Home › Find a journal › British Food Journal

British Food Journal

Submit your paper | Overview | Author guidelines | Editorial team | Indexing & metrics | Reviewers | Calls for papers & news

For over 125 years, the British Food Journal continues to be highly respected worldwide for its broad and unique interdisciplinary coverage of the latest food-related research. It links all sectors of this dynamic industry, keeping abreast of emerging trends, topical and controversial issues and informing and stimulating debate.

ISSN: 0007-070X
eISSN: 1758-4108

What's here?

- Aims and scope
- Featured articles
- Related journals

The current issue and full text archive of this journal is available on Emerald Insight at:
https://www.emerald.com/insight/0007-070X.htm

The circular potential of a Bio-District: indicators for waste management

Stefano Poponi, Alessandro Ruggieri and Francesco Pacchera
Department of Economics, Engineering, Society and Business (DEIM), University of Tuscia, Viterbo, Italy, and
Gabriella Arcese
Università degli Studi Niccolò Cusano, Roma, Italy

Received 30 December 2022
Revised 11 April 2023
Accepted 26 April 2023

Abstract

Purpose – This work aims to assess the potential of a Bio-District as a model for applying the circular economy concerning the waste scope. It aims to understand the capability of organic farms to manage waste with a circular perspective, starting with the use of indicators that directly or indirectly impact the waste scope.
Design/methodology/approach – This study is based on previous work that identified and systematised the circular indicators of the agri-food sector within a dashboard. With this research as a basis, the indicators within the waste scope in the dashboard were extracted. Cross-linked indicators with an indirect connection to the waste scope were also systematised and tested in a case study. Primary and secondary data were used for the study. The primary data came from a semi-structured interview, and the secondary data were from official databases.
Findings – The work highlights two important results. The first allows the definition of a subclassification of indicators by product and organisation, extracting those with a cross-linked characteristic concerning the waste scope. Secondly, the indicators' application shows the farm's circular and waste valorisation potential within the Bio-District. The study also made it possible to test a new indicator, the "Potential Energy Biomass Recovery", to measure the farm's potential to produce energy from waste.
Originality/value – This research proposes a new circular economy approach to evaluate waste management in the agri-food sector.

Keywords Waste management, Food loss and waste, Circular economy, Indicator, Bio-district, Agri-food
Paper type Research paper

1. Introduction

The European legislation on organic production follows strict rules that intervene in production, from the production process and the use of seeds to the final processed product. The organic regulation (Regulation 2018/848) intervenes with specific provisions concerning various products. This obliges companies to make radical choices between traditional products and those that include a food production system based on organic principles. These include interactions between best practices in the environment and climate action, increasing and sustained high biodiversity levels, natural resource preservation, strict animal welfare criteria and rigorous production standards. These characteristics align with the preferences of an increasing number of consumers for produce grown with natural substances and processes (European Parliament and European Council, 2018).

Therefore, applying organic production means complying with legislative standards and principles to encourage production that is more attentive to human health, environmental protection and biodiversity. With these provisions, Europe desires to stimulate a new link with the consumer based on production quality and create a new trust in these products (European Commission, 2020). This approach prompted producer specialisation and favoured their territorial concentration on the model of industrial districts (Pyke *et al.*, 1990; Beccatini, 1998, 2000), allowing the emergence of Bio-Districts.

British Food Journal

0007-070X
DOI 10.1108/BFJ-12-2022-1137

The International Network of Eco-Regions also associates the term, Bio-District, with the terms Organic-District and Eco-Regions, defining them as "territories where farmers, citizens, public authorities and other local actors realise a formal agreement aimed at the sustainable management of local resources, based on the principles and model of organic farming and the agroecological best practices, in order to boost the economic and sociocultural development of their community". The first Bio-Districts were developed in France, Italy and later Portugal, but it is in Italy that where an explosion of these territorial entities can be seen. The number of Bio-Districts in Italy has grown rapidly over the last ten years. Since 2009, with the legislative recognition of the first Cilento Bio-District (Campania Region, BURC n.63 of 19 October 2009), the number has risen to 26 in 2017 (Giuca *et al.*, 2017) and reached 41 recognised Bio-Districts in 2021 (Pugliese *et al.*, 2013, 2015; Basile *et al.*, 2021). In the environmental transition path taken by Europe, Bio-Districts can play a central role in implementing a new sustainable production and consumption model. Indeed, with the New Green Deal (European Commission, 2019) and the European Farm to Fork strategy, organic farming is identified as a vital tool for providing ecosystem services to society (European Commission, 2020). The EU has set a critical target to be reached by 2030: increasing the share of organic farmland to at least 25% of the total agricultural area (European Commission, 2020). Many producers have opted to convert conventional agricultural production to organic, with a 7.7% growth in dedicated land in Europe in 2018 (Solfanelli *et al.*, 2021). However, the emergence and impetus that can result from Bio-District are crucial in achieving these goals.

The Bio-District is an innovative model that can be used as an effective tool to improve certain aspects of economic and environmental sustainability. Their creation provides an opportunity for the development and growth of local economies through better environmental protection, biodiversity conservation and multi-level exploitation that integrates agriculture with all sectors of the local economy (CREA, 2019a). In Italy, the district contract has stimulated the reorganisation of relationships between different supply chain actors operating in the district territory (Ministry of Agricultural Food and Forestry Policies, 2016). Moreover, it has allowed overcoming the constraints of the linear economy paradigm to adopt the more ethical approach of the circular economy (CE) (Poponi *et al.*, 2020). Indeed, the creation of Bio-Districts stems from economic policies aimed at supporting the reorganisation of local agricultural and agri-food production systems, ensuring the development of rural communities (Truant *et al.*, 2020; Assiri *et al.*, 2021; Poponi *et al.*, 2021a). This links to the potential benefits of organic agriculture in terms of sustainable development, particularly the adoption of CE models for biodiversity, job creation, the attraction of young people, and food and health security.

The pandemic and the energy and food crises are helping accelerate the change process within the districts. As pointed out by Toccaceli (2018), their development model has shifted from definitions with a purely agricultural connotation to that of a processing district to poly food development. The added value generated by Bio-Districts is determined by the territory's characteristics, such as soil, climate and local traditions, and the integration within supply chains that contribute to improving business performance (Mazzocchi *et al.*, 2021). This translates into the definition of a new development model based on production specialisation and the ability to integrate stakeholders with sustainable development objectives.

In general, the agri-food chain can be made more sustainable. However, it is vital to act on a systemic level, using tools that can consider the different stages that characterise the complex food system (Notarnicola *et al.*, 2012; Ingrao *et al.*, 2019). Applying the CE and its principles can be the key to transforming society and making production systems and communities more circular (Gravagnuolo *et al.*, 2019; Caputo *et al.*, 2020; Paiho *et al.*, 2020). Indeed, the definition of CE proposed by Kirchherr *et al.* (2017) emphasises the concept of end-of-life and the importance of intervening in waste management for spatial dimensions, which can be macro, meso, or micro. The CE operates at the micro level with products, companies and consumers, at the meso level, functioning as part of eco-industrial parks, and at the macro level in a city, region, nation and beyond to achieve sustainable development. It simultaneously creates environmental quality, economic prosperity and social equity for the benefit of current and future generations. Additionally, it is empowered by new business models and responsible consumers (Kirchherr *et al.*, 2017).

The Bio-District fits into this definition, offering a cross-sectional view of the potential for applying the CE, integrating the role of companies at the micro level, activating industrial symbiosis at the meso level and welcoming the potential of the entire supply chain at the macro level. Indeed, the creation of value in the supply chain, as pointed out by Dsouza *et al.* (2021), can also occur through the recovery of resources by either closing the loop in a closed loop approach (BSI, 2017), by favouring the exchange of products between adjacent supply chains, or by sharing complementary resources (Jouan *et al.*, 2020) in an open loop approach (BS 8001).

