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Review

The Circular Economy and the Food System: A Review of Principal Measuring Tools

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Abstract: With average food demand on the rise and increasing pressure on sustainability, it is essential to outline the cultural framework in which food systems are evolving, with the goal of studying solutions that target concrete actions and achieve communicable and more transparent results for the market and consumers. The objective was to analyze indicators, methods, and good practices, highlighting their positive aspects, criticalities, and possible gaps, for monitoring the impact the food system has on the environment, economy, and society from a circular economy perspective. A review of scientific literature was conducted to define the framework for implementing a circular economy in the food sector. The nations most involved in circular economy research with a focus on the food system were mapped, and circular strategies and indicators were classified according to the three different scales of implementation to which they apply: micro, meso, and macro. The literature review showed that most indicators focus on material flows and end-of-life strategies, without focusing on nutrient circularity in food systems and the circular bio-economy. This work suggests a potential and original framework for analyzing food and agriculture systems that can provide a holistic assessment of the impacts, actions, and outcomes achieved by these systems.

Keywords: food circular bio-economy; agri-food pattern; indicators; assessment models; experiences and good practices; system thinking

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1. Introduction

1.1. Circular Economy and Its Cultural Context

Environment and economy are two closely connected worlds that reciprocally influence each other. The equilibrium that regulates these two systems is compromised by various factors, in particular industrialization, which pushes for a model of economic growth centered on the quantitative consumption of goods. The growing exploitation of natural resources means that the economic system strengthens and weighs increasingly heavily on the environmental system [1]. In recent years, the circular economy (CE) has been receiving increasing attention around the world as a way to overcome the current production and consumption model based on continuous growth and an ever-greater flow of resources [2]. There is no question that it has become one of the most vital topics in public debates on new and more sustainable industrial paradigms and strategies [3]. Explaining what the circular economy is and what it represents is not simple, as it incorporates many concepts and numerous strategies, but the definition that can best contain, in our opinion, this multiplicity of aspects is the one proposed by Kirchherr et al. [4]: "an economic system that replaces the 'end-of-life' concept with reducing, alternatively reusing, recycling and recovering materials in production/distribution and consumption processes. The primary goal of the Circular Economy is to replace the dominant model of decades of linear economics, under which raw materials are extracted from the environment in order to be processed into final products and disposed of at the end of their useful life [3]. Such products are short-lived and designed for a single purpose. The idea of [the] Circular Economy is to extend the life cycle of these products while trying to limit the impact on the environment. It operates at the micro level (products, companies, consumers), meso level (eco-industrial parks) and macro level (city, region, nation and beyond), with the aim to accomplish sustainable development, thus simultaneously creating environmental quality, economic prosperity and social equity, to the benefit of current and future generations. It is enabled by novel business models and responsible consumers".

The circular economy could play a decisive role in the transition towards a process of degrowth (less use of resources with increased well-being) which seems inevitable in particular in those industrialized economies that have exceeded ecological limits [2,5]. By now, there is a general recognition of the need for valid monitoring and assessment tools able to gauge and quantify progress toward a more circular economy. Conceptually, circularity metrics should provide an indication of how well the principle of CE is applied to different levels. In literature, in fact, it is common to classify circular strategies or indicators based on the levels to which they are implemented. Therefore, three different implementation scales have been identified for the development of this research:

- Micro: products, services, businesses, consumers, etc.;
- Meso: eco-industrial parks, supply chain, industrial symbiosis, urban level, etc.;
- Macro: regions, nations, globe.

Micro means implementing circular economy principles in individual businesses; therefore, to evaluate the circular economy at this level, every company must set specific indicators based on their own characteristics, circumstances, and existing problems. At this level, the transition to a circular economy requires the adoption of greener production and ecological design. By promoting an improved use of materials and resources, eco-design can contribute to enhancing the circular economy approach as it considers all environmental impacts of a product from the initial planning phases [2,6].

Production plants, parks, and industrial networks are evaluated at the meso level. These sites are mostly specific to China, which represents one of the biggest producers and consumers of energy in the world. The elevated consumption of energy in the process industries creates many serious environmental problems. By applying circular economy and sustainable development concepts, measurement indicators will help to control the performance of these parks and ensure appropriate decisions are taken [7].

Lastly, implementation at a macro level (e.g., in cities) shows interesting improvements in circular economy aspects, such as zero waste programs in Japanese and Chinese eco-cities. Additionally, the indicators used and the monitoring of experiences of collaborative consumption (e.g., car sharing) seem to indicate that the quality of consumption models has an influence on environmental impacts. In both the European Union and China, the transition to a circular economy should bring about a separation of environmental pressure from economic growth. Some other countries, such as Japan, the United States, India, Brazil, and Russia, also strive for decoupling, but so far complete decoupling has only been reached in Europe and China for certain production models, sectors, and materials [2]. At the macro level, sustainability and circular economy indicators are necessary to evaluate, monitor, and improve various policies and programs.

Policymakers must have information available in order to be able to select specific indicators to fully cover the strategic objective of development and the sustainability of the circular economy [7].

1.2. Circular Economy in the Food System

One of the greatest challenges the world is facing is ensuring equitable access to food for a growing population with an increasing demand for food, while increasing pressure on sustainability puts a great strain on both the environment and society. On the global scale, the current food production system is transgressing the operational limits of environmental safety when it comes to nitrogen and phosphate use, biodiversity, and soil use, and is jeopardizing the global capacity to produce sufficient and nutritious food for the population [8].

In the last few years, concern about food security and resource conservation, increased interest in sustainable development that reduces food loss and waste, and the circular bioeconomy have contributed to increased public awareness [9]. In the context of food systems and waste management, "nutrient circularity seems to generally encompass the reduction of nutrient losses and increased recovery of nutrients from various organic residual streams for reuse in agricultural production" [10].

For nutrients, it is possible to refer to the definition of the term set out by Braungart et al. [11] which distinguishes between biological nutrients, useful for the biosphere, and technical nutrients, useful for what we call the technosphere, systems of industrial processes. Products can be constituted from materials that biodegrade and become food for biological cycles, or from technical materials that remain in the closed-circuit technical cycle, in which nutrients of value to industry constantly circulate.

A technical nutrient means a material or a product that was designed to go back into the technical cycle, into the industrial metabolism from which it came. Some of them are toxic, but others are nutrients potentially still of value to the industry but are wasted and dumped. Separating them from biological nutrients allows them to be upcycled instead of recycled, maintaining their high quality in a closed-circuit industrial cycle. By "upcycling" we mean the process by which materials are maintained within a closed technical cycle in order to preserve their characteristics and quality over time. The Ellen MacArthur Foundation defines the power of pure inputs as lying "in the fact that uncontaminated material streams increase collection and redistribution efficiency while maintaining quality, particularly of technical materials, which in turn extends product longevity and thus increases material productivity" [12].

