2019; Pagotto and Halog, 2016) have been used.

For water resource management, once again LCA is a commonly used method to quantify the resources used and their impacts, especially for packaging (Abejón et al., 2020; Del Borghi et al., 2018; Šerešová and Kočí, 2020), and several studies used the *water footprint* as a more precise method of measurement and comparison (Borsato et al., 2019; Lovarelli et al., 2018; Pellegrini et al., 2016).

Negative externalities are quantified with methods traceable to LCA, capable of quantifying the impacts on global warming, toxicity potential, acidification potential, eutrophication potential (Abejón et al., 2020; Borsato et al., 2019; Del Borghi et al., 2018; Laso et al., 2018), along with MFA (Pagotto and Halog, 2016) and related input-output methods (Kucukvar et al., 2019).

Waste management is key for the CE (Leder et al., 2020), where agri-food waste can be used as energy inputs (Pagotto and Halog, 2016) that are evaluated according to the economic convenience of the choice (Ioannidou et al., 2020; Sgarbossa and Russo, 2017), a convenience that is also reflected in food waste generated by an inefficient system (Vázquez-Rowe et al., 2020). These systems (e.g., *supply chains*) are optimized through models proposed in the literature (Cobo et al., 2018; Younis et al., 2020).

2.1.2. Economic

Considering economic aspects, studies have focused on specific indicators proposed to assess the adoption of circular practices or choices to highlight the economic benefits derived from them.

This area includes indicators related to profit and productivity performance, profitability indicator (PI), and investment by highlighting the relationship between profitability and the amount of waste treated, a crucial point for success (see, e.g., Sgarbossa and Russo, 2017; Vasa et al., 2018). Other authors have used several economic indicators (e.g., the net present value (NPV), minimum selling price (MSP), cost of manufacture (COM), minimum feedstock requirement (MFR), and payback period) to evaluate the implementation of biorefineries fed by agro-industrial waste (Ioannidou et al., 2020).

Considering the value chain of an agri-food sector, studies have used life cycle costing (LCC) combined with a value-added assessment to evaluate its eco-efficiency (Laso et al., 2018), while focusing on the issue of food waste along the supply chain. Other authors, to assess both the economic and nutritional efficiency of these sectors, have defined a new indicator, the nutritional cost footprint (NCF) (Vázquez-Rowe et al., 2020). To make value chains more efficient, models have been proposed in the literature that can optimize performance from a circular perspective (e.g., CLSC) (Younis et al., 2020).

2.1.3. Social

Regarding social aspects, the proposed indicators are few and mostly related to qualitative analyses that take as reference human well-being (Ioannidou et al., 2020), worker conditions (see for e.g. Dammert et al., 2018), participation and social inclusion (Santagata et al., 2017; Segneanu et al., 2018), the willing-to-pay approach (Benoît Norris et al., 2020), or customer satisfaction (Younis et al., 2020) or try to adopt more structured metrics such as sustainable development goals (SDGs) (Priyadarshini and Abhilash, 2020).

Using the (Global) Multiregional Input-Output (MRIO) model of Kucukvar et al. (2019), we identified the impact of sustainable choices (e.g., compensation adapted to workers' skills) in the agri-food supply chain. Using the same approach, other authors (Dammert et al., 2018; Simas et al., 2014) analyzed the "bad labor" footprint agri-food sector in the most underdeveloped countries. Instead, we consider a possible reduction in food waste in Europe. A study using the *Modular Applied GeNeral Equilibrium Modeling Tool* (MAGNET) demonstrated the socio-economic and environmental implications of such choices (Philippidis et al., 2019). The social impacts linked to the adoption of circular practices (e.g., CLSC) in a company, on the other hand, are more difficult to quantify, which is why some authors have qualitatively assessed the results (Sgarbossa and Russo, 2017).

Participation and social inclusion appear to be key factors to be considered for sustainable change in the sector, and this evidence is little addressed in the literature (Borrello et al., 2017; Iacovidou et al., 2017).

The figure of the consumer appears to be poorly investigated in the literature on the CE of the agri-food (e.g., (Younis et al., 2020). Consumer satisfaction is taken as a reference, and it is also found in more generic CE studies (Rosa et al., 2019).

The *National Indicator Framework* (NIF) uses a more systematic and agreed-upon methodology based on the SDGs (Priyadarshini and Abhilash, 2020).

This plethora of indicators and methodologies still makes the literature very fragmented. Therefore, the research focus is to systematize the indicators with respect to the different contexts of their application, which is the aim of the next sections of the paper (Table. 1).

3. Methodology

The desk-based research design consists of six main stages (Fig. 1). These steps were taken to identify indicators used in the agribusiness literature to quantify circular and sustainability practices (Table A in Supporting Information Appendix 1). After a comprehensive analysis of the main databases (Scopus, Web of Science, and search engines GoogleBooks and Scholar), the authors chose to focus the analysis on the Scopus database. The Scopus database was consulted on 31 July 2020.

In the first step, a TITLE-ABS-KEY query "circular economy" and "agri-food" and "indicator" was used, yielding only 5 document results. The lack of representativeness of literature on this subject led us to make a second query ALL "circular economy" AND "agri-food" AND "indicator", which allowed us to identify 234 document results. After deletion of duplicates between the first and second queries, selection based on title and abstract led us to a restricted set of 45 articles, which became 16 after selection based on full-text analysis. Finally, to improve the robustness of our research, we also analyzed specialized reports and articles, such as the ICESP reports (reconnaissance of measurement initiatives (ICESP, 2018), the new Circular Economy Action Plan (European Commission, 2015), Resource Efficiency Scoreboard (European