In particular, De Boni *et al.* (2022) and Torres-León *et al.* (2018) emphasise the impact of agri-food waste on all areas of sustainability: economic, social and environmental, as food waste implies a loss of resources (Amicarelli *et al.*, 2021b) and also results in a significant environmental impact (FAO, 2013; UNEP, 2021). Some authors (Drejerska *et al.*, 2019; Ingrao *et al.*, 2018; Özyurt and Realff, 2001; Zeller *et al.*, 2020) argue in favour of recovering and assigning value to agri-food waste, whether animal or vegetable, to generate energy or new materials. In the latter case, it is possible to work on processes for high waste valorisation, where agri-food waste becomes the second raw material for creating new products with high added value (Poponi *et al.*, 2019a; Poponi *et al.*, 2022b). In this context, it is also important to intervene in the application of CE principles to measure the performance of companies and/or organisations attempting to adopt this new paradigm.

In the literature, measuring the CE goes through a plethora of indicators or heterogeneous methodologies that address the problem from a limited point of view (Franklin-Johnson *et al.*, 2016; Di Maio *et al.*, 2017; Kazancoglu *et al.*, 2018; Virtanen *et al.*, 2019; Rossi *et al.*, 2020; De Pascale *et al.*, 2021; Alberto López Ruiz *et al.*, 2022). Among the most widely used methodologies to evaluate CE strategies found in the literature are the life cycle thinking methods (Pauliuk, 2018; Corona *et al.*, 2019; Moraga *et al.*, 2019; Sassanelli *et al.*, 2019; Esposito *et al.*, 2020; Alberto López Ruiz *et al.*, 2022). These methods offer a vision focused on the product life cycle and define the phases on which to act to implement the circular approach (Peña *et al.*, 2021). Other authors point to CE indicators that focus on a single objective or activity and thus do not fully express the environmental benefit generated (Haupt and Hellweg, 2019; Helander *et al.*, 2019; Niero and Kalbar, 2019; Roos Lindgreen *et al.*, 2021).

The combination of multiple indicators overcomes this limitation, and the literature agrees on the need for adequate and effective measurement tools that enable a circular transition (Peña *et al.*, 2021; Rigamonti and Mancini, 2021; Saidani *et al.*, 2019). This also supports decision-makers (Cristóbal *et al.*, 2018; Peña *et al.*, 2021) and helps identify weaknesses and strengths in the different stages of production (Genovese *et al.*, 2017; Di Maio *et al.*, 2017; Vasa *et al.*, 2018). Therefore, according to the scientific literature, a harmonised measurement system is needed to give an overall picture of an organisation's actual ability to be considered circular and comply with CE principles. For an adequate measure of circularity, the use of measurement tools that are adaptable and appropriate to the observed context is required.

These critical issues were addressed in a previous study (Poponi *et al.*, 2022a) by proposing a dashboard for the application of CE indicators in the agri-food sector. The dashboard systematises the circularity indicators according to their spatial dimensions (micro, meso and macro), their areas of application (economic, environmental and social), and the scope of application, such as soil, water and waste. The dashboard further represents a reference tool to support decision-making processes and strategies through the targeted use of indicators; it constitutes the first important tool to systematise the CE indicators for the agri-food sector. However, it is necessary to extend its application potential considering the context to which it applies and the specific objective of the analyses. Some indicators have achieved the characteristic of being cross-sectional (Ruggieri *et al.*, 2022) and are thus applicable across different spatial dimensions, i.e. at the micro, meso and macro level. This increases the versatility of the dashboard and its applicability, raising further reflections on the indirect effects of cross-linked indicators on individual Scopes. Although not considered within a scope, such indicators may indirectly impact the waste scope.

Therefore, this paper aims to assess the potential of the Bio-District model for applying the CE concerning the waste scope. A particular aim is to evaluate the possibility of managing waste from a circular perspective inside Bio-Districts. The evaluation has been developed by applying indicators that could directly or indirectly assess the impacts on the waste scope. For this purpose, the waste scope indicators in the dashboard were extracted. Also, cross-linked indicators indirectly connected to the waste scope were systematised and tested in a case study. The farm used to test the indicators is part of the Etruscan Roman Bio-District, located in Italy within the Lazio Region, and produces several varieties of vegetables. This made it possible to assess the indicators' effectiveness, an organisation's waste management capacity using a CE approach and its ability to respond to a measurement system based on circular indicators.

2. Materials and methods

2.1 Methodology

To meet the research purpose, the study was built on previous work that identified and systematised circular indicators of the agri-food sector within a dashboard (Poponi, Arcese, Pacchera *et al.*, 2022a, b). Based on this research, indicators from the waste scope were extracted. In addition, indicators with a cross-linked effect with the waste scope and applicable at the micro level were recorded and systematised. In the literature, the waste scope considers indicators that can represent the critical issues related to food waste, life cycle flow, and product economical and nutritional value. The definition of food waste and loss proposed by Amicarelli *et al.* (2021a) was considered. However, for this study, only the definition of food losses was adopted, which states that it is a waste "which mostly take[s] place during agricultural production, postharvest[,] and processing stages due to logistic or technical reasons". This resulted in extracting ten indicators, seven belonging to the waste scope and three cross-linked indicators attributable to the energy scope. The explanation and use for each indicator in the literature are given below. Table 1 codifies and reports the formulas used.

Vázquez-Rowe *et al.* (2020) used three indicators to assess the circularity of the agri-food supply chain in Spain. The first indicator, the nutrient rich food score ($NRF_{9.3}$) (1), measures the impact or loss of nutritional value related to wasted food. It considers the nine nutrients that are encouraged for daily consumption, specifically protein, fibre, the minerals calcium, iron, magnesium and potassium, and vitamins A, C and E. Likewise, the three nutrients to be limited are saturated fat, added sugar and sodium. The second indicator, economic food loss and waste (EFLW) (2), measures the economic impact of wasted food. It is a monetary valuation, expressed in euros, considering the amount of food wasted and the cost at its origin. The third and final indicator is the nutritional cost footprint (NCF) (3), which combines the NRF with the EFLW to measure the overall economic and nutritional impact related to wasted food.

Pagotto and Halog (2016) assessed the circularity of Australia's agri-food system using the waste sent to landfill (WSL) indicator (4). This indicator measures the amount of food waste disposed of in landfills and considers the number of products disposed of in landfills and the total tons of finished products made by the agri-food industry (functional unit kg/t). Furthermore, the package-to-product (PtP) indicator (5) was used to assess the environmental

Scope	CODE	Indicator	Acronym	Unit of measure	Equation
WASTE	1	Nutrient rich foods score	$NRF_{9.3}$	Score/ 100 kcal	$NRF9.3 = \sum_i w_i \left(\sum_{l=9} \frac{NR_l}{DV_l} \times 100 - \sum_{m=3} \frac{LIM_m}{MRV_m} \times 100 \right)$
	2	Economic FLW indicator	EFLW	€	$EFLW_i = \sum_j FLW_{i,j} \times V_{i,j}$
	3	Nutritional cost footprint	NCF	Number	$NCF_i = a_i \frac{NRF9.3i}{NRF9.3} + \beta_i \frac{EFLW_i}{EFLW} = a_i N_i^* + \beta_i C_i^*$
	4	Waste sent to landfill	WSL	kg/tonne of finished product	$\frac{Discared\ products}{Total\ finished\ products}$
	5	Package to Product	PtP	%	$P_t P_{cc}(\%) = \sum CC_{Pa} / \sum CC_{P_r} \cdot 100$
	6	Nutrient circularity indicators	NCI	Range of variation (0–1)	$CI_i = \frac{\Sigma_{k=1}^{m} \Sigma_{J=1}^{n} R_{iJk} \cdot \eta_{r_i j} \cdot \eta_{Pik}}{w_i}$
	7	Recycling rates	Rr	%	$RR = \frac{Amount\ of\ waste\ recycled}{Amount\ of\ waste\ produced} \times 100$
ENERGY	8	Recovery of energy by using waste	EE_P	GW/year	$EE_P = w \cdot Q \cdot CP_{ee}$
	9	Energy required	EE_R	GW/year	EE_R
	10	Energy self-sufficiency indicator	ESS_{EE}	Number	$ESS_{EE} = \frac{EEp}{EEr} = \frac{w \cdot Q \cdot CP_{ee} P}{EE_R}$

Source(s): Our elaboration on the Dashboard of (Poponi *et al.*, 2022a)

Table 1. Explanation of micro and cross-linked indicators of Waste Scope

impact of food packaging (Šerešová and Kočí, 2020). It is calculated as the ratio of the climate change impact caused by the packaging to that of the product. Additionally, Cobo *et al.* (2018) applied the nutrient circularity indicator (NCI) (6) to assess circularity in food waste management, considering the amount of nutrients in the food and in the food waste. Next, the recycling rates indicator (Rr) (7) monitors the amount of agri-food waste that is recycled and recovered and which was used by Pagotto and Halog (2016) to make a general assessment of the circularity system of the agri-food system in Australia.