To ensure nutrient security and try to moderate the negative effects of pollution, societies around the world should consider the possibility and opportunity of better recovering nutrients from organic residuals—such as crop and food residues and animal and human manures—for reuse in, for example, agricultural production. It is in this light that "nutrient circularity", "closing the nutrient loop", "circular nutrient solutions", and "circular nutrient economy" emerge to be very topical and of growing interest. "When analyzing nutrient circularity, it is essential to consider how agricultural production, consumption, and organic residual management patterns and practices interact across different relevant units of analysis: the farm (production), households and industries (consumption), the international market (trade), and public or private utilities (organic residual management). The concept of nutrient circularity seems generally to include the reduction of nutrient losses—during agricultural production, processing, distribution and consumption—along with the comprehensive recovery of nutrients from organic residuals, for reuse in agricultural production" [10].

This literature review offers an overview of the various indicators, tools, and decision-making processes, showing the countries that developed them and their main characteristics (see Table S1: Supplementary Material). This will be useful as a mapping to understand which nations are most involved in circular economy research and study and the transition from a linear economy to a circular economy, with a focus on the food system.

From Figure 1, it can be seen that Italy and the UK, followed by the Netherlands and the USA, are among the nations that in recent years have been most committed to implementing a circular system and identifying tools for this purpose.

In this context, it is essential to delineate the cultural framework, from an environmental, social, and economic perspective, in which the food system is evolving, with the aim of understanding its critical issues and associated problems and studying solutions for the management of material, energy, and knowledge flows that aim for concrete actions and achieve results that can be communicated, and are thus more transparent for the market and consumers.

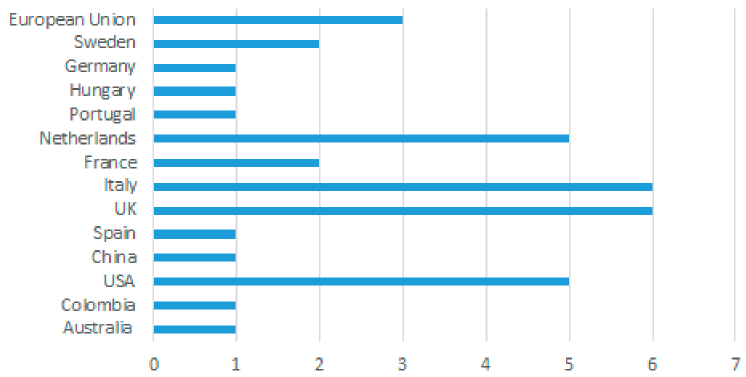

Figure 1. Geolocalization of indicators.

Therefore, the objectives of this study are (i) to analyze the sets of indicators, methods, experiences, and good practices used so far (at a national and international level), highlighting their positive aspects, critical issues, and any potential gaps, for the monitoring of the impact that the food system has on the environment, the economy and society from a circular economy perspective and (ii) to highlight any gaps in the scientific literature in terms of measuring circularity and sustainability in the food system.

2. Bibliographical Research Plan

To this end, a review of the scientific literature was carried out in order to define the framework for the implementation of the circular economy (CE) in the food sector and to identify circularity indicators and tools applicable to the food system.

Initially, therefore, documents were gathered relating to the most recent indices and tools able to provide information about the circularity of a system and to analyze the contribution of circular strategies. Then, attention was focused on CE implementation in the food system, analyzing documents that propose and/or analyze indicators to measure circularity performance in the food sector. The Scopus database was used as a search engine. The terms used for the selection of the sample were identified based partly on previous articles that reviewed CE-related topics [13–15]. For the selection of the articles, the following combinations of search strings were used: *circular*, *econom* and circularit*; food industr* and "food system", indicator*, metric*, index and indic*. The search on Scopus produced 378 documents published in English. The results were re-examined to identify the documents that theoretically contribute to the CE framework applied to the food system. For a document to be selected for a detailed review, it had to include the discussion or development of a concept from the CE framework applied to the food sector. When a document was selected for review, a "snowball" method was used, in other words, a non-probability sampling technique, to complete the final sample. In particular, the document's list of references or citations was used to identify additional documents.

These documents were reviewed in such a way that the only ones taken into consideration were those that presented a detailed analysis clearly focused on (i) the CE paradigm applied to certain aspects of the food system and (ii) the use of methodologies based on indicators or metrics to evaluate the system's circularity level. The documents published by the aforementioned sources, such as the additional material found through a snowball approach, were skimmed to find a clear reference to CE metrics and were otherwise excluded from the analysis. Through these selection criteria, reports, online CE evaluation tools, and white papers were included in the review [14].

The literature search and snowballing [16] were carried out until new interactions were no longer found. The research led to the identification of 47 articles for review and the snowballing completed the set with the inclusion of 22 documents. Duplicates were eliminated and not considered.

3. Literature Review

The circular economy has been presented as a way to decouple economic growth from environmental degradation, increase the profitability and competitive advantages of businesses, and create new local job opportunities [17]. It is a starting point for calculating sustainability, as it offers a set of practices that can generate more sustainable operations, making sustainability in organizations more feasible and analyzable. The circular economy has led to innovations that imply the development of circularity indicators to measure them, mainly at the micro and meso level (enterprises and products/services). Moreover, the complexity of the circular economy requires a set of multidimensional indicators instead of just one [18]. Hence, there is a clear need for a robust and valid circularity metric, so one must examine the available options for measuring circularity at the product/service/enterprise level and try to fill gaps or address any weaknesses inherent in each of these options.

Most circularity metrics developed so far have been criticized for not representing the systemic and multidisciplinary nature of the circular economy and are concentrated exclusively on tracking the extent to which material cycles are closed [19]. These methodologies generally do not consider the types of circular cycles (e.g., shorter or longer) and the multi-dimensional aspects of sustainability, i.e., environmental, economic, and social [20].

An interesting classification has been proposed by Corona et al. [20], which holds that the circularity metrics found in the literature can be divided into two groups:

(1) Circularity measurement indices, which aim to provide a value expressing how circular a system is. These indices were developed by defining the main attribute of the CE (e.g., recirculated materials in a product) and then assigning it a number on a scale from 0 to 100%, which represents the circularity degree.

(2) Circularity assessment tools are designed to examine the contribution of circular strategies to CE principles. This category of metrics is mainly oriented towards analyzing the environmental or economic impacts in the society of the circular strategy, rather than on intrinsic circularity. This category can then be subdivided into "CE assessment indicators" and "CE assessment frameworks". The first, through single (or aggregate) scores, uses only one indicator to provide assessments of the circularity of a system, while the second group is assessment tools that provide multiple indicators adaptable to specific case studies that can examine different aspects of a system's circularity.

This review has identified and analyzed the most recent indicators primarily used to measure circularity, based on this classification, specifically seven circularity measurement indices and eight circularity assessment tools. In addition, this study also reports other measurement tools, which might be more suitable for measuring the food system. In particular, an in-depth analysis of two monitoring tools applied to the food system, six waste management indicators, seven decision-making processes, and ten experiences and good practices was carried out.

3.1. Circularity Measurement Indices

In the following section, therefore, the main circularity indices reviewed in the literature (Table 1) is described. The scope, developer, and implementation level are provided for each one, with critical factors and functionalities, where found (see Table S2: Supplementary Material).

Table 1. Circularity measurement indices under analysis.

