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A multi-level tool to support the circular economy decision-making process in agri-food entrepreneurship

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Abstract

Purpose – The present study is aimed at developing a multi-level framework for assessing circularity in agri-food industries by providing the user with a step-by-step approach and selecting a customized set of indicators capable of accurately assessing the circular economy (CE) level.

Design/methodology/approach – The framework is composed of four stages. In the first stage, a CE theoretical model based on operations, product and services, culture, organization and ecosystem criteria has been implemented and adapted to the agri-food sector. In the second stage, users are required to collect a set of indicators capable of measuring each criterion. In the third stage, a weight is assigned to each indicator using analytical hierarchy process (AHP). Lastly, a geometric multi-criteria decision-making (MCDM) model, called axial distance-based aggregated measurement (ADAM) model, is used to normalize, assess and aggregate the results and produce final scores for the different alternatives to be ranked based on their final circularity scores.

Findings – The model can be a useful tool to support corporate decisions in the CE, making entrepreneurs aware of their starting level. It indicates the extent to which companies are implementing circular business models across different dimensions and, thus, where they are still lacking.

Originality/value – Beyond the attempts to measure the circularity of corporate performance from a purely environmental perspective, the study adopts a holistic view, considering the complexity and disruption of all the principles of the CE.

Keywords Circular economy, Circular assessment, Agri-food sector, Business model, MCDM method, Circular transition

Paper type Research paper

1. Introduction

There is growing consensus on the need for a gradual transition to a more sustainable economic growth. Global warming, pollution and the rapid absorption of natural resources require swift and immediate action to limit and reverse their impact on the environment. Circular economy (CE), when applied to various business models across a variety of sectors and at different levels, offers a clear solution to addressing these global challenges (United Nations, 2019).

In recent decades, CE has emerged as a prominent topic in both natural science and management literature (Alhawari *et al.*, 2021). The CE concept came to the fore in 2010 thanks to the popular activity of the Ellen MacArthur Foundation (2015), which revived, among others, the most recent cradle-to-cradle approach (McDonough and Braungart, 2002). Since then, CE insights have never stopped going forward. However, since there is no single

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theoretical definition of CE, the originality and scope of new contributions on the subject have not always been clear, often making the concept confusing (Borrello *et al.*, 2020).

Based on several scientific contributions, CE can today be defined as a regenerative system in which resource and waste inputs, emissions and energy losses are minimized by slowing down, closing and narrowing of material and energy loops (Boulding, 1966). Seen as a new business model (), CE reconciles the relationship between economic development and environment protection, which is achieved through seven main actions: long life design, maintenance, repair, reuse, remanufacturing, reconditioning and recycling (Afuah and Tucci, 2003; Zott and Amit, 2010).

A growing interest in CE can be also highlighted in the European Union (EU) policy looking for developing guidelines to support CE organizational strategies on the national level. In 2015, the European Commission launched a Circular Economy Action Plan (European Commission, 2015) to stimulate Europe's transition toward a more CE, to boost global competitiveness and to foster sustainable economic growth. Beginning with a limited focus on waste recycling, CE has steadily shifted to broad efficiency-oriented operations through an increase in the effectiveness of resource allocation, resource utilization and productivity, in a variety of areas, including agri-food (Su *et al.*, 2013).

The implementation of the CE in companies is the subject of several controversies and debates, reflecting the complexities and challenges associated with this approach.

According to Ghisellini *et al.* (2018) the adoption of the CE requires significant changes in the way companies produce, distribute and manage products. This transition can be costly and time-consuming and some enterprises may be hesitant to adopt circular practices due to operational challenges and the large initial investments required (Rizos *et al.*, 2016; De Bernardi *et al.*, 2023). However, different authors demonstrate that the implementation of CE leads to significant savings in resources, supply chain effectiveness, waste reduction and new business opportunities, overcoming any initial costs (Gusmerotti *et al.*, 2019; Asgari and Asgari, 2021; Debnath *et al.*, 2023). Moreover, some studies argue that some kind of products can be difficult to reuse or cost-effectively repair, especially with rapid design and technology changes (Linder and Williander, 2017; Jaeger and Upadhyay, 2020). However, other authors have proved that circular design and product renewal can mitigate these critical issues, creating more durable products that are easy to disassemble and repair (Terzioğlu, 2021; Bocken *et al.*, 2016). Furthermore, although the idea of recycling is central to the CE, the reality is that some materials can be difficult to recycle efficiently and some recycling processes can consume a lot of energy and resources (Coelho *et al.*, 2020). However, technological innovations and investments in research and development are progressively improving recycling efficiency for a wide range of materials (Kuisma *et al.*, 2013; Kumar *et al.*, 2022). Even the combined use of recycling, up-cycling and biodegradation techniques can help reduce waste and improve materials management (Allwood, 2014). A further element of challenge is represented by the cultural change both corporate and individual that the transition to the CE requires (de Morais *et al.*, 2021; Bertassini *et al.*, 2021). This can be difficult to accomplish, as established habits and behaviors can be resistant to change. However, growing awareness of environmental challenges, combined with growing consumer demand for sustainable products and responsible businesses, is driving many businesses to implement circular practices (Tsolakis *et al.*, 2022). Awareness campaigns and educational programs can play a significant role in accelerating this cultural shift.

The application of CE principles in the agri-food sector appears to be an important and necessary change to transform society and face future challenges (European Commission, 2020).

The increasing global food demand, in fact, is forcing the agri-food companies to identify effective new strategies for production, distribution and consumption (Accorsi *et al.*, 2019).

The agri-food value chain has many aspects to invest in to make production systems more sustainable and circular and resource recovery is only one of the most relevant aspects (Kyriakopoulos *et al.*, 2019). CE, in fact, is a concept that is not limited to improving the sustainability of production processes, but enters into the organizational logic of the company, becoming a long-term goal whose progress must be monitored.

