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FROM ORGANIC WASTE TO AGRICULTURAL FERTILIZER: A MEASUREMENT OF THE LEVEL OF CIRCULARITY AND AN ASSESSMENT OF ECONOMIC FEASIBILITY

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Abstract

Rapid population growth is generating a dual challenge: growing pressure on agricultural land to meet global food demands and increasing complexity in managing organic waste. This study investigates the environmental, social, and governance (ESG) circularity of a composting plant as a case study to determine whether the circular economy can positively influence business performance in the composting sector by improving cost efficiency and identifying higher-value markets. Unlike most previous studies, which have mainly focused on technological innovations for process optimization, this research quantifies circularity through the UNI/TS 11820:2022 standard, an emerging methodological framework that integrates environmental, social, and economic dimensions to measure the transition from linear to circular systems. The composting plant analyzed, located in Sicily, achieved a Circularity Level (CL) of 65.5% in 2023, demonstrating strong adherence to circular principles across six groups of indicators. The highest score (96%) was obtained for waste and emissions management, confirming the company's strong environmental commitment, while the lowest score (38.8%) was registered for energy and water resources, highlighting potential for improvement through renewable energy adoption and resource efficiency measures. Despite achieving high circularity, the plant's economic analysis revealed structural weaknesses, mainly due to high residue disposal costs and the limited market value of compost (currently €0.10 per ton). The findings emphasize that circularity can act as both an operational and strategic asset, supporting the market repositioning of organic fertilizers as premium products. By integrating circular performance metrics into business strategies and communicating results transparently, composting enterprises can strengthen competitiveness, enhance profitability, and align with the European Green Deal objectives. The research demonstrates that measuring circularity provides not only an environmental indicator but also a managerial tool for driving sustainable growth and resilience within the bio-waste valorization sector.

Key words: circular economy, composting plant, organic fertilizer, sustainability

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1. Introduction

A rapidly growing population is placing significant pressure on agricultural lands. To tackle this challenge on a global level, it is essential to continually expand the food production ecosystem. Currently, chemical fertilizers play a crucial role by

supplying nutrients that promote plant growth and boost crop yields. This surge in population not only strains food resources but also leads to a rise in solid waste production, which should be targeted to zero (Mazzariol and Pitardi, 2022).

A major socioeconomic challenge within the waste management system is managing the vast

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amount of waste generated across various sectors (Sharma et al., 2024).

The production of biological fertilizer and its derivative products offers a valuable opportunity to utilize sustainable organic compounds and beneficial microorganisms derived from organic waste, particularly for intensive farming systems. Composting organic waste not only optimizes urban waste, but also ensures the supply of biological compost derived from circular processes. These components are crucial for enhancing crop nutrition, vegetative growth, plant health, and overall productivity. Today, compost is widely available on the market, and it is crucial for improving structure and biological fertility (Zaccardelli et al., 2011).

However, composting plants face different challenges which jeopardize the economic feasibility of such important projects. A crucial study identifies a considerable range of potential obstacles on a global scale, encompassing technical, financial, economic, informational, and legislative challenges. These obstacles were further examined and classified into four primary categories: technological and scientific, economic and market-related, institutional and policy-driven, and behavioral and informational (De Corato, 2020).

Anaerobic composting and digestion are among the principal technologies for the treatment of organic waste and recycling its value in the circular economy. Anaerobic digestion (AD) is a biochemical process through which organic material is broken down by microorganisms in an environment without oxygen. The process produces biogas, a renewable energy, and a solid and liquid by-product known as digestate. Digestate is treated further and used as organic fertilizer, and it is made possible to recover the nutrients. It has been established (Kocetkovs and Zvirbule, 2025) in recent studies that technical and economic feasibility of including chicken manure management in a circular economy is achievable, transforming it into a utility resource for the production of bioenergy and organic fertilizers. For this purpose, the authors find it pertinent that life cycle assessment (LCA) and technical-economic analysis are fundamental approaches to ascertain environmental effects and profitability of such systems. Composting is an aerobic microbial process through which organic material is decomposed in the presence of air to be transformed into a soil conditioner called compost. This forms the foundation for the processing of solid organic waste (Lohri et al., 2017) and can be applied to different types of waste, including sewage sludge (Neczaj et al., 2021), food waste (Wang et al., 2024), and even alperujo (Pareja-Sánchez et al., 2025). On this front, recent research aims treatment of complex waste. In particular, composting can be integrated with other technologies to treat complex waste such as sewage sludge, further increasing pathogen inactivation and biochar production through pyrolysis (Odey and Li, 2025). Use of technology such as digital twins is becoming prevalent to improve and authenticate production and

service systems in waste management even in low-tech environments (Vargas et al., 2025). These digital resources support improved process understanding and control that facilitates their scaling. Both anaerobic digestion and composting are pillars of the circular economy, as they facilitate recovery of value and nutrients from materials otherwise considered waste. The research objective of this paper is not only that of process efficiency, but to also measure the quality of the end-product (compost, fertilizers) and most critically, its economic feasibility, through the use of "circularity" metrics.

This article focuses on economic and market-related barriers by analyzing a real case study of a composting plant located in Sicily, by identifying the revenue streams, analyzing the cost structure and measuring the circular economy performance. Not surprisingly, the economic assessment of the composting plant confirms the findings of De Corato (2020): market channels may work as barriers in the developing and implementing process of circularity converting organic wastes into biological fertilizer. If there are only a few channels and those recognize very low prices for biological compost, then the economic feasibility of such an investment may be absent.