Indicators	Scope	Implementation Level	Bibliographic Reference
New Product-Level Circularity Metric	The metric makes it possible to calculate circularity that is reliable and robust in regards to market dynamics and innovation.	Micro	Linder et al. (2017) [17] Linder et al. (2020) [21]
Material Circularity Indicator (MCI)	Evaluates circularity at the product and business level.	Micro	Ellen MacArthur Foundation (2015) [22]
Circular Economy Indicator Prototype (CEIP)	Measures the performance of a product in regards to circular economy (CE) principles.	Micro	Cayzer et al. (2017) [23]
Global Circularity Metrics	Measures the circularity of the global economy based on the share of recycled materials as part of the total inputs of material.	Macro	Brown et al. (2018) [24]
Cumulative Service Index (Circ(T))	Provides the relative measure of the cumulative mass of a material present in a system over a certain time interval in terms of an ideal reference case, where all the material remains in functional applications throughout the entire accounting period.	Micro/meso/macro	Pauliuk et al. (2018) [25]
Circular Economic Value (CEV)	Illustrates the effects of the use of renewable energy resources on the improvement of the flow of energy and materials.	Micro/meso	Fogarassy et al. (2017) [26]
Circular Economy Index (CEI)	Introduces the economic value of materials incorporated into consumer products as a property to measure and account for.	Micro/meso	Di Maio and Rem (2015) [27]

One of the most recently developed product-level circularity metrics has been proposed by Linder et al. [17]. This metric, the "New Product-Level Circularity Metric", defines circularity as "the fraction of a product that comes from used products". The metric focuses only "on circularity vis-à-vis products' composition in terms of virgin and recirculated materials and the activities required to recirculate materials" and measures only the degree of recirculated direct material in the product weighted by direct costs; the indirect resources used in the production process are not included. It also fails to report information on toxicity, job creation, environmental impact, and how the products are sold, and considers two products with different lifespans to be equal. According to Linder et al. [21]: "It treats all recirculation pathways—reuse, repurpose, refurbishment, remanufacturing, recycling, etc.—principally the same and tends to reward so-called 'tight' cycles (e.g., remanufacturing and refurbishment)". It can be applied to different product categories and has a high degree of generality.

Still considering circularity at the product level, the metric developed by the Ellen MacArthur Foundation, which assesses circularity at a product and company level (Material Circularity Indicator or MCI) is probably the most ambitious tentative to develop a circularity metric at a product level and is able to quickly measure the degree to which a product's material flows are restored with relatively little input data. The MCI is made up of two elements: the level of a linear flow and the utility factor. It is sufficiently general that it can be extended to be applied to numerous industrial sectors, clear, easy to use, and rapidly understood.

However, concentrating on the flow of mass, it is not able to distinguish between different types of components in the product and focuses only on technical cycles and in particular on non-renewable resources excluding all biological production [22].

Another interesting approach to measuring the circularity of a product is the CEIP (Circular Economy Indicator Prototype) index, proposed by Cayzer et al. [23], which attempts to identify the characteristics that indicators need to measure the performance of products within the circular economy model proposed by the Ellen MacArthur Foundation (EMF CE). Through the administration of a questionnaire based on the principles of the EMF CE, from which relevant and measurable variables are extrapolated, and grouped according to the phases of a product's life cycle, the use of this indicator makes it possible to calculate a final score (in %) that defines a product's circularity. It is characterized by speed of application, simplicity, and ease of dissemination. However, it has some limitations such as hiding complexity, potentially misleading results, superficial engagement in decision-making, and dependence on context-specific assumptions.

Pauliuk [25], on the other hand, has proposed the Circ(T), or cumulative index of services based on MFA (Material Flow Analysis). This indicator provides "a measurement of the cumulative mass of a material present in a system, in a certain time interval, in terms of an ideal reference case where all the material remains in functional applications throughout the entire accounting period" [25]. It considers only the recirculation of materials and covering only (and partially) the resource efficiency CE objective.

Reasoning, however, from a system perspective, the research carried out by Fogarassy et al. [26] which introduces a pilot project focused on the use of solar energy through the implementation of circular energy sharing solutions may be noteworthy. The circular efficiency of the system was measured through the Circular Economic Value (CEV), which aims to show the impact of the use of renewable energy resources on the improvement of energy flow. It represents "the circularity of the system by accounting for reduced use of virgin materials, reduced output of waste, increased use of renewable energies and increased energy output during EoL (End of Life)" [20]. Basically, through a calculation of renewable energy assessment, it illustrates how their use can improve the flow of energy and materials. However, it does not specify how to tackle the problem of resource allocation.

One interesting suggestion is the Circular Economy Index (CEI), proposed by di Maio and Rem [27], which is able to combine the strategic, economic, social, and environmental aspects of recycling and is, therefore, useful as a useful decision-making tool. This indicator is, in fact, considered the ratio between the material value produced by the recycler (market value) and the intrinsic material value entering the recycling facility. The Circular Economy Index (CEI) aims to introduce the economic value of the materials incorporated into consumer products as a property to measure and account for. It is easy to calculate, uses easily available data, and does not require additional human resources in order to be calculated.

Finally, following reasoning from a product and system perspective, it is fundamental to reason from a global perspective, in response to the alarming statistic that only 9.1% of the global economy is circular.

The Global Circularity Metric was proposed in the first Circularity Gap Report [24]. Therefore, it is crucial to close the circularity gap, which could help preserve the environment and not lead to increased social inequality. Hence, this metric measures the circularity of the global economy based on "the share of cycled materials as part of the total material inputs into the global economy" [24]. It does not consider asset sharing, lifetime extension, or remanufacturing. Any quality loss and degradation in processing is not considered but can set a zero measurement for the globe and track progress over time. The Circularity Gap Report 2021 states that only 8.6% of our current economy is circular, still leaving an enormous circularity gap. The prospects are gloomy, and we must speed up adopting circular strategies with the aim of opening the way to the systemic transformations necessary to correct the course of the global economy, going well beyond the limits of current policy and national commitments on the climate.

3.2. Circularity Assessment Tools

In the following section, the main circularity assessment tools found in the literature (Table 2) will be analyzed. The scope, developer, and implementation level are provided for each one, with critical factors and functionalities, where found (see Table S3: Supplementary Material).

Table 2. Circularity assessment tools under analysis.