Therefore, measuring the circularity of a product or a process should be the fundamental objective of all companies intending to apply CE. Otherwise, the "profuse" commitment cannot be evaluated, and the results achieved are not quantifiable and, above all, comparable.

Measurement allows the entrepreneur to understand which actions to implement to improve circularity performance and which to avoid. It gives a contextualized dimension, in which to set improvement objectives.

In this context, this work is aimed at developing a novel comprehensive CE assessment framework that is flexible, easy to use and accurate when determining the best business organization choices that fit the CE model in agri-food companies. The developed model can be applied to the transformation and industrial processes, thus excluding the agricultural and consumption phases. The goal is achieved through a dual methodological approach based on a literature review and multi-criteria decision-making (MCDM) methods.

Following this introductory section, the remainder of the study is structured as follows. The background (Section 2) is divided into two microsections aimed at investigating the CE in the context of agri-food industries (Section 2.1) and the role of entrepreneurship in circular transition (2.2). Section 3 contains a review of the CE evaluation proposals already present in the literature. Section 4 presents the proposed evaluation framework, which is applied as an example in section 5. The study is concluded in section 6.

2. Background

2.1 Circular economy in agri-food companies

The agri-food sector is considered as one of the main challenges related to the achievement and application of CE strategies (Muscio and Sisto, 2020). The agri-food sector includes activities of other industrial sectors and it is defined as a syneresis of several economic activities, such as natural processes managed by anthropic actions and industrial processes, fully under human control. This sector is creating unsustainable resource consumption and waste creation, which has environmental, economic and social consequences (Agnusdei and Coluccia, 2022). According to The concept of CE within agri-food sector is becoming a challenge for researchers and practitioners and it is declined in the objectives of Sustainable Development Goals (SDGs) as it plays a key role in the transition to a sustainable food system. Responsible Consumption and Production is the key objective of SDGs in which sustainability strategies are applied to the agri-food sector. The interest in this field is also highlighted by the European Commission which is addressing the shift from a linear model to a circular model. Therefore, reducing food loss and waste along the whole supply chain can be considered the main action to achieving sustainability in the sector. Practitioners, scientists and policymakers are working toward food loss and waste reduction strategies adopting sustainable production and consumption approaches (Shafiee-Jood and Cai, 2016). However, CE can be applied to all stages of the agri-food chain: from the cultivation and processing of food to packaging, up to the management of waste and by-products. The latter represent a unique resource to produce biomaterials with several applications (Esposito *et al.*, 2020). In addition to the important environmental benefits, applying a CE approach to the food sector makes it possible to obtain concrete industrial and economic advantages, such as an increase in capital inflow, the attraction of talents and aware consumers, the increase in brand value and the adaptation to constantly evolving European regulations (Mehmood *et al.*, 2021). A CE approach in agri-food allows for the recovering of resources by significantly reducing the negative externalities of the production cycles. Among the applications proposed in the literature, actions aimed at reducing food waste throughout the supply chain receive the greatest attention (Agnusdei *et al.*, 2022; Principato *et al.*, 2019). Other authors have focused on reducing packaging, on its recycling and on preferring biodegradable materials (Meys *et al.*, 2020; Silva and Pålsson, 2022; Guillard *et al.*, 2018). An important trend has dealt with the improvement of efficiency along the entire supply and distribution chain (Tsolakis *et al.*, 2021; Cravero *et al.*, 2021; Pagotto and Halog, 2016), giving new life to production waste, through recycling or revaluation of materials (La Scalia *et al.*, 2021; Kapoor *et al.*, 2020). Finally, many authors have valued the downstream stages of the supply chain, promoting the consumption of eco-sustainable foods and favoring a plant-based diet (Coluccia *et al.*, 2022; Cappellozza *et al.*, 2019).

2.2 The role of entrepreneurship in circular transition

Scholars and practitioners focus on the role that governments and institutions can play in the transition toward circular models (Jolly *et al.*, 2016). However, human and organizational factors have an important role in the implementation of CE practices (Jabbour and de Sousa Jabbour, 2016; Jakhar *et al.*, 2019). According to Cuerva *et al.* (2014), the CE is a process of innovation and entrepreneurs represent innovators, i.e. individuals with the function of identifying and exploiting new opportunities through the staging of new combinations, which translate into new products, methods of production, sources of raw materials and markets, as well as new forms of organization (Schumpeter, 1939).

Management approaches generally maintain a vision of individuals as crucial actors working in consolidated contexts and advocate, with their decisions, intercepting or creating business opportunities for innovation (Alvarez *et al.*, 2021). In this organizational perspective on entrepreneurship, circular entrepreneurship is defined as the process of exploration and exploitation opportunities in the CE domain (Zucchella *et al.*, 2019; Zhu *et al.*, 2022; Singh and Singh, 2018). In this sense, as CE is considered a strategy to achieve sustainability outcomes (Geissdoerfer *et al.*, 2020), circular entrepreneurship is a form of sustainable entrepreneurship. Martín-Navarro *et al.* (2023) illustrate an upward trend in publishing papers relating entrepreneurship to the food industry. According to Crecente *et al.* (2021) circular entrepreneurship is one of the emerging forms of sustainable entrepreneurship that aims to care for and protect people and their environments. Many scholars use the term "eco-preneurship" to label environmentally oriented entrepreneurs more specifically. While economic profits are the goal, ecopreneurs would include environmental goals as an integral part of the business. For these entrepreneurs, the organizational challenge is to better integrate environmental performance into the business logic. To this end, entrepreneurship can relate to other forms of entrepreneurship, such as organic entrepreneurship (focusing on health and well-being), green entrepreneurship (focusing on climate and ecosystems) and blue entrepreneurship (focusing on clean water) (Crecente *et al.*, 2021). All of these forms of entrepreneurship come close to circular entrepreneurship. Born-circular businesses, which are start-ups formed to provide circular value propositions and investigate CE possibilities, can be seen as an example of circular entrepreneurship (Zucchella *et al.*, 2019). By developing new environmentally friendly institutions, services and products through actions that are riskier for incumbents, new circular businesses help to solve environmental issues (Rowley, 2017; Suchek *et al.*, 2022). At the same time, expanding circular firms, or well-established businesses switching to less-impactful activities and embracing circularity principles, can be seen as examples of circular entrepreneurship (Zucchella *et al.*, 2019). In this sense, companies, by applying this business model, obtain both direct and indirect economic advantages. For example, they become a niche opportunity for customers who are particularly sensitive to sustainable consumption (Linder and Williander, 2017; Šebestová and Sroka, 2020), lower the costs of financial profitability and reduce waste and process inefficiencies, with a positive impact on the consumption of raw materials and energy (Ormazabal *et al.*, 2018). By implementing CE principles in the enterprise, they can help transition at scale. However, in order for the CE to be fully implemented in companies, it needs to be evaluable by entrepreneurs (Moraga *et al.*, 2019). Since the CE is an economic model, it needs to be quantifiable in order to track its success (Murray *et al.*, 2017). By measuring circularity, operators know the level of efficiency of their management, being able to limit costs and impacts. In practice, the companies are aware of the material and economic balance of the resources used and reintroduced into the system. All this also involves the evaluation of factors related to durability, the number of users who use a service or the intensity of use of the product. An organization capable of measuring circularity can identify any critical issues and related improvement actions, being able to share the results obtained (positive and negative) with its stakeholders (Suchek *et al.*, 2022).