Another research suggested several measures to decrease those barriers, including: utilizing alternative technologies for on-farm compost production, seeking financial incentives to offset the high costs of compost production and application, exploring alternative sources of biomass that do not compete with other sectors, such as clean energy, introducing more flexibility within existing policies and institutional frameworks, and enhancing the dissemination of information, training, and results to farmers to promote the recycling of agricultural biomass waste through modern composting techniques (Viaene et al., 2016). However, the level of circularity, if high, may be used as a strategic leverage in finding new clients and attach to biological compost a premium market price. To this scope it is crucial to analytically measure the degree of circularity and communicate to the market the environmental effort in shifting from a linear to a circular economy across different business departments and, at the same time, ensuring the best quality product (Scuderi et al., 2024; Wiścicka-Fernando, 2018).

To insert circular economy as a strategy and communication tool, it is crucial to quantify the level of circularity first. While various papers have proposed methodologies to assess circularity EC, 2015; Ellen MacArthur Foundation, 2022; Foti et al., 2018; Padilla-Rivera et al., 2021; Prieto-Sandoval et al., 2018; Scuderi et al., 2016; Velenturf and Purnell, 2021), there is still no universally accepted practice among scholars and practitioners. The EC (2015) examines circular economy (CE) approaches and their measurement across different areas of application considered foundational for sustainability, such as design, production, consumption, use, and disposal. Consequently, CE metrics should incorporate qualitative, quantitative, and semi-quantitative data,

adopting a multidimensional and heterogeneous approach (Huysman et al., 2015; Moraga et al., 2019).

Poponi et al. (2022) further contributed by developing a set of 102 indicators to aid the transition of the agri-food sector from a linear to a circular model. These indicators are categorized into three sustainability dimensions (environmental, social, and economic) and by spatial scale (macro, meso, and micro). Moreover, Ruggeri et al. (2022) delved deeper into the data from each element to provide a more detailed analysis of circularity in the agri-food sector. The most significant gap in the literature is the poor measurability of processes.

The standard UNI/TS 11820:2022, "Measurement of Circularity – Methods and Indicators for Measuring Circular Processes in Organizations," issued by the Technical Commission, for the first time harmonizes these different approaches, offering a common framework to assess circularity across various economic systems. This standard defines an 'economic system that, through a systemic and holistic approach, seeks to maintain the flow of circulating resources, preserving, regenerating, or enhancing their value, while also contributing to sustainable development.' It draws upon the six principles of ISO/CD 59002 "Circular economy – Framework and principles for implementation" (International Organization for Standardization, n.d.), the six principles of the BS 8001:2017 standard 'Circular Economy', the 10 R framework, the three principles advocated by the Ellen MacArthur Foundation, and the seven empirical principles developed by Suarez-Eiroa et al. (2018). This newly established standard provides definitions, principles, and a set of indicators to measure circularity within organizations, incorporating both qualitative and quantitative data to evaluate the progress towards circular economy objectives. While this methodology has been little applied in the academic literature because of their recent issue (Matarazzo et al., 2024), it seems to be highly relevant for both academics and practitioners interested in measuring the level of circular economy. There are 114 different definitions of circular economy (Kirchherr et al., 2017) and hundreds of methods to quantify it (Arfò and Matarazzo, 2022), UNI/TS could unify these diverse approaches allowing comparability of circularity scores across or within sectors, over different time intervals and/or in different geographies.

2. Material and methods

2.1. Case study context

The organization under analysis is a composting plant built in the 90s inside the industrial area of Dittaino (Enna), Sicily, and had been operating for about twenty years when it closed due to financial distress. The plant was then acquired in 2020 by a waste management company located in Catania,

Progitex srl, for synergies purposes. The main services offered prior to the acquisition were the following: collection and transportation of municipal solid waste, sweeping, washing, and disinfecting public streets, removal of illegal dumpsites and asbestos removal, pest control and rodent control, waste brokerage, installation and maintenance of plants. With this acquisition, the organization added management of organic wastes as a new service.

The information collected in this section was provided by the managers of the companies analyzed. The data is primary and was obtained through interviews with company managers, who are also co-authors. After several improvements and restorations, the composting plant obtained the ministerial certification of biological compost producer for agricultural uses, as well as some crucial voluntary certifications such as ISO 9001 (2015), ISO 14001 (2015) and ISO 45001 (2018). Enhancing the composting process and maximizing its benefits, combined with cutting-edge technologies and broad applicability, are essential strategies for achieving a sustainable future (Pajura, 2024).

The plant, operating since 2023 with eight employees, is structured as follow: closed pretreatment room of 800 m², open compost storage of 2000 m², administration office, mechanical workshop, bio-container area of 2000 m², curing area of 1000 m² and final compost area of 3000 m² (Fig. 1). The plant services cover eighteen municipalities from different Sicilian areas in collecting organic municipality wastes from public (80%) and private (20%) organizations. The transformation process takes nineteen days from the collection of organic waste and MOW to the generation of the final output. Although the composting process used to be slightly faster by inserting sludge purchased from private water depuration companies, the management decided to no longer use it due to the uncertainty on the final output quality, which used to differ from lot to lot. There are a lot of factors influencing the timing and the quality of compost, among them humid acids are crucial within the process (Atiyeh et al., 2002; Gholami et al., 2018).

There are two different composting processes wastes that may be further managed to reduce environmental impact: percolate and "sovvallo". Percolate (i.e., a liquid waste moving through a medium, often soil or a landfill, filtering through the material and potentially causing contamination) may be regenerated through other filtration processes to obtain clean water again, while "sovvallo" is non recoverable or recyclable as it is a residue that remain after the separation and treatment of municipal solid waste to be sent to a landfill or other forms of disposal.