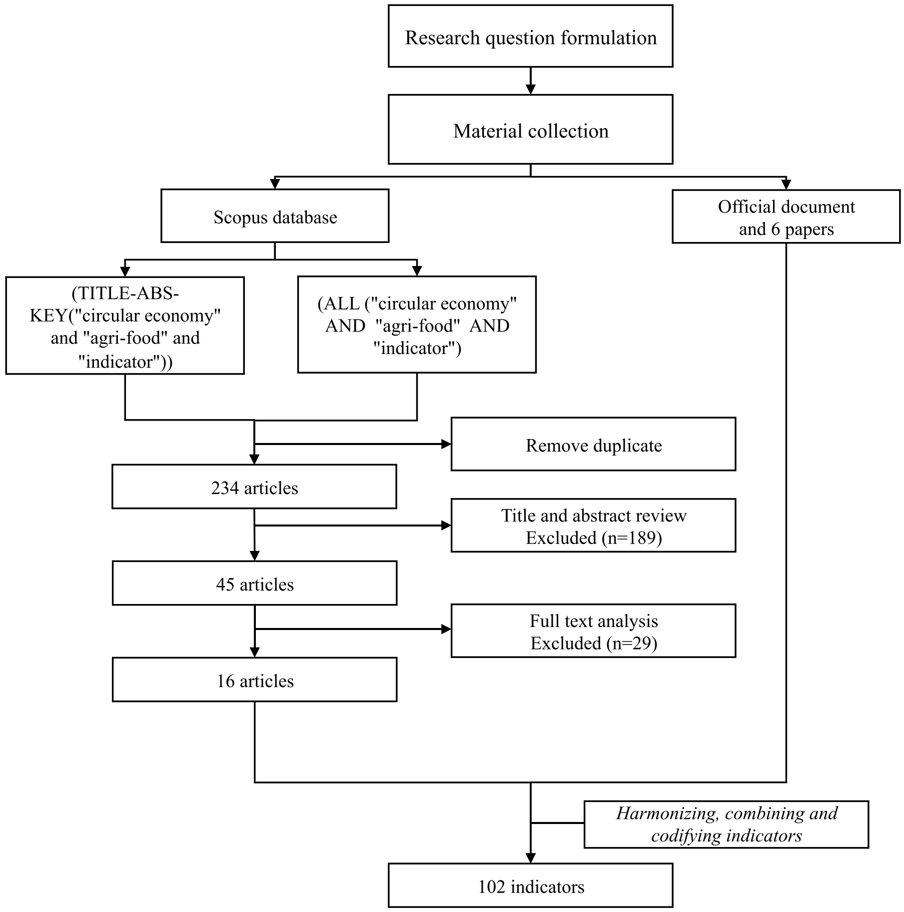

Fig. 1. Overview of research. Source: Author's elaboration.

Commission, 2016), global indicator framework for Sustainable Development Goals (UNSD, 2020) and 6 scientific articles (in particular systematic review) (Borrello et al., 2017; Dammert et al., 2018; Iacovidou et al., 2017; Santagata et al., 2017; Segneanu et al., 2018; Simas et al., 2014), which were considered interesting for the aim of the paper. The results allowed us to identify 8 scopes and 102 indicators to evaluate CE in the agri-food sector on multiple levels (SD and AS). The classification of the indicators was achieved through an iterative approach.

To enable reproducibility and reliability of the classification (Neuendorf, 2016; Wester and Peters, 2000), each author independently classified the indicators and then discussed the results to arrive at a common and shared result. To do this, a classification process is followed that considers three keys aspects to encode an indicator: the scope, the spatial dimension (SD), and the Areas of sustainability (AS).

For scope refers to the context within which the indicator is applied. To associate the indicator with the scope, the authors consider the use of it in the literature, the nature of the indicator, the unit of measure and its field of application.

The classification for SD takes up the definition adopted by Kirchherr et al. (2017), which considers the macro-meso-micro level, with respect to the three AS, economic, environmental and social, introduced in the theoretical background. In this definition the CE is seen as an *"economic system that replaces the concept of "end of life" with the reduction, reuse, recycling and recovery of materials in the 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 of achieving sustainable development, simultaneously creating environmental quality, economic prosperity and social equity, for the benefit of current generations and future. It is empowered by new business models and responsible consumers."* (Kirchherr et al., 2017)

The focus on the agri-food sector is justified by the importance of this industry in the transition to the CE, and at the European level, agri-food is considered a strategic sector for intervention (European Commission, 2020b, 2020a). The paper uses a value chain approach and a market perspective, which involves the use of indicators applied along the entire agri-food chain. This allows us to broaden the research perspective to all actors and not to focus the analysis only on a particular context of agri-food.

There are several studies in the literature that classify indicators for measuring the CE according to both the various levels of the SD (e.g., De Pascale et al., 2021) and the economic, social, and environmental dimensions (e.g., Corona et al., 2019). This study aims to extend these analyses to fill the gap. Specifically, the aim is therefore to create a dashboard of indicators that can be used on the various spatial levels to guide the agri-food sector toward a CE and sustainable development.

4. Agrifood indicators for CE

4.1. Overview of indicators for each scope

The extraction of the 118 indicators was made based on two main conditions: the presence of a measurable indicator and its application for the CE in the agri-food sector. These indicators have been systematically analysed to produce a harmonized list that is addressing the commonalities between indicators, combining and codifying them as reported in the methodology. As a result, we obtain 102 indicators, grouped in the following scopes: Air; Water; Soil; Energy; Waste; Cost, Value and Productivity; Equality; Knowledge and Innovation. The Scopes are a function of the applicative nature of each indicator, i.e., they relate to the context to which they are linked or applied (by way of example only, the Green Water footprint indicator has been associated with the Water Scope). The next analysis concerned the classification of indicators by SD (macro-meso-micro) and AS (economic, social, environmental) based on the definition of Kirchherr et al. (2017). Finally, Table A (in Supporting Information Appendix 1) summarizes all information, combining Scopes, SD, and AS, and assigns a numerical code to each indicator.

4.1.1. Air scope

In the “Air” scope we include the indicators used in agri-food for the CE that have an effect on climate change and the risks associated with human health.

Indicators with a more general connotation are included, such as Global Warming Potential (GWP), Agriculture total emission or Ozone layer depletion potential. Plus, more specific ones such as photochemical oxidant, particulate matter formation, or indicators that express the potential harm of the chemicals released into the environment.

The management of these indicators in Agri-food makes it possible to compare the opportunities for reducing emissions between the SD and the connected AS (Table. 2).

4.1.2. Water scope. Along with the other Scopes, CE can contribute to reaching the UN Sustainable Development Goals, reducing water contamination, toxicity and preservation.

For this reason, the "Water" Scope allows to identify a series of indicators, such as green, blue or gray water footprint to consider the human impacts on freshwater systems, considering a production for single product or the entire supply chains (Hoekstra et al., 2011). Therefore, the proportion of water used for agri-food practices and water used in the total system (nation, company) allows a quantification of the water load of agri-food production on the ecosystem.

In this scope, the focus of the indicators shifts also to water resources. These allow us to quantify the use of the resource throughout the life cycle and its potential pollution due to the production of food. It, therefore, allows us to understand how much water is used in that given process or product and highlight how the resource can be sustainably managed throughout the life cycle. Quantifying the pollution related to the agri-food sector can direct the sector toward the choice of less polluting and more circular practices (Table. 3).

4.1.3. Soil scope. Considering the “Soil” Scope, instead, the focus shifts to how it is managed. In the agri-food literature, the need to improve resource efficiency and sustainability of agricultural production by adopting CE practices is emphasized e.g. Velasco-Muñoz et al., 2021) attributing the responsibility for soil contamination due an inappropriate use of pesticides, fertilizers or herbicides (Aznar-Sánchez et al., 2019).