3. Literature review

There are no commonly accepted methods to measure circularity (Kristensen and Mosgaard, 2020). An increasing number of scholars and practitioners have focused on the assessment of the progress of CE initiatives and, accordingly, on the development of performance measurement tools (Vinante *et al.*, 2021). However, literature shows that advanced research and data availability on CE assessment tools and indicators are lacking (Yazdani *et al.*, 2021). Quite simply, developing a framework for assessing CE is a challenge that must be coupled with the collection of framework, metrics and indicators. This is because, developing the right framework and selecting the correct indicators that capture different CE practices is the essential starting point for measuring circularity (Kumar *et al.*, 2019). The number of CE frameworks is relatively small and most of them are missing some important CE oriented strategies (European Commission, 2015; Rainville, 2021). The available frameworks tend to focus primarily on physical parameters and materials circularity without considering other CE aspects such as policies and regulations, customers contribution, organizational aspects and technological advancement (Chauhan *et al.*, 2022). From the literature analysis, it emerged that many of the reviewed frameworks are not intended to assess the circularity, but rather focus on a very specific stage(s) or area(s) of a selected product or process, such as end-of-life and waste generation.

There are numerous studies using the Life Cycle Approach to measure circularity (Laso *et al.*, 2016; Thakker and Bakshi, 2021; Cavaleiro de Ferreira and Fuso-Nerini, 2019; Avdiushchenko and Zając, 2019; Coluccia *et al.*, 2022).

Other authors have combined Life Cycle Assessment (LCA) with MCDM, which allows greater flexibility, allowing the user to choose his own set of indicators based on his measurement needs (Alamerew and Brissaud, 2019; Ahmed *et al.*, 2022).

To date, it is very challenging to achieve a predefined set of standard indicators for CE at the micro level. This is mainly due to the unlimited variety of goals, objectives, characteristics and challenges that different companies, businesses and products have. Different sets of indicators have been developed by different organizations to capture the circularity of different products and processes (European Commission, 2021). However, even the different taxonomies only focus on the operational aspects of the CE, such as material flow and waste generation. It is therefore difficult to find a single complete set of indicators that takes into account the environmental, organizational, economic, social and technological factors of the model that implements a circular business model (de Arroyabe *et al.*, 2021).

At the institutional level, the best-known model is Circulytics (Ellen MacArthur Foundation, 2017). This tool measures the CE performance of companies' materials and water flow and other services provided along with energy use. However, the focus of the model is on the balance of the materials, without considering that CE is a process that includes governance and organizational aspects. Another assessment tool is the Cradle to Cradle Certified by Cradle-to-Cradle Products Innovation Institute (MBDC, 2021). The tool lacks flexibility even on the product level as it does not assess products that operate on non-renewable energy sources.

Most of the approaches proposed to assess circularity provide only partial information, mainly focusing on the analysis of environmental sustainability performance. In general, the available frameworks have recurring weaknesses, mainly revolving around their limited selection of indicators that fail to capture different aspects and phases of CE. Furthermore, a lack of assessment of circularity in the agri-food sector is evident, despite its complexity and its strategic role in the circular transition.

Beyond the attempts of measuring the firm's performance circularity, what is lacking is an approach that can assess the circularity status of a company in a holistic vision, considering the complexity and disruption of all CE principle.

In this context, this work is primarily aimed at developing a novel comprehensive CE assessment framework that is flexible, easy to use and accurate when determining the best business organization choices that fit the CE model in agri-food companies. The developed model can be applied to the transformation and industrial processes, thus excluding the agricultural and consumption phases. The literature gaps are addressed by providing the user with a step-by-step approach, leading up to the selection, weight and use of a customized set of indicators that are capable of accurately assessing the level of CE.

4. Theoretical model

This section describes the approach for the evaluation of agri-food firms in terms of circularity using a novel assessment framework. As shown in Figure 1, the framework is composed of four stages. In the first stage, through the analysis of the literature, a theoretical model which provides a holistic vision of the CE was implemented and adapted to the agri-food sector, as presented in Section 4.1. In the second stage, users are required to collect a set of indicators capable of measuring each sub-criterion, as presented in Section 4.2. In third stage, a weight is assigned to each indicator using the analytical hierarchy process (AHP), which is a pairwise comparison methodology (Section 4.3).