As opposed to other businesses, circular economy companies receive revenues from two different moments (Al-Sari and Haritash, 2024). At the beginning of the process when municipalities pay for disposing their wastes, and then when the company sells its product (i.e., the biological compost).

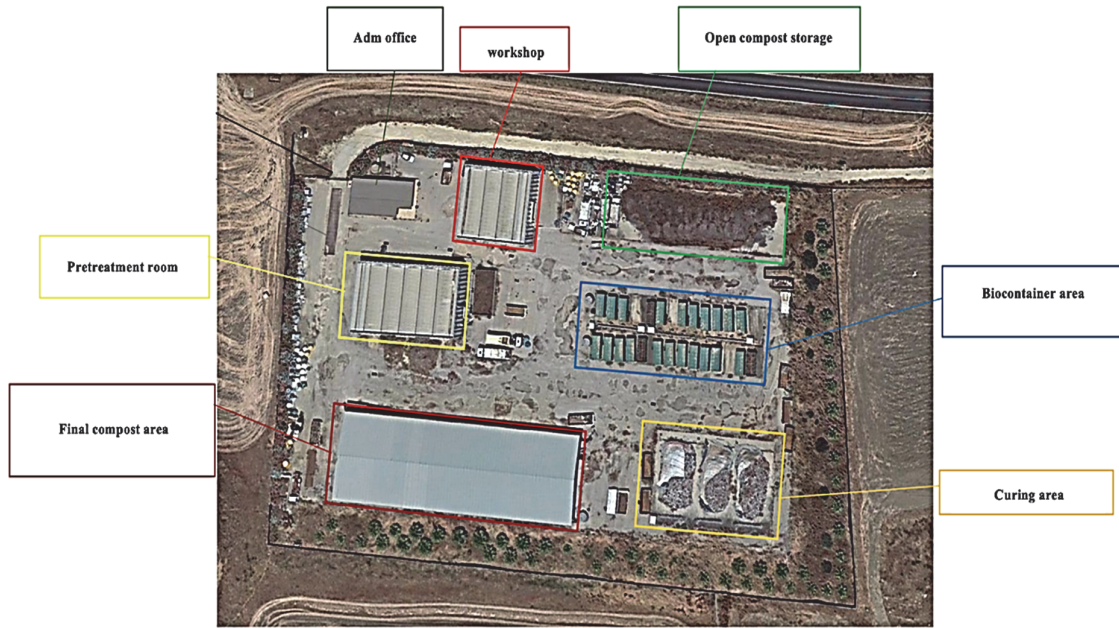


Fig. 1. Layout of the composting plant

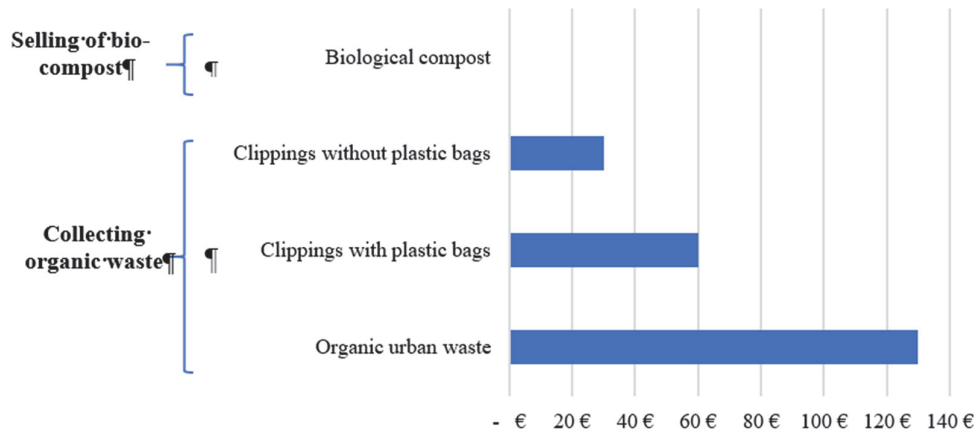


Fig. 2. Prices per ton applied by the composting plan (Authors' elaboration)

The source of revenue for the composting plan under analysis may be divided into revenue from the waste collection service (clipping without plastic bags, clipping with plastic bags and organic urban waste) and revenue from selling of biological compost. From Fig. 2 it is evident that the sale price of bio-compost (i.e., 0.10 euro), as process output, is by far lower compared to the price that public or private organizations pay to the plant to dispose their organic wastes (30 euro for clipping without plastic bags, 60 euro for clipping with plastic bags and 130 euro for organic urban waste). From the Italian Compost Consortium, it emerges that even bio-compost market prices are dramatically higher to what the composting plant under analysis asks of the market, ranging from between 6 euro to 150 euro according to the quality and the composition (<https://www.compost.it>).

The management of Progitex explains that the reason behind such a low price is twofold: first they have not found market channels to sell it at an adequate price, and second the plant has not enough space to store the huge quantities of compost daily generated. As a consequence, the plant needs to dispose of the compost even at the symbolic price of 10 cents.

As far as the cost structure is concerned, labour force, utilities and administration costs represent about 74% of total revenue, which is quite a high percentage. In addition to that, the plant produces some residue from the composting process, i.e., percolate and "sovrillo", which must be disposed:

● Percolate: the plant pays about 70 euro per ton to dispose of it. It may be regenerated into clean water after process.

●Sovvallo: the plant pays about 160 euro per ton to dispose of it because regeneration is much more difficult and costly.

Although, the price paid by the company to dispose process residue are higher compared to the prices to collect wastes and sell bio-compost, the corresponding quantities play a crucial role in keeping the business financially sustainable. Revenue stream from input is calculated on 100% quantity, while the cost related to residue disposal is calculated on 38% quantity.