The scope contains measurement indicators, related to organic production and biodiversity, to the use of fertilizers and pesticides or organic materials. In general, it can guide to quantify the load of pollutants in the soil and identify the potential impact on the ecosystem, within CE perspective (Table. 4).

4.1.4. Energy scope. The "Energy" scope collects the indicators used within the CE to quantify the use of energy and energy performance.

These indicators provide an overview of the use of energy in the agri-food sector or for single production and identify the factors that influence its performance.

They also enable to quantify the load that agricultural practices have on the wider system (nation, company, production process). Otherwise, to measure the proportion between the energy used for agri-food (sector, production efficiency) and the energy used by the total system (Nation, company). Additionally, these indicators allow us to quantify the impact of sustainable energy production on the total production / use of energy from nonrenewable sources, thus permitting to measure the effective sustainability of the source and its load on the ecosystem.

Their use in an integrated approach allows the agri-food sector to be oriented toward circularity, considering the complexity that characterizes its production (Table. 5).

4.1.5. Waste scope. The EU Directive 2008/98 / EC and the subsequent amendment with Directive (EU) 2018/851 define the types of waste, in its declinations, and the exclusions of specific areas. Waste is one of the cornerstones around which the principles of the circular economy revolve, but within the agri-food sector it assumes completely different management, compared to other areas such as the production of technical materials (Velasco-Muñoz et al., 2021). In the "waste" scope we consider indicators capable of representing the critical issues relating to food waste, reconstructing flow throughout the life cycle, and expressing its economic and nutritional value. Their use in the agri-food sector can be useful in understanding how the waste is managed on the food chain, its impact and its social importance. Quantifying these aspects can help build a more sustainable and inclusive value chain (Table. 6).

4.1.6. Cost, value, and productivity scope. In this section are grouped the indicators that quantifying the cost of production, the economic value generated and result indicators. In the literature, the potentiality of the circular economy is emphasized for concurrent economic value creation and sustainable development (Ranta et al., 2018) on a global scale among businesses (MacArthur, 2013) and policymakers (European Commission, 2015).

In the agri-food sector, knowing aspects related to the quantity, the production costs and the life cycle enables addressing the most advantageous choices from an economic or sustainable perspective, because of the different possible alternatives. Having a picture of the economic dimension, the costs and generated value, allows us to define the productivity of the sector and its efficiency over time. This also allows to view the sustainability of production from the environmental, economic and social perspective and consequently also the indirect repercussions (e.g. on employment). In general, these indicators make it possible to direct the sector toward circularity by measuring the cost-effectiveness of adopting sustainable practices (Table. 7).

4.1.7. Equality. Within the “Equality” scope are grouped the indicators that foster social inclusiveness. In literature, the S-LCA guidelines certainly represent a reference point for increased knowledge and to provide a representation of the product life cycles from a social perspective (Benoît Norris et al., 2020).

In this scope, for the agri-food sector, a series of indicators related to the healthy, safe and sufficient food to meet the needs of all people have been grouped. We consider social inclusion, child labor as well as the equitable distribution of wealth and poverty. These are purely qualitative indicators, with a few quantitative exceptions, that make it possible to evaluate and orient production toward social sustainability, promoting actions aimed at inclusion, security, and respect for human rights. Knowledge of these aspects is necessary to ensure sustainable development and a circular approach in the sector (Table. 8).

4.1.8. Knowledge and innovation scope. The “Knowledge and innovation” scope refers to indicators that allow us to quantify the development of the sector in terms of people training, knowledge and innovation. Investment in new technologies and in Research and Development make the agri-food sector more competitive, productive, and more efficient from an environmental point of view. In the literature, technology is associated with the agri-food system as an inseparable element and involves the use of new drivers for the innovation of the CE (Miranda et al., 2021). Managing these indicators according to the principles of CE will contribute to promote new practices and the adoption of new circular business models (Table. 9).

4.2. Agri-food indicators for the spatial dimensions of sustainability

In the literature, the topic of measuring the CE is under development. Several studies have been carried out at different levels, and many have focused on the micro level (Elia et al., 2017; Kristensen and Mosgaard, 2020; Rossi et al., 2020; Vinante et al., 2021), with others on the micro and macro levels (Moraga et al., 2019), and still others considered only *meso* and macro levels (Harris et al., 2021) and some at all SD (De Pascale et al., 2021). The issue is less discussed in the agri-food sector, where despite the presence of several studies on the CE, there is no specific reference literature for its measurement. Therefore, articles assessing circularity and sustainability performance in the sector were analyzed to create a baseline. The indicators grouped into 8 scopes collecting methods and measures to assess the CE in agri-food. This is in line with the literature on the CE, where several authors have highlighted this issue (De Pascale et al., 2021; Saidani et al., 2019).

The analysis then focused on classifying the indicators that emerged according to the SD (Table A in Supporting Information Appendix 1). Most of the indicators identified can be used at the macro level (69), followed by the micro level (63) and then the *meso* level (23). Only 17 indicators can be used for all three levels.

4.2.1. Macro level. At the macro level, the indicators make it possible to assess various aspects linked to the agri-food production of a country, a region, or a city. Of these 69 indicators, 13 are linked to the ability to assess the load on the ecological system (Indicators: 11;12; 25;26;37–41;45;62–64), 19 indicators are linked to the impact of human activities on the ecosystem and the economy (Indicators: 15;16;27–29;33; 35;51;57;65–68;82;88–90;94–95), 20 indicators are used to measure the sector's impact on sustainable development (Indicators: 17–19;24;30–32;34;52;58;81;83–85;97–102), and 17 indicators assess the impact along the life cycle (Indicators: 5;13;14;46–50;;56;61;79;80;86;87;92;93;96). At this level, there are several indicators for monitoring sustainable development. It denotes an increased focus on monitoring and guiding the sector and/or countries toward sustainable development. In fact, at the macro level, the indicators are distributed almost evenly across the 8 scopes (except for Air scope). There is almost exclusive use of the indicators in the Environment Area for the Air, Water, Soil, Energy and Waste scopes. For the Equality and Knowledge and Innovation scopes the indicators have an economic and social nature. Cost, Value, and Productivity scope has a homogeneous distribution among the three Areas. There are a variety of Life Cycle based indicators, mostly related to mapping the flow of products and resources. The productivity of resources and the efficiency of production processes are key aspects of the sector's transition. A pivotal point is human resources, where investment in training and research and development can drive the whole sector. Human health is another key point, which is achieved through product safety and social inclusion.

