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Sustainability and Circularity of the Agri-food Systems: How to Measure It? A First Attempt on the Italian System

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Abstract: The agri-food sector is undergoing profound transformations driven by ecological and digital transitions, as well as evolving consumer and nutritional choices. These shifts pose significant challenges but also open new opportunities for businesses to enhance sustainability and competitiveness through circular economy principles. In response, Spoke 9 of the National Agritech Center (PNRR) has launched a survey to analyze agri-food companies and sustainability practices and promote circular strategies. A large-scale survey conducted in early 2024 gathered data from 3002 agri-food companies, covering 20 Italian regions and six major supply chains (wine, olive oil, dairy, milk, fruit and vegetables, and beekeeping). The study is the first attempt in Italy to get metrics on these topics from agri-food companies, and it provides a comprehensive assessment of circular economy practices in the sector. The key objectives of the work are as follows: (1) developing integrated sustainability indicators; (2) sector-specific circular metrics; (3) identifying best practices and gaps; (4) supporting policy and decision-making; and (5) benchmarking and monitoring.

Keywords: agri-food system; metrics; sustainability; circular economy; sampling

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1. Introduction

The transition toward a circular economy (CE) represents a strategic response to increasing environmental pressures and the challenges associated with resource sustainability. The traditional linear economic model, centered on production, consumption, and disposal, has revealed significant limitations, notably by exacerbating environmental degradation and fostering dependency on virgin raw materials [1]. In contrast, the CE model seeks to overcome these shortcomings through strategies that reduce waste, enhance recycling and reuse, and optimize resource recovery, thereby contributing to the closure of production loops and more efficient material utilization [2]. Nonetheless, despite the widespread adoption of the concept, measuring circularity remains a complex and unresolved issue, characterized by heterogeneous methodological approaches and the absence of universally standardized indicators [3]. Evaluation efforts of CE efficiency have predominantly focused on industrial sectors and waste management systems, while applications within more fragmented sectors, such as the agri-food industry, have received comparatively less attention [4]. The literature indicates that while the implementation of CE has largely developed within material-intensive manufacturing sectors, the agricultural and agri-food

sectors, despite offering unique opportunities for valorizing by-products and optimizing resource use, face significant challenges in adopting circular strategies on a large scale. Measuring circularity in this context is notably intricate: many of the sustainability metrics employed in CE analyses serve as indirect indicators, or proxies, that do not always directly capture circular practices [5]. Traditional methodologies for evaluating CE, such as material flow analysis and life cycle assessment, provide valuable insights but tend to emphasize a technical-environmental perspective, often overlooking the economic and social implications of transitioning to circular production models [6]. Moreover, the pronounced heterogeneity in production models and territorial contexts complicates the application of standardized metrics, thereby limiting the ability to effectively compare circularity levels across different sectors and regions [7]. Consequently, there is a critical need for more comprehensive evaluation tools that account for sector-specific and regional particularities to supply reliable empirical data and support strategies for transitioning toward a more sustainable economic system [8]. This study aims to contribute to the literature on CE evaluation by providing a detailed and multidimensional description of the current state of the Italian agri-food industry. Through an exploratory data analysis, the research examines sector-specific characteristics, sustainability practices, and regional circularity dynamics. Utilizing survey data representative of various agri-food sub-sectors, the study intends to identify the principal industry trends, territorial disparities, and structural challenges that influence the adoption of circular practices within the Italian agri-food sector. A more precise measurement of circularity will enable the development of targeted strategies and more effective support tools, ultimately contributing to a more sustainable management of resources. The approach adopted herein not only evaluates explicit CE indicators but also considers indirect metrics and proxies, thereby offering a broader perspective on resource management strategies. In this way, the present study enriches the discourse on CE evaluation, highlighting the importance of integrated approaches and adaptable methodologies to steer the agri-food sector toward a more efficient and resilient future, while offering an expansive view of CE strategies within the Italian agri-food domain.

2. Literature Review

A growing body of research has underscored the importance of developing robust, multidimensional sustainability indicators to support the transition toward a circular economy [7], particularly within the agri-food sector. Traditional linear models, with their focus on production, consumption, and disposal, have increasingly given way to more resource-efficient and regenerative systems that emphasize waste reduction, recycling, and resource recovery [1]. However, the complexity inherent in measuring circularity calls for the development of integrated indicators that capture not only technical-environmental performance but also economic and social dimensions [1,7]. Several studies have laid the groundwork for this multidimensional approach. For instance, ref. [9] has proposed spatially differentiated dashboards that enable agri-food enterprises to align their sustainability strategies with local environmental and socioeconomic contexts. Similarly, ref. [10] has advanced the integration of safety, cost, and environmental impact metrics into comprehensive decision-support tools, which are crucial for transparent and informed management decisions in the agri-food domain. These efforts highlight the need for indicators that can effectively bridge the gap between traditional sustainability metrics and the specific challenges posed by circular practices. To address these methodological challenges, ref. [11] developed a composite indicator to quantify sustainability in the agriculture, livestock, and agri-food sectors across the European Union. Their methodology, based on a system of indices tailored to the European agri-food context, enables cross-country comparison under a homogeneous criterion. Building on this approach, ref. [12] proposed an extended