2.2. Data collection

To advance understanding and promotion of the circular economy within the composting plant, the primary data acquisition process was crucial. Using a structured direct interview focused on analyzing key input, output and processes, this approach was essential for collecting the data needed to estimate various indicators outlined in the UNI/TS 11820:2022 standard as well as to conduct the economic feasibility analysis, respectively described in the following paragraphs.

The data collected correspond to a specified perimeter ensuring consistency and coherency across different input and output categories of the plant production process: material resources and components, energy and water resources, waste and emissions, logistics, product and service and human resources, assets, policy and sustainability.

The direct interview was carefully designed to capture relevant variables to compute UNI/TS 11820 indicators. Four different interviews were administered through in-person sessions during an on-site inspection in two different days. To ensure the robustness of the collected data, a validation mechanism is employed. This includes cross-referencing responses with the 2022 corporate sustainability disclosures and other documented records, along with follow-up phone interviews.

In particular, the data related to material resources and components, logistics, product and service and human resources, assets policy and sustainability were obtained by interviewing the sustainability management internal team of Progitec srl, while data related to energy and water resources as well as waste and emissions were acquired through an external engineering office. Additionally, the authors personally carried out the analysis and validated the data acquired by physical inspections to the composting plant in Dittaino (Enna) and conversing with workers in charge of logistics, waste collection and human resources. While the interview phase took approximately the first twenty days of March 2024, the personal inspection occurred the last weekend of the same month. Considering the interview design process as first and the data elaboration procedure subsequently, it took around forty days of structured data acquisition. After data collection, an analysis was performed to derive meaningful insights and a preliminary estimation of indicators, which were then

reviewed with the organization's sustainability managers. The reliability of data is high because data may be proved or measured any given time and no estimates or other proxies were used to implement the model.

2.3. Indicator framework

The Italian technical specification UNI/TS 11820:2022 identifies 71 ESG (Environmental, Social, and Governance) indicators to evaluate an organization's degree of circularity. They are divided into six themes, ranging from the management of material and energy resources to logistics and company policies. The system categorizes the indicators into three categories: "Core" (obligatory), 'Specific' (at least 50% of which are to be fulfilled under each category), and "Bonus" (optional). In this way, the evaluation system is made flexible but stringent.

Through a weighted formula, the firms are given a final score of 0 to 100 that attests to the level of circular economy. The objective is to offer a measurable and transparent tool to monitor progress and support actions towards greater sustainability, both for single companies and for consortia. Finally, UNI/TS provides a final formulation to calculate the overall Level of Circularity (LC) of an organization (Eq. 1):

$$LC = \frac{\sum P_c + \sum P_s + 50\% \sum P_r}{nP_c + nP_s} \quad (1)$$

where the numerator is represented by the sum of both core and specific indicators plus a half value of rewarding indicators. The technical standard prescribes to count only fifty percent of rewarding indicators due to their optionality nature and their number is not present at denominator to incentive organization to include as many indicators as possible without negatively affecting the final circularity score. The denominator corresponds to the number of the core and specific indicators applied to the organization. It is evident that equation 1 is a weighted sum providing a value between zero and a hundred percent. Therefore, the higher its output the greater the circularity performance of the organization. This model supports organization in the transition from linear to circular economy by quantifying the level of circularity for each firm department.

The study quantifies 35 indicators out of the total set specified by the norm (of which 7 core, 26 specific and 2 rewarding) since not all of them are applicable to the composting plant organization under analysis. As Table 2 shows, circularity indicators of energy and water resources are related to either self-produced or purchased electricity and water recycled electricity, because Progitech srl does rely on thermal energy. From the complete set of material resources and components matrices (Table 3), four indicators are excluded from UNI/TS 11820 since some are not applicable to the business model of a composting plant under analysis.

Table 1. Number of indicators per category and typology according to UNI/TS 11820:2022 (Authors' elaboration)

<i>Category</i>	<i>Core indicators</i>	<i>Specific indicators</i>	<i>Rewarding indicators</i>	<i>Total</i>
Material resources and components	3	3	-	6
Energy and water resources	-	3	-	3
Waste and emissions	2	1	-	3
Logistics	-	3	-	3
Product and service	-	11	1	12
Human resources, asset, policies and sustainability	2	5	1	8
Total	7	26	2	35

As shown in Table 4, the study implements three indicators to assess the level of circularity regarding waste and emissions. Two of these aim at quantifying urban and municipality special waste sent respectively to landfill and collected separately. While the other is a qualitative indicator to understand whether the organization is compliant with carbon footprint measurement regulation.

From a total of six UNI/TS indicators related to logistics, the authors calculate half of the matrices selected on the base of the characteristics of the composting plant (Table 5). The indicators 'waste

treated at local valorisation plants' and 'actual load capacity used by vehicles' as a fraction of their local quantity are crucial circularity measures, because the organization generates process residue (i.e., percolate and sovrillo) and has numerous operating vehicles.

Table 6 reports twelve indicators related to the composting plant output. Three of them have a qualitative nature to gauge the circular design of the organization. The other quantitative matrices are highly relevant in assessing the product area in terms of input/output of the composting plant under the scope of circular economy.

Table 2. Indicators on energy and water resources from UNI/TS 11820:2022 (Authors' elaboration)

<i>Energy and water resources</i>				
<i>N.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
11	Is	Quantitative	Self-produced electricity from renewable resources or recovery	Total electricity consumed
13	Is	Quantitative	Purchased electricity from renewable resources	Total electricity purchased
15	Is	Quantitative	Inbound water from reuse and recycling	Total water need

Table 3. Indicators on material resources and components from UNI/TS 11820:2022. (Authors' elaboration).