Sgarbossa and Russo (2017) used three indicators to measure the impact of energy on the CE approach from a closed-loop perspective. The first was the recovery of energy by using waste indicator (8) (EE_P), which was used to measure the amount of energy produced by waste recovery. The authors aimed to understand whether the amount of energy generated by the waste balances the energy demand. Secondly, the energy required (9) (EE_R) indicator calculates the energy required by the production process where the waste is generated. Lastly, the energy self-sufficiency (10) (ESS) indicator expresses the degree of energy self-sufficiency as a function of waste recovery and valorisation. The authors used these indicators to assess the circularity of a meat company. At the same time, they can be considered cross-linked because their application indirectly impacts the waste scope.

2.2 Data sources

Italy was taken as the reference territory for the study, given the considerable expansion that Bio-Districts have had in the last ten years in Europe in general and in Italy in particular. To ensure the coherence and comparability of the analysis, the Lazio Region was identified, which hosts the highest number of Bio-Districts in Italy and is the region where the agri-food sector is highly developed and characterised by high-quality production with a strong link to the territory (Regione Lazio, 2016). The Lazio region is the fifth-largest Italian region regarding the number of certified products (Protected Denomination of Origin, Protected geographical indication). This particularly well-suited territory has allowed the region to qualify its agri-food production to the maximum. Compared to previous years, growth led to approximately 130 million euros generated by the sale of certified products in 2021 (ISMEA; Fondazione Qualivita, 2022). A further characteristic of the Lazio region is the significant presence of organic farms; it is the seventh region with the most organic farms in Italy (ISMEA, 2021). The Lazio region was also the first to publish a specific law to recognise Bio-Districts (Poponi *et al.*, 2021a, b). However, despite the presence of several Bio-Districts at a national level, the recognition process was hindered by a complex accreditation mechanism. The selected Bio-District in the Etruscan Roman Bio-District was the first to be recognised with the new Regional Law No. 11 of 12 July 2019 (provisions for the regulation and the promotion of organic districts).

The Etruscan Roman Bio-District was formed by six farms representing 20% of the organic production in the area. Their business activities focus on high-quality production in agriculture, animal husbandry, food processing, catering and accommodation. The farms cover an area of about one thousand hectares (ha) and have an average annual turnover of 4.5 million euros and about 70 employees. Agricultural production consists of cereals (13%), fruit and vegetables (26%), and fodder crops (61%) and has a production yield greater than 2000 tonnes. The livestock farm produces over 30 tonnes of meat and ensures the production of over 5 tonnes of cheese and half a tonne of ice cream.

The farm identified within the district for the analysis has a production specialisation in fruit and vegetables with a regional identity (Table 2). It also has an advanced farm monitoring system, allowing timely data extraction. This farm was selected because it has the most advanced organisational structure and can manage all internal data flows concerning raw materials, production and cultivated land through software. The selected case study represents the first step to test the methodology and prepare the next phase to extend the analyses to all the district's companies.

The farm is organised in the form of a cooperative enterprise. It covers 30 hectares and produces traditional local fruit and vegetables. The cultivation method used is organic, while crop rotation allows for year-round production, with the only interruption being in August. Regarding production practices, the land is prepared for sowing mechanically using proprietary equipment and machinery. At the same time, the crops are cultivated using irrigation systems. To this end, the land has been divided into two sections: 7 hectares irrigated with water from a reservoir within the farm and 23 hectares irrigated by drawing on the water network that takes advantage of the proximity of the Tiber River basin. The farm can also use underground pipelines for a centralised supply system. Production takes place in open fields and inside cold greenhouses. The primary energy sources are electricity from the grid to drive the irrigation pumps and diesel for the agricultural and traction machinery; no power generation plants exist.

Furthermore, products are not stored on the farm but are sold in the field immediately after harvesting. The sales process is computerised and organised using a just-in-time approach (Damodar *et al.*, 1991). The process starts with receiving the product order via telematics, followed by product preparation and collection of the goods directly in the field, all within 24 h. Products are collected the morning of the day after the order. Based on this sales

Product	Production (ton.)	Waste Loss (ton.)	Vegetable waste (ton.)
Lettuce	39.0	3.9	3.9
Cauliflower	45.0	4.5	31.5
Beet	70.0	7.0	7.0
Chicory	23.0	2.3	2.3
Cabbage	26.0	2.6	18.2
Potato	20.0	2.0	8.0
Tomato	29.0	2.9	11.6
Pumpkin	80.0	8.0	32.0
Zucchini	33.0	3.3	13.2
Aubergine	20.0	2.0	8.0
Carrot	30.0	3.0	12.0
Melon	20.0	2.0	8.0
Watermelon	33.0	3.3	13.2
Total	*468.0*	*46.8*	*168.9*

Source(s): Our elaboration on data

Table 2. Farm production and waste

system, planting is done based on a contractualisation made upstream with the farm's customers. It is based on estimated quantities to be collected progressively over time. The farm's main sales channels are collective catering, direct sales, home delivery, natural food shops and large-scale distribution.

The waste generated by the production process is in the form of vegetable biomass that remains in the field and consists of roots and leaves. The waste varies depending on the crop obtained from harvesting. On the other hand, the food loss is represented by a percentage of unsold products which, together with the harvest waste, remains on the field. This material helps to improve soil fertility and regenerate its structure through its function as green manure.

Primary and secondary data were used for the study. The primary data came from a semi-structured interview conducted with the farm owner, following the approach described by Eisenhardt and Graebner (2007). The protocol was shared between the authors to understand the characteristics of the farm and the specific organic crops it produces. The interview was conducted at the farm's premises by one of the authors in September 2021 and lasted approximately 2 h. The collected data were processed iteratively to ensure the reproducibility and reliability of the results (Neuendorf, 2016). In addition, secondary data were used to supplement the technical information needed for the analysis and enabled the calculation of the indicators. This information was not available from the farm as it was exclusively technical concerning the nutritional characteristics, prices at origin and calorific value of the biomass. For the extraction of these data, the food composition tables (CREA, 2019b), ISMEA database (2022) and Ecoinvent database (Ecoinvent, 2022) were used. The approach used for collecting and managing the secondary data followed the documentary analysis of Fitzgerald (2012). The data processing and sources used for each indicator are outlined in the following subsections.

2.2.1 NRF $_{9.3}$. For the calculation of the NRF indicator, the methodology proposed by Fulgoni *et al.* (2009) was followed. NRF scores were calculated as the sum of nutrients to be encouraged (NR) weighted with daily values (DV) and the subtraction of nutrients to be restricted (LIM) weighted with corresponding DV. Nine nutrients to be encouraged (protein, fibre, the minerals calcium, iron, magnesium and potassium, and vitamins A, C and E) and three nutrients to be restricted (saturated fat, added sugar and sodium) were used per 100 kcal. 100 kcal was used as the functional unit because the literature recommends it as the best way to compare the nutritional values of products (Drewnowski, 2010). The data were collected from the food composition tables database (CREA, 2019b), and the NRF was calculated and expressed as a score per 100 kcal. The data show the nutrient levels in foods, with values from original experimental data and residually from a literature selection. The values in the database refer to 100 g of product. The value of the kcal present in 100 g of product is shown for each product in the tabs. To extract the quantity that refers to 100 kcal of product, a proportion of the kcal present in 100 grams of product was made. Data from EFSA (2017) and WHO (2015) were used for the reference DVs.