4.2.2. Meso level. At the *meso* level, indicators allow various aspects of production in an eco-industrial park to be measured. Of the 23 proposed indicators, 5 fall within the ecosystem weight assessment (Indicators: 27;69–71;94), 2 indicators are measurement and sustainable development indicators (Indicators: 19;52), and 16 are life cycle-based indicators (Indicators: 5;13;46–50;56;61;79;80;86;91–93;96). For the *meso* level, there are fewer indicators, in line with the literature on the CE, which required its development in the assessment of the environmental impacts of this model (Harris et al., 2021). Most indicators fall under Energy, Cost, value and productivity, and Equality. In the first case they concern the use of energy (renewable or non-renewable) and its sharing. In the second case, an economic evaluation of the investment and profitability of such a model can be performed. In the third, there are also indicators that can quantify the social impact of such applications (e.g., job opportunities). Residual indicators quantify the environmental impacts of the system or the impacts that such a system can have and calibrate its operation. By reviewing the product flow, the use of materials and byproducts can be made economically and materially efficient.

4.2.3. Micro level. At the micro level, indicators measure various aspects related to the production of a company or an individual product. Of the 63 indicators, 16 fall within the critical load and critical level indicators (Indicators: 8–11;25;26;37;39–45;63;64) and help the company understand its impact on the ecological system, 13 indicators allow the economic and social assessment of some of its choices (Indicators: 27–29;69–77;94), 3 indicators allow us to understand the contribution that the product/company can make to sustainable development (Indicators: 19;52;81), and 31 indicators allow us to understand how choices and production methods affect the life cycle (Indicators: 1–7;13;14;20–23;36;46–50;53–56;59–61;78–80;93;96). The micro indicators are mostly focused on all scopes, particularly on the use of life cycle-based methodologies that allow a systemic view of the impact of products and companies. Indicators that provide an understanding of how the company or product contributes to the sustainable development of the agri-food sector are scarcely present, in line with the literature on the CE (De Pascale et al., 2021). The load that companies or products have on the ecosystem is conditioned by the production choices and practices adopted, where the use of waste as a resource or the low/-absent use of pesticides and fertilizers can be a turning point toward a CE. The use of an organic production system, renewable resources and sustainable, integrated water management are other key points for the switch. Other key aspects are the assessment of the nutritional values of products and the implementation of sustainable packaging.

The fragmentation of indicators and methodologies does not assist agri-food companies and the industry in general in monitoring circularity, where a fundamental step for change is a shared method and indicators to guide companies toward the CE (Saidani et al., 2019).

5. Discussion and conclusions

The study aimed to create a dashboard that can be used at various spatial levels to guide the agri-food sector toward a CE and sustainable development, starting from the relevant literature. We identified 102 indicators classified into 8 scopes, 3 SD and 3 AS.

The dashboard provides a toolbox for directing decision-making processes and strategies through a targeted use of indicators with respect to the different contexts in which the CE is applied. The mechanism is a double entry table that returns the circular indicators in the agri-food sector at the point of intersection between columns and rows (Fig. 2). The columns of the dashboard contain the SD, macro, *meso* and micro and for each of them the AS, economic, environmental and social, to which they refer. The rows show the scopes referred to the field of application. At this point, the dashboard will provide the different combinations of indicators between the row and column elements that will be selected for analysis.

First, we choose the SD (macro, *meso* or micro) and the related AS (economic, environmental or social). According to a given scope, we obtained the related indicators. Equally, it is possible to start from the scope and to decide the SD and the AS for the extraction of indicators. For example, if we want to act at the country level, which is at the macro scale, considering the environmental area, to stimulate the energy scope, 38–41 and 45–52 can be used. In particular, the Cumulative energy demand (CED) indicator (46) can be used to assess the amount of direct energy (conventional fuels) and indirect energy (fertilizers, pesticides, machinery) needed for the agri-food production of a country along the whole chain (Ghisellini et al., 2016). This will allow the production system to be made more energy-efficient by acting on critical points and on the circularity of resources (E_i represents the CED of each input flow, f_i indicates the flow (input or output) of material or energy that contributes to E_i while c_i is the flow conversion coefficient):

Scope	MACRO Env.	MACRO Ec.	MACRO Soc.	MESO Env.	MESO Ec.	MESO Soc.	MICRO Env.	MICRO Ec.	MICRO Soc.
Air	5			5			1,2,3,4,5, 6,7		
Water	11,12,13, 14,15,16, 17,18,19, 24	16		13			8,9,10, 11,13,14, 19,20,21, 22,23		
Soil	25,26,27, 28,29,30, 31,32,33, 34,35,37			27			25,26,27, 28,29,36, 37		
Energy	38,39,40, 41,45,46 47,48,49, 50,51,52	51		46,47,48, 49,50,52			39,40,41, 42,43,44, 45,46,47, 48,49,50, 52		
Waste	56,57,58, 61			56,61			53,54,55, 56,59,60, 61	53,54,55	
Cost, Value, and Productivity	81,82,83, 84,85	62,63,64, 65,66,67, 68,79,80, 82,86	66,67		69,70,71, 79,80,86		81	63,64,69, 70,71,72, 73,74,75, 76,77,78, 79,80	
Equality			87,88,89, 90,92,93, 94,95,96			91,92,93, 94,96			93,94,96
Knowledge and Innovation		97,98,99, 100,102	98,101, 102						

Fig. 2. – Dashboard for CE in the Agri-food sector. Source: Author's elaboration.

$$CED = \sum^{E_i} = \sum^{f_i} . \, c_i \, . \, i = 1, \; \dots, \; n$$

Moreover, to intervene at the *meso* or micro level, considering the Equality scope to stimulate the social circularity of companies, indicator 94 "employment possibilities" can be taken as a reference, which associates the adoption of CE strategies with the creation of new jobs (Sgarbossa and Russo, 2017). We use the rate of people with new jobs or skills:

$$\frac{Employee\ with\ new\ circular\ jobs\ or\ skills}{Total\ of\ employee}$$

Still at the *meso* or micro level, to evaluate circular investments for the economic closing of the cycle, it is possible to use the profitability indicator (PI) (69), which expresses the ratio between the net present value of the annual cash flow (FK) and the total capital investment (TCI) (*i* indicates the annual interest rate and *k* considers the year of evaluation (Sgarbossa and Russo, 2017)):