<i>Material resources and components</i>				
<i>Nr.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
2	Is	Quantitative	Inbound raw materials and secondary resources from local suppliers	Total inbound raw material and secondary resources
3	Is	Quantitative	Inbound material res. equipped with tracking systems	Total inbound material res. equipped with tracking systems
4	Ic	Quantitative	Inbound by products and(or) secondary resources	Total inbound material res.
7	Ic	Quantitative	Renewable of recycled res. for packaging	Total packaging used
9	Is	Quantitative	Total restricted or authorized substances	Total inbound material res.
10	Ic	Quantitative	(Inbound resources – Residues produced)	Total residues produces

Table 4. Indicators on waste and emissions from UNI/TS 11820:2022. (Authors' elaboration)

<i>Waste and emissions</i>				
<i>N.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
16	Ic	Quantitative	Urban and(or)special waste sent to landfills	Total urban and(or)special waste generated
17	Ic	Quantitative	Municipal and(or)special waste collected separately	Total urban and(or)special waste generated
19	Is	Qualitative	Has the organization carried out the assessment of its carbon footprint according to UNI EN ISO 14064 in year n and/or n-1 and/or n-2?	

Table 5. Indicators on logistic from UNI/TS 11820:2022. (Authors' elaboration)

<i>Logistics</i>				
<i>N.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
22	Is	Quantitative	Waste treated at local valorization plants	Total waste treated at valorization plants (local or not)
25	Is	Quantitative	Actual load capacity used by vehicles (round trip)	Total capacity of the vehicles
26	Is	Quantitative	Number of employees adhering to sustainable mobility	Total employees

Table 6. Indicators on products and/or services from UNI/TS 11820:2022 (Authors' elaboration)

<i>Products and/or services</i>				
<i>N.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
29	Ir	Quantitative	Outbound resources with a tracking system	Total outbound resources
40	Is	Quantitative	Quantity of products generated	Quantity of resources employed
41	Is	Quantitative	Value of products and services from local suppliers	Total value of products and services
43	Is	Qualitative	Has the organization made investments in the circular design of its products and/or services in years n and/or n-1 and/or n-2?	
44	Is	Qualitative	Has the organization made investments in circular design of its processes in years n and/or n-1 and/or n-2?	
45	Is	Qualitative	Has the organization made investments in circular design of its assets in years n and/or n-1 and/or n-2?	
46	Is	Quantitative	Investment in R&D links to the circular economy	Total investment in R&D
49	Is	Quantitative	Inbound water resources from industrial symbiosis	Total inbound water resources
50	Is	Quantitative	Outbound water res. valorized with industrial symbiosis	Total outbound water resources
51	Is	Quantitative	Inbound energy resources from industrial symbiosis	Total energy water resources
52	Is	Quantitative	Outbound energy res. valorized with industrial symbiosis	Total outbound energy resources

Table 7. Indicators on Human resources, assets, policy and sustainability from UNI/TS 11820:2022 (Authors' elaboration).

<i>Human resources, assets, policy and sustainability</i>				
<i>N.</i>	<i>Type</i>	<i>Measure</i>	<i>Numerator definition</i>	<i>Denominator definition</i>
56	Is	Qualitative	Has the organization already carried out staff training on the circular economy in the current year and in the two years before?	
57	Ic	Semi quantitative	Which is the average energy performance index of buildings for civil use of the organization? Class A = 100%; Class B-C = 50%; Class D-F = 25%; Class G = 0%.	
59	Ic	Qualitative	Has the organization developed and implemented a circular economy strategy?	
60	Is	Qualitative	Does the organization carry out external communication of its sustainability and circularity performance (through sustainability reports, non-financial statements, etc.)?	
67	Is	Qualitative	Has the organization planned to carry out internal staff information and training activities on the circular economy?	
68	Is	Qualitative	Has the organization carried out external training and information plans on the circular economy aimed at stakeholders?	
69	Ir	Qualitative	Does the organization have an energy efficiency plan?	
71	Is	Qualitative	Does the organization adopt an Environmental Management system?	

Table 7 illustrates the matrices related to human resources, assets, policy and sustainability. Seven indicators are qualitative gauging whether the company has been compliant with relevant voluntary certifications, has trained its employees and stakeholders and has developed and carried out circularity actions. Qualitative indicators are valued one if the answer is 'yes' and zero if not. One semi-quantitative indicator measures the average energy performance index of buildings for civil use and ranges between zero and one in accordance to the interval scale (0, 0.25, 0.5, 0.75 and 1). Finally, UNI/TS provides a final formulation to calculate the overall Level of Circularity (LC) of an organization (Eq. 1).

3. Results and discussion

3.1. The circularity level of the composting plant

The implementation of UNI/TS 11820:2022 indicates that the composting plant's Circularity Level in 2023 (LC) is 65.5%. It is important to note that the present model has been little applied in literature since the methodology was established in 2022. There is not much evidence in comparing and benchmarking the

obtained results, but since it is more than fifty percent it is reasonable to conclude that it is a high level of circularity.

In other terms, obtaining certified biological agricultural fertilizer from organic wastes underscores the proactive stance towards environmental preservation by the observed organization, indicative of a promising trajectory toward circular and sustainable practices in subsequent endeavours. Furthermore, the application of this assessment tool enhances its utility by pinpointing areas ripe for enhancement. More precisely, the circularity levels per indicator group correspond to the following values:

- (a) 70.17% for material resources and components;
- (b) 38.80% for energy and water resources;
- (c) 96.00% for waste and emissions;
- (d) 45.33% for logistics;
- (e) 57.50% for products and/or services and
- (f) 68.80% for human resources, assets, policy, and sustainability.

