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Experiences in Assessing the Impact of Circular Economy Interventions in Agrifood Systems – a Review

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Experiences in Assessing the Impact of Circular Economy Interventions in Agrifood Systems—A Review

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Abstract: The circular economy (CE) offers a promising model for sustainable resource management, yet assessing its performance remains challenging. In agrifood systems, circularity can enhance resource efficiency, reduce waste, and support food security, but few studies have examined CE implementation in this unique context, highlighting a need for tailored assessment tools. This study aims to provide insights and recommendations for advancing CE interventions and their performance assessment within agrifood systems. We conducted a realist literature review to examine the approaches and dimensions used, followed by a discussion on insights from agrifood system assessments to help address identified knowledge gaps. Our review highlighted a significant lack of widely accepted methodologies and metrics for performance evaluation. Most existing frameworks focus narrowly on technical or environmental dimensions, with few tools addressing multiple aspects. This trend is likely due to the predominance of lab-based research, underscoring the need for a stronger emphasis on social assessments in real-world contexts. We identify three key aspects to improve CE intervention assessments: i) using systems approaches to highlight multiple dimensions and their interactions; ii) considering scale and local adaptability for context-specific performance metrics; and iii) involving stakeholders in the assessment process to ensure practicality and facilitate improvement.

Keywords: circular economy; agrifood systems; food systems; impact assessment; performance evaluation

1. Introduction

The concept of circular economy (CE) has gained traction in recent decades as a model for both environmental sustainability and economic development due to its potential to revolutionize the way we produce, consume, and manage resources[1]. Assessing the impact of CE interventions is, therefore, of paramount importance [2–4]. First and foremost, such assessments allow us to gauge the effectiveness and impact of these interventions on environmental sustainability. In a world facing escalating ecological challenges – mostly the result of the traditional linear economic model with its take-make-dispose approach – assessing CE interventions helps determining if they are truly reducing waste, conserving valuable resources, and mitigating environmental harm. By measuring outcomes such as reduced carbon emissions, minimized waste generation, and enhanced resource efficiency, we can ensure that these interventions align with global goals for a more environmentally sustainable and resilient future [5].

Despite the importance of measuring the impact of CE interventions, little is known about how this can be done [2,3]. A literature review conducted by Sassanelli et al. [2] revealed that the interest in measuring CE performance is limited and that methodologies and metrics are mostly lacking. Based on a literature review of circularity metrics, Corona et al. [6] classified the assessment tools that have been used into two groups: i) assessment frameworks comprising multiple indicators for measuring various aspects of circularity within a system, which can be adjusted for specific cases;

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and ii) assessments that are done by using one single (or aggregated) scoring indicator. Such assessments are foundational to understanding and mapping the potential benefits and adverse impacts of CE interventions.

Circularity in agrifood systems offers a promising approach to optimizing resource use, minimizing waste, reducing environmental impacts, enhancing economic performance while generating positive food security consequences [7–9]. Agrifood systems have different conditions, such as the products' perishable nature, the existing close interrelation with ecosystems, and production seasonality [7,10]. This requires suitable frameworks and tools to assess the performance of CE in agrifood systems [7,8,11]. Until date, however, only few studies have assessed the implementation of CE in the agrifood sector, taking into account these particular conditions. This has created a lack of available relevant and practical indicators [7].

Finally, the geographical context of CE interventions is an important element to be taken into consideration in impact assessments. Most low- and middle-income countries (LMICs) have not profited from the linear take-make-dispose economic model [12,13]. Attention to circularity in LMICs was initially limited but has gained traction in recent years [14]. LMICs' contexts and priorities differ substantially from those of high-income countries (HICs) – where many of the current assessment frameworks and tools have been developed [15] – which calls for different assessment methodologies and metrics. For instance, CE is often promoted in HICs to reduce pollution and the large ecological footprint of production and consumption – often from a techno-economic perspective involving large businesses [16] – while in LMICs, CE is often encouraged as a key strategy to address the multiple challenges related to limited access to key resources. So far, its implementation has mostly been informal, and driven by poverty and unemployment [17]. It is therefore important that CE assessment frameworks for LMICs not only look at technological and economic feasibility but also include a social dimension, which are often missing from the frameworks used to describe CE in HICs [18].