$$PI = \frac{\sum_K \frac{F_K}{(1+i)^k}}{TCI}$$

If we want to work at the company level (micro) in the environmental AS to understand which indicators we should use, from a circular perspective, to analyze the potential impacts of waste, indicators ranging from 53 to 56 and 59–61 are recommended. In particular, the indicator Package-to-Product (Ptp) (59) can be used to assess the environmental impact of the packaging of a food product and act from an eco-design perspective to prevent packaging waste (it is an indicator based on the quantity of packaging material and on the product environmental footprint and LCA methodology). It denotes "the ratio of the environmental impacts of the packaging when compared to the packaged product. The higher the PtP ratio, the more significant the environmental impact of the packaging system" (Šerešová and Kočí, 2020):

$$P_tP_{cc}(\%) = \sum^{C} C_{Pa} \Big/ \sum^{C} C_{P_r} \; 100$$

At the same time, from an economic perspective, always at level of Waste in the micro level, the indicators we can use the nutritional cost footprint (NCF) (53) to assess the economic and nutritional impacts of food loss (Vázquez-Rowe et al., 2020). This is composed of the Nutrient Rich Food Index (NRF9.3) and the Economic Food Loss and Waste Index (EFLW) combined through linear programming (N_i^* indicates the nutritional impact value, normalised by the weighting factor a_i, while C_i^* indicates the economic impact, normalised by the weighting factor β_i):

$$NCF_i = \; a_i \frac{NRF9.3i}{NRF9.3} + \; \beta_i \frac{EFLW_i}{EFLW} = \; a_i N_i^* + \beta_i C_i^*$$

The analysis reveals a different context in which there are many indicators and many methodologies that sometimes serve the same function. This evidence is in line with the literature on the CE (De Pascale et al., 2021). These indicators were then classified according to the SD (micro-macro-*meso*). As already mentioned, analyses show that most of the indicators are usable at the macro (69) and micro (63) levels, with the residual at the *meso* (23) level. Only 17 indicators can be used for all three levels.

As seen from the analyses at the country (macro) level, there are numerous indicators that fall homogeneously into the scopes identified. The presence of indicators capable of driving countries toward sustainable development demonstrates the commitment of decision makers in interpreting this development at a territorial level. Innovation, investment in training, social inclusion, and food safety show how the social sphere is an important point in the transition. The productivity and efficiency of production systems drive the conversion process.

The *meso* level is little addressed in terms of the environmental impacts that the application of a symbiosis model or exchanges between sectors can generate. Here, process efficiency is also a key aspect to be assessed. However, indicators should be used to assess the impacts that such solutions may have at a social level, in terms of jobs and security, and at an economic level in terms of profitability.

To assess products and enterprises (micro level), there are indicators that are more in line with life cycle methodologies, which allow a broad and systemic view on impacts. Few indicators point products and companies toward sustainable development. Companies can achieve a CE through innovative and environmentally friendly production techniques. They must act both in the production phase and in the product design and selling phase.

The importance of developing a common reference point for the measurement of the CE is an aspect highlighted by several studies in the literature, where this lack appears to be a barrier to the development (Saidani et al., 2019). Many authors have focused on filling this gap, but to date, there is no shared and recognized system of indicators (Kristensen and Mosgaard, 2020). In the agri-food sector, where the transition to a circular model is a key point of new European policies (European Commission, 2019), this gap is even more evident. This study aims to fill this gap by identifying a possible set of indicators that can be used to measure circularity and sustainability at different levels of application. It is not possible to assess circularity by monitoring individual indicators. This could generate distortions with respect to the observed context. For example, as Haupt and Hellweg (2019) reported: "[..]the energy demand for recycling can increase drastically at very high recycling rates and may offset the environmental gains obtained through the recovery of secondary material". Consequently, we should also consider rebounding effects, and their counterproductive impacts (see for e.g. Hertwich, 2005). Moreover, Haupt and Hellweg (2019) state that the indicators " [..] should assess not only circularity, but also environmental performance since circularity is not necessarily equivalent to environmental sustainability". We consider that CE indicators in the agri-food sector, as highlighted in the literature, are still in an early stage of affirmation. And besides, many sustainability indicators are used to understand the circularity at different levels (macro, *meso*, micro), but there are still few specific indicators to monitor circularity in the agri-food sector. The BS 8001: 2017 (BSI, 2017) and the XP X30–901 (AFNOR, 2018) are the only standards of reference until now (Poponi et al., 2021). The development of the new ISO standard for the Circular

Table 1-
Literature background classified by Areas.

Area	*Description*	*Authors*
Economic	Economic impacts of circular and sustainable practices adoption within a company and in the value chain, whit respect to firm or Sector	(Chaudron et al., 2019; Ioannidou et al., 2020; Laso et al., 2018; Sgarbossa and Russo, 2017; Vázquez-Rowe et al., 2020; Younis et al., 2020)
	Economic impacts of circular and sustainable practices adoption within a national agri-food system	(Kucukvar et al., 2019; Pagotto and Halog, 2016; Priyadarshini and Abhilash, 2020; Vasa et al., 2018)
Environmental	Environmental impacts of circular and sustainable practices adoption within a company and in the value chain, whit respect to firm or Sector	(Borsato et al., 2019; Chaudron et al., 2019; Cobo et al., 2018; Ilija Djekic and Igor Tomasevic, 2018; Ioannidou et al., 2020; Laso et al., 2018; Lovarelli et al., 2018; Pellegrini et al., 2016; Sgarbossa and Russo, 2017; Vázquez-Rowe et al., 2020)
	Environmental impacts of circular and sustainable practices adoption within a national agri-food system	(Ghisellini et al., 2016; Kucukvar et al., 2019; Pagotto and Halog, 2016; Philippidis et al., 2019; Priyadarshini and Abhilash, 2020; Vasa et al., 2018)
	Environmental impacts of circular and sustainable practices adoption within a product	(Abejón et al., 2020; Del Borghi et al., 2018; Šerešová and Kočí, 2020)
Social	Social impacts of circular and sustainable practices adoption within a company and in the value chain, whit respect to firm or Sector	(Ioannidou et al., 2020; Sgarbossa and Russo, 2017; Younis et al., 2020)
	Social impacts of circular and sustainable practices adoption within a national agri-food system	(Dammert et al., 2018; Iacovidou et al., 2017; Kucukvar et al., 2019; Philippidis et al., 2019; Priyadarshini and Abhilash, 2020; Santagata et al., 2020; Segneanu et al., 2018; Simas et al., 2014; Vasa et al., 2018)
	Social impacts of circular and sustainable practices adoption within a product	(Borrello et al., 2017)

Source: Authors' elaboration.

Table 2
Air scope indicators.