In particular, Table 8 quantifies the value for each single indicator, specifying category, type (core, specific or rewarding), identifying number and unit (kg, kWh, euro, m³ or 0,1 in the case of qualitative data).

Table 8. Indicators results and description from UNI/TS 11820:2022 (Authors' elaboration)

<i>Indicator category</i>	<i>Type</i>	<i>N.</i>	<i>Unit</i>	<i>Value</i>
Material resources and components (a)	Is	2	kg	1
	Is	3	kg	0
	Ic	4	kg	1
	Ic	7	kg	0.67
	Is	9	kg	0.71
	Ic	10	kg	0.83
Energy and water resources (b)	Is	11	kWh	0.49
	Is	13	0.1	0.054
	Is	15	m ³	0.62
Waste and emissions (c)	Ic	16	kg	0.88
	Ic	17	kg	1
	Is	19	0.1	1
Logistics (d)	Is	22	0.1	1
	Is	25	0.1	0.36
	Is	26	n	0
Products and/or services (e)	Ir	29	kg	0
	Is	33	0.1	0.82
	Is	40	kg	0.96
	Is	41	euro	1
	Is	43	0.1	1
	Is	44	0.1	1
	Is	45	0.1	0.18
	Is	46	euro	0
	Is	49	kg	0.89
	Is	50	kg	0
Human resources, assets, policy and sustainability (f)	Is	51	kWh	0.48
	Is	56	0.1	1
	Ic	57	alternative	0.5
	Ic	59	alternative	1
	Is	60	0.1	0
	Is	67	0.1	0
	Is	68	0.1	1
	Ir	69	0.1	1
	Is	71	0.1	1

In addition, the analysis continues by assessing the level of circularity corresponding to each single category in process input and output (Fig. 3). Waste and emission score the highest record (96%) because it represents the core business of the company under analysis. Indeed, the degree of 'urban and (or) special waste sent to landfills' seems one of the largest with respect to the total special waste generated by the plant and, at the same time, municipal and (or) special waste are entirely collected separately.

Also, material resources and components contribute to reaching such a positive score. Inbound raw materials and secondary resources from local suppliers, inbound by products and (or) secondary resources and the difference between inbound resources and residues produced are the main factors that leverage the result upwards.

While human resources, assets, policy and sustainability obtain a circularity level of 68.75%, the reliability of such a value is doubtful since the methodology suggests to use only qualitative and semi-quantitative indicators in the assessment. Being zero or one the range of output, the possibility of distortion might seem high. However, it is known that UNI/TS 11820:2022 is currently under review by the

technical commission and possibly this issue will be adjusted. The product and (or) service and logistic category contains around fifty percent of circularity. Energy and water resource register the lowest value of sustainability (38.8%) because the plant should purchase electricity from renewable resources provider to increase the performance. Unfortunately, there are no other case studies or specific industry averages that provide a benchmark for comparison with the LC score of 65.5%. However, the score obtained can be considered a benchmark parameter for the company to evaluate future activities from a circular economy perspective.

3.2. Economic implications, management implications, and policy instruments

Extrapolating the economic and managerial implications of a composting plant that exhibits a high level of circularity while still being in its startup phase, due to the target market not yet being consolidated, proves to be a complex task. The composting plant's operations reflect the dual revenue streams and the substantial costs associated with both the input and output phases.

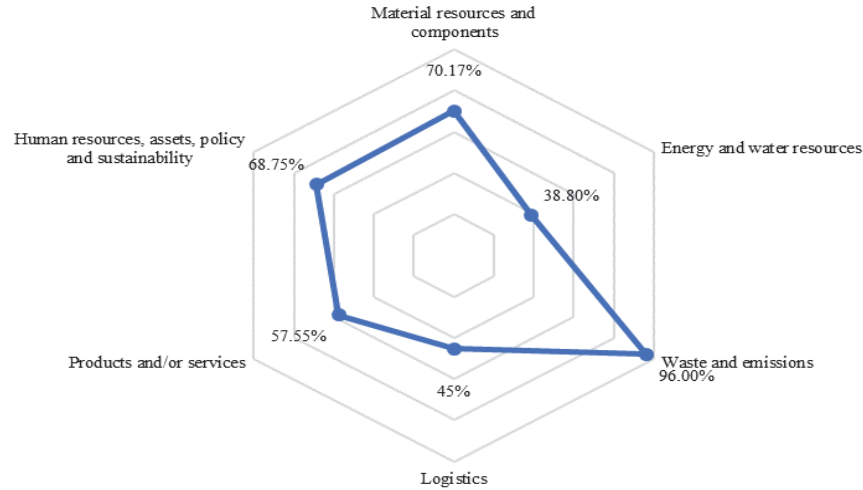


Fig. 3. Radar chart for each indicators' category from UNI/TS 11820:2022 (Authors' elaboration)

Revenue is generated initially when municipalities pay the plant to dispose of organic urban waste and clippings, with different rates depending on the nature of the waste. Specifically, the plant charges €130 per ton for organic waste, €60 per ton for clippings with plastic bags, and €30 per ton for clippings without plastic bags. This input-based revenue model is a critical component of the plant's financial viability, as it provides a steady income stream at the beginning of the waste management process. However, the core stream of the business model should be selling the biological fertilizer which results in a challenge for the management.

