The Concept of Circular Economy in Agriculture. A Review of the Literature and a Possible Way Forward

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Abstract

The EU prioritises the circular economy to foster sustainability, optimise resources, and minimise waste. Despite its potential, lacking a clear definition for circular economy in agriculture limits its benefits and cumulative knowledge. This study systemically identifies a consensus concept of circular economy in agriculture and its relationship with circular bioeconomy. We conducted a two-stage review and coding analysis of academic and grey literature, 22 documents define circular economy in agriculture and 12 define circular bioeconomy. Results indicate that circular economy in agriculture closes production loops, reduces, manages, and repurposes waste, primarily through the R's principles - reduce, reuse,

recycle. Its aims include environmental, economic, health and food security benefits. Circular economy in agriculture is overarching and synergistic to circular bioeconomy, since cascading mechanisms improve sustainable resource management. As circular economy evolves, this study offers a foundation for future research integrating expert validation and qualitative assessments with implementation and monitoring strategies.

Keywords: circular economy, circular bioeconomy, sustainability, concept, coding

JEL Classification codes: Q53, Q56, Q57

1. Introduction

Population growth and the produce-use-dispose model have driven actual estimates in which we use more than the available amount of raw materials on Earth (United Nations Development Programme, 2023). This situation makes circularity indispensable for sustainable development. The European Union (EU), through the European Green Deal and the Circular Economy Action Plan, promotes a sustainable development through the circular economy, defined as an economic system that optimises the use of materials, maintains the value of resources, and minimises the generation of waste (European Commission, 2015). The agricultural sector is strategic for transitioning to the circular economy, given its high use of natural resources, specifically water and nutrients (European Commission, 2022). Furthermore, if circular economy in agriculture promotes sustainability, it will maintain the economic, social, and environmental bases so that food security and nutrition for future generations are not compromised (FAO, 2018).

Despite its widespread presence in the policy debate, the definition of a circular economy remains ambiguous, with scholars and practitioners adapting the idea of circularity according to their contexts and expertise. Much of the literature on circular economy has focused on practical and technical levels, leaving aside the evaluation of its values, structure, and potential (Korhonen, Nuur, et al., 2018). Furthermore, different definitions have been applied from

diverse perspectives, either a post-political stand (Borrello et al., 2020) or different backgrounds and geographic regions, making the circular economy an "umbrella concept" (Homrich et al., 2018). The vagueness of the concept of circular economy poses the risk of obstructing its benefits (Arru et al., 2022; Borrello et al., 2020) and a collapse of the model due to impeded cumulative knowledge (Kirchherr et al., 2017).

A clear theoretical framework recognised by researchers, policymakers and practitioners is essential for realising the potential of circularity in agriculture, as it would connect technological advances in a comprehensive knowledge base and provide the foundation for effective supporting policies (Rinaldi & Biaggi, 2025). Modern research and technologies in the areas of waste recovery, wastewater treatment, biochar application, and clean energy (Amoah-Antwi et al., 2020; Barros et al., 2020; Hidalgo et al., 2019; Maaß & Grundmann, 2018) are expanding opportunities to enhance resource efficiency and value creation. Yet, the integration of circularity into agricultural production remains fragmented, largely due to a lack of consensus on definitions (Tamasiga et al., 2022; Velasco-Muñoz et al., 2021). Current conceptualisations in the agrifood sector tend to be narrow in scope, focusing either on compiling circular practices (De Boer & van Ittersum, 2018) or on specific components such as livestock systems (Van Zanten et al., 2019), rather than offering a comprehensive and operational framework.

Usually, sustainability tends to be an effect associated with a circular economy. Businesses and policymakers view the circular economy as an approach to pursuing sustainable development (Ghibelline et al., 2016; Ministero della Transizione Ecologica, 2022; Murray et al., 2017). However, being more circular does not always translate into being more sustainable. The relationship between circularity and sustainability often has trade-offs, such as the environmental impact of the energy required to recycle materials (Barcelos et al., 2021; Geissdoerfer et al., 2017). Also, improvements in the different pillars of sustainability may

happen separately, such as specifying benefits in environmental sustainability (Koppelmäki et al., 2021; Van Zanten et al., 2019). The achievements of a circular economy may vary depending on the interest of the government to reach specific sustainable development goals, sometimes resulting in trade-offs with other objectives (Livingstone et al., 2022).

The circular bioeconomy is a term often used in the agricultural sector to talk about the circular economy due to the biological nature of the main resources used in this field. However, there is still debate about the connection between circular economy and bioeconomy, which influences the definition used for circular bioeconomy (Leipold & Petit-Boix, 2018)[1]. Furthermore, bioeconomy has been thought to be circular inherently due to the material circularity of nature (Konstantinis et al., 2018). Hence, circular economy in agriculture has often been used interchangeably with circular bioeconomy (Velasco-Muñoz et al., 2021), but the relationship between these concepts has not been properly assessed.

Previous research has looked for a consensus definition of a circular economy (Kirchherr et al., 2017), but they do not focus on the characteristics of the agricultural sector (i.e., being based on managing biological resources), that must be instead considered to give precise guidelines (Ellen MacArthur Foundation, 2019c). Most studies still focus on circularity in the agri-food industry and distribution phases rather than the production phase (Martínez-Moreno et al., 2024; Velasco-Muñoz et al., 2021), although this last one is the biggest contributor to the European agrifood circularity index (Arru et al., 2022). Further research is thus needed to compare understandings of circularity in agricultural production and to systemically address the connection between circularity and sustainability.

In this research we aim to fill this gap by proposing a new, comprehensive definition of circular economy applied to agriculture. This definition is built answering the questions: i) what

[1] The circular economy and the bioeconomy may be in fact connected in five possible ways: i) separate but reinforcing, ii) completely integrated, iii) partially antagonistic, iv) bioeconomy a precondition to circular economy, v) circular economy a tool in transitioning to the bioeconomy (Leipold & Petit-Boix, 2018).

principles define the concept of a circular economy presently applied to agriculture by scholars and practitioners? ii) what is the relationship between circularity and the economic, social and environmental sustainability of farms? Then, given the close relationship between the concepts of circular economy in agriculture and of circular bioeconomy, we also address a complementary research question: iii) what is the connection between the identified definition of circular economy applied to agriculture and the concept of circular bioeconomy?

The approach we followed for this review article is the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) statement 2020 (Page et al., 2021), followed by a coding analysis. The novelty of this work with respect to the existing literature is, first, the focus on agriculture when explaining the concept of circular economy, and second, the use of the literature review combined with a coding framework to get a structured consensus definition and its connection with sustainability.

2. Method and data

The method used in this research consists of collecting documents, coding their information, and analysing the classified information to construct a unified concept. The circular economy may be considered a social construct since its definition has depended on the users' perspective of circularity practices. Dahlsrud (2008) recognise that though it is not possible to develop an unbiased definition of social constructions, studying similarities and differences of the available definitions through a coding framework allows identifying a consensus idea. To find a consensus concept, Singh & Aggarwal (2022) used an open coding process to unpack and repack qualitative data.

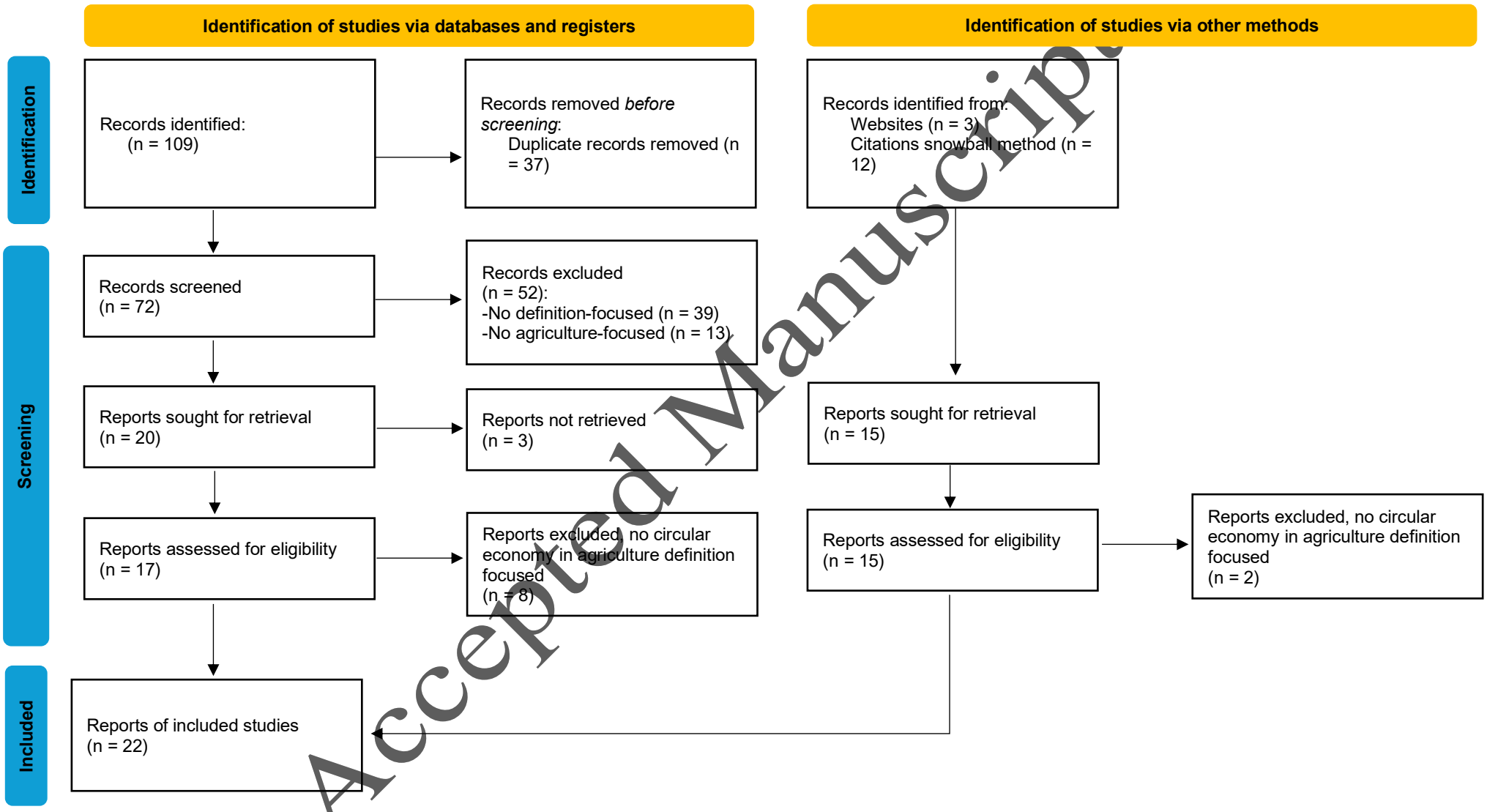
The PRISMA statement 2020 was used to identify, select and review documents to recognise a consensus concept of circular economy in agriculture. The PRISMA approach allows users to construct a transparent, accurate, and complete systematic literature review (Page et al., 2021).