Assessments of CE interventions can help LMICs to identify opportunities for more sustainable resource management, reduce their dependence on expensive imported resources and mitigate environmental degradation. By identifying options to reduce waste and optimize resource use, these assessments can point to significant environmental, social and economic benefits that are especially vital in regions where resources are scarce, and the impacts of resource depletion are most keenly felt such as in LMICs.

This study is to provide insights and recommendations to support further development of CE interventions – and assessing their performance – in agrifood systems. This could be especially relevant to agrifood systems in LMICs, as we found a gap in the literature addressing this specific context.

To assess the current understanding in this topic, we conducted a realist literature review [19], to examine and explore a wider set of lessons learnt in assessing CE interventions within the agrifood system which is followed by a discussion on how the identified knowledge gaps can be supported by the literature. The following research questions guided this realist literature review:

1) What approaches (incl. models, tools etc.) are used for monitoring and assessing the impact of CE interventions within agrifood systems?

2) What dimensions (technical, environmental, social, and economic) are included in monitoring and assessing the impact of CE interventions within agrifood systems?

3) Based on the review of agrifood assessments, how can the development and implementations of CE interventions within agrifood systems be improved?

This study is organized as follows: Section 2 provides the background framing of CE and CE interventions in agrifood systems. Section 3 outlines the methodology used for the realist literature review. Section 4 discusses the results of the literature review on CE assessments in agrifood systems. Section 5 provides key insights on broader assessment methodologies in the domain of agrifood systems and section 6 outlines the essential lessons for evaluating CE interventions in these systems.

2. Background

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2.1. Defining Circular Economy (CE)

The use of the CE concept has grown, both in consolidating and differentiating its understanding [1]. The concept has gained attention of scholars, policymakers and practitioners, as it provides a tool to operationalize and implement the often-perceived vague framing of (environmentally) sustainable development [6,20]. Still, critique has grown that many definitions of CE lack applicability [21], although consensus on some of the core principles has increased [1]. A recent review by Kirchherr et al. [1] shows that 70-80% of the studies acknowledge 'reuse' and 'recycle' as the two foundational principles of CE. The authors also report an increase in the call for a 'fundamental systemic shift' to instigate CE transitions. In addition, compared to their 2017 review, the authors reported that more definitions frame CE as a tool to reach environmentally sustainable development ─ including important enablers (e.g., consumers and business models) – and fewer include economic prosperity as a goal [1].

One of the most commonly used framings of CE, and also used in this study, is from the Ellen MacArthur Foundation. They frame CE as '*a system where materials never become waste and nature is regenerated. In a circular economy, products and materials are kept in circulation through processes like maintenance, reuse, refurbishment, remanufacture, recycling, and composting. The circular economy tackles climate change and other global challenges, like biodiversity loss, waste, and pollution, by decoupling economic activity from the consumption of finite resources*' [22]. In their definition, CE is driven by three principles, namely i) eliminating waste and pollution; ii) circulating products and materials; and iii) regenerating nature.

2.2. CE Interventions in Agrifood Systems

The agrifood system refers to the entire interconnected network of activities, processes, and actors involved in the production, processing, distribution, and consumption of agricultural products and food [23]. Agrifood systems are complex and multifaceted systems that involve various stakeholders, including farmers, processors, distributors, retailers, consumers and policymakers. Therefore, agrifood systems encompass all stages of the food supply chain, from the cultivation of crops and the raising of animals to the delivery of food products to consumers. Agricultural production, which is one of the main components of agrifood systems, contributes to 30% of global greenhouse gas emissions [24], and has contributed to the degradation of one fourth of the soils and the loss of one third of forest cover globally [25], while at the same time, one third of the food is wasted [26]. The hidden costs of these environmental, social, and human health consequences of the global agrifood system were estimated at close to $13 trillion in 2020 [27].

In this context, CE interventions are promoted to lower the environmental impact of agrifood systems by encouraging the reduction of resource use, waste and pollution from agricultural production and food consumption, the use of chemical fertilizers, biodiversity loss from land use change, and land, water, and carbon footprints [25,28]. Widespread adoption of circularity in agrifood systems can lead to more profitable, resilient and low-emission systems that ultimately support sustainable production and consumption practices [28].

Within the context of CE, the goal is to create closed-loop systems where materials, energy, and resources are efficiently managed, reused and recycled [29]. From the perspective of agrifood systems, this includes CE interventions addressing food waste reduction, wastewater use, upcycling and valorization, water recycling, regenerative use of resources, local and short supply chains, biological nutrient cycling, food packaging innovation, food redistribution, circular business models, bio energy and bio materials [30,31].