Assessment Tools	Scope	Implementation Level	Bibliographic References
Sustainable Circular Index (SCI)	Makes it possible to assess the sustainability and the circularity of manufacturing companies, with an educational orientation because it could be considered a guideline for managers to reach a defined level of sustainability or circularity.	Micro/meso	Azevedo et al. (2017) [28]
Ecocosts/Value Ratio (EVR)	Analyses the sustainability of products, services and their business models.	Micro/meso	Vogtländer et al. (2002) [29]
Global Resource Indicator (GRI)	Integrates aspects of evaluation of resources to better characterise them. Combines scarcity, geopolitical availability and recyclability.	Micro/meso	Adibi et al. (2017) [30]
Longevity indicator	Shows the length of time for which a material is retained in a product system.	Micro	Franklin–Johneson et al. (2016) [31]
Reuse potential indicator	Measuring the extent of technological development, the reuse potential indicator expresses the usefulness of the material with an actual value on a scale from 0 to 1.	Micro	Park and Chertow (2014) [32]
Value-based Resource Efficiency indicator (VRE)	Key parameter for measuring the efficiency of resources.	Micro/meso/macro	Di Maio et al. (2017) [33]
Material Durability Indicator (MDI)	Integrates in a single calculation the chemical and mechanical durability, along with the environmental impacts associated with the material.	Micro	Mesa et al. (2020) [34]
Hybridised sustainability metrics	Evaluates the environmental performance of (bio-based) products, independently or compared to their commercial counterparts.	Micro	Lokesh et al. (2020) [35]

The Sustainable Circular Index, suggested by Azevedo et al. [28], represents the degree of sustainability and circularity of a business or organization. The indicator takes into account four dimensions: economic, social, environmental, and circularity. "This index gives companies insights into not only their sustainable behavior but also whether they are respecting circular economy concerns regarding the use of recycled and reused materials, the lifetime and intensity of the products, and the efficiency of recycling processes".

Another approach is the Eco-costs/Value Ratio (EVR), based on Life Cycle Assessment (LCA). The Eco-costs/Value Ratio (EVR) model was developed to examine the necessary separation of economy and ecology at the product and system level: the EVR is a unique indicator of sustainability. This indicator is based on the concept of combining the "value chain" with the ecological consequences of this value chain in terms of ecological costs. The EVR model links the production side of the environmental problem (in other words, the manufacture of products with lower ecological costs) to the consumer side (in other words, increasing the relative value of environmentally sustainable products so that consumers are motivated to buy them) [36].

The Global Resource Indicator (GRI) proposed by Adibi et al. [30], on the other hand, integrates various aspects of evaluating resources to improve their characterization. This multi-criteria indicator is characterized by different aspects of availability, including recyclability and geopolitical availability of resources. While always thinking in terms of recyclability and reuse of resources, Park and Chertow [32] have come up with the Reuse Potential Indicator, based on the principle that what creates an opportunity for the reuse of waste material is the knowledge of where and how to use it. Therefore, measuring the extent of technological development, this indicator expresses the usefulness of the material with an actual value on a scale from 0 to 1. Thus, even if the reuse potential indicator does not explicitly analyze the physical, chemical, or mineralogical properties of a material, it indirectly represents the material properties as a result of technological progress. This quantitative indicator is able to support material and waste managers in making informed choices about the technical feasibility of reusing waste, even if requires a large amount of technical data that can be hard to obtain.

From a similar perspective comes the Longevity Indicator, developed by Franklin-Johnson et al. [31], useful for evaluating the performance of a product and seeking to show the amount of time a material is retained within a system. "Such retention is a means to maximize resource exploitation in the same product system through product use and reuse, as well as materials recycling", they write. This indicator "seeks to determine the degree to which a system is circular, or the extent to which materials contained in products remain within that system for as long as possible". It can be a useful resource for all stakeholders to better understand the impacts of their own performance and is suitable for a variety of materials and/or products and industries, involving use on a very large scale, even if it does not take into account the entire consumption process and the hypothesized life cycle of the product and does not take into account the complexities of restructuring and recycling.

Reasoning, however, in terms of the efficiency of resources, a very interesting indicator widely used in the decision-making process is economic value, as seen in the Value-based Resource Efficiency (VRE) indicator devised by di Maio et al. [33]. This is an indicator suited to monitoring, guiding, and managing the activities and operations of all the stakeholders involved in the supply chain, and therefore the entire supply/value chain, functional for preserving or even improving the value of components and waste streams, both on a local and a global scale [33].

Finally, analyzing the impacts of materials, the Material Durability Indicator (MDI) proposed by Mesa et al. [34] turns out to be a very interesting attempt that integrates into a single calculation three main components: chemical durability, mechanical duration, and environmental performance. The MDI can be interpreted as a compromise between chemical and mechanical durability and the environmental impacts associated with the generation, processing, and recycling of materials. It thus integrates into a single calculation the chemical and mechanical durability, along with the environmental impacts associated with the material. Implementation of the indicator depends to a great extent on the type of material considered in the selection process. Reliable values are necessary for the parameters and the availability of databases could be a limitation.

Continuing in this direction, Lokesh et al. [35] have additionally proposed a new series of first-line hybridized sustainability indicators, which draw on the principles of green chemistry and the circularity of resources (material and energy). These indicators (hazardous chemical use, feedstock intensity (FI), circular-process feedstock intensity (CPFI), waste factor (WF), circular-process waste factor (CPWF), and product renewability (PR)) could fill the significant gaps found in contemporary methodologies for evaluating environmental impact. We evaluated the environmental performance of (biobased) products independently of or relative to their commercial counterparts.

4. Monitoring Tools Applied to the Food System

4.1. Food Loss and Waste in the Food System

Over 1.9 billion tons of solid waste are generated every year around the world, of which more than 1.3 billion tons correspond to goods that are wasted or lost along the food supply chain. The actual rate of food loss is responsible for considerable environmental impacts, in addition to economic and social costs as it accounts for one-third of global food production. The issue of food waste and loss is now on the rise and affects all actors in the food supply chain [37].

Consequently, by convention in the EU when referring to food waste (FW) is defined as all food products that are absolutely edible but instead of being destined for human consumption are lost throughout the food chain.

The huge quantities of FL and FW, with the significant consequent environmental, economic, and social problems, determine the need to go beyond the concept of a linear economy and to think about the development of a production process with a circular economy perspective. According to the "solid waste hierarchy" as a function of FL and FW reduction and/or management, FL and FW prevention activities are preferable to landfilling [38] in order to potentially have a greater improvement in environmental and socio-economic results [39].

Despite the available evidence, there is still a lack of knowledge about this problem, with few aware of the extent of waste and its effects on the environment. According to the Food Waste Index Report 2021 [40], food waste generated in 2019 by households, retailers and the food service sector amounted to 931 million tons, with not-insignificant impacts on climate change; the majority of this waste occurred in homes (61%) followed by food service (26%) and retail (13%). In Europe, with 88 million tons of food wasted every year (equal to 173 kilos a head), it is estimated that 15% of the total environmental impact of the food production chain can be attributed to food waste.

The Food Waste Index Report 2021 [40] aims to support the objectives of Sustainable Development Goal (SDG) 12.3 through the latest collection of data, analysis, and modeling on food waste. Through this collection, it was possible to re-estimate global food waste and devise a methodology for countries to measure food waste at the household, food service, and retail levels in order to monitor national progress until 2030. SDG 12.3 has two components, Loss and Waste, which should be measured by two separate indicators. Two indices have therefore been proposed for these components: a Food Waste Index (FWI) and a Food Loss Index (FLI) (see Table S4: Supplementary Material).