131 The literature review is divided into two stages: the first stage was the collection of
132 definitions of circular economy applied to the agricultural sector and the second was on the
133 collection of definition of circular bioeconomy to allow for comparison among the two (for a
134 detailed description of the steps followed, please refer to Annex 1).

135 Figure 1 presents the flow diagram with information about the selection of documents
136 for the literature review, following the PRISMA approach. We found 109 records during
137 database search. After removing duplicates, we screened 72 records, from which we reviewed
138 17 full-text documents, and finally included 9 documents. Later, we searched references of the
139 initially included studies, using the snowball method. We also added relevant documents from
140 the Ellen MacArthur webpage. 13 extra documents that fulfilled inclusion criteria were found
141 in these searches. The final number of documents analysed, including academic and grey
142 literature, was 22 (see Table A. 1).

143

Figure 1. PRISMA 2020 flow diagram of the systematic review of definitions of circular economy applied to agriculture.



Source: our elaboration based on the format of Page MJ, et al. BMJ 2021;372: n71. Doi: 10.1136/bmj.n71.

Figure A. 1 presents the flow diagram with information about the selection of documents for the second stage literature review, following the PRISMA approach. We found 57 records during database search. After removing duplicates, we screened 55 records, from which we reviewed 18 full-text documents, and finally included 12 documents (see Table A. 3).

Building on the literature defining circular economy applied to agriculture and the literature defining circular bioeconomy, we performed a conceptual comparison of the two perspectives. This analysis examines how each concept frames circularity, with particular attention to their respective principles and economic, social, and environmental aims.

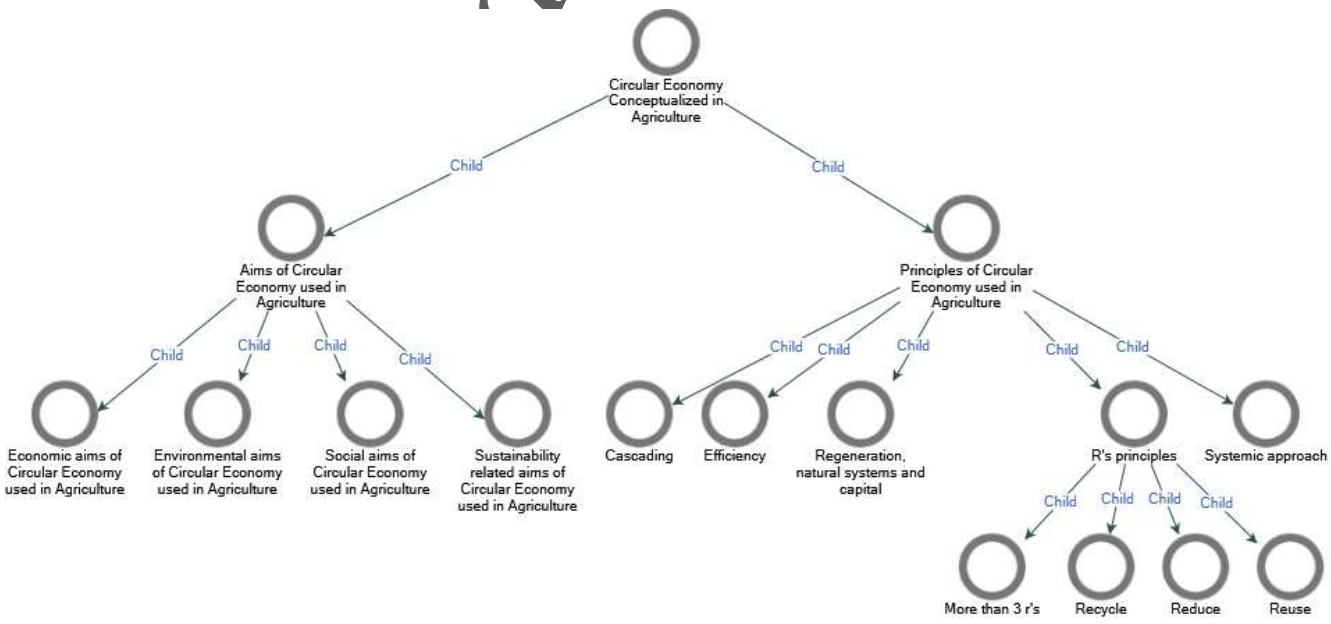
3. Results

The following text presents the coding framework used to analyse the information collected through the literature review, which leads to the replies to the research questions. Section 3.1 replies to the first research question by identifying the principles that define the circular economy in agriculture; section 3.2 replies to the second research question on the relationship between circular economy and sustainability aims, and finishes by presenting the new comprehensive definition of circular economy in agriculture which englobes principles and aims; while section 3.3 defines circular bioeconomy and its relationship with the definition of circular economy in agriculture.

The coding framework for circular economy applied to agriculture, generated after analysing the collected literature, is presented in Figure 2. This figure is a graphic representation of how the concept of circular economy in agriculture has been structured: the connection between the ideas is represented by straight lines connecting the nodes, a “child” is a subordinate idea depicted at a lower level, and “sibling” ideas are the ones represented at the same horizontal level. Figure 2 identifies five core principles: cascading, efficiency, regeneration, systemic approach, and the R’s principles.

The aims of the circular economy applied to agriculture are categorised as economic, social, environmental, and those explicitly referring to sustainability. This classification of the aims enables recognising the difference between circularity associated explicitly with sustainability and its three pillars and circularity associated with aims only in economic, social, or environmental aspects. With this categorisation of the aims we intend to identify if the common critique of circularity's relationship with sustainability applies also to the agricultural sector, meaning that when circular economy is said to be sustainable, it refers to economic and environmental sustainability only, leaving behind social sustainability (Schöggl et al., 2020). Furthermore, we contribute to the broader discussion about the components of sustainability, which suggests that the unjustified use of the three-pillar model may blind us from a better understanding of the complex synergies and trade-offs between the three pillars of sustainability (Purvis et al., 2019).

Figure 2. Coding framework map of the concept of circular economy applied to agriculture.



Source: our elaboration

3.1. Circular economy principles in agriculture

Looking at the words mentioned in the literature (see Figure A. 2), the principles of circular economy in agriculture refer to "Waste" and "Products", discussing closing the loop production patterns, reducing waste, effectively managing waste, and using waste as a resource.

The most used principles are the R's - reduce, reuse, and recycle (see

Figure A. 3**Errore. L'origine riferimento non è stata trovata.**). Within the R's principles, "recycle" is the leading topic, followed by "reuse", while "reduce" is mentioned in less than 50% of the documents analysed. Recycling refers to closing the loop for waste, such as using agricultural and livestock residues to generate agricultural inputs. Yuille et al. (2022) refer to recycling as a way to design out waste and obtain resources to replenish the system's self-supporting capacity, while the Ellen MacArthur Foundation (2019b) and Ruiz et al. (2009) add that waste passes from being a cost to a potential source of value. Furthermore, Fassio & Tecco (2019) and Pimbert (2012) go back to the foundation of the circular economy, mentioning that the principle of recycling originates from the proposal of mimicking the dynamics of natural ecosystems adopted by industrial ecology[2].

Reusing includes the conservation of water, secondary raw materials, and food. Food redistribution is recognised as a more valuable use of resources than recycling (Ruiz et al., 2019). Recycling is only recommended when reusing is impossible, as when food surplus becomes food waste. Food waste is generated when edible food surplus becomes inedible due to the lack of preparation or preservation (Jurgilevich et al., 2016). Food redistribution improves the environmental performance of the whole agri-food value chain. Unclaimed food

[2] Industrial ecology proposed increasing efficiency whilst decreasing the use of non-renewable resources in agriculture (Pagotto & Halog, 2016; Trokanas et al., 2014).

implies unnecessary greenhouse gas emissions during production, processing, transportation, storing, distribution and retail (Papargyropoulou et al., 2014).