The cost structure reveals that a substantial portion of revenue (84%) is consumed by salaries, wages, utilities, and office supplies. This high percentage highlights the labour intensive nature of the composting process and the overhead costs required to maintain operations. In addition to these fixed costs, the plant faces substantial expenses related to the disposal of process residues. For example, the disposal of percolate costs the company €70 per ton, and the disposal of non-recyclable waste fraction costs €160 per ton. These costs are disproportionately high compared to the minimal revenue generated from the sale of the biological compost, which is currently sold at only €0.10 per ton due to storage limitations and a lack of effective distribution channels. This significant disparity between the costs associated with residue disposal and the revenue from compost sales severely erodes the plant's profitability. From a managerial perspective, the economic implications suggest an urgent need to optimize both revenue streams and cost structures. Strategies could include exploring new markets or distribution channels for the compost to increase its selling price, thereby enhancing output-based revenue. Additionally, reducing the costs associated with residue disposal, possibly through more efficient waste processing technologies or partnerships with other waste management entities, could help improve the plant's financial sustainability.

It is possible to adopt good practices and optimization strategies to improve the economic performance (Kapoor et al., 2020) or to implement technology innovation to exploit long-term value creation (Olivieri et al., 2023). Ultimately, while the plant's current operations are economically feasible, the high cost-to-revenue ratio indicates that significant improvements are necessary to ensure long-term profitability and sustainability. A cross-sectorial approach is essential to close the gap between agricultural residue research and business opportunities, fostering the integration of an agricultural residue industrial ecology within the framework of a circular economy (Gontard et al., 2018).

The implementation of the UNI/TS 11820:2022 standard, which reveals that the composting plant achieved a Circularity Level (LC) of 65.5% in 2023, offers significant strategic marketing opportunities, particularly in the context of selling organic fertilizer at a premium price. A high circularity level not only demonstrates the plant's commitment to sustainable practices, but also provides a strong value proposition to environmentally conscious consumers and businesses. In today's market, where sustainability increasingly influences purchasing decisions, a composting plant that can verify and promote its high level of circularity stands to differentiate itself from competitors. These statements take into account logistical, regulatory, or market constraints in real-world contexts.

To justify the higher price and a sustainable market differentiation, the quality of the compost should be even greater than average. To this end, advanced composting processes need to be carried out such as the 'co-composting' techniques, a circular economy approach to waste management offering economic potential and environmental benefits by promoting nutrient recycling and reducing waste (Ofei-Quartey et al., 2023) or other aerobic/anaerobic digestion technologies (Breitenmoser et al., 2019;

Wainainab et al., 2020)

Achieving a 65.5% circularity level, as calculated using the UNI/TS 11820:2022 framework, underscores the plant's proactive approach to environmental preservation. This level, although relatively new and not yet widely benchmarked in the industry, already positions the plant favorably, allowing it to communicate its environmental achievements effectively. By emphasizing its high circularity, the plant can appeal to a market segment that prioritizes sustainable products, thereby justifying higher prices for its organic fertilizer. This strategic positioning taps into the growing demand for products that contribute to the circular economy, where the reuse, recycling, and reduction of waste are paramount.

Furthermore, the detailed circularity levels across various indicator groups (e.g., 70.17% for material resources, 96.00% for waste and emissions, and 68.80% for human resources, policy, and sustainability) provide the plant with specific data information that can be leveraged in marketing campaigns. For instance, the nearly complete circularity in waste and emissions management (96%) is particularly compelling, as it directly aligns with the core mission of reducing environmental impact. Such data can be used to create targeted marketing messages that highlight the plant's efficiency and commitment to minimizing waste, appealing to both consumers and regulators.

However, the plant must also address areas with lower circularity levels, such as energy and water resources, which scored 38.80%. Improving these areas, for example, by sourcing renewable energy, could further enhance the plant's circularity and strengthen its market position. By continuously improving and transparently communicating its circularity metrics, the plant can not only justify higher prices for its products, but also build long-term brand loyalty among environmentally conscious consumers and businesses. In conclusion, the high level of circularity achieved by the composting plant is not just a regulatory achievement, but also a strategic asset that can be effectively used to enhance the marketability and profitability of its organic fertilizer.

When analyzing policy instruments, it should be noted that the EU Green Deal includes measures aimed at reducing greenhouse gas emissions, promoting renewable energy, and improving energy efficiency (EC, 2019). These approaches are complementary: the sustainability of the food system is fundamental to achieving the broader climate goals of the Green Deal. The new European policies, starting with the Green Deal promoted by the new European Commission, are strongly inspired by the 17 global sustainability goals which, in relation to agri-food systems, are essentially embodied in the two attached strategies, Farm to Fork and Biodiversity 2030, in which the key role of improving soil health appears in all its importance. This aspect is also integrated into the new European soil strategy, EU

Soil Strategy for 2030, launched by the EC (2021), and closely linked to the other two strategies, Adaptation to Climate Change and Zero Pollution Action Plan, in which reducing nutrient losses and pesticide use are key aspects. The aim of the European soil strategy is to ensure that this resource enjoys the same level of regulatory protection as air and water quality. The research proposed in this paper fits specifically into these strategic instruments.

3.3. Sensitivity analysis

The data analyzed in the paper reflect a series of aspects upon which a sensitivity analysis can be set up, both economically and circularly, taking as a reference the UNI/TS 11820:2022 model.

Firstly, there are three major variables that play most in favor of the sustainability of the plant. The first is the sale price of the compost, which currently is just €0.10/ton, while in the market it is between €6 to €150/ton. The second concerns the cost of residue disposal: €70/ton for leachate and €160/ton for screenings. Additionally, certain circularity indicators show very low numbers, particularly the energy and water (38.8%), logistics (45.3%), and products/services (57.5%) ones.

