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Analysis of global warming potential: Organic vs. conventional tomatoes

Alessandro Scuderi, Giuseppe Timpanaro, Mariarita Cammarata*

Department of Agriculture, Food and Environment, University of Catania, Catania, Italy

**Corresponding author: alessandro.scuderi@unict.it*

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Abstract: Climate change threatens the possibility of ensuring sufficient and quality food for the population. The agricultural sector, considered to be one of the main contributors to the increase of CO_2-equivalents (CO_2-eq) in the atmosphere, faces one of the most difficult challenges for the sector: increasing production while reducing its impact on the environment. The improvement of adopted practices should be preceded by the quantification of generated emissions. This study aims to provide information on the analysis of the global warming potential (GWP) of tomatoes in Sicily, comparing organic and conventional cultivation methods. The methodology applied is the Life Cycle Assessment, which revealed a reduction in CO_2-eq for the organic method compared to the conventional one due to the use of organic fertilisers and crop protection products allowed by organic specifications. The possibility of reducing tomato GWP offers farmers the opportunity to act on the cultivation stage by making it more sustainable and at the same time to communicate the beneficial action, towards the environment, through the product label. The research also highlights that organic production, with the application of new production and pest management techniques, is comparable in terms of quantity produced per hectare to conventional production and with excellent fruit quality.

Keywords: CO_2 equivalents; environment; Life Cycle Assessment (LCA); open field; sustainability

Sufficient and quality food availability, as set out in the United Nations SDGs (Sustainable Development Goals), is threatened by climate change and related challenges. Agricultural production is fundamental for ensuring food security. It also determines the impact on the natural environment, climate, and environmental component uptake (Prandecki et al. 2021). The challenge for the agricultural sector is to increase production without compromising the environment (Zarei et al. 2019). Climate change is partly due to human activity and partly results from natural processes. Studies in this field and statistics clearly show that increasingly violent climate processes are anthropogenic in nature and the effects on the climate are large enough to reach the tipping point, causing an imbalance in nature (IPCC 2013). Europe aims, with the Green Deal, to improve the economy through environmentally friendly practices to combat climate change and protect the natural environment (European Commission 2019). Within it, the Farm to Fork strategy includes the reduction of pesticides by 50 %, nutrient loss during fertilisation, the use of antimicrobials in animal husbandry and aquaculture, and increased organic farming. (European Commission

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2020). These offer valuable help in reducing carbon dioxide emissions into the atmosphere.

Since the issue of global warming has gained prominence on the global environmental agenda, the use of global warming potential (GWP) has become commonplace, albeit in a modified form compared to the past. Carbon emissions from agriculture in Europe account for around 10% of the total, so a pathway to carbon neutrality as envisaged by the Green Deal by 2050, is needed. This means quantifying carbon emissions by establishing CO_2-equivalents (CO_2-eq) produced, the unit of measurement of GWP, to identify practices for improvement. To suggest increasingly sustainable cultivation models, the aim of the research is to provide an analysis of GWP in tomato cultivation by comparing organic and conventional methods. The comparison highlights the virtuous practices to apply to reduce the horticultural footprint, combat climate change, and ensure food supply (Scuderi et al. 2021b). The study was conducted in Sicily, a particularly suitable area to produce tomatoes, which is one of the main horticultural crops grown. Furthermore, the research can be replicated in other soil and climate contexts, as Sicily has similar characteristics to other contexts where this type of cultivation is performed. The research is based on the application of the consolidated Life Cycle Assessment (LCA) methodology. This is an operational tool that allows farms to become aware of their environmental impact and shows them the way to become carbon neutral; at the same time, it allows the consumer to choose more environmentally friendly products (Scuderi et al. 2021a). The quantification of GWP from a life cycle perspective still has knowledge gaps. These mainly concern the small number of fruit and vegetables analysed, the comparison of products with different production processes, and the analysis of different agro-climatic contexts reflected in the environmental footprint (Parajuliet al. 2018). Input-output quantification using Life Cycle Assessment (LCA) methodology offers a solution to overcome these gaps. It makes possible the identification of environmental hotspots along the life cycle of a product (Poudelet et al. 2012), thus overcoming difficulties such as the detection of specific agro-management practices to be modified (Parajuli et al. 2021).