Reducing in agriculture means minimising the use of natural resources, chemical fertilisers, food waste, and pollution. The reduction is motivated by the finitude of resources (Jurgilevich et al., 2016; Paño Yañez, 2021) and to separate income from material inputs (Pimbert, 2012). Jun & Xiang (2011) define reducing as the diminished use of scant and non-renewable resources, keeping fixed production and consumption targets. Conversely, Barañano et al. (2021) consider the principle of reduction as a general decrease in the number of resources used and the quantity extracted, the number and amount of products discarded. The circular economy is also expected to reduce pollution (Therond et al., 2017), by using local inputs in opposition to a globalised food system based on commodity trade.

Cascading, which means using resources sequentially and consecutively at their highest value (Ellen MacArthur Foundation, 2019c), is considered by only 60% of the documents assessed. Cascading is commonly referred to as "optimising" the management of the stock of resources (Fassio & Tecco, 2019; Paño Yañez, 2021). Barañano et al. (2021) explain that cascading is applied when biomass is converted into products, the waste from this process is used as input for a lower-level production, this step is repeated until the waste can no longer be transformed into products, and finally, the waste is burned to provide energy. The highest-value use of resources is based on prioritizing plant biomass for human food production. In this hierarchy, edible biomass should first be used to produce food for humans, by-products should be reused or recycled, and inedible biomass should be used as animal feed. Livestock can then convert this biomass into additional food, manure, and ecosystem services (Van Zanten et al., 2019; Velasco-Muñoz et al., 2021). However, the opportunities for valorising residues and by-products are determined by the purity of the waste and the effectiveness of the collection system (Ellen MacArthur Foundation, 2019b).

3.2. *The relationship between circular economy in agriculture and sustainability*

Circular economy applied to agriculture targets sustainability mainly through environmental and economic aims, and least frequently, though still considered by 70% of the documents analysed, social aims (see Figure A. 4).

The environmental aims of the circular economy are the most extensively described. Figure A. 5 section a in the Annex presents the keywords used in their description, which refer to the environmental aims of using fewer inputs, generating less waste, and improving soil.

Table 1 shows the specific environmental aims of the circular economy with the reference documents mentioning them, which are the basis of the subsequent information. According to these documents, the circular economy in agriculture aims at restoring nature's balance, thereby shifting the agricultural sector from a contributor to climate change to a solution. This framework operates by maximizing resource efficiency, reducing pollution, and fostering the regeneration of soil, agrobiodiversity, and ecosystems. By alleviating the strain on natural ecosystems, the circular economy model simultaneously improves food production and rejuvenates marginal lands, preserving the integrity of landscapes. Crucially, the return of nutrients to the soil enhances food production, promotes carbon sequestration and mitigates pollution. Effective waste management practices, including composting, further amplify these results by conserving water resources. Such soil enhancements strengthen resilience against adverse weather conditions like wind, floods, and droughts. Additionally, soil improvement and waste management decrease the reliance on chemical fertilizers, thus diminishing resource extraction and lowering energy consumption and transportation-related pollution. Using local resources further minimises the environmental footprint of transportation activities. Moreover, strategies focusing on water demand reduction and wastewater reuse alleviate the strain on hydrological resources. Using waste for energy generation serves to both mitigate resource depletion and combat improper waste disposal practices.

290 Table 1. Environmental aims of the circular economy applied to agriculture.

Circular economy strategy	**Environmental aims**	**Reference**
Regenerate nature	Climate change solution	Velasco-Muñoz et al., 2021; Ellen MacArthur Foundation, 2019b; Freeman et al., 2022; Yuille et al., 2022
Resource efficiency, pollution reduction, and enhancing soil, agrobiodiversity and ecosystems	Climate change solution	De Rosa et al., 2021; Ellen MacArthur Foundation, 2019b; Pimbert, 2012; Therond et al., 2017; Velasco-Muñoz et al., 2021
Reduce stress on natural ecosystems	Improve environmental conditions of marginal lands while preserving landscapes	EIP-AGRI, 2015; Freeman et al., 2022; Paño Yañez, 2021
Soil improvements	Resilience to wind, floods, and droughts	Ellen MacArthur Foundation, 2019b; SYSTEMIQ & Ellen MacArthur Foundation, 2017
Composting residues	Improve soil	Bos & Broeze, 2020; Ellen MacArthur Foundation, 2019b; Yuille et al., 2022

Circular economy strategy	Environmental aims	Reference
Local resource use	Minimize pollution	Barcelos et al., 2021; Jurgilevich et al., 2016; Therond et al., 2017
Water demand reduction and wastewater reuse	Alleviate pressure on hydrological resources	Velasco-Muñoz et al., 2021
Carbon sequestration capacity enhancement	Reduce carbon emissions and improve resilience to environmental challenges	SYSTEMIQ & Ellen MacArthur Foundation, 2017
Waste used to produce energy	Reduce resource depletion and pollution from waste disposal	Barcelos et al., 2021; EIP-AGRI, 2015

Source: our elaboration

The aim of economic sustainability under the framework of circular economy is expected from the efficient use and reuse of materials, as well as logistic and resilience improvements (see Figure A. 5 section b in the Annex).

Table 2 shows the economic aims of the circular economy with the reference documents that mentions them, which are the basis of the subsequent information. According to these documents, the circular economy is expected to bring sustainable economic growth while reducing resource consumption. This is achieved by efficient resource use and recycling. Reducing excess nitrogen (N) and phosphorus (P) and reusing resources like water in fertirrigation improves productivity. Furthermore, the circular economy reduces dependence on costly and risky external sources like agrochemicals, transgenic technologies, and fossil fuels. Adopting circular practices also enhances resilience by promoting adaptation to climate change. Circularity is a way to achieve long-term higher yields and performance thanks to

304 environmental protection. Additionally, it encourages the renewal of infrastructure and the
305 creation of networks for better resource management, fostering innovation and multiple
306 revenue streams, such as generating income from biomass energy.
307
308 Table 2. Economic aims of the circular economy applied to agriculture.

Circular economy strategy	**Economic aims**	**Reference**
Efficient resource use and recycling	Economic growth	Burgo-Bencomo et al., 2019; De Rosa et al., 2021; EIP-AGRI, 2015; Ellen MacArthur Foundation, 2019a; Fassio & Tecco, 2019; Jun & Xiang, 2011; Ruiz et al., 2019; Velasco-Muñoz et al., 2021
Minimise resource use	Economic growth	Hens et al., 2018; Velasco-Muñoz et al., 2021
Valorisation of organic waste	Business opportunities	Ellen MacArthur Foundation, 2019b
Control excess N and P	Productivity improvements	Yuille et al., 2022
Regenerate nature	Benefit profitability	SYSTEMIQ & Ellen MacArthur Foundation, 2017
Reduced dependence on external agrochemical inputs, transgenic technologies, and fossil energy	Reduced costs and risks	EIP-AGRI, 2015; Pimbert, 2012; SYSTEMIQ & Ellen MacArthur Foundation, 2017; Yuille et al., 2022
Local transport of inputs	Reduced costs	Barcelos et al., 2021

Circular economy strategy	Economic aims	Reference
Environmental protection	Improved resilience, better incomes, higher yields	Ellen MacArthur Foundation, 2019a, 2019b; Freeman et al., 2022; SYSTEMIQ & Ellen MacArthur Foundation, 2017; Burgo-Bencomo et al., 2019; Ellen MacArthur Foundation, 2019a; Jun & Xiang, 2011; Kristensen et al., 2016; Velasco-Muñoz et al., 2021
Renewal of infrastructure and the formation of networks	Improved resource use	Barcelos et al., 2021; Fassio & Tecco, 2019
Innovative entrepreneurship	Multiple revenue streams	Ruiz et al., 2019; Velasco-Muñoz et al., 2021; EIP-AGRI, 2015; Ellen MacArthur Foundation, 2019a; Therond et al., 2017

309 Source: our elaboration

310 Social sustainability is aimed by circularity in agriculture through two main aspects:
311 human health protection and food security. Additionally, some mention improved human
312 capital and technology (See Figure A. 5 section c). Table 3 shows the social aims of the circular
313 economy with the reference documents mentioning them, which are the basis of the subsequent
314 information. The circular economy lessens the negative impacts of production that damage
315 human health, including extraction of raw materials, waste production, hazardous substances
316 emission, and pollution of soil, water and air. Besides, human health may benefit from the
317 consumption of food with a higher-quality nutrient profile. Circular Economy practices are

318 expected to increase soil organic matter and improve soil health, which can enhance nutrient
319 availability and favour micronutrient uptake by plants, potentially leading to crops with a richer
320 nutrient profile. Food security might also improve by reducing food waste and enhancing the
321 production and resilience of agriculture. Furthermore, energy and water security would
322 improve through reduced pollution and the use of renewable resources. The circular economy
323 might also reduce poverty because it allows farmers to have multiple revenue streams. The
324 participation and importance of women in business may also increase, as circular economy
325 provides an opportunity for the creation of new businesses in which women may contribute
326 and lead. Social development may be improved by promoting farmers' knowledge and
327 technology application to create biobased products. Moreover, circular economy in agriculture
328 is expected to allow farmers to improve their quality of life by investing in health and education
329 with the money they save through simplified logistics and self-sufficient production.
330
331 Table 3. Social aims of the circular economy applied to agriculture.