3. Methodology

We conducted a realist review approach focusing on in-depth and qualitative analysis that seeks an explanation rather than an empirical truth [19]. In this study, peer-reviewed literature was searched via Scopus (Elsevier) and Web of Science (Thomson), the two largest scientific databases for the social and environmental sciences. Beforehand, we determined the keywords and conducted

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a quick sensitivity test of keywords in Scopus. For this test, we included a set of geographical sets of indicators focusing on LMICs. Unfortunately, the database search was very sensitive to the line on regions with only 29 hits as a result. We decided upon removing this line to keep the search as broad as possible. In Table 1, we present the final set of key words that were used in the search databases.

Table 1. Keywords used in the search databases.

'Monitor*' OR 'Assess*' OR 'Evaluat*' OR 'MEL' OR 'MEAL' OR 'M&E'[1]
AND
'Circular Economy' OR 'Circularity' OR 'CE' OR 'Climate Neutral Economy' OR 'Circular'
AND
'Food' OR 'Agri*' OR 'Agro'

[1] ME(A)L stands for Monitoring, evaluation (accountability) and learning.

The initial search resulted in 2510 articles, which were pre-selected based on their title and abstract according to the inclusion/exclusion criteria presented in Table 2. This pre-selection resulted in 367 studies, which were further narrowed down to 178 articles after a more detailed review of the articles. Information was extracted from these articles according to the following codes 'CE intervention type', 'measures and approaches for M&E', 'M&E dimensions', 'Challenges and enablers for M&E', and contextual notes (geographical location or societal context).

Table 2. This is a table. Tables should be placed in the main text near to the first time they are cited.

Inclusion criteria	Exclusion criteria
English language	Exclude if not about agriculture or food systems
Peer reviewed journal articles	Exclude if not in LMIC
CE interventions, technologies and innovations	Commentaries, opinion papers, and editorials

4. Results Literature Review

4.1. Approaches and Dimensions Used to Monitor and Assess CE Interventions

Our literature review showed that approaches to monitor and assess CE interventions in agrifood systems mostly focused on the technological dimension and on technical interventions and parameters (140 studies). This includes laboratories (e.g., [32,33]) or trial sites for field experiments (e.g., [34,35]). In these studies, focus was mainly on efficiency of a technical process or its circular feasibility. Examples of circular processes described in the studies were: reuse of crop residue, biorefinery processes, and reuse of waste for animal feed. Indicators in these studies often included technical parameters related to: production (e.g., yields and growth rates – [36–38]), conversion ratios (e.g., feed conversion – [39]), mass balance analysis [40] or chemical indicators (e.g., P balances, K or N levels, nutritional composition – [41,42]).

The second dimension mostly considered in the studies we reviewed was the environmental dimension (49 studies). Some studies used environmental assessments including carbon footprint [43], residual fertilization effects and nitrogen leaching [44,45], or risk of outbreaks, pollution/contamination [46,47] and peak global warming potential [45,48–50]. Studies often referred to indicators related to greenhouse gases (GHG) fluxes and emissions [51,52], plant growth and development [53], soil-plant analysis development (SPAD) index (54), microbial activity [55], and chemical analysis of NPK [41,42].

Our literature review also showed that there was a distinct lack of studies exploring the social or economic dimension of CE interventions. In total, 10 studies considered the social dimension,

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and 14 studies considered the economic dimension. For instance, the social dimension included: legislation [47], consumer preferences [56], perspectives on use/impacts or as part of the LCA (or social life cycle assessment) or strength, weakness, opportunity, threat (SWOT) analysis [57–59]. One study also highlighted a political economy perspective, discussing the social-ecological impacts of the transition from a fossil-based to a biomass-based economy [60]. Focusing on the bioeconomy in the sugar-ethanol sector, the authors reported that resulting socio-ecological problems range from an increasing concentration of landownership to the negative impact of agrotoxins [60]. From an economic perspective, commonly discussed measures are market value [61], as part of SWOT analysis [59], production value or costs [62–64], and cost benefit analysis [65–67] or an agro-economic value assessment [68].

In some cases, a more holistic approach was used such as the planetary boundaries framework [58] or environmental risk assessment [44] through risk quotients [69].