Indicator	Description	Authors
Aquatic acidification	Ambient air quality concentrations of oxides of nitrogen and sulfur to potential surface water acid neutralizing capacity (ANC) within a NAAQS framework.	(Borsato et al., 2019) (Ioannidou et al., 2020)
Global warming potential	Cumulative radiative forcing, both direct and indirect effects, over a specified time horizon resulting from the emission of a unit mass of gas related to some reference gas [CO2: (IPCC 1996)].	(Del Borghi et al., 2018) (Laso et al., 2018) (Abejón et al., 2020) (AbejIlija Djekic and Igor Tomasevic, 2018) (Ioannidou et al., 2020)
Photochemical oxidant creation potential	Quantifies the relative abilities of volatile organic compounds (VOCs) to produce ground level ozone	(Abejón et al., 2020) (Ioannidou et al., 2020)
Particulate matter formation	Harmful effect on human health caused by emissions of particulate matter and its precursors (e.g. NOx, SOx, NH3)	(Ioannidou et al., 2020)
Agriculture total Emission	Total emissions from agricultural production	(Vasa et al., 2018)
Ozone layer depletion potential	Ratio of the global loss of ozone (i.e., integrated over latitude, altitude, and time) from that compound at steady state per unit mass emitted relative to the loss of ozone due to emission of unit mass of a reference compound, usually taken as CFC-11 (CFCl3) (Wuebbles, 1983; Fisher et al., 1990; Solomon et al., 1992)	(Abejón et al., 2020) (Ioannidou et al., 2020)
Human toxicity potential	Potential harm of a unit of chemical released into the environment, is based on both the inherent toxicity of a compound and its potential dose	(Del Borghi et al., 2018) (Ioannidou et al., 2020)

Source: Author's elaboration.

Table 3
– Water scope indicators.

Indicator	Description	Authors
Green Water Footprint	Use of rainwater that remains in the roots	(Borsato et al., 2019)
blue water footprint	water that comes from irrigation and is incorporated by the plants	(borsato et al., 2019)
gray water footprint	the volume of water needed to dilute pollutants until water quality standards are restored	(borsato et al., 2019)
Total area Equipped for irrigation	Area with direct access to water supplies	(Vasa et al., 2018)
Water withdrawal by agriculture	Water supply demand from the agri-food sector (irrigation, livestock and aquaculture)	(Vasa et al., 2018)
Water use	Water used as an input by the agri-food sector	(Pagotto and Halog, 2016)
Water scarcity index	Ratio of water consumed to available water	(Del Borghi et al., 2018)
Water exploitation index	Sustainability of the water abstraction process by considering the availability of the water resource	(European Commission, 2016)
Water productivity	Economic value generated by cubic metres of extracted water	(European Commission, 2016)
Level of water stress: freshwater withdrawal as a proportion of available freshwater resources	Ratio of available water resources to withdrawn resources	(UNSD, 2020)
Change in water use efficiency over time	Assessing the degree to which a country's economic growth depends on the use of water resources	(UNSD, 2020)
Degree of integrated water resources management implementation	Degree of implementation of integrated water resources management	(UNSD, 2020)
Eutrophication potential	Increase in aquatic plants due to excessive release of nutrients from fertilization (e.g. nitrogen and phosphorus)	(Laso et al., 2018) (Abejón et al., 2020) (Ilija Djekic and Igor Tomasevic, 2018) (Ioannidou et al., 2020)
Marine eutrophication	Reaction of a marine ecosystem to an excessive availability of a limiting nutrient	(Ioannidou et al., 2020)
Freshwater eutrophication	Excessive growth of aquatic plants or algal blooms, due to high levels of nutrients in freshwater ecosystems such as lakes, reservoirs and rivers	(Borsato et al., 2019) (Ioannidou et al., 2020)
Freshwater ecotoxicity	Heavy metal emissions to the freshwater from the comminution-beneficiation process and phosphorus associated with the water treatment processes resulting from the comminution-beneficiation process	(Del Borghi et al., 2018) (Borsato et al., 2019) (En15804 + A1) (Borsato et al., 2019) (EN15804 + A2)
Conservation of fish genetic resource (in number)	Conservation of the current state to preserve the biodiversity of the aquatic environment	(Priyadarshini and Abhilash, 2020) (Vasa et al., 2018)

Source: Author's elaboration.

Table 4
Soil scope indicators.

Indicator	Description	Authors
Fertilizer consumption	Amount of plant nutrients (nitrogenous, potash, phosphate) used per unit of arable land	(Vasa et al., 2018)
Use of pesticides	Annual agricultural use of total pesticides in active ingredients. The sum of active ingredients is divided by the area of cropland	(Vasa et al., 2018)
Area under organic farming	Land that is cultivated organically	(European Commission, 2016) (Priyadarshini and Abhilash, 2020) (Vasa et al., 2018)
Gross nutrient balance on agricultural land – phosphorus	Degree of presence of the nutrient in the soil, defines the impact of agricultural practices on soil quality	(European Commission, 2016)
Gross nutrient balance on agricultural land – nitrogen	Degree of presence of the nutrient in the soil, defines the impact of agricultural practices on soil quality	(European Commission, 2016)
Proportion of land that is degraded over total land area	Land that suffers a loss of productivity (biological or eonomic)	(UNSD, 2020)
Proportion of degraded land to net sown area	Land that suffers a loss of productivity (biological or eonomic) compared to sown areas	(Priyadarshini and Abhilash, 2020) (Vasa et al., 2018)
Percentage change in the use of nitrogen fertilisers in the coastal states	Variation over time in the use of nitrogen fertilizers in the coastal states	(Priyadarshini and Abhilash, 2020) (Vasa et al., 2018)
Index of common farmland bird species	Alterations in biodiversity and environmental quality due to changes in the population abundance of selected bird species present in specific habitats	European Commission, 2016)
Number of accessions conserved in the base collection (−18 °C) at National Gene Bank	Number of Accession Conserved in the seed Genebanck (−18 °C)	(Priyadarshini and Abhilash, 2020) (Vasa et al., 2018)
Arable land	Land under cultivation	(Vasa et al., 2018)
Acidification potential	Acid deposition of acidifying contaminants on soil, groundwater, surface waters, biological organisms, ecosystems, and substances	(Laso et al., 2018) (Abejón et al., 2020) (Ilija Djekic and Igor Tomasevic, 2018) (Ioannidou et al., 2020)
Average carbon content in the topsoil as% in weight	Soil quality measured by the presence of carbon	(Vasa et al., 2018)

Source: Author's elaboration.

Economy (ISO/WD 59,004) will become the new benchmark, but the technical Committee TC/323 is still working. For this reason, the application of the dashboard should be a reference point for evaluating the transition to the circular economy in the agri-food sector, according to Haupt and Hellweg (2019), who explains that "environmental indicators and targets are needed to ensure that the economy does not only become circular, but also sustainable".