Circular economy strategy	**Social aims**	**Reference**
Reduced extraction of raw materials from nature, waste production, greenhouse gases and hazardous substances emission	Human health protection	Burgo-Bencomo et al., 2019; Ellen MacArthur Foundation, 2019a, 2019b; Kristensen et al., 2016; Yuille et al., 2022
Production of food with a higher-quality nutrient profile	Human health benefit	Ellen MacArthur Foundation, 2022; SYSTEMIQ & Ellen MacArthur Foundation, 2017

332

Circular economy strategy	Social aims	Reference
Reduction of food waste, enhanced production and resilience of food production systems	Food security improvement	Burgo-Bencomo et al., 2019; Fassio & Tecco, 2019; Jurgilevich et al., 2016; Kristensen et al., 2016; Yuille et al., 2022; Ellen MacArthur Foundation, 2019a, 2019b
Reduced pollution and production of energy from renewable sources	Energy and water security	Pimbert, 2012
Opportunity generator of multiple revenue streams	Poverty reduction	Pimbert, 2012; EIP-AGRI, 2015; Ellen MacArthur Foundation, 2019a
Innovation to create biobased products	Social development	Burgo-Bencomo et al., 2019; Fassio & Tecco, 2019
Participation and importance of women in business	Social development	Fassio & Tecco, 2019
Farmers' knowledge and technologies reinforcement	Social development	Fassio & Tecco, 2019
Costs reduction by simplified logistics	Health and education investments	Barcelos et al., 2021

333 Source: our elaboration

Based on the results of Section 3.1 and 3.2, we propose a comprehensive concept of circular economy applied in agriculture, which departs from the basics and reaches the objectives that emerge from the available documents:

"*Circular economy in agriculture is a comprehensive framework that integrates the principles of reusing resources and recycling waste through cascading processes that maximize resource value, it strives to reduce materials used whenever possible, with the ultimate goal of regenerating nature. This approach aims for numerous benefits for environment conservation, improving the condition of soil, water and air, and tackling climate change; thus, enhancing human wellbeing by improving health and nutrition, and consequently bringing opportunities for sustainable economic growth.".*

3.3. Circular bioeconomy concept and its relationship with circular economy in agriculture

In this section we present the results of the search for the definition of circular bioeconomy which drives the identification of the relationship with the concept of circular economy in agriculture.

The definition of circular bioeconomy is not unique; it is influenced by the definition of bioeconomy from which the literature departs. Nevertheless, most documents agree that the circular bioeconomy relies on using bioresources while applying some circular economy principles, from which cascading is central (Jarre et al., 2020). A common statement is that circular bioeconomy constitutes the way towards zero waste (Barañano et al., 2021; Hodson de Jaramillo, 2018a). However, the paper by Giampietro (2019) marks a straight difference from the other publications. It states that the circular economy represents the target outcome of decoupling resource use from natural resources, while the bioeconomy describes the biophysical processes needed to achieve this result. Konstantinis et al. (2018) combine both approaches, considering that circular bioeconomy means using non-fossil resources for

359 complete economic exploitation while preserving environmental sustainability. Liobikienė &
360 Miceikienė (2023) extend this analysis, indicating that the final aim of circular bioeconomy is
361 improving sustainability. Yet, in a couple of cases, the circular bioeconomy is tightly associated
362 with technological advances and biorefineries are part of its definition (Ptak et al., 2022).

363 A few recent documents compile previous publications to propose a synergistic
364 definition, gradually driving towards the definition of circular economy in agriculture. Tan &
365 Lamers (2021) and Tolić (2022) compare a series of definitions of the circular bioeconomy,
366 they cite Giampietro (2019), Ptak et al. (2022), Robert et al. (2020), and others highlighting
367 efficient use of biobased renewable resources. Tan & Lamers (2021) propose that circular
368 bioeconomy is a synergy of circularity and bioeconomy, focused on carbon management. Tolić
369 (2022) expands this concept to include reduced resource consumption, recovery, waste
370 recycling, and as last resource safe disposal. Other documents are on the way to this
371 compilation, including in the concept of circular bioeconomy some aspects of circular economy
372 in agriculture that are not commonly used. Pyka et al. (2022) define circular bioeconomy as
373 using biomass effectively and efficiently through cascading, recycling, reusing, and reducing
374 waste. However, the reduction mentioned in this study referred to waste only, rather than inputs
375 consumed. Ptak et al. (2022) align more closely with the circular economy aims, addressing
376 pollution and costs of resources transport. According to Therond et al. (2017), the circular
377 bioeconomy is an improvement of bioeconomy in territorial socio-economic dynamics,
378 aligning with the systemic approach of circularity in agriculture.

379 Sustainability and climate change are frequently mentioned in the description of circular
380 bioeconomy, while the strategies to achieve improvements in the three pillars of sustainability
381 are not identified. According to Ptak et al. (2022) sustainability and resource efficiency are part
382 of the definition of a circular bioeconomy, similarly Pyka et al. (2022) define circular
383 bioeconomy as an extension of bioeconomy to achieve goals in sustainability and climate

384 change. On the contrary, Tan & Lamers (2021) argue that circular bioeconomy does not mean
385 sustainability. This argument is supported by studies in which the circular bioeconomy aims
386 for sustainability when complying with conditions like cascading for optimum valorisation of
387 biomass (Barañano et al., 2021) or a systemic approach including different sectors and nations
388 (Hodson de Jaramillo, 2018a).

389 Economic and environmental aims are the most commonly mentioned within circular
390 bioeconomy, based on the conservation of biomass and reduced extraction and dependence on
391 natural resources (Tan & Lamers, 2021). Addressing climate change is an expected result
392 mentioned in the 2020s (Barañano et al., 2021; Ptak et al., 2022; Pyka et al., 2022; Tolić, 2022).
393 Aims for human well-being are not frequently mentioned, except for Tolić (2022) who
394 underlines that the safe disposal of unavoidable waste should benefit human health. The
395 circular bioeconomy, like the circular economy applied to agriculture, is expected to bring
396 sustainability benefits and tackle climate change, but the concept of circular economy applied
397 to agriculture presents a clearer description of the strategies to achieve these aims.

398 **4. Discussion**

399 *4.1. Discussion on circular economy principles in agriculture*

400 According to the most used terms to define circular economy in agriculture, managing
401 waste to close loops is the idea behind this framework. Research about agricultural waste has
402 experienced exponential growth during the last 20 years. Duque-Acevedo et al. (2020) explain
403 that government and academic authors have influenced the direction of the studies to focus on
404 maize and wheat waste management due to the relevance of their production in the places of
405 research. Furthermore, the consistent application of measurement tools for agricultural waste
406 may facilitate monitoring and understanding the implications of waste reduction. In the EU, up
407 to the year 2018, there was no clear definition or common measurement method for waste.
408 Wastes and byproducts have been considered only marginally in literature, they are not

409 adequately conceptualised in economic terms, and the circularity of flows is not usually
410 highlighted (Viaggi, 2022).

411 According to most of the documents analysed, circular economy is based on the
412 principles of recycling, reusing, regenerating natural systems, and cascading the use of
413 resources. Nevertheless, in agreement with Velasco-Muñoz et al. (2021), the application of
414 circular economy in agriculture generates an overlapping of principles through specific
415 techniques, like combining livestock raising and crop production activities. Several circular
416 economy principles, namely, reducing, reusing, and recycling, applied through these
417 techniques, still need to be recognised by literature, which has tended to simplify these
418 interactions and define them as recycling only. In this direction, recent research proposes the
419 adaptation of circularity indicators to biological and agricultural goods by integrating the
420 assessment of waste generation with the evaluation of product performance, measured through
421 yield efficiency and the bioavailability period of agricultural inputs (Escribà-Gelonch et al.,
422 2023).

423 The principle of reducing is the least mentioned within the three R's, maybe due to the
424 thought that reducing resources used would constitute a barrier to economic growth. There has
425 been a hesitant inclusion of this principle in previous research; Velasco-Muñoz et al. (2021)
426 indicate that the goal of circular economy in agriculture is not to minimise (reduce) the use of
427 resources, but to keep cycles (either recycling or reusing) which would benefit economic and
428 environmental aspects; nevertheless, the same authors mention that the principle of reducing
429 should become integral to the circular economy due to its efficiency benefits. Indeed,
430 practitioners' expectations from the circular economy and policies that promise economic
431 growth without highlighting the limits of natural resources tend to mould the development of
432 the circular economy. This is a critique recognised in previous research (Giampietro, 2019;
433 Kirchherr et al., 2017; Korhonen, Honkasalo, et al., 2018), and, Temesgen et al. (2021) explain

434 that relying on recycling ignores ecological economists' concern regarding the actual economic
435 model's dependence on increased consumption and production, instead of a sustainable scale
436 of production targeting human wellbeing.