framework of composite indicators developed through expert consensus using the Delphi method. This framework organizes sustainability metrics into three core dimensions—environmental, economic, and social—allowing for more nuanced and policy-relevant assessments within the circular economy paradigm. These integrated approaches underscore the necessity of moving beyond single-parameter analyses to develop a suite of indicators that reflect the multifaceted nature of sustainability within the CE framework. Furthermore, the enhancement of traceability systems has emerged as a critical factor in measuring and validating sustainability performance. Robust traceability mechanisms contribute to increased transparency and accountability across agri-food supply chains, thereby reinforcing circular economy principles. Studies by [13,14] reveal that both industry stakeholders and consumers value traceability for its role in substantiating sustainability claims, which in turn supports the broader adoption of circular practices. Economic assessments, such as those conducted by [15,16], further illustrate the cost–benefit potential of implementing advanced traceability systems, thereby strengthening the case for their integration as key sustainability indicators. Moreover, sector-specific analyses have contributed significantly to our understanding of how circular economy practices can be operationalized in diverse agri-food contexts. Research focusing on meat [17], wine [18], fruits and vegetables [19,20], and cheese [21] has shown that tailored traceability and sustainability indicators can enhance production efficiency and bolster consumer confidence. These studies collectively argue that the unique challenges of the agri-food sector—characterized by heterogeneous production models and territorial disparities—demand bespoke sustainability indicators that reflect both local conditions and broader circularity principles. Emerging research also emphasizes the role of communication in translating complex sustainability metrics into actionable insights. Clear and accessible food labeling, as demonstrated by [22], and the strategic use of digital platforms [23,24] have been instrumental in disseminating traceability data and sustainability metrics. By effectively communicating technical evaluations to a broader audience, these strategies help foster consumer engagement and support the practical implementation of circular practices in the agri-food sector.

3. Methods and Sample Overview

Building on the insights from the literature review, which highlighted the complexities of measuring circularity in the agri-food sector and the necessity for integrated sustainability indicators, this study adopts a structured methodological approach to analyze circular practices among Italian agri-food enterprises. Given the sector's heterogeneity and the diverse territorial contexts identified in prior research [25], a robust sampling strategy was implemented to ensure a representative assessment of circular economy adoption. To this end, the target population was defined as Italian agri-food companies, with a stratified sampling framework encompassing Italy's 20 regions and six key production chains, namely cereals, dairy, wine, olive oil, fruit and vegetables, and honey chains. This approach resulted in a final sample of 3002 companies of varying sizes, facilitating an in-depth examination of sectoral and regional circularity dynamics. To complement the existing informational framework on agri-food sustainability, an ad hoc questionnaire was designed and administered using a mixed CATI/CAWI methodology. This dual-mode approach ensured comprehensive coverage while enhancing the reliability and comparability of the collected data. The questionnaire consisted of over 120 questions (qs.), systematically organized into the following four primary thematic areas: (i) company demographic data; (ii) questions applicable to all production chains; (iii) questions specific to large enterprises; and (iv) questions tailored to individual production chains. Particular emphasis was placed on section (ii), which was further subdivided into five distinct sub-sections, each addressing a specific dimension of the multidimensional spectrum of agri-food sustainability. This

structured design, illustrated in Figure 1, enabled a comprehensive and comparative analysis, allowing for both a broad industry-wide assessment and a more granular examination of sector-specific challenges. By capturing diverse aspects of circular economy implementation, the questionnaire facilitated a holistic understanding of sustainability practices within the Italian agri-food sector.

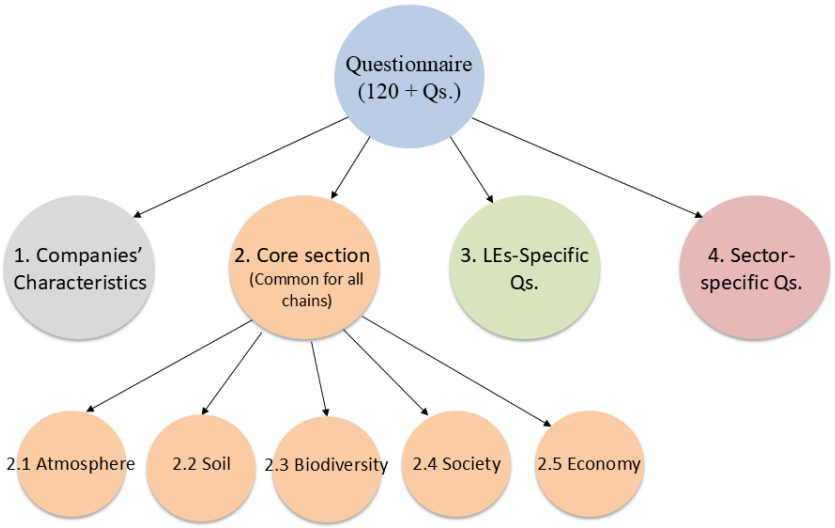

Figure 1. Hierarchical structure of the questionnaire.

The collected data were analyzed using a range of statistical techniques, including arithmetic means and measures of central tendency and variability, to ensure the highest degree of interpretability. Graphical representations were also employed to facilitate clearer visualization of key patterns and trends. Recognizing the structural differences within the industry, the analysis distinguishes between large enterprises (LEs)—defined as those with more than 50 employees and an annual turnover exceeding 30 million euros—and small and medium enterprises (SMEs). This distinction mitigates the effects of distributional asymmetry in key variables and enables a more precise identification of disparities in circular economy adoption. LEs are 5% of the entire sample, in line with the dimensional distribution of the enterprises of this sector.