A careful review of the existing literature revealed a lack of available data concerning open-field organic tomatoes, whereas detailed research has been carried out in the case of greenhouse crops (Bosona and Gebresenbet 2018). For this reason, open field cultivation has been considered, located in the areas of Southern Italy, in the centre of the Mediterranean Basin. Due to the environmental issues mentioned above, there is an increasing demand for information on the environmental impact of food by consumers and actors in the food supply chain. This requires expanding the knowledge base on the impact of the agricultural sector and the development of innovative and sustainable food production methods (Nascimento et al. 2018). In this respect, organic food production is receiving more attention than ever before (Bosona and Gebresenbet 2018). Quantifying emissions allows for food labelling and communication with consumers, information-based decision-making in food production and supply chain management.

MATERIAL AND METHODS

Production system. Tomato growing in Mediterranean areas, particularly in Sicily, has an important role both in terms of the quantities produced and the populations' food uses. In Italy, tomato production in open fields in 2021 was 547 699.2 tons of which 155 245 tons were produced in Sicily. (ISTAT 2022). Eastern Sicily, specifically the provinces of Catania, Syracuse. and Ragusa, is the area taken into account where the production of open-field tomatoes is 31 065 tons. Due to the importance of this crop in this area, the study is based on a comparison between conventional and organic tomato cultivation in open fields. In the absence of official data on organic production quantities, it is estimated that these are around 3 000 tonnes, which, thanks to the soil and climate characteristics of the area in question, are cultivated in spring-summer. The sample analysed is a representative case study of open-field tomato cultivation and is not comparable with greenhouse cultivation, which has different growing periods, materials used and environmental impacts. These two farming systems mainly differ in the type of fertiliser and pesticide treatment products used. Organic cultivation involves the application of manure to increase the organic matter content of the soil before transplanting the seedlings. It is also characterised by the use of potassium sulphate (K_2SO_4), which is permitted in organic farming. Protection of organic cultivation is achieved through the application of copper and sulphur. Conventional cultivation, on the other hand, is characterised by nitrogen fertilisers and synthetic pesticides, which are not permitted in organic farming. It is characterised by the use of mineral fertilisers such as NPK and N-CaO-MgO. Crop protection against pests is instead carried out with products based

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on Acetamiprid, and Hemamectin benzoate. The number of operations, type of machinery used, and quantity of seedlings are the same in both methods, so it is possible to attribute the difference in detected impacts to the variation in products used. In both cases transplanting and harvesting are manual. Another difference between the two cultivation methods lies in the yield obtained, while in conventional methods it is about 5 kg·plant^{-1} in all harvests carried out on the crop in organic methods a total of 4.75 kg·plant^{-1} is recorded. The data used to conduct the evaluation were collected directly on the farm through face-to-face interviews during which questionnaires were administered to the farmers. The questionnaire realised using an Excel spreadsheet is characterised by several sections according to data required for the analysis. Specifically, the first part concerns the farm characteristics such as cultivated area and location. The second part deals with soil tillage throughout the entire tomato production cycle in open fields. The next sections were responsible for collecting information on fertilisation, weed control and crop protection from animal pests. Another part of the questionnaire was dedicated to irrigation details in order to collect data regarding the amount of water used, the type of irrigation system and the dates of watering. Finally, the last section was designed to collect data on the procurement and quantities of all materials used in the production process such as fertilisers, crop protection products, water, fuel for machinery and seedlings for transplanting. The selected farms are located in the same cultivation area in order to exclude soil and climate variables; they are located in eastern Sicily (Figure 1), which is particularly suited to growing tomatoes in open fields.

Figure 1. Investigated area of open-field tomato cultivation

Source: own elaboration

Interviews were conducted by the entire research team involved in the study. The farmers were chosen with the same professional skills to avoid errors during data collection (Scuderi et al. 2021a). These are agricultural entrepreneurs with high school qualifications and specialising in the production of open-field tomatoes for the fresh market and not for processing industries. The sample analysed consisted of 10 farms that cultivate tomatoes conventionally and 10 farms that practice organic farming by applying the dedicated regulations. The cultivation cycle lasts four months, with transplanting in April and harvest beginning in June. All data considered refer to the year 2022. Table 1 details the scenarios considered, while the quantities of all products used in both cultivation methods are summarised in Table 2.