Various studies used cross-cutting framings or approaches to evaluating CE interventions, including life cycle assessments (LCAs) [43,44,50,57,58,70–78]. LCA enables the evaluation of environmental impacts of a product, service, or system throughout its entire life cycle [79,80]. According to Djekic & Tomasevic [71], who review the meat value chain, "Life-cycle assessment (LCA) is considered as the best method in calculating environmental impact from all stages of agricultural and food production and comprises of the following steps: (i) mapping the process, (ii) setting scope and boundaries, (iii) collecting inventory data, and (iv) interpreting the results". Camana et al. [81] (p. 631) point out that "*Life cycle thinking can be a promising tool to assess the multidisciplinary effects of policies both operatively and strategically*.", thereby enabling an overall assessment of the sustainability of strategies. However, LCAs have a number of constraints. They are developed for a specific product or process which makes it difficult to translate its results to a higher scale [6] and focus often on short-term and individual benefits only [80]. Konstantinidis et al. [75] argue that LCAs are highly dependent on the defined product system and certain elements such as infrastructure, capital goods and equipment are not included due to their long lifespan. Moreover, LCAs tend to measure impacts that are easily quantifiable and are bound by assumptions and data availability/quality [80].

Other studies suggested approaches such as Recipe 2016 analysis [75], associate sensitivity analysis [43], integrated sustainability assessment [82], and combined value-chain analysis and social life-cycle analysis [83]. However, despite the cross-cutting nature of these assessments, social factors were often less considered.

4.2. From Technology to Implementation

Besides the results showing a focus on the technological and environmental dimensions, we have also noticed the dominance of lab or experimental studies. For example, examining how dietary changes affect performance or monitoring the impact on animal production was a common focus [84–87]. In total, 39 papers were lab-based (e.g., [74,88], and 35 field- or animal trial-based (e.g., [86,89]). This technological and experimental focus of CE assessments limits the understanding of the impacts of CE interventions on broader societal goals. Moreover, since most studies are conducted in highly controlled environments, this limits contextual dynamics, including the response to or adaptation by users. We only found three studies which focused on consumption, namely: Maschio et al. [90] on the total utilization of foods in Brazil, Akter et al. [91] on organic food purchase in Bangladesh, and Lami et al. [56] on the role of carbon footprint in the consumption of beef in Spain. The lack of understanding of consumption patterns, the social dimensions of end-users, and how they can be transformed are some of the barriers to the success of most CE interventions [64]. The demonstration perceptions of CE interventions by stakeholders such as farmers, laborers or households are imperative for the social acceptance of these interventions [64].

The majority of lab, experimental or field trials-focused studies may also underline the low frequency of LMIC-focused articles (n=9) because these controlled environment studies aim to exclude contextual factors (besides the biophysical elements) such as location. However, the social

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and economic factors in the context of LMICs will be foundational in the implementation and feasibility of CE interventions in these countries. Considering bioeconomy, Kleinschmitt et al. [92] argue that it '*has its roots in the discourse of ecological modernization arguing that economic growth and development can be aligned with environmental protection*'. While the bioeconomy and CE concepts differ slightly, both advocate for sustainably sourced and efficiently used biological materials, supporting environmental health and reducing reliance on non-renewable resources. Consequently, CE also stems from the idea that economic growth and development can coexist with environmental protection. From a critical perspective, knowledge production including CE interventions are situated in social contexts and constructions. These are underlined by power relations and institutions. Therefore, without social contextualization of interventions, there is a risk that socio-ecological challenges will increase [60]. Previous policy analyses have shown that bioeconomy plans mainly support conventional areas of innovation [60,93,94]. This has led to critical perspectives by researchers and organizations fearing that interventions would further develop socio-ecological problems, such as biodiversity loss or land tenure issues [60]. Likewise, CE interventions may also increase the risk of similar consequences. In order to minimize or even avoid such consequences in already challenging geographies (e.g., most LMICs), studies focusing on the implementation and contextual development of CE interventions in these geographies are therefore crucial, including the development of assessment methodologies that consider the interconnected dimensions of technical, environmental, economic and social in the specific context of LMICs.