4. Discussion of the Results

Starting with the analysis of the respondents to the questionnaire, higher participation of employees is observed in large companies (45.8%) and of owners/entrepreneurs in SMEs (69.6%). This distribution is also reflected in the analysis of SMEs broken down by main production chain in Table 1, where the participation of owners/entrepreneurs amounts to 74.7% in the cereal chain, 56.2% in the dairy chain, 79.6% in the honey chain, 65.2% in the fruit and vegetable chain, and 71.8% in the wine chain. With respect to the main production chain, there is a clear predominance of the fruit and vegetable sector among LEs (36%), followed by the cereal sector (22.3%) and the dairy sector (21.3%). A partially similar distribution is observed for SMEs, where the highest percentages are recorded for the olive oil chain (26.8%), followed by the fruit and vegetable chain (20.6%) and the wine chain (19.7%), while the cereal and dairy chains have lower incidences (about 13%). The honey chain is at the bottom of the ranking, with the participation of 3%; this reflects also the numerosity of producers in the agri-food sector. Regarding the role played along the chain, 64.75% of LEs mainly engaged in processing, 58.6% in production, 56% in marketing, and 42% in distribution and logistics, while a small share (7.0%) is involved in brokering activities. Among SMEs, 79.1% declare they are actively

involved in production, while 59.6% engage in both processing and marketing; the role of distribution and logistics is covered by 27.3% of SMEs, whereas brokering involves only 8.6%. These distributions highlight that LEs frequently cover the entire chain from the beginning to the end, while SMEs are mostly involved in only one or two steps, namely the production and/or processing of products. The most common legal form of agri-food enterprises, for both large and SMEs, is the corporate or company form, with incidences of 83.0% and 92.4%, respectively, confirming a limited heterogeneity of organizational structures nationwide. The data confirm that Italian agri-food enterprises predominantly adopt basic and individual organizational structures, with a strong preference for the corporate or company form. This trend also emerges in the different production chains, where the adoption rates of this legal form hover around or exceed 90%. The limited heterogeneity in organizational structures highlights a low inclination towards aggregation among companies in the sector. Nevertheless, also participation in consortia is limited: it stands at 41.0% for LEs and 31.5% for SMEs, with the sole exception of the wine sector, where participation reaches 54.5%. This suggests that while most agri-food enterprises operate independently, the wine sector stands out for its greater willingness to collaborate and establish more structured organizational networks. The average age of Italian agri-food companies indicates a relatively recent landscape, with an average year of establishment of 1980 for LEs and 1989 for SMEs. The data suggest that the Italian agri-food sector is relatively young, with most companies having been established in recent decades. At the level of individual production chains, the average years range from 1984 in the dairy sector to 1996 in the fruit and vegetable sector. Interestingly, no substantial differences emerge between family-run and non-family SMEs, with their respective founding years being 1988 and 1993. This indicates that ownership structure does not significantly influence the longevity of businesses in the sector. The sample analyzed includes both historical companies, founded as far back as the 1700s, and newly established companies (up to 2024). Despite the presence of historical companies dating back to the 1700s and newly established firms up to 2024, the distribution of founding years does not show a strong skew. The majority of companies were founded within a relatively concentrated timeframe: between 1965 and 2010 for LEs and between 1980 and 2010 for SMEs. This suggests a steady and consistent renewal of businesses in the agri-food sector rather than a predominance of either long-standing or newly established firms. In conclusion, an analysis of the demographic data shows a highly skewed and variable distribution in terms of company turnover, affecting both large and SMEs. Among LEs, the median turnover is 50 million euros, but there is a significant disparity: while 10% of companies exceed 220 million euros, 25% report figures below 30 million euros. For SMEs, the distribution is even more pronounced, with 90% generating less than 6 million euros in annual turnover and 25% not exceeding 60,000 euros. These figures highlight the financial challenges faced by smaller businesses in the agri-food sector. Examining the annual turnover of SMEs by production chain highlights further disparities. The median turnover varies significantly, from 1.3 million euros in the dairy sector to just 45,000 euros in the honey sector. Intermediate values include 400,000 euros for fruit and vegetable enterprises and around 200,000 euros for the cereal and wine industries. Overall, these results underscore the considerable financial heterogeneity within the sector, with a stark contrast between the most profitable and the least profitable enterprises. Such disparities suggest differing levels of market competitiveness, structural challenges, and sector-specific economic conditions that shape the financial landscape of Italian agri-food businesses.

Table 1. Structural characteristics of the companies included in the sample.

Variable	Categories	LEs	SMEs
Respondent role (%)	Owner	16.2	69.6
	Manager	24.5	7.2
	Employee	45.8	14.9
	Other	13.5	8.3
Main production chain (%)	Cereals	22.3	12.6
	Dairy	21.3	13.1
	Honey	0.7	3.0
	Oil	12.9	26.8
	Fruit and Vegetables	36.0	20.6
	Wine	5.3	19.7
	None of the previous	5.3	4.2
Role among the chain (%)	Production	58.6	79.1
	Transformation	64.7	59.6
	Distribution and Logistics	42.0	27.3
	Commerce	56.0	59.6
	Brokerage activities	7.0	8.6
	Other	3.8	3.8
Legal form (%)	Corporate or Company	83.0	92.4
	Cooperatives	15.5	7.0
	Non-profit	1.1	0.4
	Other	0.4	0.3
Consortia (%)	No	59.0	68.5
	Yes	41.0	31.5
Family (%)	No	40.8	23.0
	Yes	59.2	77.0
Foundation Year (years)	Mean	1980	1989
	Median	1988	1998
	Min	1890	1700
	Max	2021	2024
Revenue (€)	Mean	98,799,480	1,901,917
	Median	50,000,000	250,000
	Min	250,000	250
	Max	1,500,000,000	28,000,000

After introducing the sample of enterprises of the Italian agri-food sector, in the following subsections, we present the results for the five sub-themes constituting the core part of the survey.