Specifically, based on the Food Loss and Waste Accounting and Reporting Standard (FLW Standard), the UN Environment Programme is working on developing the Food Waste Index. The FWI gauges the tons of food wasted per capita by analyzing a mixed set of products from the processing stage to consumption [40]. The Food Loss Index (FLI), on the other hand, examines food losses from production up to (and not including) the retail level. It measures the percentage change in losses for a basket of 10 major products per country compared to a base period. This could help to understand possible impacts and improvements of policies and investments implemented to make the supply chain more efficient. In order for countries to improve the efficiency and operation of their food supply system, it is strongly recommended that data be collected at all stages of the supply chain, thus taking into account harvest, post-production, storage, transport, primary processing, and wholesale [41].

The International Food Policy Research Institute (IFPRI) has developed a methodology to monitor food losses that occur throughout the food supply chain, taking into account all stakeholder categories. This approach is both a quantitative measure of food losses, but also a qualitative one taking into account product deterioration leading to economic losses.

This methodology deals primarily with monitoring both food and economic losses in a wide range of products in developing countries, identifying, in particular, the crucial points and production processes where most losses occur [42].

4.2. Waste Management as a Solution to Waste in the Food System

Global food security is becoming an increasingly serious problem and it is now clear that food waste is one of the key issues because of the significant negative environmental, social, and economic impacts it causes, so it is also the key to a more sustainable resolution of the global waste challenge. Resource and waste management can be considered sustainable if it takes into account all the stages in which waste can be generated, so it must cover the entire production cycle up to consumption. In view also of the major climate crisis we are facing, it would make sense to use resources efficiently by using them at more sustainable levels, which would allow greenhouse gas (GHG) emissions to be significantly reduced, as well as achieve economic and social benefits. Among the change strategies, the waste hierarchy, based on the principle of the 3 Rs (reduce, reuse, and recycle), helps to rank waste management options from the perspective of environmental protection, where waste prevention is considered the best and disposal the worst. The scope of the waste hierarchy is to identify the options that have the greatest probability of providing the best overall environmental result [43].

The EU's waste management policy must aim at the prevention of waste. The basis of a recycling society is to make more efficient use of resources so as to reduce their environmental impact and limit waste generation [44]. There are various types of decision-making processes in solid waste management; among them, the most widely used are Life Cycle Assessment (LCA), Cost-Benefit Analysis (CBA), Multi-Criteria Decision-Making (MCDM), and the energy-water-food nexus towards a greener future by enhancing CE. Kyriakopoulos et al. [45] write: "The LCA only considers potential environmental aspects when evaluating waste management systems and ignores other decision-making options such as economic and social effects. Instead, CBA is a monetary valuation method, the main goal of which is to maximise economic efficiency. CBA analyses costs and benefits, including economic aspects, natural resources, and environmental impacts due to waste minimisation—which can be especially introduced in emerging countries where open dumping and open burning are the main waste treatments implemented". This means that CE indicators can be defined and calculated with the aim of reintroducing urban solid waste from urban areas into the CE context. Once the collected data on waste generated have been standardized, it is possible to outline and define what the environmental situation of the analyzed urban areas actually is, promoting easier management of environmental policies and the carrying out of regular comparative analyses on waste generation [44].

Therefore, in the next section, the main indicators for waste management are summarized (Table 3). The scope, developer, and implementation level are provided for each one, with critical factors and functionalities, where found (see Table S5: Supplementary Material).

In 2019, the Waste Generation Index and Recycling Index were added to the Verisk Maplecroft Environment Dataset. This dataset consists of approximately 50 indices involved in areas related to climate change, environment, and natural hazards. In particular, the Waste Generation Index (WGI) through the quantitative assessment of certain waste categories, including municipal solid waste (MSW), hazardous waste, food waste, and plastic waste, is able to determine how much waste is generated per country. As well as better understanding the exposure to risk, companies could use this index to prevent and control possible risks associated with the waste generation or address problems with specific types of waste crucial to their business. The Recycling Index, on the other hand, assesses a country's interest and capacity to manage solid waste in such a way as to encourage circular flows of materials. This index "identifies countries where the inability to recover and recycle solid waste is likely to result in risks to businesses" [46].

Table 3. Waste management indicators under analysis.

Indicators	Scope	Bibliographic Reference
Global Waste Index (Waste Generation Index)	Provides a quantitative evaluation of the rate of waste production per country.	Nichols and Smith (2019) [46] Sensoneo Global Waste Index (2019) [47]
Recycling Index	Evaluates the willingness and ability of countries to manage solid waste and promote circular material flows.	Nichols and Smith (2019) [46]
Zero Waste index	Assesses the performance of waste management and the replacement of materials with waste management systems in various cities.	Zaman and Lehmann (2013) [48]
Waste recycling	Shows Europe's progress rate towards the objective of recycling more waste.	EEA (2019) [49]
Contribution of recycled materials to raw materials demand	Used to monitor progress towards a circular economy in the thematic area of secondary raw materials.	Eurostat (2020) [50]
Trade in recyclable raw materials	Shows the quantities (in units of mass) and the monetary value (in euros) of selected waste sent across internal borders and outside the EU.	Eurostat (2020) [51]

The Zero Waste Index, proposed by the International Zero Waste Alliance in 2004, on the other hand, is an innovative tool as it predicts the number of virgin materials, energy, water, and greenhouse gas emissions that can be saved by using resources recovered from waste streams. This gives a broader picture of the effective performance in different cities of waste management and the possible substitute resources that can be obtained. This indicator was limited to urban waste management systems for six broad categories of waste: paper, plastic, metal, glass, and organic and mixed municipal solid waste [48]. Therefore, it is essential to expand the use of this zero-waste index system and to ensure that it can also analyze other waste categories. Among these waste management systems, increasing attention is being paid to the 9R framework, which represents a generic classification system based on maximizing resource and product use, with the aim of achieving a more sustainable production capacity. Taking into account the waste hierarchy system, the 9R framework (Figure 2) consists of three major circuits: "short loop", "medium loop", and "long loop" [52]. According to this hierarchy of waste, producing the decision to promote short and medium circuits is certainly advisable and preferable to the application of the traditional long circuit [52].

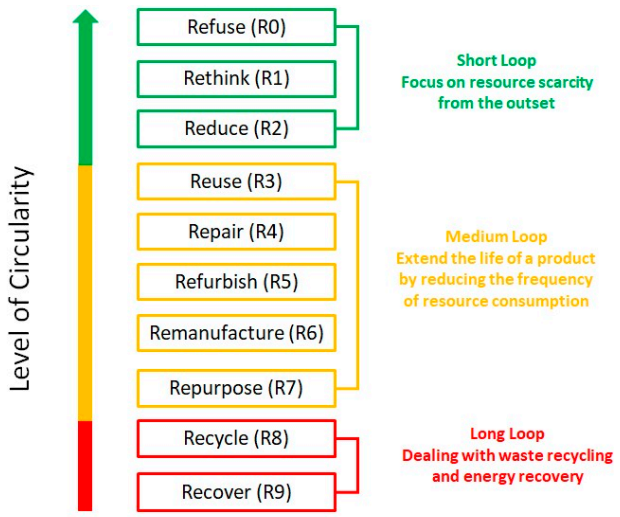

Figure 2. Application of the waste hierarchy model to the 9R framework.