437 Unfortunately, the scarce inclusion of the principle of reduction is also evidenced in the
438 definition of circular economy in agriculture. The effect of "reducing" on economic,
439 environmental, and social wellbeing must be considered by policymakers, who support actions
440 that may not bring substantial economic benefits to the industry but could benefit people's
441 welfare. The livestock sector illustrates this tension, as reducing production inputs and
442 pollution levels can improve environmental outcomes. A reduction in livestock production may
443 be facilitated by redistribution strategies, accounting for local animal-feed resources, land
444 availability for manure distribution, and potential manure exports to neighbouring areas which
445 rely on synthetic fertilizers (Madelrieux et al., 2023). Yet, literature emphasizes the need for
446 more information about biomass flows to effectively implement such strategies (Dourmad et
447 al., 2019).

448 The principle of regeneration of natural systems has been increasingly used and is basic
449 for achieving most sustainability aims. Contrary to the results of Velasco-Muñoz et al. (2021),
450 who indicated that most documents discussing circular economy in agriculture analyse
451 technical efficiency, the definition of circular economy in agriculture talks about the best
452 management of resources to regenerate nature. This is positive, as, at least from a theoretical
453 point of view, circular economy in agriculture is driving towards sustainability, considering the
454 negative long-term effects of a narrow focus on efficiency. Focusing on the regeneration of
455 natural systems may be essential to achieving the expected benefits from the circular economy
456 in countries that have already advanced in circularity strategies. For instance, Italy has
457 improved its efficiency in resource use during the last 20 years, it reached a significantly low
458 rate of landfill disposal of waste among the EU countries and invested in one of the most

advanced systems of organic waste management (Ministero dell'Ambiente e della Tutella del Territorio e del Mare, 2017). Yet, the circular economy is considered a pathway to face Italy's scarcity of raw materials. Complementarity between the applicability of circular economy principles and theoretical research may facilitate their effective implementation.

The increased use of the term regeneration has led to a deeper evaluation of its application. In this respect, Morseletto (2020) highlights the difficulties in measurement, which impact the application of this principle. Quantifying environmental and economic damages from production is challenging due to complex interactions and unknown regeneration time, while assessing soil regeneration's value and costs is also difficult. Nevertheless, the importance of this principle has not diminished and is considered a metaphorical framework, meaning the *"ability of nature to revive itself, recover from disturbances, and rebuild its functions*" (Morseletto, 2020: 769), that in agriculture is translated into fertility promotion, nutrient cycling, and ecological services (Arfini et al., 2025; Vollaro et al., 2017).

4.2. The relationship between circular economy in agriculture and sustainability

The environmental aims are cited in most literature defining circular economy applied in agriculture, and their description is the most detailed. The definition of circular economy in agriculture has benefited from a clearer identification of its expected achievements compared to the circular economy general definition, which has been criticised for poorly reflecting the position of natural capital and ecosystem services (D'Amato & Korhonen, 2021). Likewise, a common agreement in literature is that circularity in agriculture should be part of the solution to climate change (Abitabile et al., 2024), although proper quantification still needs to be developed. Cantzler et al. (2020) identified low greenhouse gas saving potential in agriculture in comparison to other industries; however, studies quantified the impacts of energy and waste management and efficiency, while regenerative agriculture and recycling nutrients, although promising, have not been evaluated (Deloitte, 2016; Ellen MacArthur Foundation, 2019b).

While the theory has advanced in identifying the possible environmental results of circular economy in agriculture, ex-post assessments after the complete concept has been applied still need development and generalisation (Escobar et al., 2025).

The economic aims are the second most mentioned. Economic growth is expected from circularity in agriculture, which would address the problem of population growth and limited resources by minimising resource use. The aim of economic growth has also called more attention in the general definition of circular economy; the first research of Kirchherr et al. (2017) identified no meaningful mention of economic growth, while in 2023 around 15% of the definitions included it (Kirchherr et al., 2023). On the other hand, circularity in agriculture also aims to improve economic resilience due to the protection of the environment, which in turn brings social benefits in food security and protects human health. Indeed, about 70% of the documents that mention sustainability as the objective of circular economy applied to agriculture also include social aims. The inclusion of social aims is an improvement in comparison to documents revising the general definition of circular economy (El Wali et al., 2021; Kirchherr et al., 2017, 2023; Murray et al., 2017).

Summarising the relationship between circular economy in agriculture and sustainability, we conclude that the circular economy supports an embedded systems approach to sustainability, aligning with other concepts in the EU political agenda, like the EU Bioeconomy strategy (Viaggi, 2019). Hence, it requires passing from the three-pillar structure of sustainability to an embedded system approach, which has sustainability of the biosphere as a base, enclosing society, and sequentially, economy (Fritsche et al., 2020). On the other hand, even though sustainability aims from the circular economy are extensive, equating these aims with quantifiable relationships is not straightforward. Shadow prices could play a crucial role in reflecting the impacts of circularity on sustainability, going beyond economic gains to environmental and social effects that are scarcely measured. Water pollution is an example

where calculating shadow prices could reflect the advantages of circularity. Koundouri et al. (2014) highlight that reliable pricing data for natural resources is scarce, and by estimating the shadow price of groundwater, policymakers could design pumping taxes that encourage farmers to reduce groundwater pollution and aquifer depletion.

Shadow prices are rarely applied in agricultural policy decisions, contributing to the failure to achieve environmental objectives (Huhtala & Marklund, 2008; Mamardashvili et al., 2016). Mamardashvili et al. (2016) explain that the high costs of pollution abatement in Swiss farms pose significant political challenges to implementing effective nitrogen surplus taxes. Furthermore, Huhtala & Marklund (2008) found that farms act within the manure application limits, therefore, shadow prices are very high. High shadow prices suggest that innovative circular economy practices may be necessary to face persisting environmental issues, particularly for intensive animal breeding where manure management remains challenging.

While shadow pricing of environmental impacts has been explored to a wider extent, its application to social aspects remains limited. Ait Sidhoum (2018) made an initial attempt to quantify social outputs from agricultural production technologies in the EU. The results suggest that social outputs - like consumer health, food security, local economic stability, rural community cohesion, and employment retention - have positive shadow prices, aligning with farmers' private interests; however, subsidies may be necessary in efficient farms that tend to prioritise private gains over social and public goods.

The definition of circular economy applied to agriculture proposed at the end of section 3.2 is driven by a wider consensus in principles and aims in comparison to the general definitions used for the circular economy. Previous research found a lack of agreement in the literature about the concept of circular economy (Kirchherr et al., 2017), with interpretations depending on the interests of its users (Korhonen, Nuur, et al., 2018). Aiming to simplify the diversity in definitions, the principles were classified into the 3R's and sustainable design

strategies – i.e. eco-design, nature-inspired design, and cradle-to-cradle (Prieto-Sandoval et al., 2018). However, in contrast to the opinion of Kirchherr et al. (2023) who fear that industry-specific studies will constitute a barrier to the broader applicability of the circular economy, we see that the focus on the agricultural sector facilitates agreement in understanding the framework while targeting its application to industry-specific resources.

Our results also suggest that the consensual definition of circular economy applied in agriculture coincides with the latest general definition of circular economy, in using recycling and reusing as principles, and sustainability as the main aim (Kirchherr et al., 2023). Furthermore, our research identified that in agriculture, the social pillar of sustainability is commonly cited, in comparison to the general definition of circular economy. The increased use of the principle of regeneration was also noted in the general definition of circular economy applied in agriculture (Kirchherr et al., 2023).

4.3. Circular bioeconomy concept and its relationship with circular economy in agriculture

We conclude that circular economy in agriculture may be considered overarching and synergistic to circular bioeconomy. This means they are not interchangeable terms, despite the common undifferentiated use. This confusion may be driven by the roots of the concepts: circular economy was mostly focused on urban contexts, while bioeconomy was defined for rural areas (D'Amato et al., 2017). Nevertheless, circularity in agriculture includes processes that involve non-biological cycles, such as the prioritization of local inputs and the efficient use of synthetic materials (Velasco-Muñoz et al., 2021). Circular economy applied in agriculture should have a synergistic effect on bioeconomy by promoting the efficient use of resources, hence making biomass availability and use sustainable. While cascading is not mentioned by more than 60% of the definitions of circular economy applied in agriculture, the

558 term is essential in circular bioeconomy definitions. This is due to the belief that cascading is
559 the most effective way to close the loop when managing biomass.

560 The cascading use of biomass is considered a way to claim circularity and sustainability
561 according to policies, as it protects natural capital and the provision of ecosystem services.
562 Policies promoting the circular economy recognise that cascading can maximise sustainability
563 by first using residues to enrich soils, leaving energy production as a lower value option
564 (Ministero della Transizione Ecologica, 2022). Policymakers also mention the role of
565 cascading in promoting efficient resource use (European Commission, 2015).

566 Indeed, the synergy between circular economy applied to agriculture and circular
567 bioeconomy is necessary to achieve the sustainability expectations of both terms. They are
568 complements, as was suggested by D'Amato et al. (2017). Both models target sustainability
569 improvements and tackling climate change. However, circular bioeconomy tends to focus on
570 economic and environmental aims, while societal outputs are overlooked due to the technical
571 focus of the framework (D'Amato & Korhonen, 2021), confirming the weakness of a
572 technology-based approach versus a socio-ecological one (Priefer et al., 2017). Finally, both
573 target economic growth. Nevertheless, sustainable economic growth is still a contested benefit
574 from these frameworks, as the literature explains that their aims may be contradictory, resulting
575 in weak sustainability (D'Amato et al., 2017; Murray et al., 2017; Tomaselli et al., 2017).
576 Complete assessments of the economic, social, and environmental results from the application
577 of these concepts may bring a clearer idea of their limitations.