4.1. Atmosphere

The role of energy and resource consumption in the circular economy is fundamental to reducing environmental impact and improving efficiency in the agri-food sector. The transition to sustainable strategies has gained significant attention in recent years, as noted by [26], yet the adoption of energy-efficient and low-emission technologies remains below the targets outlined in the 2030 Sustainable Development Goals ([27]). Assessing electricity, gas, diesel, and water consumption provides critical insights into the sector's energy dependency and its progress toward circularity.

Electricity consumption serves as a key proxy for energy efficiency and reliance on non-renewable energy sources. The agri-food sector exhibits a wide range of energy uses, spanning from agricultural production and product processing to logistics and distribution. As reported in Table 2, large enterprises (LEs) present a median electricity expenditure of €100,000 per year, with substantial variability ranging from €18,000 to €500,000. Medium and small enterprises (SMEs) display even greater heterogeneity, with a lower median of €6000 per year but consumption values fluctuating between €1500 and €20,000. If we relativize the consumption of energy to company revenue, SMEs exhibit higher electricity intensity (0.15 kWh/euro) than LEs (0.02 kWh/euro), indicating potential inefficiencies that could be mitigated through circular economy strategies such as process optimization

and renewable energy integration. The olive oil sector and the dairy sector have the highest energy intensive, with 0.19 kWh/euro and 0.18 kWh/euro, respectively, highlighting priority areas for intervention. These findings highlight the structural challenges common among SMEs, primarily their limited capacity to invest in advanced technologies and the difficulty in optimizing energy management. The absence of economies of scale, which characterizes smaller enterprises, makes them particularly vulnerable to energy costs. These costs, in turn, can negatively impact their competitiveness and long-term sustainability. In this context, it would be beneficial to explore solutions that enable SMEs, both in the wine industry and the broader agri-food sector, to improve energy efficiency. Such solutions could include incentives for adopting green technologies, training in optimal energy management practices, and support in accessing more competitive energy rates. Strengthening these aspects could help narrow the gap between SMEs and LEs, enhancing the sustainability and competitiveness of these entities in the long run. Renewable energy adoption is a direct indicator of circular economy integration. In the agri-food sector, the self-production of renewable energy is becoming a strategic element not only for reducing energy costs but also for meeting the growing demand for environmental sustainability. Even smaller enterprises are thus engaging in addressing the environmental and economic challenges associated with the energy transition. The survey data indicates that 78% of LEs have implemented renewable energy systems and about half of SMEs. The median renewable energy production is for LEs 200,000 kWh per year and 7000 kWh. The dairy sector, with a median of 20,000 kWh, is the chain with the highest value. Among various solutions, photovoltaic systems are the most adopted due to their ease of installation and favorable economic returns. Companies can benefit from self-consumption, reducing energy costs associated with purchasing power from the grid. Furthermore, for companies that produce an energy surplus, there is the possibility of feeding the excess energy back into the grid, creating an additional revenue stream. This not only contributes to the stabilization of the energy system but also represents an opportunity for companies to diversify their revenue streams, creating a more sustainable economic model.

Gas and diesel consumption further illustrate resource dependency, reinforcing the need for sustainable alternatives such as biogas and electrification of farm equipment. Half of LEs consume more than 15,000 cubic meters of gas per year, while more than half of SMEs do not consume gas at all. The dairy sector is the largest consumer, with half of the companies that consume more than 2000 cubic meters per year. These values reflect a common trend observed in SMEs across the entire agri-food supply chain, where the use of gas is limited and does not have a significant impact.

The use of diesel fuel, although beneficial for agricultural activities such as soil tilling and transporting raw materials, is generally modest relative to the overall turnover in the agri-food sector. Diesel usage follows a similar pattern to the above described, with a median consumption of 60,000 L for LEs and 4500 L for SMEs. Again, the incidence relative to turnover is higher for SMEs (36 L per 1000 euros). The highest incidence is found in the honey sector.

Water consumption is a critical indicator within circular economy frameworks, reflecting the sector's efficiency in waste reduction and its capability to implement closed-loop systems. This metric not only measures the direct usage of water resources but also evaluates how effectively these resources are managed to sustain environmental and economic vitality. Water consumption is also a crucial aspect of evaluating corporate sustainability, given its significant impact on the production process, particularly in companies involved in the manufacturing and processing of products. Efficient management of water resources is essential not only for reducing environmental impact but also for ensuring the long-term viability of these businesses. LEs report a median consumption of 14,000 cubic meters per year, whereas SMEs have 700 cubic meters. Again, the impact on revenue is more significant for SMEs, with

water use amounting to 2.86 cubic meters per 1000 euros of turnover. This ratio highlights the economic weight of water management in the operational budgets of these companies.

Table 2. Atmosphere-related variables analyzed.