Therefore, a zero-waste strategy is becoming increasingly popular as best practice. Analyzing, in particular, the European context, the Waste Recycling Index aims to monitor Europe's progress in waste management and recycling. This indicator analyzes in particular the recycling rates for different types of waste—urban waste, packaging waste, total waste excluding major mineral waste, and waste electrical and electronic equipment (WEEE)—at the European level, to support an early-warning mechanism. As a result, it analyzes if Europe is making progress in waste management and if it is promoting circular economy actions [52]. In the working document, "Measuring progress towards circular economy in the European Union—Key indicators for a monitoring framework", the European Commission [53] also presented two indicators that analyze these issues in particular. Unlike the other indicators that monitor collection or recycling rates in the various waste streams and present an assessment of waste management, the "Contribution of recycled materials to raw material demand" measures the contribution of recycling to material demand by material type and with reference to "secondary raw materials" takes into account any progress towards a circular economy [50]. Meanwhile, the "Trade in recyclable raw materials between EU Member States and with the rest of the world" shows the quantity (in units of mass) and monetary value (in euros) of sorted waste that is shipped across internal and external EU borders. This dataset is drawn from the International Trade in Goods Statistics (ITGS) published by Eurostat (2020) [51].

4.3. Decision-Making Processes Applied to the Food System

Once the main indicators that are currently able to monitor circularity inside the food system have been described, it becomes also necessary to analyze the decision-making processes most used within food systems. Decision-making processes are a set of methods that in turn incorporate other tools adapted to show information about circularity.

The following table (Table 4) identifies the selected decision-making processes that are summarized in the subsequent section. The scope, developer, and implementation level are provided for each one, with critical factors and functionalities, where found (see Table S6: Supplementary Material).

Table 4. Decision-making processes applicable to the food system under analysis.

Indicators	Bibliographic Reference
Multi-Criteria Decision-Making (MCDM)	Shukor et al. (2018) [54]
Life Cycle Assessment (LCA)	Klöpffer (1997) [55] Sassanelli et al. (2020) [56]
NEXUS Thinking Approach WEFCNI	Scott et al. (2015) [57] Rodias et al. (2021) [58] Tortorella et al. (2020) [59] Laso et al. (2018) [39]
Multi-Sectoral Water Circularity Assessment (MSWCA) framework	Nika et al. (2020) [60]
Material Flow Analysis (MFA) applied to the Italian meat industry	Amicarelli et al. (2021) [61]
Material Circularity Indicator (MCI) adapted to biological cycles	Rocchi et al. (2021) [62]
Material Circularity Indicator (MCI) adapted to biological cycles	Razza et al. (2020) [63]

Among the first to talk about MCDM (Multi-Criteria Decision Making) was Triantaphyllou [64], defining it as a framework for supporting decisions that can evaluate multiple criteria in conflict and use a different methodology to carry out pairwise comparisons. More recently, Shukor et al. [54] applied it to their work, using a multi-level hierarchical structure that consists of objective criteria, sub-criteria, and alternatives for the selection of an appropriate technology for waste management. Such a tool can lead to better results and more complete support for decision-makers and be more valid for the interested parties. One of the more broadly used methods is the Life Cycle Assessment (LCA), which analyzes the effects the entire life cycle of a product may have on the environment (quantifying and assessing emissions, resources consumed, and health and environment pressures). This approach takes into account all the activities involved in the creation of a product, such as extraction of raw materials, production, transport, distribution, use, and disposal [65].

Today, the challenges relating to energy and resources to shift society toward more sustainable solutions are enormous and pressing. Welfare and social and economic sustainability are highly dependent on water, food, and energy. In fact, the increase in world population and the demand for ever higher standards of living only enhances the demand and consequently the need for sustainable development. It is in this context that the WEF Nexus approach fits in, which with a holistic perspective of sustainability seeks to strike a balance between the different objectives, demands, and requirements of people and the environment [58]. In particular, then, the Water–Energy–Food–Climate Nexus Integrated Index (WEFCNI) represents a new methodology to examine various waste management solutions. "Nexus Thinking" and its multi-sectoral approach promote sustainable and effective resource management, perfectly in line with the SDGs, the Paris Agreement, and the European goal of climate neutrality. The Nexus approach is, therefore, the main method capable of understanding and modeling the interactions between different resource sectors (water, food, energy) [59]. Therefore, this indicator monitors food production processes by analyzing direct and indirect water and energy consumption, examines the nutritional component, and measures GHG emissions from waste management [39]. It additionally aims to efficiently manage water, energy, and food systems, minimizing possible conflicts and improving the interaction between the systems with the aim of ensuring a safe and sustainable use of resources. The WEF Nexus today represents the most comprehensive methodology that can contribute to sustainable development.

However, when analyzing in detail only water circularity, the Multi-Sectoral Water Circularity Assessment (MSWCA) framework is very interesting. Through a multi-sectoral systemic approach, it deals mainly with Material Flow Analysis (MFA), natural systems modeling and economic assessment. Through symbiotic management of resources such as water, energy, and nutrients, it examines different socio-economic sectors (e.g., urban water, agribusiness, energy, industry, and waste management) and non-economic sectors (e.g., the natural environment). Analyzing the MFA component from a food system perspective, it is worth citing a study by Amicarelli et al. [61] which applied Material Flow Analysis (MFA) to the Italian meat industry and verified its applicability in sustainability evaluations. The MFA is able to represent a snapshot of the food chain as it allows the quantification and qualification of food waste streams, calculates the related material cycles, and takes into account eco-efficiency indicators. However, this approach encounters several limitations, the first of which is imposed by the lack of data. Additionally, various efforts are necessary to improve the robustness and reliability of the MFA.

Finally, the degree of uncertainty inherent in MFA calculations should not be underestimated. One of the main problems is the fact that it is complex to distinguish "consumed" (goods that change from one form to another, but without losing their intrinsic usefulness), "used" (goods that have already been used for their intended purposes, including those collected or discarded without being used at all), and "by-products", which are not counted in current statistics.

Not surprisingly, current waste statistics include only those legally defined, leaving the amount of high-value waste unclear and making its measurement very complex.

Pursuing the review of decision-making processes applicable to the food system, it may be relevant to consider again the Material Circularity Indicator (MCI) previously analyzed in Section 3.1. For circularity measurement indices, despite the disadvantage that they concentrates only on technical cycles and in particular on non-renewable resources, covering only partially the circularity concept and excluding all the biological production with a high impact on the environment, a modification has recently been proposed to adapt it to biological cycles. The MCI modification can be considered an initial attempt to create an index dedicated to biological cycles, reflecting their main characteristics and specific features. Nevertheless, the proposed methodology applies to the individual product, meaning that "crossed circularity along the supply chain or generation of value through the cascade cycles have not been considered" [62]. Another adaptation of the MCI to biological cycles was applied by Razza et al. [63], which introduced two important modifications: "(i) the mass of the bio-based component corresponds to the recycled material in input and (ii) the mass of the bio-based component leaving the system through composting or biodegradation in soil is accounted as recycled". The modified MCI promotes the eco-design of innovative bio-based (BB) products and the comparison of their circularity, keeping in consideration the biological source and the intended end-of-life treatment process, e.g., biodegradation. The proposed MCI is only significant if, with reference to national and European laws and standards, BB products comply with health and safety requirements for materials.