578 Policy documents about circular economy and circular bioeconomy collect information
579 from scholars and practitioners about the principles, strategies, and sustainability aims of these
580 approaches, but raw conceptualizations of these terms, which focus only on technical aspects,
581 may mislead from the expected benefits. Alternatively, technical limitations should be
582 mentioned more clearly in policies to make their expectations more credible. As recognized by

583 Kirchherr et al. (2023), when defining circular economy academics, policymakers, and the
584 private sector each can obtain benefits from learning from the other.

585 **5. Conclusions**

586 In this paper we intended to construct a consensus concept of circular economy applied
587 in agriculture. We found that the vast majority of literature, including academics and
588 practitioners, define this concept as a model founded on waste management through the 3Rs,
589 which expects to achieve sustainability in its three pillars through the regeneration of nature.
590 The concept of circular economy applied in agriculture can benefit from the circular
591 bioeconomy approach that prioritizes the cascading of biomass to achieve high efficiency when
592 striving towards zero waste. Furthermore, generalized guidelines on the meaning and
593 application of circular economy are needed to avoid deviations from the sustainability
594 objectives towards merely technical or economic interests. Future economic, social, and
595 environmental wellbeing may depend on the application of circular economy practices,
596 therefore, continuous advancement in solving the main barriers to this framework is
597 fundamental, together with adequate tools to follow up on the progress toward circular
598 economy aims. Nonetheless, we must remember that circular economy is not the panacea to
599 achieve all possible sustainability solutions, but a beneficial framework, when properly applied
600 according to the needs and capacities of each location.

601 Our study identified needed directions of future research, which mainly relate to the
602 measurement of the application and benefits of circular economy. A constant question concerns
603 whether the broad strategies and aims of the circular economy can be achieved. In this context
604 and considering the increasing promotion of the circular economy in EU regulation, we
605 discussed the relationship between the definition of circular economy in agriculture, policies,
606 and measurement tools needed to assess policy objectives. Existing research has centred on
607 assessing specific aspects guided by policies and new technologies, such as energy production

from biomass, leaving aside fundamentals of circularity like an exhaustive measurement of waste. Furthermore, evaluating the environmental and social damages of production and the counteracting power of circular economy remains a challenge for which frames of evaluation, like shadow prices, need to be extended.

A limitation of this study is the use of only one database for the literature review. We chose the Scopus database from Elsevier because it is an internationally recognized source that includes a vast number of scholarly articles, but more information to enrich this study could be obtained from other popular databases. Furthermore, having a single researcher carry out the coding process carries potential interpretative bias. Although we applied a structured coding protocol within NVivo and engaged in continuous peer discussions to mitigate this risk, future studies could enhance reliability through inter-coder agreement measures. Moreover, we did not include external experts during the construction of the coding framework. Expert opinions may further improve the understanding of the common aspects expected from the concept of circular economy. Finally, we recognize that the definition of circular economy in agriculture is a changing concept, which will be affected by new technologies, practices, and expectations, but we hope that this research serves as a starting point for more synergies in the theory and practice of this concept.

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Annex 1

1. First stage literature review

The first stage of the literature review was collecting definitions of circular economy applied to the agricultural sector. The documents selected aim to define circular economy in agriculture, state a definition of circular economy and present cases in which circularity is applied in agriculture or farms, followed by indicators to evaluate circularity at the micro level with measurements applicable to agriculture. Documents published in any year up to October 2025 were included, as this research aims to assess a global concept of circular economy in agriculture.

Academic literature was retrieved from the Scopus database from Elsevier, in October 2025. The expressions searched were:

- "circular economy" AND "definition" AND "agriculture"
- "circularity" AND "definition" AND "agriculture"
- "circular economy" AND "meaning" AND "agriculture"
- "circularity" AND "meaning" AND "agriculture"
- "circularity" AND "farm level"
- "circular economy" AND "farm level"

Additional academic and grey literature was identified using the "snowball" method, by reviewing the reference lists of publications eligible for full-text review. First-level references were screened, applying the same inclusion criteria as for the database-collected documents. We included grey literature since significant contributors to the development of the circular economy involve non-academic entities (Schut et al., 2016; Velasco-Muñoz et al., 2021).

1023 Additional grey literature was retrieved from the Ellen MacArthur Foundation[3] webpage, due
1024 to the relevance of this organisation targeting the conceptual and practical development of the
1025 circular economy.

1026 The list of academic and grey literature retrieved was skimmed according to the
1027 following criteria: i) exclusion of documents that focus on the application of the circular
1028 economy without first explicitly analysing its definition, or ii) exclusion of documents that
1029 analyse circularity in other levels of the value chain, not agriculture or farm level (see Figure
1030 1 in the main document for the resulting excluded items). Table A. 1 shows the 22 final
1031 documents analysed.

1032

1033 Table A. 1. Database containing the reviewed literature about the circular economy in
1034 agriculture.

No.	Authors and Year	Document title	Link
1	Barañano et al., 2021	Contextualization of the bioeconomy concept through its links with related concepts and the challenges facing humanity	https://www.mdpi.com/2071-1050/13/14/7746
2	Barcelos et al., 2021	Circularity of Brazilian silk: Promoting a circular bioeconomy in the production of silk cocoons	https://www.sciencedirect.com/science/article/pii/S0301479721014353
3	Bos & Broeze, 2020	Circular bio-based production systems in the context of current biomass and fossil demand	https://onlinelibrary.wiley.com/doi/full/10.1002/bbb.2080

[3] The Ellen MacArthur Foundation is a non-profit organisation committed to creating a circular economy. It works with business, academia, policymakers, and institutions to mobilise systems solutions, produces evidence-based research, offers formal learning opportunities, and develops resources to support effective policies, innovative business models, and better product design (Ellen MacArthur Foundation, 2025).

4	Burgo-Bencomo et al., 2019	The Economy circular a sustainable alternative for the development of agriculture	http://bdigital2.ula.ve:8080/xmlui/bitstream/handle/654321/6527/a19v40n13p02.pdf?sequence=1&isAllowed=y
5	De Rosa et al., 2021	The Root towards More Circularized Animal Production Systems: From Animal to Territorial Metabolism	https://www.mdpi.com/2076-2615/11/6/1540
6	EIP-AGRI, 2015	EIP-AGRI Workshop 'Opportunities for Agriculture and Forestry in the Circular Economy' Workshop Report 28-29 October 2015	https://ec.europa.eu/eip/agriculture/sites/default/files/eip-agri_ws_circular_economy_final_report_2015_en.pdf
7	SYSTEMIQ & Ellen MacArthur Foundation, 2017	Achieving 'growth within'	https://www.ellenmacarthurfoundation.org/achieving-growth-within
8	Ellen MacArthur Foundation, 2019a	Cities and Circular Economy for Food	https://emf.thirdlight.com/link/7ztxaa89xl5c-d30so/@/preview/1?o
9	Ellen MacArthur Foundation, 2019b	Completing the Picture: How the Circular Economy Tackles Climate Change	https://emf.thirdlight.com/link/w750u7vysuy1-5a5i6n/@/preview/1?o
10	Ellen MacArthur Foundation, 2022	A circular economy for food will help people and nature thrive	https://ellenmacarthurfoundation.org/topics/food/overview
11	Fassio & Tecco, 2019	Circular Economy for Food: A Systemic Interpretation of 40 Case Histories in the Food System in Their Relationships with SDGs.	https://www.mdpi.com/2079-8954/7/3/43
12	Freeman et al., 2022	On-farm circular technologies for enhanced sustainability: The case of Uruguay	https://www.sciencedirect.com/science/article/pii/S0959652622030517
13	Hens et al., 2018	On the evolution of "Cleaner Production" as a concept and a practice	https://www.sciencedirect.com/science/article/pii/S0959652617327427

14	Jun & Xiang, 2011	Development of Circular Economy Is A Fundamental Way to Achieve Agriculture Sustainable Development in China	https://www.sciencedirect.com/science/article/pii/S1876610211011982
15	Jurgilevich et al., 2016	Transition towards circular economy in the food system	https://www.mdpi.com/2071-1050/8/1/69
16	Kristensen et al., 2016	Enabling Sustainable Agro-Food Futures: Exploring Fault Lines and Synergies Between the Integrated Territorial Paradigm, Rural Eco-Economy and Circular Economy	https://link.springer.com/article/10.1007/s10806-016-9632-9
17	Pimbert, 2012	Fair and sustainable food systems: from vicious cycles to virtuous circles	https://www.iied.org/sites/default/files/pdfs/migrate/17133IIED.pdf
18	Ruiz et al., 2019	Measuring the circular economy: Frameworks, Indicators and Impact Management	https://foretica.org/wp-content/uploads/informe_medida_economia_circular_foretica.pdf
19	Therond et al., 2017	A new analytical framework of farming system and agriculture model diversities. A review	https://link.springer.com/article/10.1007/s13593-017-0429-7
20	Velasco-Muñoz et al., 2021	Circular economy implementation in the agricultural sector: Definition, strategies and indicators	https://www.sciencedirect.com/science/article/pii/S0921344921002275
21	Paño Yañez, 2021	Viability of circular economy in no industrialised countries and its adjustment to a proposal based on transformative economies: an approach to the Latin-American scenario	https://ojs.uv.es/index.php/ciriecespana/article/view/15979/18378
22	Yuille et al., 2022	UK Government Policy and the Transition to a Circular Nutrient Economy	https://www.mdpi.com/2071-1050/14/6/3310

1035 The time horizon covered is 2011-2025. While we did not define a time limit during the
1036 search of literature, the time frame covered by the identified documents is relevant, as 2011
1037 marks a turning point in the development of the framework. The Ellen MacArthur Foundation's
1038 active work began in 2011, popularising the discussion of this concept not only in research but
1039 also among businesses. Similarly, the European Commission's *Roadmap to a Resource*
1040 *Efficient Europe* was released in 2011, which is considered the first formal step toward a
1041 circular economy policy framework in the EU.