5. Descriptive Analysis of Agrifood System Assessments

Building on the knowledge gaps identified in the literature review, we have outlined several agrifood system framework domains designed to evaluate the impact of specific agricultural or food system interventions through holistic and interconnected approaches. These agrifood system assessment frameworks were selected because they are widely recognized in the agrifood system field and can offer valuable insights applicable to the development of CE assessments.

5.1. Food Systems Frameworks and Their Assessments

The increased attention, and recognition, of the food system concept has led to the development of several food system frameworks supporting the understanding and analysis of complex networks of interconnected activities, processes, and stakeholders within agricultural and food systems [95,96]. As such, various frameworks have been developed assessing the performance of food systems [95,97–102]. Others address specific approaches within agrifood systems such as agroecology [103–106], or sustainable intensification [107].

Particularly for LMICs, agrifood systems are seen as to be more complex and heterogenous compared to those in HICs [108,109]. Moreover, agrifood systems in LMICs are more vulnerable to challenges such as climate change and price shocks [102,109]. The development of food system frameworks specific to LMICs, therefore, demand acknowledgement of this complexity, and a diversity of scholars and organizations have indeed developed their own [102,108]. One of the most commonly used frameworks is that of the High-Level Panel of Experts (HLPE) on Food Security and Nutrition of the Committee on World Food Security [110]. Other examples are the frameworks developed by Nguyen [111] for the Food and Agriculture Organization of the United Nations (FAO) and Van Berkum et al. [99] for Wageningen University and Research (WUR). Reviewing existing literature, Brouwer et al. [98] found that some food system frameworks take a linear, supply-led perspective, focusing on how to feed a growing global population by prioritizing production and consumption. Other frameworks adopt a circular view, emphasizing agroecology, nutrient recycling, or waste reduction, with the aim of minimizing the negative impacts of agricultural intensification. Another group of frameworks expand their focus to include supply chain analysis, addressing the question of how food reaches the population. Depending on the goal(s) of the assessment and complexity of the food system, the use of a specific framework can be justified.

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Food systems frameworks can assist in assessing the impacts of food systems on key outcomes such as environmental sustainability, economic development, social equity, and human health [95,98,101]. Assessments are crucial for decision makers as they provide insights into the potential impacts (positive or negative) of different policy interventions in food systems. While these assessments themselves will not drive food system transformation, they help identify trade-offs and synergies between development objectives and guide investment decisions to achieve desired multi-dimensional outcomes [96,112].

In general, there is a consensus in the food system literature that a more systemic approach is key for analytical purposes but also to support policy makers in their decision making. A systemic approach will support the understanding of the complexity of the interdependencies between food system components, the trade-offs and synergies between multiple outcomes, and the feedback loops that will drive the system's future trajectories. There is, however, still a lack of clarity on how to implement food system frameworks in practice [95,98]. As Bustamente et al. [96] state '*how can we progress from analyzing the drivers and outcomes of food systems to (...) informing and supporting policy processes and interventions that progress in the transformation toward more sustainable food systems*.'

The process of operationalizing assessment tools for food systems depends on various resources such as the type of food system framework, indicator complexity, scale and context specifications, and data availability [100]. Properly conducted assessments also help build community capacity, promote food systems thinking, connect initiatives, and enhance policy coherence. Integral to the assessment, effective indicator design should foster frequent and effective communication and collaboration among sectors and institutions [100]. Various frameworks in the agrifood system domain aim to assess the impact of specific agricultural or food system interventions by using holistic and interconnected approaches. There are, however, a number of significant challenges in conducting assessments of a holistic nature. They require a broad scope, substantial resources, a reasonable timeframe and a multidisciplinary team with shared goals [113]. There is tension between the complexity and simplicity of indicators: how to encompass all dimensions of food systems and, simultaneously keeping indicators simple enough to remain practical and effective [100].

5.2. Assessing the Performance of Particular Approaches Within Agrifood Systems –Agroecology

A diversity of approaches has been developed to tackle the complex challenges facing agrifood systems. Examples include agroecology, sustainable intensification, organic farming, conservation agriculture, regenerative agriculture, and ecological intensification [114]. In recent years, agroecology in particular has attracted growing attention in scientific and political dialogues as a promising approach for transforming agrifood systems by fostering ecological, economic and social sustainability while addressing multiple complex and interdependent food system challenges [104,114–117]. Agroecology emphasizes the interconnections between plants, animals, humans, and the environment, while also addressing the need for equitable and just food systems [114,117]. It is a holistic and integrated approach to sustainable agrifood systems that integrates traditional knowledge and ecological principles and concepts with social and economic goals and is adaptable to location-specific contexts and various scales [115–117]. Agroecological practices foster circularity by embracing ecological and social principles within agricultural practices: enhancing nutrient, energy, and waste recycling [117,118].