2.2.2 EFLW. The EFLW indicator, expressed in euros, was calculated as the sum of the wasted food of each product category multiplied by its corresponding economic value according to the methodology proposed by Garcia-Herrero *et al.* (2019). Moreover, the value communicated through the interview by the manager was used for wasted food. This value is an estimate and amounts to 10% of the production of each product. For the price, the average at the origin of the organic fruit and vegetables was used for the year the interview was conducted (ISMEA, 2022). Unfortunately, it was impossible to calculate the indicator for beet, chicory and pumpkin because there is no economic data in the ISMEA database. So the ISMEAs' prices formed in the initial phase of product exchange.

2.2.3 NCF. The NCF index was calculated as the sum of the normalised $NRF_{9.3}$ index and the normalised EFLW index following the study of Vázquez-Rowe *et al.* (2020). The normalisation was performed by dividing the $NRF_{9.3}$ and EFLW indices with the respective indices with the highest value in the sample. A weighting procedure was then performed using the same weight values as Garcia-Herrero *et al.* (2019) ($\alpha = \beta = 0.5$). The indicator is expressed in a scoring unit. The data for the $NRF_{9.3}$ index came from the food composition tables database (CREA, 2019b), while that for the EFLW were calculated using scrap data from the interview and average prices at origin (ISMEA, 2022).

2.2.4 WSL. Pagotto and Halog (2016) proposed the WSL indicator, which expresses the ratio of recycled waste to the total waste generated. It was calculated as the ratio of produced waste sent to the landfill to total agricultural production. Since no waste is sent to the landfill, the indicator has a value of zero.

2.2.5 PtP. To calculate the PTP indicator, the methodology proposed by Šerešová and Kočí (2020) was followed and is defined as the ratio of the climate change impact (GWP_{100}) of the packaging to the climate change impact of the product (GWP_{100}) and expressed as a percentage. However, the farm's products were found to be without packaging, as it produces fruit and vegetables and sells them directly on the farm without any packaging. The only packaging present is the crates in which the products are collected but reused on the farm for future produce collection, and they are a stock of material. Therefore, given the absence of packaging, the indicator is zero.

2.2.6 NCI. The NCI was determined by applying the methodology described by Cobo *et al.* (2018) and calculated as the ratio of the amount of nutrients recycled to the amount of nutrients in the waste. The result is a value between 0 and 1.

2.2.7 Rr. The Rr indicator was calculated as proposed by Pagotto and Halog (2016) as the ratio of recycled waste to produced waste and is expressed as a percentage. The farm's waste corresponds with waste material (roots, leaves and slices) and unsold products. These types of waste are entirely recycled as they remain in the field to nourish the soil.

2.2.8 EE_P. The methodology proposed by Sgarbossa and Russo (2017) was used to determine the EE_P indicator (energy produced from waste recovery and treatment). It was calculated as the multiplication between the quantity of waste generated (w), the quantity produced (Q), and the unit energy produced from the recovery of one tonne of waste (CP). The waste generated (w) value was obtained through a direct interview with the farm manager and expressed in tonnes. This value refers to production waste (roots, leaves and slices) and unsold waste remaining in the field, with the indicator expressed in Gigawatt (Gw)/year. The value of the quantity produced was also obtained through a direct interview. In the case analysed, the value of CP is zero, as there is no energy recovery activity from the waste produced on the farm.

2.2.9 EE_R. For calculating EE_R (energy required by the production process where the waste is generated), the methodology recommended by Sgarbossa and Russo (2017) was used. The EE_R indicator was calculated as the annual consumption used to produce the farm's products. The farm's two main types of waste are generated throughout the production process. As previously reported, these are mainly production waste (roots, leaves and slices) and unsold produce that remains in the field. For the calculation of the energy required for the production process, data from the direct interview were used. These refer to the electrical energy needed to pump water for irrigation and the diesel needed for agricultural vehicles. For practical purposes, the unit of the indicator was expressed in Gw/year; conversion factors were used as reported by the Universities and Colleges Climate Commitment for Scotland (2010).

2.2.10 ESS. The last extracted indicator is the ESS index. Sgarbossa and Russo (2017) determined this indicator as the ratio between EE_P and EE_R. The indicator is expressed in Gw/year. For the first indicator, EE_P, there is no energy recovery of waste in the farm; therefore, the indicator has a zero value. For the EE_R indicator, the energy required for farm production is calculated.

3. Results

This section discusses the results obtained by applying the indicators in the case study. The work highlights two first significant results depending on the nature of the indicators used. The first group of indicators is only applicable at the product level. This is the case for indicator no. 1-NCF, no. 2-EFLW, and no. 3-$NRF_{9.3}$, which apply to the waste scope (Table 3). The second group is characterised by indicators applicable at the organisation level, ranging from No. 4 to No. 10 (Table 4). In particular, indicators no. 4 and 7 are cross-sectional, i.e. applicable between the spatial dimensions at the macro, meso and micro levels. On the other hand, indicators 8, 9 and 10 are cross-linked and belong to the energy scope but indirectly impact the waste scope. Overall, the results highlight the indicators' ability to provide an initial overview of circularity starting from the individual product.

3.1 Product indicator

The EFLW indicator expresses the economic measure of the loss of value of the wasted product. Although the indicator refers to the two types of waste mentioned in the methodology, the data collection, given the nature of the activity observed, only allows for the extraction of data related to food loss. Therefore, the indicator makes it possible to identify each unsold product and the economic value lost. The quantity of unsold products remaining in the field (not harvested) is around 10%. However, this value has been taken as a reference value by convention. The analysis of the quantities and the interview with the owner shows how this surplus can undoubtedly be considered a waste. However, it takes on a different meaning at a commercial level, representing the so-called safety stock. In other words, the prudential value that the entrepreneur keeps in the field to respond to fluctuations in demand, productivity variation of the land, or to cope with the risks of non-production. These risks could be caused by diseases or adverse weather events that could expose the farm to insolvency concerning what was defined in the contractual phase with the end customers. Another aspect highlighting this indicator is the total value of economic production waste per available *ha*. The total value can be estimated by default at € 30,000.00, considering the

Product	EFLW (€)	NRF (score/100 kcal)	NCF (unit)
Lettuce	€ 7,137.00	393.35	0.81
Cauliflower	€ 5,040.00	380.36	0.65
Beet	n.a	637.51	n.a.
Chicory	n.a.	130.26	n.a.
Cabbage	€ 2,470.00	53.22	0.21
Potato	€ 920.00	61.65	0.11
Tomato	€ 3,944.00	222.07	0.45
Pumpkin	n.a.	411.08	n.a.
Zucchini	€ 3,300.00	211.14	0.40
Aubergine	€ 1,960.00	142.69	0.25
Carrot	€ 1,440.00	430.21	0.44
Melon	€ 860.00	212.86	0.23
Watermelon	€ 2,145.00	27.51	0.17
Total	*€ 29.216,00*		

Source(s): Our elaboration on data

Table 3.
Results of product indicators

Scope	COD	Indicator	Value	Unit of Meausure
WASTE	4	WSL	0	kg/tonne of finished product
	5	PtP	0	%
	6	NCI	1	(0–1)
	7	Rr	100	%
ENERGY	8	EE_P	0	GW/year
	9	EE_R	0.233	GW/year
	10	ESS	0	Unit

Source(s): Our elaboration on data

Table 4.
Results of indicators at organization level

impossibility of finding data on beet, chicory and Pumpkin products for the entire farm extension; this means that waste weighs € 1,071.00 per hectare.

The $NRF_{9.3}$ score for each product indicator shows the nutrient loss compared to the recommended daily value. The $NRF_{9.3}$ indicator does not reflect the final output of the farm (food loss or waste) since it can be calculated using literature data. However, it is functional in calculating the subsequent NCF indicator, which relates the nutritional value with the EFLW. The NFC expresses the nutritional and economic footprint of the wasted product. In this specific case, it can be observed that the weight of certain products, such as lettuce or cauliflower, generates a significant footprint on the total waste of the farm. However, the indicator has limitations concerning its application. The first certainly relates to the complexity of use due to the difficulty of mediating literature values with farm values. The second refers to the comparability of the result. Although the applied formula uses normalisation techniques, comparing the results obtained for each product is only possible within the observed case study. The relationship between product wastage and the size of the area used to cultivate it is also not considered, which would imply relating the final result to a functional unit and not normalisation. Only then can the value comparison between several case studies be made. However, comparing results over a defined period could help highlight the performance of each product over time. Still, the fact remains that products from different companies cannot be compared. The third limitation identified relates to the degradation time of nutrients (edible and non-edible) that varies between products, as highlighted by Garcia-Herrero *et al.* (2019).