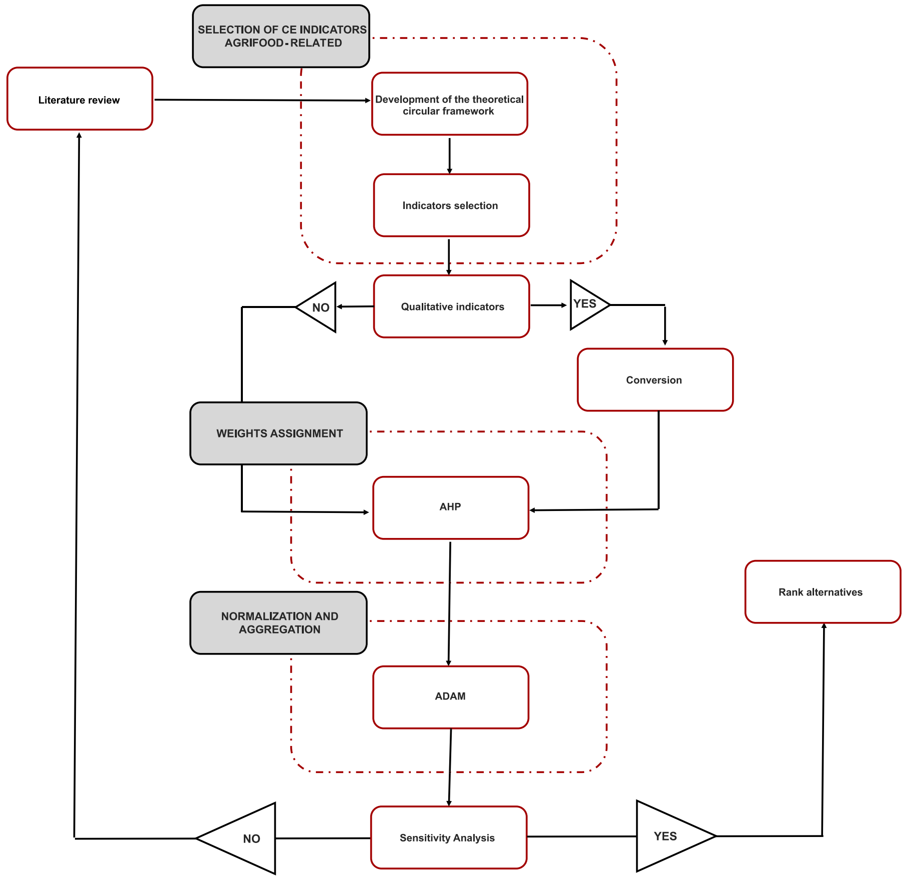
Lastly, a geometric MCDM method, called the axial distance-based aggregated measurement (ADAM) model is used to normalize, assess and aggregate the results and produce final scores for the different alternatives to be ranked based on their final circularity scores (Section 4.4).

4.1 Development of a theoretical circular framework

In this first phase a theoretical framework was developed, thus providing the basis for the selection of criteria and sub-criteria of the general model. Based on some of the available CE assessment frameworks in the literature (Ahmed *et al.*, 2022; Vinante *et al.*, 2021; Lacy *et al.*, 2020; Krstić *et al.*, 2023) a methodological framework was developed capable of capture all aspects of circularity, following a systemic and holistic vision. It indicates the strategic areas that need to be considered to assess the level of CE of companies, in order to ensure a reliable assessment:

(1) *PROCESS EFFICIENCY (PE)*: considering the value lost through the business processes across energy, emissions, water and waste.

(2) *QUALITY AND DURABILITY (QD):* rethinking the design, lifecycle and end of use of a product to optimize usage, eliminate waste and close product loops.



Source(s): Authors work

Figure 1. CE assessment procedure

(3) *CULTURE AND ORGANIZATION (CO):* embedding circular principles into the fabric of an organization through redefined working practices, policies and procedures.

(4) *PARTNERSHIP (P)*: collaborating and partnering with public and private sector actors to create an enabling environment for collective transformation.

In the present study, each of the above four dimensions was used as criteria for the evaluation of CE in agri-food firms. All these criteria are composed of sub-criteria (Table 1), which can be measured using a set of indicators that are thought to be important for a valid evaluation of the circularity of agri-food firms.

The *PROCESS EFFICIENCY* criterion was investigated taking into account four main sub-criteria in which companies typically focus their circular operational initiatives: energy (PE_1), emissions (PE_2), water (PE_3) and waste (PE_4).

Circularity in terms of *QUALITY AND DURABILITY* (QD) was evaluated by considering the four key stages of a product's lifecycle as sub-criteria: design (QD_1), use (QD_2), use extension (QD_3) and end of use (QD_4).

In order to evaluate the circular *CULTURE AND ORGANIZATION* (CO), we focused on the following four sub-criteria: vision (CO_1), innovation (CO_2), people (CO_3) and governance (CO_4).

Finally, we define a circular *PARTNERSHIP (P)* the network of organizations collaborating and partnering to create an enabling environment for collective transformation. Therefore, in order to capture the potential of the partnership, we selected four key sub-criteria: sharing (P_1), collaboration (P_2), investment (P_3) and policy (P_4).

Through these dimensions it is possible to detect the degree of circularity of a firm, understood as the extent to which it is implementing circular business models for all four