The creation of a baseline in the agri-food sector is extremely necessary for two reasons, the first relating to the absence of studies on these issues and the second concerning the importance that the agri-food sector has in the transition toward the CE. There are several studies in the literature on measuring the CE using indicators, but there is no study that refers exclusively to the agri-food sector, with the only exception of Velasco-Muñoz et al. (2021), who focus on the agricultural sector.

Regarding the level of applicability of the indicators, several studies refer exclusively to the micro level (Kristensen and Mosgaard, 2020;

Table 5
– Energy scope indicators.

Indicator	Description	Authors
Agriculture and forestry energy use as a% of total Energy use	Direct energy used by the agri-food sector on total energy demand	(Vasa et al., 2018)
Agricultural machinery, tractors	Number of agricultural machineries use in the agri-food sector during the reference year	(Vasa et al., 2018)
Bioenergy production as a% of renewable energy	Bioenergy produced for the agri-food sector out of total renewable energy produced	(Vasa et al., 2018)
Wood fuel production	Fuelwood or firewood (in log, brushwood, pellet or chip form) obtained from natural or managed forests or isolated trees. Also included are wood residues used as fuel and in which the original composition of wood is retained. Charcoal and black liquor are excluded	(Vasa et al., 2018)(UNSD, 2018)
Energy selfsufficiency indicator	Capability of the system to produce an amount of energy necessary for its operation	(Sgarbossa and Russo, 2017)
Recovery of energy by using waste	Amount of energy produced by waste recovery	(Sgarbossa and Russo, 2017)
Energy required	Amount of energy needed for waste recovery	(Sgarbossa and Russo, 2017)
Total Energy consumption	Direct energy used	(Vasa et al., 2018) (Kucukvar et al., 2019)
Cumulative Energy Demand indicator	Amount of direct energy (conventional fuels) and indirect energy (fertilizers, pesticides, machinery) needed for the agri-food production	(Ghisellini et al., 2016)
Use of primary energy	Direct energy used	(Abejón et al., 2020) (Ioannidou et al., 2020) (Pagotto and Halog, 2016)
Use of primary renewable energy	Direct use of renewable energy	(Abejón et al., 2020) (Ioannidou et al., 2020)
Use of primary nonrenewable energy	Direct use of non-renewable energy	(Abejón et al., 2020) (Ioannidou et al., 2020)
Nonrenewable energy demand	Demand of energy resources from the non-renewable origin	(Del Borghi et al., 2018)
Energy productivity	Ratio of the amount of economic output that is produced per unit of gross energy available	(European Commission, 2016)
Renewable energy share in the total final energy consumption	Ratio of renewable energy consumption to total energy consumption	(UNSD, 2020)

Source: Author's elaboration.

Table 6
– Waste scope indicators.

Indicator	Description	Authors
Nutritional cost footprint	Economic and environmental impact of wasted food	(Vázquez-Rowe et al., 2020)
Nutrientrich foods score	Ratio of 9 nutrients that should be consumed to 3 nutrients that should be restricted	(Vázquez-Rowe et al., 2020)
Economic FLW indicator	Economic valuation of food that becomes waste	(Vázquez-Rowe et al., 2020)
Waste sent to landfill	The amount of waste from the food industry that is disposed of in landfills	(Pagotto and Halog, 2016)
Food waste	Amount of food that becomes waste	(European Commission, 2015)
Global Food Loss and Waste	Amount of food wasted globally, both at the time of production and harvest and after consumption	(UNSD, 2020)
PackagetoProduct	Ratio of the environmental impacts of packaging to the packaged product	(Šerešová and Kočí, 2020)
Nutrient circularity indicators (carbon, nitrogen and phosphorus)	Amount of component that extends its lifetime by providing a service in upstream processes compared to the amount of that component present in the collected (downstream) waste	(Cobo et al., 2018)
Recycling rates	Amount of recycled waste from the food processing industry	(Pagotto and Halog, 2016)

Source: Author's elaboration.

Rossi et al., 2020; Vinante et al., 2021), while other studies also analyze the macro level without considering the *meso* level (Moraga et al., 2019), while others still consider only the *meso* and macro levels (Harris et al., 2021).

This study aims to broaden these aspects to include other levels of applicability. There are studies in the literature that consider all SD (De Pascale et al., 2021) but that start from a top-down classification by using keywords to guide their research. Our study arrives at the same spatial classification at a later stage, but starting from the opposite direction, with a bottom-up approach.

As in other studies (Harris et al., 2021; Kristensen and Mosgaard, 2020; Rossi et al., 2020; Vinante et al., 2021), this article takes into account not only the scientific literature but also reports and sources from decision makers and businesses. This has allowed us to include some indicators that are fundamental for assessing key aspects. Furthermore, the classifications are addressed to the AS (economic, environmental, social) they focus on (Corona et al., 2019), to the CE category they fall into (De Pascale et al., 2021; Elia et al., 2017), to the CE principles of BS 8001 and to the business model (Rossi et al., 2020), along the value chain (Vinante et al., 2021), according to strategy and purpose (Moraga et al., 2019). This breadth of classifications does not make the application of indicators for the end user straightforward.

Velasco-Muñoz et al. (2021) proposed 4 strategies to adopt circular agricultural models: narrowing strategy, slowing strategy, closing strategy, and regenerating strategy. Following this example of approach, the dashboard is configured for practical and simple classification for immediate applicability by the users to guide development policies and strategies within the CE. In fact, the dashboard represents a generalized tool that is applicable to several other productivity sectors with adaption to a scalable approach. It should be considered that some indicators may have a different degree of applicability within the sector. Therefore, it could be appropriate to adapt to the single context, company reality or single test phases, sector by sector. This is an example of the differences between crop plant-based, animal-based, and horticultural-based products (Prag and Henriksen, 2020). Furthermore, the cross-linked effects resulting from the application of the indicators should be considered. Following the logic of the dashboard, intervening in an SD and on an AS stimulates circular effects, which can also have a cascading effect within further dimensions or areas.

At the same time, the dashboard allows us to highlight missing aspects. The first concerns the indicators within the contexts in which the CE is applied. The empty boxes resulting from the combination of AS and scopes are a clear example of how important it is to extend studies to such contexts. Second, new scopes need to be introduced. From the possibilities noted in the analysis of the literature, certain aspects, such as customer satisfaction (taste and quality, freshness, shelf-time of food products, willingness to pay) or biobased products are missing. This study highlights how the use of indicators can support the development

Table 7
– Cost, value, and productivity scope indicators.