Economically, the base case suggests that the most important revenues come from the delivery of waste (€30 to €130/ton), while sales of compost, at such low prices, generate marginal revenues. At the same time, most of the revenues are absorbed by fixed and variable costs, in particular labor and utilities (74–84%), along with the cost of residue disposal, which is about 38% of treated material. In these situations, a relatively modest increase in the sale price of compost would make a significant difference: €10/ton would reduce substantially the gap between turnover and expenses, while €50/ton would make compost the main source of turnover. On the other hand, a decrease in disposal costs, e.g., by lowering the cost of oversize waste from €160 to €100/ton, would enhance net profitability by approximately a third. The coincidence of the two levers, higher sales prices and more efficient disposal can permit a net balance to be achieved with no increase in the volumes disposed of.

Circularity-wise, the overall rate is 65.5%, but with significant discrepancies between the categories. The plant is especially robust in the areas of waste and emissions management (96%) as well as material resources (70%), but lagging in the areas of energy and water (38.8%) and logistics (45.3%). In all of these, the improvement opportunities are quite obvious: by purchasing 100% of its energy from renewables, the energy/water segment would be driven above 80%, putting the total score above 70%. By improving logistics efficiency, for example, from vehicle capacity utilization from 36% to 70%, the logistics segment would be more than 60%. Finally, product improvement, from traceability to industrial synergies to R&D spending would also drive the products/services segment to a position of around 70%.

Table 9. Sensitivity analysis results (Authors' elaboration)

<i>Scenario</i>	<i>Materials</i>	<i>Energy & Water</i>	<i>Waste & Emissions</i>	<i>Logistics</i>	<i>Products/ Services</i>	<i>HR/ Policy</i>	<i>Weighted LC (%)</i>
Baseline	70.17	38.80	96.00	45.33	57.50	68.80	65.50
Energy → 80%	70.17	80.00	96.00	45.33	57.50	68.80	66.73
Logistics → 60%	70.17	38.80	96.00	60.00	57.50	68.80	64.59
Products → 70%	70.17	38.80	96.00	45.33	70.00	68.80	66.15
Energy 80% + Logistics 60%	70.17	80.00	96.00	60.00	57.50	68.80	68.47
Energy 80% + Products 70%	70.17	80.00	96.00	45.33	70.00	68.80	70.03
All three improvements	70.17	80.00	96.00	60.00	70.00	68.80	72.02

Short, on the economic side, the most important variable is the cost of compost, and on the environmental side, the most important lever is the transition to renewable energy. Pairing the search for new market channels that can afford to take on compost at a high price with green energy supply would see the plant raise its profitability levels and achieve a level of circularity between 70% and 75%, thus making the business as a whole more sustainable.

4. Conclusions

The study on the composting plant's circularity level, as measured by the UNI/TS 11820:2022 framework, reveals significant insights into the plant's operational and strategic positioning within the circular economy. Achieving a Circularity Level (LC) of 65.5% in 2023 is a noteworthy accomplishment, particularly considering that the UNI/TS 11820:2022 standard is relatively new and has not been widely applied or benchmarked in the industry. This high level of circularity reflects the plant's commitment to sustainable practices and positions it favorably in a market that increasingly values environmental stewardship.

The detailed breakdown of circularity across various indicator groups provides a comprehensive view of the plant's performance. For instance, the plant scored 70.17% for material resources and components, 96.00% for waste and emissions, and 68.80% for human resources, policy, and sustainability. These figures highlight the plant's strengths, particularly in waste and emissions management, where the near-complete circularity of 96% underscores the core mission of minimizing environmental impact. This achievement can be effectively leveraged in marketing campaigns to appeal to environmentally conscious consumers and regulators, thereby enhancing the plant's marketability and competitive edge.

However, the analysis also identifies areas where the plant's circularity could be improved, particularly in energy and water resources, which scored the lowest at 38.80%. This area presents an opportunity for the plant to enhance its circularity by sourcing renewable energy or implementing more

efficient water management practices. Addressing these gaps is crucial not only for improving the plant's overall sustainability performance, but also for strengthening its market position and justifying higher prices for its products.

Economically, the plant faces challenges related to its cost structure, with a substantial portion of revenue consumed by operational costs, including salaries, wages, utilities, and office supplies. The disparity between the high costs of residue disposal and the minimal revenue generated from compost sales highlights the need for strategic adjustments. To improve profitability, the plant must explore new markets or distribution channels for its compost, optimize its revenue streams, and reduce disposal costs through more efficient technologies or partnerships.

In conclusion, the composting plant's achievement of a 65.5% circularity level is a significant regulatory milestone that also serves as a strategic asset. By continuously improving its circularity metrics and effectively communicating these achievements, the plant can enhance its marketability, justify premium pricing for its organic fertilizer, and build long-term brand loyalty among consumers who prioritize sustainability.

This proactive approach positions the plant for future success within the circular economy, where the reuse, recycling, and reduction of waste are key drivers of value creation.

All studies have limitations and therefore form the basis for further research. First, the dataset was limited to the case study, which may limit the generalizability of the results. This limitation means that the observed effects on CE may not fully represent the entire market spectrum. Furthermore, the analysis is based on a short time frame, which limits the ability to observe long-term trends and temporal fluctuations in market dynamics. Future research should address these limitations by incorporating a wider range of analyses and extending the scope of data and the collection period, thus providing a more comprehensive view of the composting ecosystem. This research should also refine and further develop the UNITS 11820:2022 model in the new 2024 version, improving assessments in management

practice. Although the 2024 version introduces greater flexibility, it is more complex in terms of indicator selection and exclusion management, requiring companies to have strong interpretative skills to ensure consistency and reliability in the assessment.

Another limitation of the study is the exclusion of the perspectives of other stakeholders (municipalities, farmers, private buyers) to contextualize market barriers and opportunities.

The objective of future studies is to integrate the social dimension by adding results related to job creation, worker training, or community acceptance to align with the ESG framework.

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