The increasing interest in and commitment to agroecology has resulted in a growing need for holistic and multi-disciplinary methodologies and tools to assess the benefits and limits of agroecological practices across different contexts [104,105]. Such assessment tools can support stakeholders in managing agroecological transitions by offering insights into barriers, levers, benefits, and trade-offs. They can also support evidence-based advocacy and policymaking by providing relevant information for decision-makers [105]. Darmaun et al. [105] pointed out that agroecological assessments should be developed considering five key requirements: i) be adaptable to local conditions; ii) consider social interactions of stakeholders involved; iii) clarify the concept of agroecology, iv) consider the temporal dynamics to understand barriers and levers; and v) use a participatory bottom-up approach.

However, assessing the performance of agroecological practices – like the performance of food systems – is methodologically challenging due to their dynamic nature, often spanning multiple geographical scales, and involving complex interrelated environmental, economic, and social dimensions [104–106]. In fact, most current agroecological assessment tools were designed for particular spatial scales or production systems, often delivering results that lack local relevance or global comparability, and do not fully reflect the multifunctionality of agroecological systems [106]. To address these shortcomings, the CGIAR Transformative Agroecology Initiative developed an agroecological assessment tool following a collaborative, multi-disciplinary process involving researchers from various LMICs. It builds on existing tools and prioritizes simplicity, reliability, and relevance to address sustainability issues in food systems at both local and global scales [106,119].

6. Lessons from Assessment Frameworks in Agrifood Systems

After identifying gaps in current approaches and dimensions for assessing CE and offering key insights on assessment tools in agrifood systems, we outline three essential lessons for evaluating CE interventions in the agri-food sector.

1. Applying system thinking

The food systems framework is increasingly used to better address food and agriculture challenges by recognizing them as complex issues that necessitate a systemic approach. As such, multiple dimensions are considered such as food security, nutrition, livelihoods, and environmental sustainability, thereby evaluating the trade-offs and synergies associated with different interventions [98]. Notably, understanding the interactions and dynamics between food system elements is essential for decision makers to enhance the performance of such systems [98]. It also emphasizes that besides the multiple dimensions within a food system, there are also interactions between these different dimensions – each with their own impacts on circularity [98,103].

The agroecological assessment framework developed by the CGIAR Transformative Agroecology Initiative can be instrumental in creating impact assessments of CE interventions by providing a comprehensive understanding of the interplay between agricultural ecosystems, biodiversity, and socio-economic factors. As part of this agroecological assessment approach, agroecological living landscapes were established in which first an assessment of the agroecological context was conducted (e.g. current state of agriculture, social structure, business models, policies). Only after this context analysis, a set of performance metrics were established to assess agroecological approaches across the food chain. These performance metrics were based on environmental, social, economic and political elements and agroecological principles [106].

Moving beyond agroecology to look more broadly at CE innovations in agrifood systems, one can distinguish other approaches. Jurgilevich et al. [120] for example, emphasize the need to look at circularity in terms of food production, food consumption, food surplus and waste management. Although our literature review points towards a focus on assessments of food production, effort should be made to produce more holistic approaches [106,121,122]. Lu and Halog [122] emphasize the need, among other aspects, to employ systems thinking – a call answered by Bos et al. [121]. The Butterfly Framework as presented by Bos et al. [121], specifically stipulates determining flows between different components in the socio-economic, technical and ecological systems. In terms of circularity of the food system these connections are also identified as the material and nutrient flow through the system [120]. The Butterfly Framework further invites the user to distinguish drivers, available instruments for decision-makers and consequences to societal goals, all specific to the case at hand. Such an approach allows for informed decision-making and the prioritization of interventions that maximize positive impacts across multiple dimensions and food system components.