4.4. Experiences and Good Practices

Various experiences of measuring circularity have been developed at a European and national level. In this review, both existing and in-development measurement models have been selected, with reference to national initiatives, certifications, and tools (Table 5). The scope, developer, and implementation level are provided for each one, with critical factors and functionalities, where found (see Table S7: Supplementary Material).

Table 5. Experiences and good practices under analysis.

Experiences and Good Practices	Bibliographic Reference
Product Circularity Data Sheet (PCDS)	Product Circularity Data Sheet (PCDS) [66]
Cradle to Cradle	Linder et al. (2020) [21] Cradle to Cradle Certified [67]
REPRO	Linder et al. (2017) [17]
Circle Assessment	Circle Economy [68]
Circular Transition Indicators	WBCSD [69]
Circulytics	Ellen Macarthur Foundation (2019) [70]
Response-Inducing Sustainability Evaluation (RISE)	Häni et al. (2003) [71]
UNI1608856 "Measuring circularity—Methods and indicators for measuring circular processes in organisations"	UNI (2021) [72]
UNI1608977 "Analysis of good circular economy practices for the evaluation of their functioning and performance and to favour their replicability"	UNI (2021) [72]
UNI/TS 11820:2022 "Circularity measurement—Methods and indicators for measuring circular processes in organizations	UNI (2022) [73]

Led by the Luxembourg Ministry of the Economy, the "Circularity Dataset Standardization Initiative" aims to establish an official standard, the Product Circularity Data Sheet (PCDS), for the communication of data on the circular economy properties of products, in consultation with other standards organizations. It can be used to establish how circular a product is and inform the circular process for which it was designed and realized. The PCDS offers a standardized format with reliable data [66].

Among the most-used tools is Cradle to Cradle, which carries out assessments of products and services by examining a core set of issues including the selection and reuse of materials, the use of renewable energy in the production cycle, water management and social responsibility [21]. The standard encourages constant improvement over time, assigning the certification based on growing levels of achievement and requiring the renewal of the certification [67] every two years.

Remanufacturing Product Profiles (REPRO), on the other hand, can be a useful tool to benchmark products against those that have been successfully regenerated, with the aim of improving regeneration rates [17]. According to Linder et al. [17], however: "The tool is weakly implemented, and has, with regard to circularity, low construct validity given that reuse and recycling are excluded".

Also worth highlighting is the Circle Assessment, an online tool that supports companies in gaining an understanding of the different operational and organizational issues of the circular economy. The results of the tool evaluate companies on their present circular thinking and instruct them on potential opportunities to be further explored [68].

Another tool is represented by the Circular Transition Indicators (CTI), a simple, objective, and quantitative framework that can be applied to businesses in all sectors, of all sizes, at all positions on the value chain, and in all geographic areas [69]. It is increasingly clear that businesses must consider their social and environmental impacts, and many are embracing the circular economy as a model that tackles global challenges such as climate change, waste, pollution, and biodiversity loss.

However, a circular economy cannot be implemented until it can be adequately measured. For this reason, the Ellen MacArthur Foundation has developed a tool, Circulytics, which supports the transition of a company towards the circular economy, independently of its sector, complexity, or size [70]. In addition to evaluating products and material flows, this company-wide measurement tool can analyze the company's level of circularity with reference to all its activities [70].

Widely used, especially in the agri-food sector, is the Response-Inducing Sustainability Evaluation (RISE), developed by the Bern University of Applied Sciences. It offers a holistic approach to advice, education, and planning. The instrument "allows the identification of strong and weak aspects of the farm and can thus induce steps to improve the sustainability (decision-oriented, response-inducing approach)" [71]. However, it is based on only 12 indicators and does not measure the interaction between the indicators themselves.

Lastly, it has been decided to include in this context three UNIs (Italian standards), currently in the experimental stage, UNI1608856 "Measuring circularity—Methods and indicators for measuring circular processes in organisations", UNI1608977 "Analysis of good circular economy practices for the evaluation of their functioning and performance and to favour their replicability" and UNI/TS 11820:2022 "Circularity measurement—Methods and indicators for measuring circular processes in organizations". The first, a specific technique, wants to define a set of indicators applied at the macro, meso, and micro levels aimed at assessing, through a rating system (not tied to sector benchmarks), the level of circularity of an organization or group of organizations. The second, a technical report, intends to collect an analysis of good circular economy practices from Italian organizations. The good practices will be subdivided into macro-areas of application for which the performances and impacts of the selected organizations have been analyzed [72]. Finally, the last one, which was published on 30 November 2022, is a method for measuring circularity improvement in business and industry policies. It consists of a set of 71 indicators that can measure material resources and components, energy and water resources, waste and emissions, logistics, product and service, human resources, assets, policy, and sustainability [73].

5. Research Limitations and Possible Solutions

The literature has shown that most circular economy indicators are focused on material flows and end-of-life strategies. However, it is crucial to develop multi-dimensional indicators to measure the circular economy in its totality, analyzing the social, environmental, and economic aspects of sustainability [23]. Therefore, a commonly accepted indicator for the circularity of nutrients in food systems and the circular bio-economy would appear to still be elusive. Currently, indicators of nutrient circularity are limited to a kind of comparison between nutrient inputs in agricultural production (as fertilizer inputs or considering nutrient inputs in general) and nutrients in organic residues (considering what is put back into circulation or what could be available) [10].

Actually, to examine the interrelationships between the environment, food system, and diet, the environmental sustainability indicators applied are focused more on greenhouse gas emissions, analyzing land use, meat and dairy consumption, and energy consumption, while indicators such as eutrophication potential, reactive nitrogen, acidification potential, social equity, and food waste are less frequently used, denoting less attention to the issue from a health and food systems perspective [74].

An increasing number of studies use the LCA technique to analyze material and energy consumption in food systems. However, a major limitation are the lack of data on specific food products or production processes, which means that many indicators presented in LCA studies are inadequate to measure the reference food system, thus leading to an inaccurate estimation of environmental impacts and displacing the need for more systemic and holistic approaches [75].

When sustainability indicators are chosen, it would be advisable that they fulfill certain quality requirements, to ensure that the indicators can effectively reflect the state of sustainability of the food system and its possible changes [76]. Therefore, the sustainability indicator should be:

- Representative: The indicator should clearly represent the aspects of sustainability the food system is measuring;
- Comparable: Find the most quantifiable and comparable component of an aspect of sustainability when choosing an indicator;
- Responsive: The indicator should reflect the status of the aspect of sustainability it represents and any possible modifications to it.

Furthermore, attention should be paid to the scale of an indicator, for example, if it represents a system-wide problem or a specific problem during a particular stage of food systems and what interconnections it may have with other indicators of similar scale [8].