Variable	Categories	LEs	SMEs
Electricity Consumption (€)	Mean	593,677.3	256,170.7
	Median	100,000.0	6000.0
	Min	0.0	0.0
	Max	7,204,081.61	150,000,000.0
Electricity Intensity (kWh/€)	Mean	0.8	0.9
	Median	0.0	0.2
	Min	0.0	0.0
	Max	112.0	304.0
Renewable energy systems (%)	No	22.5	50.4
	Yes	77.5	49.6
Renewable energy produced (kWh)	Mean	1,178,049.4	112,925.3
	Median	200,000.0	7000.0
	Min	0.0	0.0
	Max	16,500,000.0	12,500,000.0
Gas Consumption (m^3)	Mean	644,827.7	9296.5
	Median	15,415.0	0.0
	Min	0.0	0.0
	Max	29,062,003.0	2,500,000.0
Diesel Consumption (liters)	Mean	56,678,268.7	22,151,820.7
	Median	60,000.0	4500.0
	Min	0.0	0.0
	Max	1,000,000,000.0	50,000,000,000.0
Diesel Intensity (L/€)	Mean	1.4	12.9
	Median	0.0	0.0
	Min	0.0	0.0
	Max	30.3	2500
Water Consumption (m^3)	Mean	4,971,767.9	504,981,558.0
	Median	14,407.0	700.0
	Min	0.0	0.0
	Max	400,000,000.0	1,000,000,000,000.0
Water Intensity (m^3/€)	Mean	4.5	1901.7
	Median	0.0	0.0
	Min	0.0	0.0
	Max	400.0	3,333,333.3
Rainwater reuse (%)	No	62.5	64.2
	Yes	37.5	35.8
Machines number (%)	Mean	14.4	4.1
	Median	5.0	3.0
	Min	1.0	1.0
	Max	200.0	80.0
Machines age (years)	Mean	12.7	15.3
	Median	10.0	12.5
	Min	2.0	0.0
	Max	50.0	66.0

In response to the increasing scarcity of water resources, many companies are adopting strategies to manage water use more efficiently. One such solution is the implementation of systems for managing and reusing rainwater, which has been integrated by only one in three agri-food companies. These systems enable the reuse of water for various purposes, including field irrigation, equipment washing, and, in some cases, cooling during the fermentation process. Such practices represent a significant step towards sustainable water resource management, helping to reduce environmental impact and enhance resilience to challenges associated with climate change.

Agricultural machinery plays a pivotal role in the circular economy by influencing both energy consumption and production efficiency. The adoption of technologically

advanced machinery can enhance the efficiency of resource use, minimize waste, and optimize energy consumption. This not only contributes to more sustainable production practices but also improves the overall environmental footprint of the agricultural sector. Such advancements in agricultural technology are crucial for enabling circular economic models where resource input and waste, emission, and energy leakage are minimized through long-lasting design, maintenance, repair, and reuse. LEs own an average of 14 machines, while SMEs have 4. The average age of machinery stands at 13 years for LEs and 15 years for SMEs, with the oldest equipment reported in the cereal (18 years), honey (16 years), and olive oil (16 years) sectors. This aging fleet signifies a substantial challenge in terms of efficiency and environmental impact. The renewal of machinery fleets and the adoption of energy-efficient equipment are crucial for reducing emissions and optimizing resource use in line with circular economy principles. Implementing modern, energy-efficient machinery can significantly contribute to sustainable agricultural practices by lowering energy consumption and minimizing the carbon footprint of these sectors.

4.2. Soil

Soil health is a cornerstone of circular agriculture, shaping nutrient cycling, carbon sequestration, and the resilience of agricultural systems. Effective soil management minimizes dependency on external inputs and enhances long-term productivity, aligning with circular economy principles. Among the primary factors that influence soil quality and fertility is the percentage of organic matter. Adequate organic matter content improves soil structure, enhances water retention, and stimulates microbial activity, thereby contributing to the soil's natural fertility. This, in turn, reduces the reliance on external fertilizers. The presence of organic matter is crucial for maintaining soil health and sustainability, as it supports a self-sustaining cycle of nutrients that benefits both crop growth and the environment. However, limited awareness of soil composition remains a barrier to sustainable practices (see Table 3). Only 9.4% of LEs and 16.8% of SMEs report knowing their soil's organic matter content, with higher awareness in specialized sectors such as wine (21%) and fruit and vegetables (23.4%). This suggests a need for improved data collection and soil monitoring through digital mapping and regular testing to optimize resource use. Organic matter is a key determinant of soil regeneration and productivity, influencing water retention, microbial activity, and erosion resistance. Its levels vary across production sectors, with olive (34.6%), dairy (27.8%), and honey (27%) industries reporting the highest values. These figures point to effective organic matter management strategies such as agroforestry, rotational grazing, and composting, which should be expanded across other agricultural chains to enhance soil circularity. These percentages, which remain similar even among companies that have embarked on certification processes, highlight a lack of awareness that can compromise not only the quality of the final product but also the sustainability and efficiency of agricultural activities. This underlines the critical need for enhanced educational and training initiatives within the sector to improve understanding of best practices and their benefits to both product quality and environmental sustainability. Increasing awareness and knowledge among farmers and agricultural enterprises is essential to drive changes that align with sustainable agricultural goals and the adoption of more efficient practices.

Fertilizer application further reflects soil sustainability. SMEs apply fertilizers at higher rates (39.1%) than LEs (15.6%), with wine (58%) and fruit and vegetables (45%) sectors leading in usage. Excessive reliance on synthetic fertilizers disrupts soil microbiota and nutrient balance, counteracting circularity principles. Shifting towards organic and bio-based fertilizers, including compost and manure, would not only mitigate these impacts but also close nutrient loops within agricultural production. Land-use patterns offer additional insight into circular soil management. LEs cultivate a median of 25 hectares, compared to 11 hectares for SMEs,

illustrating differences in operational scale. The cereal sector, with its 25-hectare median, requires rotational systems and intercropping to sustain soil fertility. Conversely, the honey sector, with a median cultivated area of just 1.5 hectares, inherently preserves biodiversity and reduces soil degradation, aligning more closely with circular economy objectives.

Table 3. Soil-related variables analyzed.