Criteria	Sub-criteria	Description
Process efficiency (PE)	Energy – PE_1	Implementing measures that reduce energy consumption, increase operational energy efficiency, and start to shift from fossil fuels to renewable sources
	Emissions – PE_2	Identifying emission points within the direct scope of core operations as well as throughout the supply chain and then making suitable interventions to reduce those emissions
	Water – PE_3	Reducing a company's water dependence by minimizing water abstraction, prioritizing water-saving opportunities and increasing water reuse to improve efficiency and reduce costs
	Waste – PE_4	Reaching zero waste by eliminating waste leakage throughout company operations and reducing waste capacity by maximizing asset utilization
Quality and durability (QD)	Design – QD_1	Conductive assessment of the current lifecycles of materials and their resource footprints
	Use – QD_2	Maximizing the value delivered through the single use of a circular product or service in its original form. The aim is to leverage a product as a service or sharing platform model to maximize product utilization
	Use extension – QD_3	Maximizing the value delivered through multiple uses of a circular product or service in its original form
	End of use – QD_4	Maximizing the value delivered through multiple uses of a circular product or service in any form. This might include identifying circular uses for waste at end of use and repurposing it by recycling
Culture and organization (CO)	Vision – CA_1	Setting a long-term goal with milestones and supporting targets to become a circular organization over time
	Innovation – CA_2	Breaking down research and development silos to encourage innovation across the organization, instilling a "laboratory" mindset to drive innovative circular thinking, sharing best practices and relevant use cases, conducting learning expeditions to embed circular principles and design in organizational centers of innovation and encouraging the operational and product/service pivot to circularity
	People – CA_3	Engaging employees with circular projects sponsored from the top of the organization, providing training and internal support systems for those workers by identifying and empowering the people who can drive the journey of change and incentivizing circular performance at all levels against clear and challenging KPiS
	Governance – CA_4	Making the circular economy a core element in the company's ways of working and structure by embedding circularity in policies, processes and procedures

(*continued*)

Table 1.
Description of criteria and sub-criteria

Criteria	Sub-criteria	Description
Partnership (P)	Sharing – P_1	Non-competitive, transparent sharing of knowledge, information, and learning to support circular thinking and performance. Initiatives in this area center around sharing insight and expertise with peers to address shared challenges
	Collaboration – P_2	Bilateral and multilateral partnerships to deliver practical circular solutions, Initiatives in this area focus on establishing bilateral partnerships and working with multilateral public-private stakeholders to bring to market circular solutions that benefit all
	Investment – P_3	Financial support to drive circular innovation. The investments can be in innovative start-ups, products, and business-model development, thought leadership, R&D, and non-commercial third parties such as NGOs or academia
	Policy – P_4	Support of an enabling regulatory environment for circularity. Initiatives in this area include engaging in local and national discussions as well as international forums to inform and/or influence relevant policy measures and regulations that would foster a regional and global circular economy

Table 1.

dimensions. Necessarily, to reach an advanced level of transformation, companies should implement the new models on all the dimensions of them in parallel.

4.2 Indicators selection

In this phase, indicators that are suitable for assessing the level of circularity achieved in each criterion and sub-criterion (non-existent, emerging, consolidated, lead and last) were identified. Table 2 summarizes the different indicators that users of the proposed framework should consider to be able to obtain a comprehensive choice of indicator set, consistent with the objectives of the CE in agri-food companies. To end up with a reliable set of indicators, the set should be targeted, measurable (even qualitative indicators should have defined qualities using words like "successful, appropriate, effective"), reliable, feasible and useful in decision-making (Church and Rogers, 2006).

4.3 Conversion of qualitative indicators

The normalization process is applied to the previously gathered data to convert qualitative indicators to scores. Other quantitative indicators pass directly to the fourth stage where the assigning of weights to indicators takes place through AHP methods. In this stage, for each qualitative indicator five scores are defined which correspond to the five levels of circular maturity identified in the literature: non-existent, emerging, established, leading and ultimate, as shown in Table 3 (Lacy *et al.*, 2020). These levels present a progression associated with the stage of consolidation of the CE practices adopted by the organization. The more professional the management, the more consolidated the practices adopted tend to be. Each level of circularity demands the formalization of a set of practices that contribute positively to making the agri-food firms circular.

4.4 Assigning weights to indicators through AHP

The AHP method was developed by Thomas Saaty for analyzing complex problems in different decision-making scenarios. The AHP generally consists of three main steps namely, decomposition of the problem, comparative judgment and generation of priorities (Janic and Reggiani, 2002). The main aim of the AHP method is to develop a hierarchical structure with

Criteria	Sub – criteria	Indicators
PE	PE_1	1. Energy consumption
		1. Energy renewable sources/Total Energy Consumption
	PE_2	2. Water consumption
		3. Blue Water footprint
		4. Green Water footprint
		5. Gray Water footprint
	PE_3	6. Waste production
		7. Food waste production
		8. Recycling rate
		9. Recycling rate of overall packaging
		10. Recycling rate of plastic packaging
		11. Recycling rate of wooden packaging
		12. Recycling rate of paper packaging
		13. Recycling rate of glass packaging
		14. Recycling rate of bio-waste
		15. Recycling rate of e-waste
	PE_4	16. Carbon footprint
		17. Imported raw materials
QD	QD_1	18. Use of software/management to process data to support business decisions
		19. Energy class of electronic equipment
		20. Food loss
		21. Packaging quality
		22. Quality of equipment
	QD_2	23. Percentage of exploitation of agricultural raw material
		24. Throughput time
		25. Supply chain certifications
	QD_3	26. Use of recycled materials for primary or secondary packaging
		27. Use of biodegradable materials for primary or secondary packaging
	QD_4	28. Food waste or by-products disposed of
		29. Food waste or recycled by-products
		30. Food waste or by-products processed by other industries to obtain new products
		31. Food waste or by-products used for energy production
CO	CO_1	32. Goals of circularity in the company's long-term planning
	CO_2	33. Investments in innovation
		34. Use of digital technologies for process efficiency
		35. Use of digital technologies for process traceability
	CO_3	36. Performance monitoring system through KPIs
		37. Capacity building: organization of courses, events and campaigns to educate employees on circularity
	CO_4	38. Circular orientation: the circular economy is a component of the company's sustainability policy
		39. Ownership of environmental quality and sustainability brands for products and services
P	P_1	40. Sharing of environmental performance results with competitors through platforms, calling of forums, consortia, hubs
		41. Sharing of equipment/machinery with other neighboring producers
	P_2	42. Activities, involving all actions related to co-operation among different actors for synergies, projects, and workshops to boost a circular economy
		43. Participation in panels for the construction of sector policies
	P_3	44. Funding of initiatives to drive circular innovation of start-ups, research centers or universities
	P_4	45. Membership in trade associations
		46. Membership in business networks
		47. Belonging to public or private partnerships for research and identification of circular economy measures

Table 2.
Indicators to be selected for the circular economy assessment in agri-food firms

the main goal at the top level, the criteria, or attributes (Indicators), are placed at the second level and the alternatives at the bottom level. For this framework, no priorities are generated since the AHP method can only be used to define weights. Therefore, the first step in the AHP is aimed at constructing a pairwise comparison matrix P_{AHP} (w*w) with the indicators aligned in the first row and the first column in the same order, as seen in Table 4.