In this review, metrics were therefore identified that could be considered among the most current strategies for measuring circularity and specifically applicable to the food system. These metrics could be inserted into an original CE assessment framework conceived for the design of a potential Circular Economy for Food Assessment (CEFFA) (Figure 3) which could be a valid tool for monitoring and measuring sustainability in the food system.

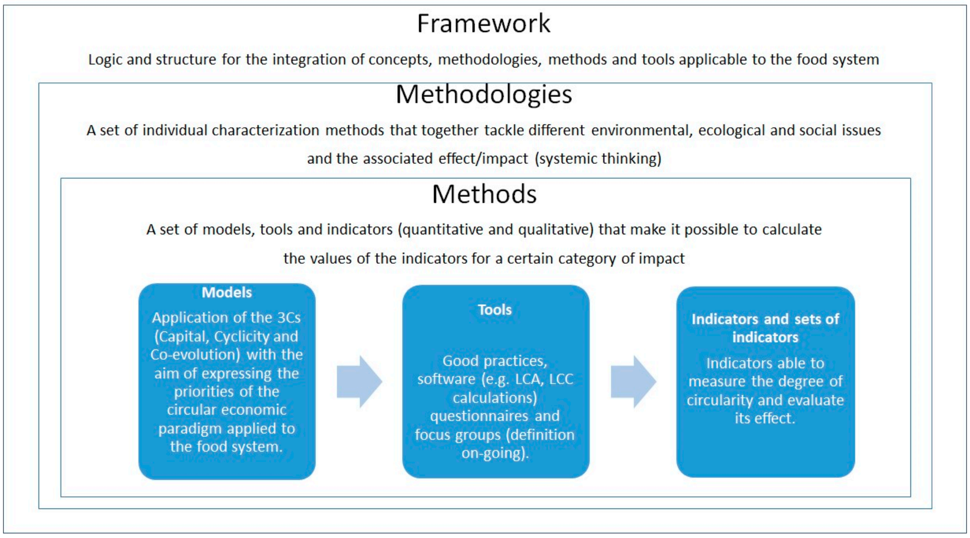

Figure 3. Classification of the metrics for measuring circularity applicable to the food system.

This conceptual framework would aim to be a classification system in line with the European taxonomy, proposed in June 2020 and developed by the European Commission [77] to help achieve the objectives of the Green Deal. Potentially, this conceptual framework could direct investments towards sustainable projects and activities but also define a common language that makes explicit and defines the concept of sustainability.

In particular, the EU taxonomy regulation establishes six environmental objectives:

1. Climate change mitigation;
2. Climate change adaptation;
3. The sustainable use and protection of water and marine resources;
4. The transition to a circular economy;
5. Pollution prevention and control;
6. The protection and restoration of biodiversity and ecosystems.

The need not to separate economic capital from natural and cultural capital is evident, so as to avoid irreversibly compromising and totally damaging the environment on which we are completely dependent for the sourcing of raw materials. Additionally, it is essential to think in a cyclical way, in other words, with a view to sustainability, the extension of producer responsibility and regeneration and renewability, all while respecting planetary boundaries and offering at the same time a fair space to civil society, in other words, from a co-evolutionary perspective. This is exactly the direction in which this classification tool could potentially move. Indeed, this system could implement indicators that would help to preserve the entire stock of natural assets that contribute to providing goods and services of value to people and are necessary for the survival of the very environment that generates them, but also the body of knowledge, values, and attitudes towards natural and social ecosystems that must be preserved and passed down as a precious legacy. Based on the European taxonomy and thus also reasoning from a regenerative perspective, the development of indicators that aim to analyze the extension of corporate responsibility, which must include the entire life cycle of the product, from the origin of raw materials to the extension of a product's life cycle (duration); metabolization, which is the final enhancement from an upcycling perspective of everything that is put on the market; and renewability, in other words, as much as possible generated and fueled by material and energy from renewable sources. Moreover, not to be underestimated is the social dimension, reasoning with a win–win logic in which multiple parties can benefit from the relationship they establish.

For this reason, according to the research conducted by Fassio [78] of the University of Gastronomic Sciences in Pollenzo, the indicators to measure the CE applied to the food system and thus the indicators for the Circular Economy for Food [79] should take into consideration the conceptual framework of the three Cs of the Circular Economy applied to food: Capital, Cyclicality, and Coevolution. Three key words that describe the cultural framework within which the new socio-economic paradigm should evolve its identity over time. This application scenario sets itself first and foremost the objective of preserving Natural Capital, in other words, the entire stock of natural assets that contribute to providing goods and services of value to people and are necessary for the survival of the very environment that generates them. To this is linked Cultural Capital, the body of knowledge, values, and attitudes towards natural and social ecosystems that must be preserved and passed down as a precious legacy, so that it can become, from generation to generation, a vision integrated with the future and capable of producing a distributed and fair source of income that supports Human and Economic Capital.

The second C is for Cyclicity, which invites us to think in a regenerative key, encompassing three fundamental concepts: extension of corporate responsibility, which must include the entire life cycle of the product, from the origin of raw materials to the extension of a product's life cycle (duration); metabolization, which is the final enhancement from an upcycling perspective of everything that is put on the market; and renewability, in other words, as much as possible generated and fueled by material and energy from renewable sources. Lastly, the C of Co-evolution, which is inspired by the mutualistic symbiosis present in nature, a win–win dynamic in which multiple subjects benefit from the relationship they establish.

A model constituted in this way could be a valid tool in the development and evaluation of actions for companies and/or agri-food systems carried out in terms of environmental, economic, and social sustainability in the management of matter, energy, and knowledge flows. It could also represent an effective means of more transparent communication towards the market and consumers in regard to the actions pursued and the results achieved.

6. Conclusions

Therefore, this work has had the objective of outlining the environmental, social, and economic frame in which the food system is currently developing and to analyze the most recent tools developed to measure the impacts of the system on the environment, the economy, and society from a circular economy perspective. In addition, a gap was identified in most indicators concerning a lack of focus on nutrient circularity in food systems, which could most likely be due to a lack of the information needed to analyze and evaluate food products and production processes and the scarcity of useful tools for measuring sustainability and/or which use a narrow boundary for the target food system, leading to an underestimation of the system's environmental impacts. Hence, this work suggests a potential cultural framework within which to place the indicators for analyzing agri-food systems, potential focuses on the basis of which to build new indicators able to provide a holistic assessment of the impacts, the actions, and the results achieved by the systems themselves. In conclusion, this work has made it possible to highlight a growing interest in the desire to monitor the effects that the food systems can have on the environment and therefore a greater intention in wanting to come up with solutions that can limit the negative impacts. Nonetheless, it is still necessary and essential to construct an indicator that is commonly accepted and built on a more systemic or holistic approach.

Supplementary Materials: The following supporting information can be downloaded at: https://www.mdpi.com/article/10.3390/su151310179/s1. Table S1. Classification of the indicators by nation; Table S2. Classification of circularity indices; Table S3. Classification of circularity assessment tools; Table S4. Classification of indicators developed within the Sustainable Development Goal (SDG); Table S5. Classification of waste management indicators; Table S6. Classification of decision-making processes; Table S7. Classification of experiences and good practices.

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