1042 The review included publications in English and Spanish. Spanish-language documents
1043 were analysed in their original language. Relevant concepts were translated into English during
1044 the coding process. All coding and framework development were conducted in English to
1045 ensure terminological and conceptual consistency across sources.

1046 *2. Coding process*

1047 We defined a coding scheme to classify the information of the definitions and facilitate
1048 the analysis. A coding scheme provides a structured approach to categorising and interpreting
1049 verbal data, converting it to numeric data suitable for analysis (Bourque, 2004). The coding
1050 framework is developed through an iterative process, departing from existing knowledge
1051 followed by inductive coding of the collected literature, where additional categories emerge.
1052 Our coding scheme is based on the framework used by Kirchherr et al. (2017), who summarised
1053 the concept of circular economy based on 114 definitions and defined their coding framework
1054 using experts' opinions, literature review and inductive refining. It consists of three
1055 dimensions: core principles, aims, and enablers.

1056 The core principles include the R's[4] and the systems perspective. The R's principles have
1057 long been used (Blomsma & Brennan, 2017) and recognised as fundamental to circular

[4] The R's principles refer to actions aimed at managing waste, most commonly include the 3 Rs: reduce, reuse, and recycle (Ghisellini et al., 2016; Kirchherr et al., 2017), but they have been extending to 4 or more Rs to include additional actions like recover (European Commission, 2008; Potting et al., 2017; Sihvonen & Ritola, 2015).

economy (Reh, 2013; L. Zhu et al., 2010; Q. Zhu et al., 2010). The composition and suggested order for the application of the R's principles vary in different studies. Reike et al. (2018) suggest that divergent perspectives on value retention options (R's principles) originate from the discipline of application: 3R's are used in the Circular Economy studied in the 2010 and over, while 4 to 6Rs dominate in studies on Reverse Logistics and Closed-Loop Supply Chain Management. Furthermore, the authors summarise a product "concept, design, and use" R's framework into 10 principles: R0 Refuse, R1 Reduce, R2 Re-sell/Ruse, R3 Repair, R4 Re-furbish, R5 Re-manufacture, R6 Re-purpose, R7 Re-cycle, R8 Recover energy, R9 Re-mine.

Additionally, since the early literature on circular economy emphasised a systems perspective (Davis & Hall, 2006; Zhijun & Nailing, 2007) and highlighted the need for fundamental changes, Kirchherr et al. (2017) specify that the circular economy requires a systems perspective, which implies change occurring at multiple levels. The principle of a systems perspective is classified into macro level (economy-wide structural changes), meso level (regional and supply-chain changes), and micro level (firms, products, and consumer changes).

Regarding aims, sustainability was identified as the primary objective, continuously highlighted by scholars, practitioners, and policymakers (Ellen MacArthur Foundation, 2013; European Environment Agency, 2016; Ghisellini et al., 2016) . Finally, for a broad definition, Kirchherr et al. (2017) included two enablers: consumers and business models.

For our coding process, we used the software NVivo®. The departure coding framework was adapted to the current research to include the main dimensions of the definitions assessed. An iterative coding process ensured consistency in assigning the codes to the coding scheme. In Table A. 2 we present examples of how text was assigned to the different codes.

1082 Table A. 2. Example of coding process application.

Text excerpt	**Code**	**Rationale**
"Circular economy is the road to achieve the harmonious development between economy and environment." (Jun & Xiang, 2011)	Environmental aims of Circular Economy used in Agriculture Economic aims of Circular Economy used in Agriculture	Natural resources protection and productivity
"The defining elements of a circular bioeconomy are the production of goods and the offer of services, based on bioresources, with high added value, and the planning on the use of bioresources/biomaterials in a cascaded way" (Barcelos et al., 2021)	Cascading	Maximising resources value by using them according to the cascading principle
"a circular economy searches for a balance between economic growth and environmental issues, through efficient resource utilization and recycling" (De Rosa et al., 2021)	Efficiency Recycling Environmental aims of Circular Economy used in Agriculture Economic aims of Circular Economy used in Agriculture	Based on efficient resource use and recycling Economic and environmental aims

1083 Source: our elaboration

Finally, we studied the coding results using figures and quantitative summaries. NVivo automatically calculated the number of references coded under each theme and sub-theme, we exported and graphed these results using MS Excel.

We acknowledge that a single-coder analysis may increase interpretative bias; hence, the structured coding protocol, theory-driven framework, transparent use of NVivo, and peer discussions were designed to mitigate this risk.

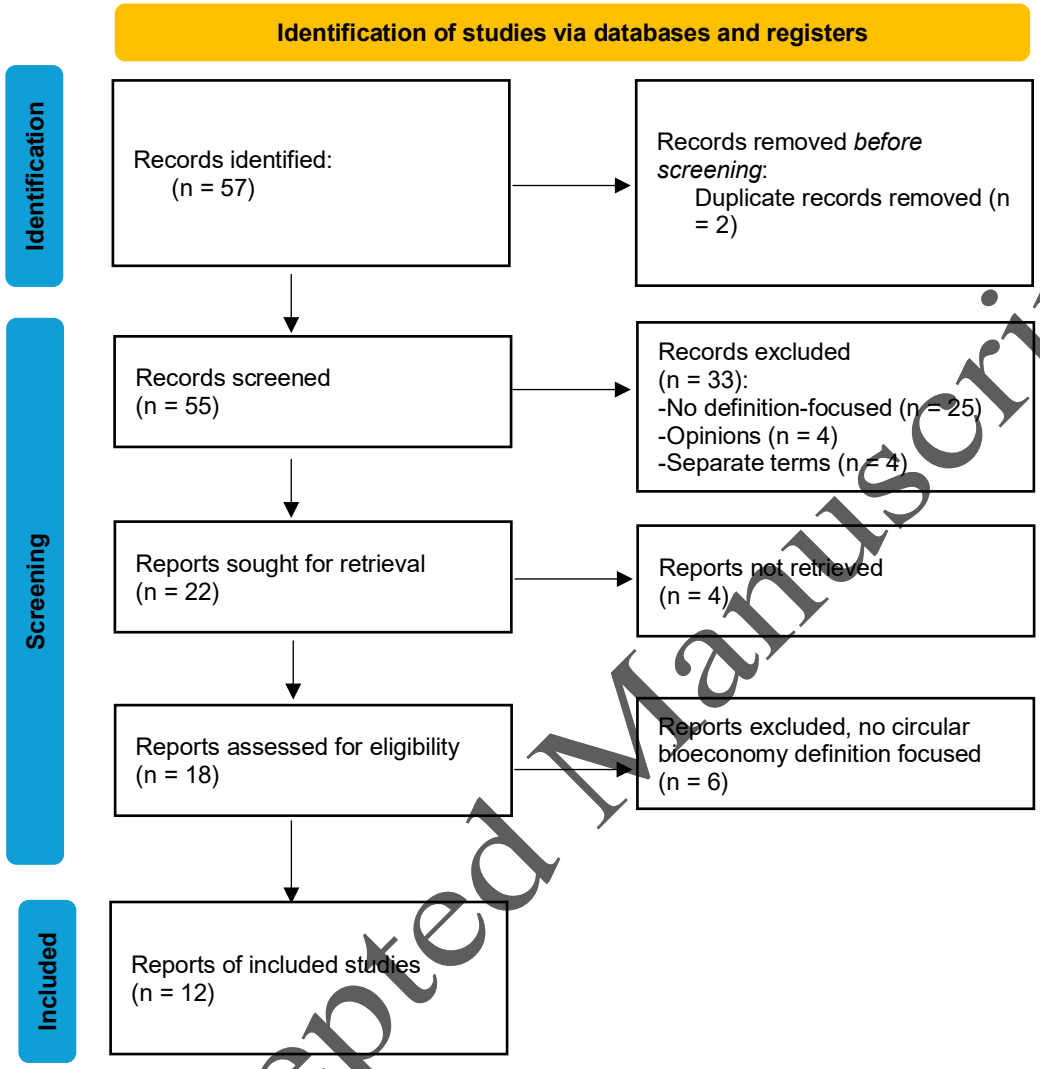
3. Second stage literature review

For the last section of this research concerning the comparison of the definition of circular bioeconomy to the definition of circular economy in agriculture, we performed a literature review in the Scopus database from Elsevier to identify the main principles and aims that define the circular bioeconomy. We looked for the expressions:

- "circular" AND "bioeconomy" AND "definition"
- "circularity" AND "bioeconomy" AND "meaning"

The literature retrieved was skimmed according to the following criteria: i) exclusion of documents that focus on the application of the circular bioeconomy without first explicitly analysing its definition, ii) exclusion of documents that present the opinions or perspectives of interviewees about the application of the circular bioeconomy without explicitly analysing its definition, or iii) exclusion of documents that analyse the circular economy or the bioeconomy definitions as separate terms only. Documents published in any year up to October 2025 – date of this search – were included, as this research aims to assess a global concept of circular bioeconomy. Figure A. 1 in the main document shows the selection process followed, while Table A. 3 shows the final documents analysed.