The same procedure is applied to the indicators belonging to each sub-criterion and to the sub-criteria belonging to each criterion. In the second step, a group of experts decide the comparative relative importance of among indicators, sub-criteria and criteria, in order to perform judgment for pairwise comparisons. The group of experts should be composed of a variable number of individuals who know the CE, but who are external to the organization, in order to provide a competent but not biased view.

Same indicators will have a relative importance of 1 as illustrated in Table 4. Other indicators are given a number from 2 to 9 and reciprocals are given to same indicators when the order is switched as seen in Table 5.

These values represent the relative importance of one alternative when compared to other keeping one indicator fixed (Singh and Malik, 2014). A normalized element is then obtained using Eq. (1).

$$r_{ij} = \frac{p_{ij}}{\sum_{i=1}^{w} e_{ij}} \tag{1}$$

where p_{ij} is an element of the original matrix PAHP (w*w) and the denominator is the summation of all the elements in the respective column. Finally, the weight vector is obtained using Eq. (2).

Linguistic term	Score
Non-existent	1
Emerging	2
Established	3
Leading	4
Ultimate	5

Table 3.
Conversion to score

	Indicator 1	Indicator 2	Indicator w
Indicator 1	1	1/a	1/b
Indicator 2	a	1	1/c
Indicator w	b	c	1

Table 4.
Pairwise comparison matrix

Linguistic term	Intensity scale
Equal importance	1
Very low	2
Low	3
Fairly low	4
Medium	5
Fairly high	6
High	7
Very high	8
Extremely high	9

Table 5.
AHP intensity of importance table

$$\boldsymbol{w} = \frac{1}{N\sum_{i=1}^{N} r_{ij}} \tag{2}$$

where N is the number of alternatives (Singh and Malik, 2014).

Subsequently, the weights obtained from the comparison between the indicators must be multiplied by the weights of the respective sub-criteria and criteria, thus obtaining the final evaluations.

4.5 Normalization, aggregation and final rank using the ADAM method

ADAM method represents a new class of MCDM techniques, known as geometric MCDM (Krstić *et al.*, 2023). This approach rates alternatives by computing the volumes of complex polyhedra made up of points (vertices) in a three-dimensional coordinate system as an aggregate measurement. Each point belongs to one of three classes: coordinate origin (O), reference points (R), weighted reference points (P). The coordinate origin is a coordinate point (0,0,0). Reference points in the x-y plane are points with the coordinates (x,y,0) that establish the value of the alternatives based on the four different CE orientations, such the point's axial distance from the coordinate origin. The weighted reference points have coordinates (x,y,z), where the coordinate z is used to obtain the axial distance of the weighted reference point from the x-y plane. These distances correspond to the weights of the indicators. A complex polyhedron volume can be calculated by summarizing the volumes of the m polyhedral (where m is the number of alternatives), by defining all the points that define it. According to the decreasing values of the obtained volumes of complex polyhedra, the final order of alternatives is determined. The step-procedure of this approach is given as follows.

Step 1: Define the decision matrix E, elements of which are evaluations e_{ij} of the alternatives i (A1, . . ., Am) in relation to indicators j (S1, . . ., Sn, W1, . . ., Wn, O1, . . ., On, T1, . . ., Tn), i.e. vector magnitudes which correspond to the evaluations of the alternatives in relation to the indicators:

$$E = [e_{ij}]_{m\times n}, \tag{3}$$

where m is the total number of alternatives and n is the total number of indicators.

Step 2: Define the sorted decision matrix S, in which the evaluations e_{ij} are sorted in the descending order according to the importance (weight) of the indicators:

$$S = [s_{ij}]_{m\times n}, \tag{4}$$

Step 3: Definition of the normalized sorted matrix N, in which the elements n_{ij} are normalized as:

$$n_{ij} = \begin{cases} \dfrac{s_{ij}}{\max\limits_i s_{ij}}, & for\, j \in B \\ \\ \dfrac{\min\limits_i s_{ij}}{s_{ij}}, & for\, j \in C \end{cases}, \tag{5}$$

where B is the set of benefit and C is the set of cost criteria.

Step 4: Find the coordinates (x, y, z) of the reference (R_{ij}) and weighted reference (P_{ij}) points that define the complex polyhedron in the following way:

$$x_{ij} = n_{ij} \times \sin \alpha_j, \forall j = 1, \ldots, n; \ \forall i = 1, \ldots, m, \tag{6}$$

$$y_{ij} = n_{ij} \times \cos \alpha_j, \forall j = 1, \ldots, n; \ \forall i = 1, \ldots, m, \tag{7}$$

$$z_{ij} = \begin{cases} 0, for R_{ij} \\ w_j, for P_{ij} \end{cases}, \forall j = 1, \ldots, n; \ \forall i = 1, \ldots, m, \tag{8}$$

where w_j is the indicators weight and α_j is the angle that determines the direction of the vector that defines the value of the alternative.

Step 5: Find the volumes of complex polyhedra V_i^C as the sum of the volumes of the pyramids of which it is composed using the following equation:

$$V_i^C = \sum_{k=1}^{n-1} V_k, \forall i = 1, \ldots, m \tag{9}$$

Step 6: Rank the alternatives according to the decreasing values of the volumes of complex polyhedra V_i^C $(i = 1, \ldots, m)$. The best alternative is the one with the highest volume value.

5. Example of the implementation of the framework

This section presents an example intended to present briefly how the assessment procedure is to be used. It is also intended to help users understand the results they obtain from the assessment framework and, accordingly, draw conclusions on the circularity and point out possible areas of improvement within processes or products assessed.