3.2 Organisation indicator

The WSL indicator monitored the farm's waste sent to the landfill. The indicator result was zero because it is possible to recycle plant material and unsold products through green manure, naturally enriching soil fertility. Therefore, this indicator is more suitable for processing activities where the type of products sent to landfills results in a higher value due to the use of machinery, processing, or raw materials that make this practice necessary. Additional non-hazardous waste produced by the farm, directly or indirectly attributable to production, is entirely sent for recycling to specialised companies. In this case, the recycling rate is 100%.

The value of the PtP indicator was also zero. In this case, the farm's business model does not involve the use of packaging. Reusable plastic crates are used for collection in the field, while in the collection phase, the customer must prepare and take responsibility for any packaging required at collection. In this way, the farm reduces the costs and impacts resulting from packaging, making the supply chain more sustainable.

Furthermore, the value returned for the NCI was a maximum due to the natural recovery activity by which green manure fully recovers nutrients. The Rr indicator also gave a maximum value, taken in its entirety, due to the type of activity and recovery capacity of the waste produced. At the same time, the different natures of the waste and the potential for utilisation must be considered. Concerning waste loss, 10% of the unsold product remains in the field. For the waste originating from vegetables, a percentage was a function of the crop produced and weighed 36% of the quantity produced (Table 2). This could potentially be valorised in a high valorisation of waste CE approach (Poponi *et al.*, 2019b).

The EE_P indicator measures the amount of energy produced by waste recovery. In the case study, this energy level is zero as no energy recovery activity occurs since the waste remains in the field. Further, the EE_R indicator monitors the amount of energy required by the production process where the waste is generated. In the case analysed, this value is 0.23 Gw/year. This represents the amount of energy required for production and is represented by the consumption of electricity for pumping irrigation water and diesel for vehicle traction. Finally, the ESS indicates the degree of energy self-sufficiency as a function of waste recovery and valorisation. This value is zero in the case analysed, as no waste energy recovery occurs on the farm.

4. Discussion and conclusion

The analysis of the indicators shows a sub-classification concerning the scope of application, related to product and organisation. Overall, applying the indicators expresses the circular potential of the farm from the production point of view. Additionally, the levels of waste loss and vegetables produced in the field and the economic value lost are emphasised. Considering the type of activity, the recyclability of production can be maximised, but waste valorisation is not necessarily optimal. As repeatedly emphasised, waste from the farm used for this case study is left in the field through green manure for natural soil enrichment. However, for value optimisation, the results of the study introduce the possibility of considering the interaction of two further factors: the economic value of the waste and that of its valorisation (Kazancoglu *et al.*, 2018; Moktadir *et al.*, 2020; Poponi *et al.*, 2022b).

The EFLW indicator calculates the economic value of waste, associating it with the amount of food that remains in the field. In the second case, energy power is derived from waste using the EEP, EER and ESS indicator package. For better comparability of the results, a new indicator was used to measure the waste's energy potential. This indicator, referred to as the "Potential Energy Biomass Recovery", has a cross-linked characteristic and expresses the calorific value that can be generated by the biomass that remains in the field. Through this, it is possible to calculate the potential energy that can be generated from the use of waste, which is not provided in the dashboard. The cross-linked indicators identified from the energy scope consider only one option, whether the farm uses waste for energy generation. In contrast, the new indicator stimulates reflection on waste value optimisation and new potential uses (Poponi *et al.*, 2022b). Table 5 expresses the total calorific value (MJ) per functional waste unit (1 kg). Overall, this indicator shows the energy potential that can be obtained from the total waste in the form of food loss and plant waste that remain on the field. The calorific value for biomass derived using Ecoinvent data (Ecoinvent, 2022) shows a potential 150% of the farm's energy needs; the net after fuel (diesel) is used for agricultural machinery. With these indicators, it is possible to compare the results obtained, highlighting the economic, energy and nutrient management implications.

From an economic point of view, the total value of the calculated waste from food loss and vegetables remaining in the field is around € 30,000.00* considering the extension of 28 ha (*value estimated in defect due to the absence of data for beet, chicory and pumpkin), this means a cost of € 1,071.00/ha. If this figure is associated with the energy potential, it is revealed that the farm can derive an energy value from the transformation of biomass that exceeds its needs. This is the net amount after the initial investment to construct a biomass plant. However, this has implications for both the individual farm and the entire Bio-District. At the farm level, it can monetise the economic value of its waste, generating excess energy. For the Bio-District, it will favour the creation of a sustainable energy plant capable of exploiting the symbiosis that can be activated between the different producers and returning the excess energy produced to the grid. The potential development of an energy plant is also justified by the possibility of the Bio-District expanding and aggregating new farms. In fact, the Bio-District comprises a small share of farms that produce organic products in the territory. In the Bio-District area, there are a further 50 organic farms that could be included in the cluster, contributing, directly or indirectly, to the creation and operation of the plant.

A further implication is the amount of nutrients not used for human consumption but reintroduced into the soil's biological cycle. In this case, the results obtained make it possible to conduct a purely economic comparison between the loss of value generated per ha and the marginal cost of the organic fertiliser (i.e. the lower cost of the fertiliser needed to enrich the soil as a result of the green manure technique). From this comparison, it is clear that the economic value of the waste, which remains in the field, is not proportionate to the marginal cost of the additional fertiliser. This figure cannot be obtained directly but can be inferred by

Table 5.
The calorific value of biomass

Product	Waste (ton.)	Calorific value 1 kg (MJ)	Calorific value (MJ)
Lettuce	7.8	1.2	9,516
Cauliflower	36.0	1.8	64,800
Beet	14.0	n.a.	n.a.
Chicory	4.6	n.a.	n.a.
Cabbage	20.8	3.0	61,984
Potato	10.0	3.5	34,800
Tomato	14.5	0.9	13,108
Pumpkin	40.0	n.a.	n.a.
Zucchini	16.5	1.3	20,625
Aubergine	10.0	1.6	16,000
Carrot	15.0	2.2	32,700
Melon	10.0	1.5	14,700
Watermelon	16.5	n.a.	n.a.
Total	*215.7*		*268,233.0*

Source(s): Our elaboration on data and Ecoinvent database (Ecoinvent, 2022) considering the cost of fertiliser in the absence of green manure. In the latter case, considering the different crops grown, the average cost of fertiliser per ha is € 680.00 (net of harvesting and management costs), below the economic value of the waste remaining on the field (€ 1.071/ha). This leaves room to intervene with a waste valorisation action both at the farm and Bio-Distric levels.

The economic reading of the data from the circular indicators for waste management shows that it is possible to intervene using circular policies within farms. The high valorisation of waste can express the potential for energy and nutrient valorisation and trace the potential for future valorisation. At the Bio-District level, this implies constructing a new supply chain for the valorisation of waste based on the inter-organisational exchange of resources (Chertow, 2000, 2007; Ruggieri *et al.*, 2016) that fosters cooperation between companies. The inter-organisational links within the Bio-District can be represented by natural resource exchanges aimed at energy production by creating new biogas plants shared between different stakeholders or through the high valorisation of waste exploiting its chemical and biological chemical properties in a CE approach. Examples include active ingredients and lignocellulosic elements (Piccinino *et al.*, 2022). This will allow the creation of integrated supply chains with primary and secondary products (Alfaro and Miller, 2014; Poponi *et al.*, 2020, 2021b) and may enable the economic and sustainable development of the area in which the district operates (Simboli *et al.*, 2015).