Variable	Categories	LEs	SMEs
Knowledge of soil's organic matter (%)	No	90.6	83.2
	Yes	9.4	16.8
Soil's organic matter content (%)	Mean	9.5	23.2
	Median	3.0	10.0
	Min	0.0	0.0
	Max	30.0	100.0
Fertilizers application (%)	No	84.4	60.9
	Yes	15.6	39.1
Cultivated hectares (ha)	Mean	9280	608.4
	Median	25.0	11.0
	Min	0.0	0.0
	Max	18,000.0	902,190.0

4.3. Biodiversity

While soil health directly affects agricultural productivity and sustainability, biodiversity plays a broader role in maintaining ecosystem functions and enhancing resilience. The integration of biodiversity into circular agriculture fosters a more self-sustaining system that reduces external inputs and mitigates environmental risks. The presence of forests, uncultivated lands, bodies of water, and hedges plays a crucial role in maintaining habitats favorable for flora and fauna, which in turn enhances soil health, aids in the natural control of invasive species, and increases CO_2 absorption. Such diversity not only supports ecological functions but also enhances the overall sustainability of agricultural practices by mitigating adverse impacts and promoting environmental stewardship. Despite these considerations, 88.8% of LEs report the absence of forested areas, while 44.8% of SMEs have them. The approach to the agriculture of SMEs is generally in contrast to intensive agriculture, which is often practiced by LEs, and this can play a significant role in maintaining forested lands. The greater presence of forested land among SMEs suggests a closer alignment with diversified farming systems, which inherently support circular principles through ecosystem services such as soil stabilization, climate regulation, and habitat connectivity. SMEs are more connected and engaged with local communities, and this could be a driver to implement environmentally sustainable practices. Sectoral disparities reported in Table 4 reveal that the wine (55.4%) and cereal (50.9%) sectors maintain more forested areas, whereas dairy enterprises (31%) present the lowest integration of this natural infrastructure, highlighting an opportunity for increased agroforestry adoption. Water bodies, essential for sustaining aquatic biodiversity and regulating microclimates, are largely absent in agricultural landscapes, with 87.7% of LEs and 78.3% of SMEs lacking ponds or other water sources. Despite some variations across production chains, the predominance of dry landscapes limits the capacity of these enterprises to enhance local biodiversity and integrate water-efficient systems into circular frameworks. Improving water retention strategies, such as wetland conservation and the creation of artificial ponds, would help bridge this gap. Hedgerows are another critical biodiversity feature, supporting pollinators, reducing soil erosion, and improving habitat connectivity. However, 70.7% of LEs and 59.5% of SMEs lack hedgerows, with particularly high absence rates in the dairy (74.7%) and olive oil (62.1%) sectors. Without these natural barriers, agricultural land becomes increasingly fragmented, reducing ecosystem functionality. Encouraging hedgerow planting and preservation can serve as a cost-effective strategy to align production landscapes with circular economy objectives. Fallow land also plays a fundamental

role in soil regeneration and carbon sequestration, yet its use remains limited. 85.5% of Les and 41.4% of SMEs do not maintain fallow areas, missing opportunities for natural soil recovery. Across sectors, dairy enterprises report the highest fallow land absence (72.8%), while the honey (13.4%) and fruit and vegetable (9.7%) sectors make the most use of fallow land. This disparity underscores the need for policies that incentivize rotational land use and regenerative agriculture, reducing dependency on chemical amendments and enhancing soil structure naturally.

Table 4. Biodiversity-related variables analyzed.

Variable	Categories	LEs	SMEs
Forested areas (%)	Absent	88.8	55.2
	Present	11.2	44.8
Water bodies (%)	Absent	87.7	78.3
	Present	8.8	20.2
	Doesn't know	3.6	1.5
Hedgerows (%)	Absent	70.7	59.5
	Present	23.2	38.1
	Doesn't know	6.2	2.4
Fallow land (%)	Absent	85.5	58.6
	Present	14.5	41.4

4.4. Society

The social dimension of the circular economy in agriculture extends beyond economic transactions, influencing employment structures, workforce inclusivity, and local economic resilience. A well-integrated circular approach seeks to retain skills, promote social equity, and foster community-driven sustainability initiatives within the sector. Workforce distribution across enterprises reflects the operational scale and labor demands. LEs employ an average of 80 workers, while SMEs average 5, indicating a reliance on labor-intensive practices in smaller-scale operations. The dairy sector has the highest employment rate (9 employees per enterprise), while honey production operates with a significantly smaller workforce (2 employees per enterprise). These differences highlight the varying labor intensity of agricultural models, influencing resource allocation and mechanization needs within a circular economy framework. Gender inclusivity remains a key challenge, with women comprising only one-third of the workforce in both LEs and SMEs, with the honey sector reporting the highest female employment rate (43.5%), as reported in Table 5. Managerial women representation remains low, with women occupying only 22.1% of leadership positions in LEs and 30.1% in SMEs. The underrepresentation of women in decision-making roles limits diverse perspectives on sustainable business strategies and circular economy adoption. The marked gender disparity, particularly in SMEs, reflects, in part, the physically demanding nature of some roles within the sector. However, it is imperative for businesses, especially larger ones, to commit to implementing inclusive policies that promote greater gender equity. Embracing diversity as a strategic value not only helps create a more stimulating and innovative work environment but also strengthens the effectiveness of management and operational processes. Such initiatives are crucial for enhancing organizational resilience and fostering a culture of inclusivity that aligns with modern social and economic expectations.