In this example, four agri-food industries operating in the pasta sector, with four different circular orientations were compared: Process efficiency orientation (A_1), Quality and durability orientation (A_2), Culture and organization orientation (A_3), Partnership orientation (A_4). Each of the four companies has decided to implement CE actions by focusing on one of the four dimensions. The first step in assessing circularity consisted in collecting the information needed to calculate the 48 indicators. The information was obtained through direct interviews with the operators of the four companies. Immediately after the calculation, since it is a mix of qualitative and quantitative indicators, they were subjected to the conversion process in the five levels of circularity, with the respective scores indicated in Table 4. Subsequently the indicators were normalized in the sorted matrix, as indicated in Equation 5.

The next step is assigning weights to the indicators through AHP method, as illustrated in Section 4.4. The weight obtained for each indicator, based on each criterion and sub-criterion, is presented in Table 6.

After obtaining the weight of each indicator, the ADAM method was used to aggregate and rank the data obtained from the indicators and present a final circularity score for each circular orientation, as highlighted in Section 4.5. Results are shown in Table 7.

The results showed that the "culture and organization" orientation is the one with the best score in terms of circularity, also expressed in graphic form in Figure 2. This emphasizes the importance of considering the CE as part of the corporate organizational strategy and not to relegate it to the sustainability of processes. The company that sets long-term circularity goals manages to be a circular organization over time. Initiatives in this area aim to develop time targets to support the circular vision and mobilize the necessary resources that can help business units prioritize and implement circular initiatives. Recognizing that established

Indicators	Weights
Energy consumption	0.0227
Energy renewable sources/Total Energy Consumption	0.0202
Water consumption	0.0031
Blue water footprint	0.0061
Green water footprint	0.0019
Gray water footprint	0.0192
Waste production	0.0083
Food waste production	0.0047
Recycling rate	0.0098
Recycling rate of overall packaging	0.0107
Recycling rate of plastic packaging	0.0191
Recycling rate of wooden packaging	0.0066
Recycling rate of paper packaging	0.0088
Recycling rate of glass packaging	0.0155
Recycling rate of bio-waste	0.0062
Recycling rate of e-waste	0.0155
Carbon footprint	0.0800
Imported raw materials	0.0160
Use of software/management to process data to support business decisions	0.0049
Energy class of electronic equipment	0.0034
Food loss	0.0043
Packaging quality	0.0093
Quality of equipment	0.0093
Percentage of exploitation of agricultural raw material	0.0130
Throughput time	0.0022
Supply chain certifications	0.0043
Use of recycled materials for primary or secondary packaging	0.0383
Use of biodegradable materials for primary or secondary packaging	0.0383
Food waste or by-products disposed of	0.0269
Food waste or recycled by-products	0.0122
Food waste or by-products processed by other industries to obtain new products	0.0300
Food waste or by-products used for energy production	0.0539
Goals of circularity in the company's long-term planning	0.1293
Investments in innovation	0.0155
Use of digital technologies for process efficiency	0.0406
Use of digital technologies for process traceability	0.0089
Performance monitoring system through KPIs	0.0135
Capacity building: organization of courses, events and campaigns to educate employees on circularity	0.0067
Circular orientation: the circular economy is a component of the company's sustainability policy	0.0178
Ownership of environmental quality and sustainability brands for products and services	0.0178
Sharing of environmental performance results with competitors through platforms, calling of forums, consortia, hubs	0.0243
Sharing of equipment/machinery with other neighboring producers	0.0728
Activities, involving all actions related to co-operation among different actors for synergies, projects, and workshops to boost a circular economy	0.0323
Participation in panels for the construction of sector policies	0.0162
Funding of initiatives to drive circular innovation of start-ups, research centers or universities	0.0668
Membership in trade associations	0.0076
Membership in business networks	0.0076
Belonging to public or private partnerships for research and identification of circular economy measures	0.0227

Table 6.
Weighted obtained used AHP method

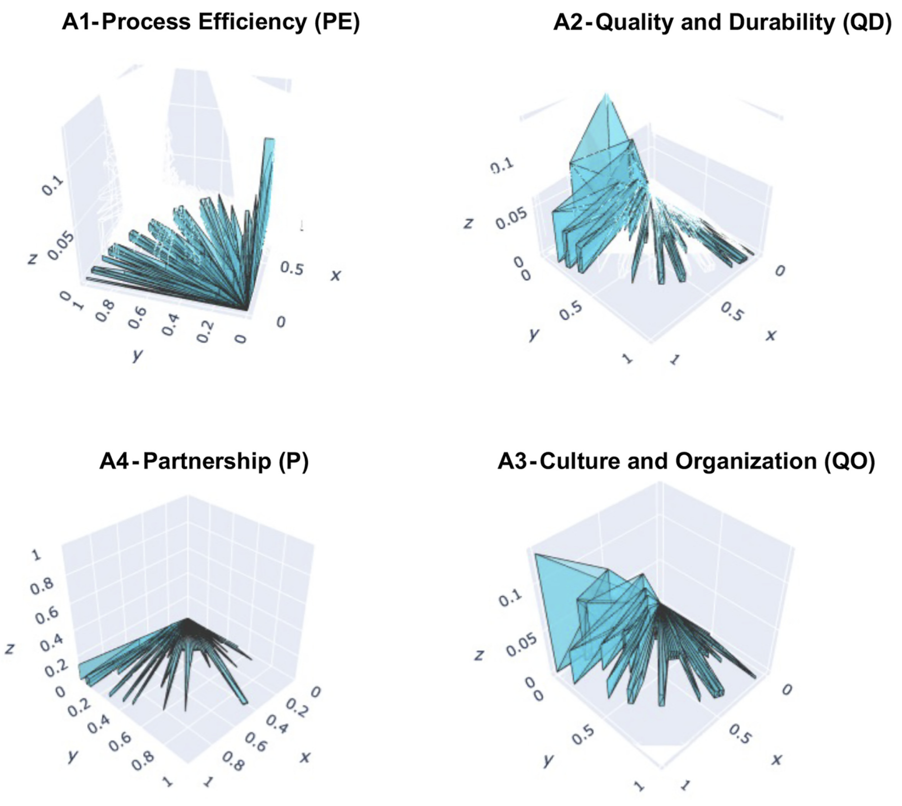
internal ways of doing business are likely to impede circular decision-making and at speed and be a barrier for further uptake, it is important to make the CE a central element in the ways of working and in the structure of the company, by incorporating the circularity in policies and processes.