2. Acknowledging scale & creating space for local adaptability

Currently, much of the literature on CE interventions in agrifood systems focuses on lab or trial-based assessments. Suggested assessments can assume generalization while being based on work in HICs. The review of Wiget et al. [103] finds few frameworks that are adaptable to a varying geographical scope (e.g., LMICs) and local conditions. While pointing toward the need for scope delineation, they acknowledge that heterogeneity exists among assessment frameworks which limits comparability. The need for scope delineation is hence generally recognized [121–123]. Even so, frameworks on the landscape or territorial food system level are mostly lacking [104], though some efforts exist (e.g.,[102]). In the agroecology framework a context analysis is conducted before determining the performance metrics. This context analysis refers to the agrifood system context (e.g., infrastructure and practices, knowledge) and the differences in how assessments are conducted [103]. To this end, there have been distinctive differences in assessment possibilities [124] and desired outcomes for circularity in HICs and LMICs.

Besides creating space for local adaptability in CE assessments, Wiget et al. [103] also point out that scale is important when considering suitability. This means to not only consider farm or production level, but large-scale dynamics relevant for policy analysis. In addition, one could also make a distinction between indicators that are globally relevant and those that are of local importance [106]. Aligning CE interventions with broader food system goals and policy objectives is essential for long-term sustainability and scalability. Food system frameworks help identify policy levers and regulatory mechanisms that can support the implementation of circular economy interventions, such as incentives for sustainable production practices, procurement policies that prioritize circular products, and regulations to reduce food waste. This is especially important in case assessments are aimed at improving CE interventions, since producers' decision-making is also dependent on decisions made by other stakeholders [125].

3. Planning for implementation & stakeholder participation

Besides important considerations on system approaches, scale and adaptability, assessment studies often mentioned the need for involvement of relevant stakeholders during the development of assessments [104–106,121]. In our literature review, we did not encounter studies that involved stakeholders in the assessment development. For action perspective, however, stakeholders would benefit from understanding their role in the larger system; and assessments are most helpful when adopted by stakeholders [121]. This involvement is especially important when clarifying the goals and desired outcomes of CE interventions (which are also needed to identify strategies and agents of change). Furthermore, to enable continued adoption and implementation of assessments by farmers or producing companies, assessments need to enjoy a certain level of ownership – facilitated by being co-developed.

Stakeholders can be involved in developing assessments for CE interventions in the agrifood system through a structured, participatory process that includes their identification, engagement, and active collaboration. This involves organizing workshops, focus groups, and advisory committees to gather diverse perspectives and co-design assessment frameworks or identify assessment questions. Incorporating local knowledge and context-specific indicators ensures relevance and practicality. Transparency is maintained through regular updates and feedback mechanisms, while pilot testing and iterative refinement enhance tool effectiveness. Capacity-building initiatives, such as training workshops, empower stakeholders to utilize the assessments, and collaborative implementation ensures coordinated efforts. To this end, assessment frameworks can also help with adapting CE interventions to different contexts and making them more effective.

7. Conclusions

Exploring the peer-reviewed literature for assessments of CE interventions in agrifood systems, we found that commonly agreed methodologies and metrics on assessing performance of CE interventions in practice are limited. Many of the assessment frameworks and tools are limited in their scope and in most cases, focus only on one dimension (often technical or environmental). Few assessments rely on tools that consider more than one dimension, such as SWOT, integrated sustainability assessment or LCA. Although these assessments have a broader scope, they do not

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systematically include all four dimensions. Therefore, there is a distinctive lack of holistic approaches.

Considering the four assessment dimensions (technical, environmental, social, economic) that were found in the literature, the majority of assessments centered on technical dimension. Key indicators associated to this technical focus concerned process efficiency (e.g., conversion rate), production and chemical analysis. A smaller number of assessments discussed environmental aspects by including indicators regarding GHGs, carbon footprint or global warming potential. Assessments on social and economic aspects were often limited to feasibility studies (e.g., impact on employment, income, return on investment). The emphasis on technical assessments could be linked to most work pertaining to lab- or trial-based experiments, resulting in little attention paid to the 'real-world' context. The literature review also demonstrated that most assessments were developed for agrifood systems in HICs, which limits their suitability for the context, scale and priorities of LMICs.

Learning from the literature on assessment frameworks used in the context of food systems and agroecology, we identify the following aspects that can help to further improve CE intervention assessments: i) apply a systems thinking approach, providing a holistic view on interacting dimensions; ii) consider the scale and local adaptability, requiring context analysis and both global and locally-adapted performance metrics; and iii) structurally plan for stakeholder participation in defining assessments, which will make these assessments understandable and also support the improvement of CE interventions.

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