Young people are a critical component in fostering innovation, as they are particularly receptive and motivated to embrace sustainable development models and integrate new production techniques. These qualities are crucial for transforming traditional industries, such as the wine sector. The youthful demographic brings fresh perspectives and a readiness

to adopt technological advances and sustainable practices, making them invaluable for the sector's evolution. Their engagement is essential not only for technological innovation but also for ensuring the sustainability and resilience of the industry in the face of global environmental and economic challenges. The presence of young workers is limited in LEs, wherein half of them the percentage of workers under 25 is less than 9%. In SMEs, these values are also worse. In only 25% of SMEs is the number of employees under the age of 25 at least one, indicating widespread difficulty among small businesses in hiring young people. This issue is consistent across all macro-regions examined, suggesting that the scarcity of young workers is not limited to specific geographic areas. This confirms a limited presence of individuals under 25 in these companies, highlighting a sector-wide challenge in attracting young talent. This challenge is due to several factors, mostly related to how the agri-food sector is perceived by young workers, namely low-tech, physically labor-intensive, and education and skill mismatch. The consistent lack of youthful employment across regions underscores the need for targeted strategies to engage and retain younger workers, which is essential for injecting innovation and ensuring the long-term sustainability of the industry.

Table 5. Society-related variables analyzed.

Variable	Categories	LEs	SMEs
Total Employees	Mean	80.4	5.0
	Median	50.0	2.0
	Min	0.0	0.0
	Max	1320.0	49.0
Female Employees (%)	Mean	34.8	34.6
	Median	33.3	33.3
	Min	0.0	0.0
	Max	90.0	100.0
Women in leadership positions (%)	Mean	22.1	30.1
	Median	10.0	12.0
	Min	0.0	0.0
	Max	100.0	100.0
Employees Under 25 years old	Mean	11.7	1.4
	Median	4.0	0.0
	Min	0.0	0.0
	Max	100.0	100.0
Employees from non-EU countries (%)	Mean	7.6	25.3
	Median	0.0	0.0
	Min	0.0	0.0
	Max	97.5	3300.0
Locally sourced employees (%)	Mean	86.7	85.0
	Median	100.0	100.0
	Min	0.0	0.0
	Max	100.0	100.0
Farms offering benefits (%)	No	45.1	68.6
	Yes	54.9	31.4
Farms employing workers with disabilities (%)	No	39.2	89.0
	Yes	60.8	11.0
Farms participating in local food policies (%)	No	81.0	85.1
	Yes	19.0	14.9

Labor mobility and local workforce retention are integral to circular economy models, reducing dependency on transient labor and strengthening local economies. In LEs, 7.6% of employees originate from non-EU countries, while SMEs report a higher reliance on foreign labor (25.3%). However, 85% of employees in both large and small enterprises are locally sourced, reinforcing the importance of regional and local labor markets in sustaining circular agricultural systems. Social inclusion extends to corporate policies that ensure

workforce well-being and participation in sustainability programs. While 54.9% of LEs provide employee benefits such as healthcare and pensions, this figure drops to 31.4% among SMEs. The analysis reveals a distinct difference between LEs and SMEs, highlighting the unique challenges and opportunities associated with the implementation of corporate welfare policies. LEs often have more resources and infrastructure to support comprehensive welfare programs, which can lead to enhanced employee satisfaction and productivity. In contrast, SMEs, while typically more constrained in terms of resources, possess the flexibility to implement innovative and tailored welfare solutions that can directly address the specific needs of their employees. This contrast underscores the need for scalable and adaptable welfare policies that can be customized to fit the diverse economic capacities and organizational structures within the corporate sector.

Similarly, only 11% of SMEs employ workers with disabilities, compared to 60.8% of LEs. Expanding inclusive employment practices aligns with circular economy objectives by fostering stable, long-term workforce participation and reducing inequalities. The integration of agricultural enterprises into local food policies is another key factor linking society to circular economy principles. Yet, participation remains low, with only 19% of LEs and 14.9% of SMEs engaged in local food initiatives. The honey (19.3%) and fruit and vegetable (18.2%) sectors report the highest participation rates, suggesting that smaller, diversified farming systems are more embedded in local food networks. Encouraging greater involvement in short supply chains, food districts, and sustainability initiatives can reinforce circular economy principles through community engagement and localized resource distribution.

4.5. Economy

The economic dimension of the circular economy in the agri-food sector is closely tied to resource efficiency, cost management, and participation in localized supply chains. Financial sustainability in circular agriculture depends on balancing production costs, securing subsidies, obtaining certifications, and integrating into short supply chains, which collectively reduce dependency on volatile global markets. Access to subsidies varies, with only 41.5% of LEs benefiting from financial support, compared to 45.1% of SMEs (see Table 6). Sectoral differences show higher-than-average subsidy access in the cereal (48.2%) and wine (50.3%) chains, while lower percentages are observed in honey (36.3%) and dairy (42.8%). The cost of securing subsidies is another key factor, with half of LEs reporting an annual expense of at least €20,000, compared to €2000 for SMEs. The high cost and bureaucratic complexity of accessing these financial incentives may limit the ability of smaller enterprises to invest in circular practices, highlighting the need for streamlined funding mechanisms. In fact, subsidizing SMEs can have a positive relationship and correlation with promoting circular economy practices in the agri-food sector. Subsidies can provide financial support for sustainable practices that frequently face economic barriers. Circular economy practices can require innovation in technologies and methods that can be expensive and risky for SMEs.