6. Discussion

This research work has advanced the research on evaluation models of the CE in the agri-food sector. In particular, an easily replicable method has been proposed which starts from the collection of corporate data, based on a precise taxonomy. This taxonomy intends to incorporate a systemic vision of corporate circularity, evaluating its main dimensions (Table 2).

Alternatives	Volume	Rank
A1	0.003871236	2
A2	0.003410277	4
A3	0.003986811	1
A4	0.003795765	3

Table 7. Final ranking



Source(s): Authors work

Figure 2. Graphic representation of the application of the ADAM method to four different circular orientations

Contrary to the frameworks already present in the literature (Agnusdei *et al.*, 2023; Pagotto and Halog, 2016; Silva and Pålsson, 2022), the model of this study is not limited to the selection and the calculation of indicators, but provides a real decision-making tool for the company. In fact, through the application of MCDM it allows to face complex decision-making problems involving multiple criteria or objectives. These methods help structure decisions, evaluate available options and select the best solution based on multiple factors involved (Munier *et al.*, 2019). In the specific case, since the CE involves a wide range of interconnected aspects, making effective decisions can become complex due to the numerous variables and objectives to be considered simultaneously (Krstić *et al.*, 2023). The proposed framework allows to manage this complexity, facilitating the decision-making process and providing a structured basis for comparing and evaluating the different options.

Other authors have used these methods to identify the main drivers of the CE in the agri-food sector (Kumar *et al.*, 2022; Krstić *et al.*, 2022, 2023 Yontar, 2023), however the present framework, conceived as a systemic and replicable decision-making tool, it certainly represents a novelty in the agri-food sector.

Its implementation, by way of example, has led to the conclusion that the strategic aspect to consider in order to improve the corporate performance of the CE is corporate culture and awareness. As demonstrated by Hofmann and Jaeger-Erben (2020), the transformation toward circular business models requires a change of mindset, a collective commitment and a long-term vision. According to van Langen (2021) culture determines how the company relates to the environment and society and a culture oriented toward the CE can lead to significant changes. Corporate culture can be reflected in the company's strategic goals and employee performance evaluation criteria. If the CE is seen as a top priority, it will be more likely to be adopted at all levels of the organization.

7. Conclusion and implications

The need to move from linear to circular production and consumption systems has now been established by both scholars and practitioners (De Bernardi *et al.*, 2023). Measuring circularity should, therefore, be a primary objective of all companies intending to apply the CE (Miemczyk *et al.*, 2022). Otherwise, the efforts made would be untargeted and could lead to non-quantifiable and non-comparable results.

The measurement tool allows the company to understand if, with respect to its business model, by applying the concepts of the CE and taking certain actions, it is improving or worsening its performance. Measurement serves to give a contextualized dimension and to inevitably set improvement objectives. To progress successfully, companies must look inward and outward across the value chain and external ecosystem. Organizations need to understand where they fall within the stages of the circular maturity and the extent to which they are implementing circular business models across different dimensions and thus where they are still lacking. While companies might tend to focus on areas within their immediate control, it is crucial to consider all dimensions holistically due to their interdependencies. The model developed in the study and based on the MCDM method, can be a useful tool to support corporate decisions of agri-food companies on the CE, making entrepreneurs aware of their level. This methodology is increasingly being used in management studies (Yalcin *et al.*, 2022).

From a theoretical point of view, the present work has brought an advance in the field of food research, proposing a framework capable of incorporating all the main aspects of the CE, making them quantifiable and prioritizing the actions to be performed, identifying any drivers and limits to the circular transition in the company.

Moreover, having a tool for measuring corporate circularity has various practical implications, both for the company and for the other actors involved. In particular, it can concretely help to identify the areas where the company has a greater negative impact and to take corrective measures to reduce pollution, resource use and waste generation. Furthermore, by measuring and monitoring the CE, the company can identify areas where there is waste and optimize the use of materials, energy and other resources, leading to greater operational efficiency and reduced costs. With accurate data on business circularity, decision makers at all levels can make more informed and strategic decisions. Finally, measuring circularity through scientifically provable methods improves the company's image by preventing *green wash*ing and increasing consumer confidence. To further improve the demonstrated CE assessment framework, engaged governments, organizations and policymakers are urged to standardize further sets of indicators based on agri-food industries and to involve sectorial expertise. Moreover, to facilitate the evaluation processes, the integration of technology into business processes would allow for easier collection of data, greater user participation and faster sharing of information. There should be a variety of platforms for data sharing that can be used to create global sets of indicators.

This would help expand the capabilities of the framework enabling it to assess circularity on larger scales. Finally, this tool can be useful to channel financial resources toward actions that can effectively enhance circularity.

The adoption of the CE requires constant monitoring of the progress and results obtained. The tool could be used to generate periodic reports or performance indicators that allow you to evaluate the effectiveness of the implemented strategies. These evolutions will depend on the emerging needs, the challenges encountered and the opportunities that will arise in the field of the CE. As the CE gains traction in both micro and macroeconomic contexts, there is a wide range of research opportunities to explore how businesses, governments and societies at large can benefit from this sustainable model. Future studies could develop similar evaluation models for other sectors, exploring how cultural and regional differences and different government policies influence the adoption and effectiveness of CE models. Overall, it would be desirable to continue developing and refining assessment tools for circularity, incorporating new theoretical models, metrics and algorithms.

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