This paper's findings have further implications at the research, managerial and policy levels. At the research level, there is a need to develop specific indicators to fill the gaps in the dashboard and to represent the context in which different farms find themselves. This was highlighted by the need to develop a new indicator to express the potential utilisation of farm waste, which is not covered by the available indicators. Moreover, results revealed the importance of introducing a new classification of indicators that refer to the product and organisation to better represent the potential of the CE. The cross-linked characteristic and their coding within the dashboard should also be considered. At the managerial level, the results point to adopting new circular business models in a district logic, integrating stakeholders, valorising secondary raw materials and activating symbiosis between operators. Lastly, at the policy level, the results outline the need to steer active policies for the CE within Bio-Districts. Currently, policies are oriented towards fostering the aggregation of organic operators and the legal recognition of Bio-Districts. New policies should stimulate the emergence of governance for Bio-District (Truant *et al.*, 2019) that can engage operators towards ethical practices aimed at creating new sustainable supply chains. This partial limitation refers to the impossibility of calculating the management costs of secondary raw materials, although the potential for valorisation appears. Nevertheless, this is an exploratory study conducted on a single case study of the Etruscan Roman Bio-District in Italy, oriented in this first phase to test the methodology. The extension to other farms of the Bio-District will allow a reference framework to highlight the dashboard's application potential and introduce further scopes and transversal indicators. In this way, it will be possible to overcome the limits that emerged in this study and explain the potential applications for CE.

References

Alberto López Ruiz, L., Roca Ramon, X., Melissa Lara Mercedes, C. and Gasso Domingo, S. (2022), "Multicriteria analysis of the environmental and economic performance of circularity strategies for concrete waste recycling in Spain", *Waste Management*, Vol. 144 No. April, pp. 387-400.

Alfaro, J. and Miller, S. (2014), "Applying industrial symbiosis to smallholder farms", *Journal of Industrial Ecology*, Vol. 18 No. 1, pp. 145-154.

Amicarelli, V., Bux, C. and Lagioia, G. (2021a), "How to measure food loss and waste? A material flow analysis application", *British Food Journal*, Vol. 123 No. 1, pp. 67-85.

Amicarelli, V., Tricase, C., Spada, A. and Bux, C. (2021b), "Households' food waste behavior at local scale: a cluster analysis after the covid-19 lockdown", *Sustainability (Switzerland)*, Vol. 13 No. 6, pp. 1-14.

Assiri, M., Barone, V., Silvestri, F. and Tassinari, M. (2021), "Planning sustainable development of local productive systems: a methodological approach for the analytical identification of Ecoregions", *Journal of Cleaner Production*, Elsevier, Vol. 287, doi: 10.1016/jclepro.2020.125006.

Basile, S., Buonomo, E. and Basile, R. (2021), "Report on organic districts (or Eco-regions or bio-districts) in Europe", available at: www.organicdistricts.eu

Beccatini, G. (1998), *Distretti Industriali e Made in Italy. Le Basi Socioculturali Del Nostro Sviluppo Economico*, Bollati Boringhieri, Torino.

Beccatini, G. (2000), *Dal Distretto Industriale Allo Sviluppo Locale*, Bollati Boringhieri, Torino.

BSI (2017), BS *8001:2017. Framework for Implementing the Principles of the Circular Economy in Organizations*, The British Standards Institution, Londra.

Caputo, P., Ferrari, S. and Zagarella, F. (2020), "Urban Renovation: An Opportunity for Economic Development, Environmental Improvement, and Social Redemption BT - Regeneration of the Built Environment from a Circular Economy Perspective", in Della Torre, S., Cattaneo, S., Lenzi, C. and Zanelli, A. (Eds), Springer International Publishing, Cham, pp. 125-135.

Chertow, M.R. (2000), "Industrial symbiosis: literature and taxonomy", *Annual Review of Energy and the Environment*, Vol. 25 No. 3, pp. 313-337.

Chertow, M.R. (2007), "'Uncovering' industrial symbiosis", *Journal of Industrial Ecology*, Vol. 11 No. 1, pp. 11-30.

Cobo, S., Dominguez-Ramos, A. and Irabien, A. (2018), "Trade-offs between nutrient circularity and environmental impacts in the management of organic waste", *Environmental Science and Technology*, Vol. 52 No. 19, pp. 10923-10933.

Corona, B., Shen, L., Reike, D., Carreón, J.R. and Worrell, E. (2019), "Resources, conservation & recycling towards sustainable development through the circular economy — a review and critical assessment on current circularity metrics", *Resources, Conservation and Recycling*, Vol. 151 No. May, 104498, Elsevier.

CREA (2019a), "L'agricoltura Biologica per Lo Sviluppo Territoriale: L'esperienza Dei Distretti Biologici", available at: https://www.reterurale.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/19806

CREA (2019b), "Tabelle nutrizionali degli alimenti", available at: https://www.alimentinutrizione.it/sezioni/tabelle-nutrizionali (accessed 10 November 2022).

Cristóbal, J., Castellani, V., Manfredi, S. and Sala, S. (2018), "Prioritizing and optimizing sustainable measures for food waste prevention and management", *Waste Management*, Vol. 72, pp. 3-16, Elsevier, European Commission, Joint Research Centre (JRC), Directorate D – Sustainable Resources, Bio-economy Unit, Via E. Fermi, 21027 IspraVA, Italy.

Damodar, Y., Gholar and Stamm, C.L. (1991), "The just-in-time philosophy: a literature review", *International Journal of Production Research*, Vol. 29 No. 4, pp. 657-676, Taylor & Francis.

De Boni, A., Melucci, F.M., Acciani, C. and Roma, R. (2022), "Community composting: a multidisciplinary evaluation of an inclusive, participative, and eco-friendly approach to biowaste management", *Cleaner Environmental Systems*, Vol. 6 No. April, 100092, Elsevier.

De Pascale, A., Arbolino, R., Szopik-Depczyńska, K., Limosani, M. and Ioppolo, G. (2021), "A systematic review for measuring circular economy: the 61 indicators", *Journal of Cleaner Production*, Vol. 281, doi: 10.1016/j.jclepro.2020.124942.

Di Maio, F., Rem, P.C., Baldé, K. and Polder, M. (2017), "Measuring resource efficiency and circular economy: a market value approach", *Resources, Conservation and Recycling*, Vol. 122, pp. 163-171, Elsevier B.V.

Drejerska, N., Juszczyk, O., Takala, J. and Golebiewski, J. (2019), "Local contribution to circular economy : a case study of a Polish rural municipality", *Economia Agro-Alimentare*, Vol. XXI, p. 3, 2019, Franco Angeli, Milano, doi: 10.3280/ECAG2019-003011.

Drewnowski, A. (2010), "The nutrient rich foods index helps to identify healthy, affordable foods", *The American Journal of Clinical Nutrition*, Vol. 91 No. 4, pp. 1095S-1101S.

Dsouza, A., Price, G.W., Dixon, M. and Graham, T. (2021), "A conceptual framework for incorporation of composting in closed-loop urban controlled environment agriculture", *Sustainability (Switzerland)*, Vol. 13 No. 5, pp. 1-28.

Ecoinvent (2022), "Database Ecoinvent", available at: https://ecoinvent.org/ (accessed 1 October 2022).

(EFSA), E.F.S.A (2017), "Dietary reference values for nutrients summary report", *EFSA Supporting Publications*, Vol. 14 No. 12, p. e15121E, John Wiley & Sons.

Eisenhardt, K. and Graebner, M.E. (2007), "Theory building from cases: opportunities and challenges", *Academy of Management Journal*, Vol. 50 No. 1, pp. 25-32.

Esposito, B., Sessa, M.R., Sica, D. and Malandrino, O. (2020), "Towards circular economy in the agri-food sector. A systematic literature review", *Sustainability (Switzerland)*, MDPI AG, Department of Business Studies Management and Innovation Systems, University of Salerno, Salerno, 84084, Italy, Vol. 12 No. 18, doi: 10.3390/SU12187401.

European Commission (2019), The European Green Deal COM/2019/640, Brussels, 11th December.

European Commission (2020), "Farm to Fork strategy", available at: https://ec.europa.eu/info/strategy/priorities-2019-2024/european-green-deal/actions-being-taken-eu/farm-fork_en (accessed 3 March 2021).