Figure A. 1. PRISMA 2020 flow diagram of the systematic review of definitions of circular bioeconomy.



Source: our elaboration based on the format of Page MJ, et al. BMJ 2021;372: n71. Doi: 10.1136/bmj.n71. This work is licensed under CC BY 4.0.

1148 Table A. 3. Database containing the reviewed literature about the circular bioeconomy.

No.	Authors and Year	Document title	Link
1	Barañano et al., 2021	Contextualization of the bioeconomy concept through its links with related concepts and the challenges facing humanity	https://www.mdpi.com/2071-1050/13/14/7746
2	Hodson de Jaramillo, 2018	Bioeconomy: A sustainable future	http://www.scielo.org.co/scielo.php?script=sci_arttext&pid=S0370-39082018000300188&nrm=iso
3	Giampietro, 2019	On the Circular Bioeconomy and Decoupling: Implications for Sustainable Growth	https://www.sciencedirect.com/science/article/pii/S0921800918317178
4	Jarre et al., 2020	Transforming the bio-based sector towards a circular economy - What can we learn from wood cascading?	https://www.sciencedirect.com/science/article/pii/S1389934118303708
5	Konstantinis et al., 2018	A Definition of Bioeconomy through the Bibliometric Networks of the Scientific Literature	https://agbioforum.org/wp-content/uploads/2021/02/AgBioForum-21-2-64.pdf
6	Liobikienė & Miceikienė, 2023	Contribution of the European Bioeconomy Strategy to the Green Deal Policy: Challenges and Opportunities in Implementing These Policies	https://www.mdpi.com/2071-1050/15/9/7139?type=check_update&version=3
7	Ptak et al., 2022	Sugar Beet Pulp in the Context of Developing the Concept of Circular Bioeconomy	https://www.mdpi.com/1996-1073/15/1/175?utm_source=researchgate.net&utm_medium=article
8	Pyka et al., 2022	Modelling the bioeconomy: Emerging approaches to address policy needs	https://www.sciencedirect.com/science/article/pii/S0959652621039767

9	Robert et al., 2020	Development of a bioeconomy monitoring framework for the European Union: An integrative and collaborative approach	https://www.sciencedirect.com/science/article/pii/S1871678420301357
10	Tan & Lamers, 2021	Circular Bioeconomy Concepts—A Perspective	https://www.frontiersin.org/articles/10.3389/frsus.2021.701509
11	Therond et al., 2017	A new analytical framework of farming system and agriculture model diversities. A review	https://link.springer.com/article/10.1007/s13593-017-0429-7
12	Tolić, 2022	Concepts of bioeconomy	https://www.taylorfrancis.com/chapters/edit/10.4324/9781003223733-2/concepts-bioeconomy-iva-toli%C4%87

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1150 Figure A. 2. Word cloud principles of circular economy applied to agriculture.

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1152 Source: our elaboration

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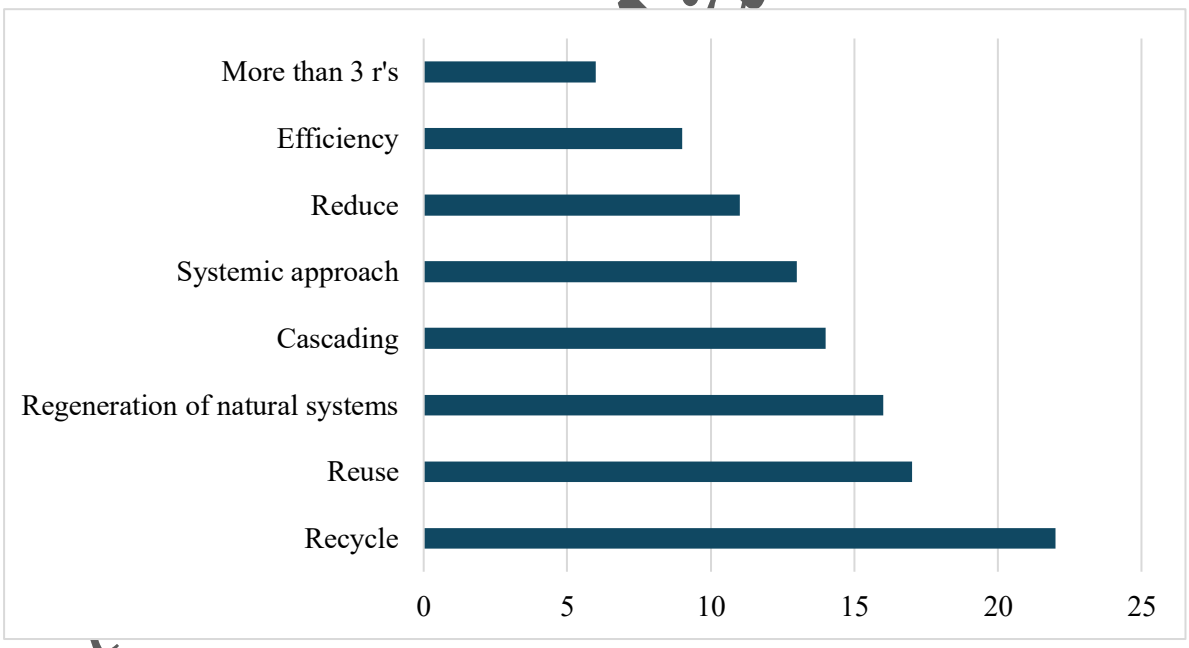
1154 Figure A. 3. Column chart of principles of circular economy applied to agriculture. Classified

1155 by number of documents coded.



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1157 Source: our elaboration

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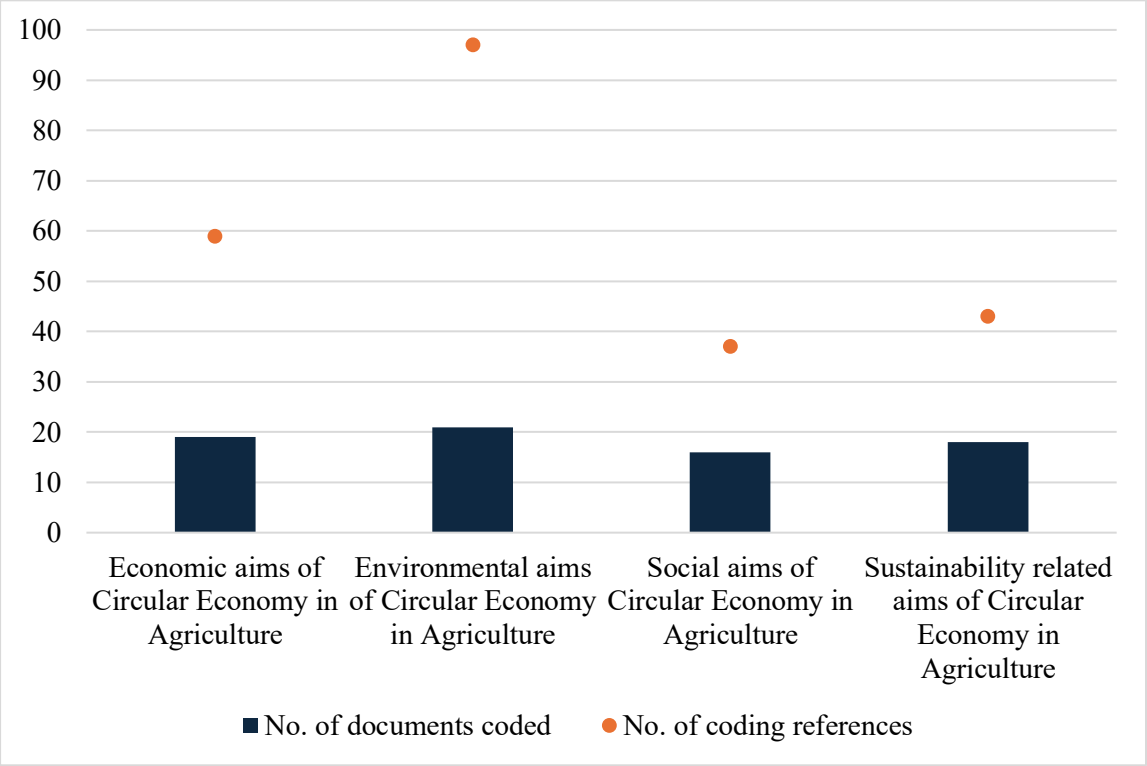
1161 Figure A. 4. Aims of Circular Economy in Agriculture: Number of documents coded and

1162 coding references.



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1164 Source: our elaboration

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1166 Figure A. 5. Aims of the circular economy applied to agriculture.

a) Environmental aims **b) Economic aims** **c) Social aims**

Source: our elaboration

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