Indicator	Description	Authors
Fertilizers Manufactured value	Economic value of the Fertilizers Manufactured per unit	(Vasa et al., 2018)
Pesticides value	Economic value of the Pesticides per unit	(Vasa et al., 2018)
Organic fertilisers value	Economic value of the Organic fertilisers per unit	(Vasa et al., 2018)
GINI index	Deviation of the distribution of income (or consumption expenditure) in an economy from a equal distribution	(Vasa et al., 2018)
Gross Value Added (GVA) in Agriculture per worker	Measure of labor productivity, net output of the agricultural sector	(Vasa et al., 2018) (Priyadarshini and Abhilash, 2020)
Total labor compensation based on total economic output	Workers' compensation on the total economic output	(Kucukvar et al., 2019)
Total GVA based on total economic output	Value added produced on total economic output	(Kucukvar et al., 2019)
Profitability indicator	Assessing the cost-effectiveness of implementing an innovation for the CE	(Sgarbossa and Russo, 2017)
Total capital investment	Total capital invested in the implementation of an innovation for the CE	(Sgarbossa and Russo, 2017)
Net present value of annual cash flow	Difference between the present value of cash inflows and outflows of an investment for innovation	(Sgarbossa and Russo, 2017) (Ioannidou et al., 2020)
Cost of manufacture	The costs incurred in producing a finished product include the costs of labor, materials and overheads	(Ioannidou et al., 2020)
Fixed capital investment	Capital invested in fixed assets (e.g. plant)	(Ioannidou et al., 2020)
Minimum selling price	Selling price that is not lower than the price incurred to make the product	(Ioannidou et al., 2020)
Payback period	Time needed to recover the cost incurred for the investment	(Ioannidou et al., 2020)
Gross profit	Difference between total revenue from sales and the cost incurred in purchasing materials	(Ioannidou et al., 2020)
Net profit	The profit obtained from an activity net of costs incurred	(Ioannidou et al., 2020)
Value added	Added value obtained from the activity	(Laso et al., 2018)
Production costs	Cost of production	(Pagotto and Halog, 2016)
Total revenue	Revenues generated	(Pagotto and Halog, 2016)
Cereal yield	Yield of cereal products (e.g. rice, maize, barley), is given by the ratio of kg produced to hectares cultivated	(Vasa et al., 2018)
Resource productivity	Economic value generated per kg of raw material consumption	(European Commission, 2016)
Livestock production index	Meat and milk production and dairy products	(Vasa et al., 2018)
Food production index	Food crops that are edible and have nutrients	(Vasa et al., 2018)
Crop production index	Annual agricultural production as a function of a reference period	(Vasa et al., 2018)
Value added to the economy	Added value generated by the agri-food sector	(Pagotto and Halog, 2016)

Source: Author's elaboration.

Table 8
– Equality scope indicators.

Indicator	Description	Authors
Food security	Condition that allows access to healthy, safe and sufficient food to meet the needs of all people	(Santagata et al., 2017; Segneanu et al., 2018)
Poverty	Population living in poverty	(Santagata et al., 2017; Segneanu et al., 2018)
Equal distribution	Equal distribution of food in the population	(Santagata et al., 2017; Segneanu et al., 2018)
Access to food	Ability to make food accessible to the whole population	(Santagata et al., 2017; Segneanu et al., 2018)
Participation and local democracy	Involvement in the adoption of circular practices	(Borrello et al., 2017 Iacovidou et al., 2017)
Social inclusion	Social involvement in the adoption of circular practices	(Borrello et al., 2017 Iacovidou et al., 2017)
Child labor	Exploitation of child labor	(Dammert et al., 2018)
Employment possibilities	Creation of new job opportunities by adopting a circular model, both in terms of new staff and skills	(Sgarbossa and Russo, 2017)
Employment in agriculture (% of total employment);	Percentage ratio of agricultural workers to total workers in a country	(Vasa et al., 2018)
Forced or compulsory labor	Condition in which work is carried out involuntarily for various reasons (e.g. debt bondage, forced child labor)	(Simas et al., 2014)

Source: Author's elaboration.

Table 9
– Knowledge and Innovation scope indicators.

Indicator	Description	Authors
Avaibility of latest technologies	Degree of presence of new technologies	(Vasa et al., 2018)
Capacity for innovation	Degree of firms' capacity to innovate	(Vasa et al., 2018)
Impact of ICTs on new services and products	Degree to which ICTs generates product and service innovations	(Vasa et al., 2018)
Intensity of local competition	Level of competition in the local market	(Vasa et al., 2018)
Extent of staff training	Investment in employee training and development	(Vasa et al., 2018)
Percentage share of expenditure in R&D in agriculture to GVA in agriculture	Ratio of investment in research and development in the agri-food sector to the total added value generated	(Vasa et al., 2018)

Source: Author's elaboration.

of the CE in the agri-food sector and how it is necessary to invest in more precise and shared tools. It can be used as a starting point on which to create new indicators for the CE in the agri-food sector and to understand which aspects should be invested in. Moreover, it can be a tool on which countries and companies can think about their production system and the directions it should take. Finally, there is a clear need for cross-sectional indicators, i.e., applicable to all SD to facilitate their use and interpretation. In fact, the analysis reveals only 17 indicators with transversal characteristics. Having more indicators with these characteristics would make it possible to implement CE strategies that can cover the three SD more easily, generating positive effects in terms of circularity.

The difficulty experienced by companies in the agri-food sector in recognizing the CE and its modeling is also emphasized by Dagevos and de Lauwere (2021). In general, this work allows us to guide interventions on the three SD in relation to specific AS, favoring their application thanks to the use of precise indicators validated by the literature. This means that public policy, as well as entrepreneurial strategies, can easily be oriented toward the use of indicators that facilitate the transition to the CE in the agri-food sector. It is not necessary to apply all the indicators proposed by the dashboard, but it will be important in the future steps of the research to define the most suitable configurations among the indicators in which CE is generated. Therefore, the next phase of the study is to test the indicators at the micro level to validate their applicability and effectiveness on a farm or a group of farms in the agri-food sector. This will allow us to select the most suitable indicators, considering that their application in the micro dimension can have a significant impact at the macro or *meso* level (Table. 1–9).

Credit author statement

S.P.: Conceptualization, Methodology, Investigation, Validation, Writing- Original draft, Writing- Reviewing and Editing. **G.A.**: Conceptualization, Methodology, Investigation, Validation, Writing- Original draft, Writing- Reviewing and Editing. **F.P.**: Conceptualization, Investigation, Data curation, Writing- Original draft, Writing- Reviewing and Editing. **O.M.**: Supervision, Investigation, Validation, Writing- Reviewing and Editing.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Supplementary materials

Supplementary material associated with this article can be found, in the online version, at doi:10.1016/j.resconrec.2021.105916.

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