European Parliament and European Council (2018), *Regulation (EU) 2018/848 on Organic Production and Labelling of Organic Product*, Official Journal of the European Union, Brussels, available at: https://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32018R0848&from=EN

FAO (2013), "Food wastage footprint, Fao", available at: www.fao.org/publications.

Fitzgerald, T. (2012), "Documents and documentary analysis", *Research Methods in Educational Leadership and Management*, Vol. 3, pp. 296-308.

Franklin-Johnson, E., Figge, F. and Canning, L. (2016), "Resource duration as a managerial indicator for Circular Economy performance", *Journal of Cleaner Production*, Vol. 133, pp. 589-598, Elsevier.

Fulgoni, V.L., Keast, D.R. and Drewnowsky, A. (2009), "Development and validation of the nutrient-rich foods index: a tool to measure nutritional quality of foods", *The Journal of Nutrition*, Vol. 139 No. 8, pp. 1549-1554.

Garcia-Herrero, I., Margallo, M., Laso, J., Batlle-Bayer, L., Bala, A., Fullana-i-Palmer, P., Vazquez-Rowe, I., (2019), "Nutritional data management of food losses and waste under a life cycle approach: case study of the Spanish agri-food system", *Journal of Food Composition and Analysis*, Vol. 82 No. February 2018, 103223, Elsevier.

Genovese, A., Acquaye, A.A., Figueroa, A. and Koh, S.C.L. (2017), "Sustainable supply chain management and the transition towards a circular economy: evidence and some applications", *Omega (United Kingdom)*, Vol. 66, pp. 344-357, Elsevier, Logistics and Supply Chain Management Research Centre, Management School, University of Sheffield, Sheffield, United Kingdom.

Giuca, S., Ricciardi, G., Sturla, A. and Vaccaro, A. (2017), *Il contributo dell'agricoltura biologica per lo sviluppo sostenibile delle aree rurali - distretti biologici e sviluppo locale*, Rete Rurale Nazionale, Rome.

Gravagnuolo, A., Angrisano, M. and Girard, L.F. (2019), "Circular economy strategies in eight historic port cities: criteria and indicators towards a circular city assessment framework", *Sustainability (Switzerland)*, Vol. 11 No. 13, doi: 10.3390/su11133512.

Haupt, M. and Hellweg, S. (2019), "Measuring the environmental sustainability of a circular economy", *Environmental and Sustainability Indicators*, Vols 1-2 No. September, 100005, Elsevier.

Helander, H., Petit-Boix, A., Leipold, S. and Bringezu, S. (2019), "How to monitor environmental pressures of a circular economy: an assessment of indicators", *Journal of Industrial Ecology*, Vol. 23 No. 5, pp. 1278-1291.

Ingrao, C., Faccilongo, N., Di Gioia, L. and Messineo, A. (2018), "Food waste recovery into energy in a circular economy perspective: a comprehensive review of aspects related to plant operation and environmental assessment", *Journal of Cleaner Production*, Vol. 184, pp. 869-892.

Ingrao, C., Faccilongo, N., Valenti, F., De Pascale, G., Di Gioia, L., Messineo, A. and Arcidiacono, C. (2019), "Tomato puree in the Mediterranean region: an environmental Life Cycle Assessment, based upon data surveyed at the supply chain level", *Journal of Cleaner Production*, Vol. 233 No. June 2018, pp. 292-313, Elsevier.

ISMEA (2021), "Bio in cifre 2021", available at: https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12441 (Accessed 25 October 2022).

ISMEA (2022), "Prodotti biologici - prezzi medi all'origine - Ortofrutta", available at: https://www.ismeamercati.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/1881 (accessed 25 October 2022).

Jouan, J., Ridier, A. and Carof, M. (2020), "SYNERGY: a regional bio-economic model analyzing farm-to-farm exchanges and legume production to enhance agricultural sustainability", *Ecological Economics*, Vol. 175, 106688.

Kazancoglu, Y., Kazancoglu, I. and Sagnak, M. (2018), "A new holistic conceptual framework for green supply chain management performance assessment based on circular economy", *Journal of Cleaner Production*, Vol. 195, pp. 1282-1299, Elsevier.

Kirchherr, J., Reike, D. and Hekkert, M. (2017), "Conceptualizing the circular economy: an analysis of 114 definitions", *Resources, Conservation and Recycling*, Vol. 127 No. September, pp. 221-232.

Mazzocchi, C., Orsi, L., Bergamelli, C. and Sturla, A. (2021), "Bio-districts and the territory: evidence from a regression approach", *Aestimum*, Vol. 79, pp. 5-23.

Ministry of Agricultural Food and Forestry Policies (2016), Ministerial Decree n. 1192 of 08.*01*.2016.

Moktadir, M.A., Kumar, A., Ali, S.M., Paul, S.K., Sultana, R. and Rezaei, J. (2020), "Critical success factors for a circular economy: implications for business strategy and the environment", *Business Strategy and the Environment*, Vol. 29 No. 8, pp. 3611-3635.

Moraga, G., Huysveld, S., Mathieux, F., Blengini, G.A., Alaerts, L., Van Acker, K., de Meester, S. and Dewulf, J. (2019), "Circular economy indicators: what do they measure?", *Resources, Conservation and Recycling*, Vol. 146 No. January, pp. 452-461, Elsevier.

Neuendorf, A. (2016), *The Content Analysis Guidebook*, Second., SAGE Publications Inc, Cleveland State University, USA.

Niero, M. and Kalbar, P.P. (2019), "Coupling material circularity indicators and life cycle based indicators: a proposal to advance the assessment of circular economy strategies at the product level", *Resources, Conservation and Recycling*, Vol. 140 No. July 2018, pp. 305-312, Elsevier.

Notarnicola, B., Hayashi, K., Curran, M.A. and Huisingh, D. (2012), "Progress in working towards a more sustainable agri-food industry", *Journal of Cleaner Production*, Vol. 28, pp. 1-8, Elsevier.

Özyurt, D.B. and Realff, M.J. (2001), "Combining a geographical information system and process engineering to design an agricultural-industrial ecosystem", *Journal of Industrial Ecology*, Vol. 5 No. 3, pp. 13-31, John Wiley & Sons.

Pagotto, M. and Halog, A. (2016), "Towards a circular economy in Australian agri-food industry: an application of input-output oriented approaches for analyzing resource efficiency and competitiveness potential", *Journal of Industrial Ecology*, Vol. 20 No. 5, pp. 1176-1186, John Wiley & Sons.

Paiho, S., Mäki, E., Wessberg, N., Paavola, M., Tuominen, P., Antikainen, M. and Heikkilä, J. (2020), "Towards circular cities—conceptualizing core aspects", *Sustainable Cities and Society*, Vol. 59 No. January, 102143, Elsevier.

Pauliuk, S. (2018), "Critical appraisal of the circular economy standard BS 8001:2017 and a dashboard of quantitative system indicators for its implementation in organizations", *Resources, Conservation and Recycling*, Vol. 129 No. September 2017, pp. 81-92, Elsevier.

Peña, C., Civit, B., Gallego-Schmid, A., Druckman, A., Pires, A.C., Weidema, B., Mieras, E., Wang, F., Fava, J., Canals, L.M.I., Cordella, M., Arbuckle, P., Valdivia, S., Fallaha, S. and Motta, W. (2021), "Using life cycle assessment to achieve a circular economy", *The International Journal of Life Cycle Assessment*, Vol. 26 No. 2, pp. 215-220.

Piccinino, D., Capecchi, E., Trifero, V., Tomaino, E., Marconi, C., Del Giudice, A., Galantini, L., Poponi, S., Ruggieri, A. and Saladino, R. (2022), "Lignin nanoparticles as sustainable photoprotective carriers for sunscreen filters", *ACS Omega*, Vol. 7 No. 42, pp. 37070-37077.

Poponi, S., Colantoni, A., Cividino, S. and Mosconi, E. (2019a), "The stakeholders' perspective within the B corp certification for a circular approach", *Sustainability*, Vol. 11 No. 6, p. 1584.

Poponi, S., Colantoni, A., Cividino, S.R.S. and Mosconi, E.M. (2019b), "The stakeholders' perspective within the B corp certification for a circular approach", *Sustainability (Switzerland)*, Vol. 11 No. 6, pp. 1-15.