Certifications serve as both a quality assurance tool and a market differentiation strategy, with 89.9% of LEs holding at least one certification, compared to 65.4% of SMEs. The wine (75.3%) and fruit and vegetable (67.8%) chains exhibit higher certification rates, reflecting stronger alignment with value-added markets. However, maintaining certifications imposes significant costs that, for both LEs and SMEs, are similar to the ones for getting subsidies. Although certification fosters consumer trust and enhances product value, its economic feasibility must be weighed against its financial burden, particularly for smaller enterprises with limited capital.

Participation in short supply chains is a fundamental aspect of circular economy integration, as it enhances local economic resilience, reduces transportation emissions, and

strengthens producer-consumer relationships. Moreover, only 37.2% of LEs are engaged in short supply chains, compared to 61.7% of SMEs. The honey (73.4%), olive (67%), and wine (62.8%) chains present the highest engagement levels, suggesting that niche and specialty markets are more conducive to localized distribution models. Direct sales are the most prevalent channel, utilized by 61% of LEs and 86.2% of SMEs, followed by online sales (24.5% and 42.6%, respectively). More structured collaborative models, such as farmers' markets, Solidarity Purchase Groups (GAS), and Community Supported Agriculture (CSA), remain underdeveloped, limiting the full potential of circular food networks. Engagement in public food procurement, such as school cafeterias, remains low, with 85% of LEs and 93.9% of SMEs not participating. This limited involvement reflects an underutilization of institutional markets as viable outlets for sustainable, locally produced food. Greater integration into public procurement policies could provide economic stability for producers while reinforcing circular supply chain principles.

Table 6. Economy-related variables analyzed.

Variable	Categories	LEs	SMEs
Access to subsidies (%)	No	58.5	54.9
	Yes	41.5	45.1
Cost of securing subsidies (€)	Mean	92,281.0	4868.1
	Median	20,000.0	2000.0
	Min	0.0	0.0
	Max	1,200,000.0	200,000.0
Enterprises with certifications (%)	No	10.1	34.6
	Yes	89.9	65.4
Cost of maintaining certifications (€)	Mean	153,008.9	5057.2
	Median	20,000.0	2000.0
	Min	0.0	0.0
	Max	15,000,000.0	400,000.0
Participation in short supply chains (%)	No	62.8	38.3
	Yes	37.2	61.7
Short supply chain participation method (%)	Direct Sales	61.0	86.2
	GAS	1.0	14.2
	CSA	1.0	2.1
	Farmers' Markets	2.2	18.6
	Online Sales	24.5	42.6
	ALVEARE	0.0	2.1
	Other channels	30.1	13.2
	None of the above	10.4	2.1
Engagement in public food procurement (%)	No	85.0	93.9
	Yes	15.0	6.1

5. Conclusions

This survey represents one of the first comprehensive and rigorous assessments of sustainability practices among Italian agri-food companies, involving approximately 3000 agri-food businesses selected through a stratified random sampling across Italy's 20 regions and six key sectors: wine, olive oil, dairy, fruit and vegetables, and beekeeping. In a context where businesses are increasingly required to disclose their sustainability performance to supply chain leaders, banks, and national and international regulations, the value of this study lies in both the representativeness of the sample and the targeted deep dive into crucial sectors [9]. The focus on small and medium-sized enterprises is justified by their vital role not only in the economy but also in preserving Italian traditions and craftsmanship.

The contributions of this innovative survey and the findings derived from it can be of valuable interest to almost three different groups of users.

First, academics can leverage the survey strategies for similar studies, or they can use the results as benchmarks for comparative analysis. From an academic point of view, the strength of the survey is the sample size, which is frequently a challenge. Academic researchers have usually small sizes, especially in dealing with enterprises.

Second, practitioners and companies in the agri-food sector can benefit from an up-to-date picture of sustainability within their sector. The analysis highlights specific characteristics and challenges faced by the agri-food sector and SMEs, providing a knowledge base for identifying strategies that can enhance their competitiveness and contribute to the overall sustainability of the production system [10]. It is important to note that the data were self-reported by the companies without verification mechanisms, a significant limitation, especially for smaller enterprises. However, the large number of companies in the sample mitigates this impact to some extent. Possible solutions to this issue include adopting digital tools for data collection and automatic validation, creating consortia among SMEs or local networks to facilitate access to verification services, and involving third parties, such as trade associations or Chambers of Commerce, to establish standardized guidelines for data collection and validation. The necessity for longitudinal analyses is highlighted, which the research team intends to undertake following this fruitful initial experimentation. Extensive data collection can also serve as a foundation for future calculations of useful benchmarks, individual company ratings, and industry rankings [25].

Third, but not less important, for policy-makers and regulators who can use the key findings as drivers for their activities. For example, large companies must continue to lead by investing in innovation and sustainable practices, serving as a model and stimulus for the entire supply chain. Simultaneously, it is crucial to ensure that new consumer attitudes, the increasing severity of operational impacts due to rising temperatures and extreme events, and regulatory pressures do not disadvantage SMEs, which are essential for the environmental sustainability of our territories and the social well-being of rural areas in the country [16]. To prevent this, targeted public policies and incentives focused on education, raising awareness of ongoing transitions, and enhancing the connection of SMEs with their territories are necessary.

In conclusion, the transitions facing producers are profound and unavoidable, and the sector's horizontal and vertical fragmentation does not facilitate addressing them. It is essential to not merely endure these evolutions but to transform them into a source of competitive advantage, leveraging the internationally recognized value of our agri-food products, our territories, and our lifestyle. By engaging with the available tools and stakeholders, proactive and visionary efforts can significantly contribute to the future resilience and prosperity of a sector pivotal to the economic, social, and environmental well-being of Italy.

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