Poponi, S., Mosconi, E.M. and Pacchera, F. (2020), "A BIO-DISTRICT for circular economy", *Le Scienze Merceologiche Nell'era 4.0. XXIX Congresso Nazionale Di Scienze Merceologiche*, Milano, Italy, FrancoAngeli, pp. 543-551.

Poponi, S., Arcese, G., Mosconi, E.M., Pacchera, F., Martucci, O. and Elmo, G.C. (2021a), "Multi-actor governance for a circular economy in the agri-food sector: Bio-Districts", *Sustainability*, Vol. 13, p. 4718, doi: 10.3390/su13094718.

Poponi, S., Arcese, G., Mosconi, E.M., Pacchera, F., Martucci, O. and Elmo, G.C. (2021b), "Multi-actor governance for a circular economy in the agri-food sector: Bio-Districts", Sustainability (Switzerland), MDPI AG, Department of Economics, Engineering, Society and Business (DEIM), Tuscia University, Viterbo, I-01100, Italy, Vol. 13 No. 9, doi: 10.3390/su13094718.

Poponi, S., Arcese, G., Pacchera, F. and Martucci, O. (2022a), "Evaluating the transition to the circular economy in the agri-food sector : selection of indicators", *Resources, Conservation and Recycling*, Vol. 176 No. September 2021, 105916, Elsevier B.V.

Poponi, S., Arcese, G., Ruggieri, A. and Pacchera, F. (2022b), "Value optimisation for the agri-food sector: a circular economy approach", *Business Strategy and the Environment*, No. November 2021, pp. 1-18.

Pugliese, P., Antonelli, A., Rota, C., Zanasi, C. and Basile, S. (2013), DIMECOBIO project - L'agricoltura Biologica in Chiave Territoriale: L'esperienza Dei Bio-Distretti in Italia.

Pugliese, P., Antonelli, A. and Basile, S. (2015), Bio - Distretto Cilento - Italy, pp. 1-26.

Pyke, F., Beccatini, G. and Sengeberger, W. (1990), "Industrial district and inter-firm co-operation in Italy", *International Istitute for Labour Studies*.

Regione Lazio (2016), *Smart Specialisation Strategy (S3)- Lazio Region*, Published in B.U.R.L. n. 48 of the 16th June 2016, Supplemento n. 1.

Rigamonti, L. and Mancini, E. (2021), "Life cycle assessment and circularity indicators", *International Journal of Life Cycle Assessment*, Springer Berlin Heidelberg, No. 26, pp. 1937-1942, doi: 10.1007/s11367-021-01966-2.

Roos Lindgreen, E., Mondello, G., Salomone, R., Lanuzza, F. and Saija, G. (2021), "Exploring the effectiveness of grey literature indicators and life cycle assessment in assessing circular economy at the micro level: a comparative analysis", *International Journal of Life Cycle Assessment*, Springer Berlin Heidelberg, No. 26, pp. 2171-2191, doi: 10.1007/s11367-021-01972-4.

Rossi, E., Bertassini, A.C., Ferreira, C., dos, S., Neves do Amaral, W.A. and Ometto, A.R. (2020), "Circular economy indicators for organizations considering sustainability and business models : plastic , textile and electro- electronic cases", *Journal of Cleaner Production*, Vol. 247, doi: 10.1016/j.jclepro.2019.119137.

Ruggieri, A., Braccini, A.M., Poponi, S. and Mosconi, E.M. (2016), "A meta-model of inter-organisational cooperation for the transition to a circular economy", *Sustainability (Switzerland)*, Vol. 8 No. 11, doi: 10.3390/su8111153.

Ruggieri, A., Poponi, S., Pacchera, F. and Fortuna, F. (2022), "Life cycle - based dashboard for circular agri - food sector", *The International Journal of Life Cycle Assessment*, Springer Berlin Heidelberg, pp. 1-16, doi: 10.1007/s11367-022-02118-w.

Saidani, M., Yannou, B., Leroy, Y., Cluzel, F. and Kendall, A. (2019), "A taxonomy of circular economy indicators", *Journal of Cleaner Production*, Vol. 207, pp. 542-559, Elsevier.

Sassanelli, C., Rosa, P., Rocca, R. and Terzi, S. (2019), "Circular economy performance assessment methods: a systematic literature review", *Journal of Cleaner Production*, Vol. 229, pp. 440-453, Elsevier.

Šerešová, M. and Kočí, V. (2020), "Proposal of package-to-product indicator for carbon footprint assessment with focus on the Czech Republic", *Sustainability (Switzerland)*, Vol. 12 No. 7, doi: 10.3390/su12073034.

Sgarbossa, F. and Russo, I. (2017), "A proactive model in sustainable food supply chain: insight from a case study", *International Journal of Production Economics*, Vol. 183 No. 2017, pp. 596-606, Elsevier.

Simboli, A., Taddeo, R. and Morgante, A. (2015), "The potential of Industrial Ecology in agri-food clusters (AFCs): a case study based on valorisation of auxiliary materials", *Ecological Economics*, Vol. 111, pp. 65-75, Elsevier B.V.

Solfanelli, F., Ozturk, E., Pugliese, P. and Zanoli, R. (2021), "Potential outcomes and impacts of organic group certification in Italy: an evaluative case study", *Ecological Economics*, Vol. 187 No. August 2020, 107107, Elsevier B.V.

Toccaceli, D. (2018), I distretti del cibo : novità e aspettative.

Torres-León, C., Ramírez-Guzman, N., Londoño-Hernandez, L., Martinez-Medina, G.A., Díaz-Herrera, R., Navarro-Macias, V., Alvarez-Pérez, O.B., Picazo, B., Villarreal-Vázquez, M., Ascacio-Valdes, J. and Aguilar, C.N. (2018), "Food waste and byproducts: an opportunity to minimize malnutrition and hunger in developing countries", *Frontiers in Sustainable Food Systems*, Vol. 2, p. 52.

Truant, E., Broccardo, L. and Zicari, A. (2019), "Organic companies' business models: emerging profiles in Italian Bio-Districts", *British Food Journal*, Vol. 121 No. 9, pp. 2067-2085.

Truant, E., Broccardo, L. and Kolte, A. (2020), "The role of organic districts in supporting companies' sustainable development", *International Journal of Managerial and Financial Accounting*, Vol. 12 Nos 3-4, pp. 265-283.

UNEP (2021), *Food Waste Index Report 2021*, Nairobi.

Universities and Colleges Climate Commitment for Scotland (2010), "UCCCfS unit converter", available at: https://www.eauc.org.uk/file_uploads/ucccfs_unit_converter_v1_3_1.xlsx (accessed 10 September 2022).

Vázquez-Rowe, I., Laso, J., Margallo, M., Garcia-Herrero, I., Hoehn, D., Amo-Setién, F., Bala, A., Abajas, R., Sarabia, C., Durá, M.J., Fullana-i-Palmer, P. and Aldaco, R. (2020), "Food loss and waste metrics: a proposed nutritional cost footprint linking linear programming and life cycle assessment", *The International Journal of Life Cycle Assessment*, Vol. 25 No. 7, pp. 1197-1209.

Vasa, L., Angeloska, A. and Trendov, N. (2018), "Comparative analysis of circular agriculture development in selected Western Balkan countries based on sustainable performance indicators", *Economic Annals-XXI*, Vol. 168, pp. 44-47.

Virtanen, M., Manskinen, K., Uusitalo, V., Syvänne, J. and Cura, K. (2019), "Regional material flow tools to promote circular economy", *Journal of Cleaner Production*, Vol. 235, pp. 1020-1025.

WHO (2015), "Healthy diet. Fact sheet N°394", available at: https://www.who.int/en/newsroom/%0Afact-sheets/detail/healthy-diet

Zeller, V., Lavigne, C., D'Ans, P., Towa, E. and Achten, W.M.J. (2020), "Assessing the environmental performance for more local and more circular biowaste management options at city-region level", *Science of the Total Environment*, Vol. 745, 140690, Elsevier B.V.

Corresponding author
Francesco Pacchera can be contacted at: francesco.pacchera@unitus.it