Goal and scope definition. Goal and scope definition is the first phase of an LCA study. At this stage, the intent of the research, the system boundaries and the functional unit are clarified. Establishing the boundaries and defining the specific life cycle systems to be studied is essential for any Life Cycle Inventory (LCI) or LCA (Boguski et al. 1996). Therefore, all operations that contribute to the life cycle of a product, process or activity of interest are included in the system boundaries (Khoshnevisan et al. 2014).

The main objective of this study is to provide an analysis of global warming potential by means of LCA to in-

Table 1. Characteristics of conventional and organic tomato production systems

Input	Input detail	**Scenario 1** Conventional farming	**Scenario 2** Organic farming
Crop	type	fresh tomato	fresh tomato
	crop period	16 weeks	16 weeks
	transplant date	5th April	5th April
	yield (market)	178 570	169 641.5
	area	10 000 m^2	10 000 m^2
	cultivation	open field	open field
Fuel	farm machinery	diesel oil	diesel oil
Water	source irrigation	tap water drip	tap water drip
Fertilisers	type	N-P-K N-CaO-MgO KNO_3	manure K_2SO_4 –
Pesticides	mix	yes	no

Source: own elaboration

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Table 2. Inputs used in tomato cultivation in organic and conventional farming (unit data)

Input	Unit	Conventional tomato	Organic tomato
Seedlings	number	35 714	35 714
Fertiliser NPK (20-10-10)	kg·ha^{-1}	140	–
Fertiliser N-CaO-MgO	kg·ha^{-1}	20	–
Fertiliser KNO_3	kg·ha^{-1}	12	–
Organic fertiliser (manure)	kg·ha^{-1}	–	1 200
Organic fertiliser (K_2SO_4)	kg·ha^{-1}	–	600
Pesticides (acetamiprid, hemamectin benzoate)	kg·ha^{-1}	0.32	–
Organic pesticide (sulphur)	kg·ha^{-1}	–	4
Organic pesticide (copper)	kg·ha^{-1}	–	4
Diesel	L·ha^{-1}	180	180
Water	m^3·ha^{-1}	1 043.28	1 043.28

Source: own elaboration

crease knowledge and environmental behaviour of this crop during the agricultural phase, both in conventional and organic methods. Basing the study on climate change, a much-studied impact category due to numerous government and industry initiatives (Gunady et al. 2012; Page et al. 2012), a cradle-to-farm-gate approach was adopted, and the focus was only on the production of tomatoes in the open field. The storage, distribution and consumption phases have been left out. The production phases of both fertilisers and pesticides from raw materials and tomatoes during cultivation were considered instead. Within these boundaries, therefore, operational inputs such as fertilisers, pesticides, water, and their distribution, as well as the use of machinery and diesel, were also considered (Figure 2). Tomato harvesting operations were excluded from the system boundaries as they were carried out manually. Greenhouse gas emissions from the production, maintenance and end-of-life of capital goods were not included in the system boundaries. Similarly, the disposal of materials and waste was not considered. The infrastructure construction, post-collection and sales processes were not included in the objectives of the study since the aim is the identification of strategies to improve production management.

As far as the functional unit is concerned since agricultural systems are multifunctional, it was decided, in accordance with Nemecek et al. (2011b), to study the land management function and production function of tomato cultivation. The former is defined in one hectare of cultivated area and the latter is described by a physical unit such as one kg of harvested tomato. The decision of applying two functional units to the study aims to clarify better the environmental performance of both cultivation systems (Timpanaro et al. 2021). These functional units (FUs) are the basis for the normalisation of input and output flows of materials and energy (ISO 14040, 2006-10a – Environmental management – Life cycle assessment – Principles and framework; ISO 14044, 2006-10b – Environmental management – Life cycle assessment – Requirements and Guidelines).

Life Cycle Inventory (LCI). The second step is the Life Cycle Inventory (LCI), in which all inputs (materials, machinery, energy) into the production process are quantified. The LCI was conducted through three

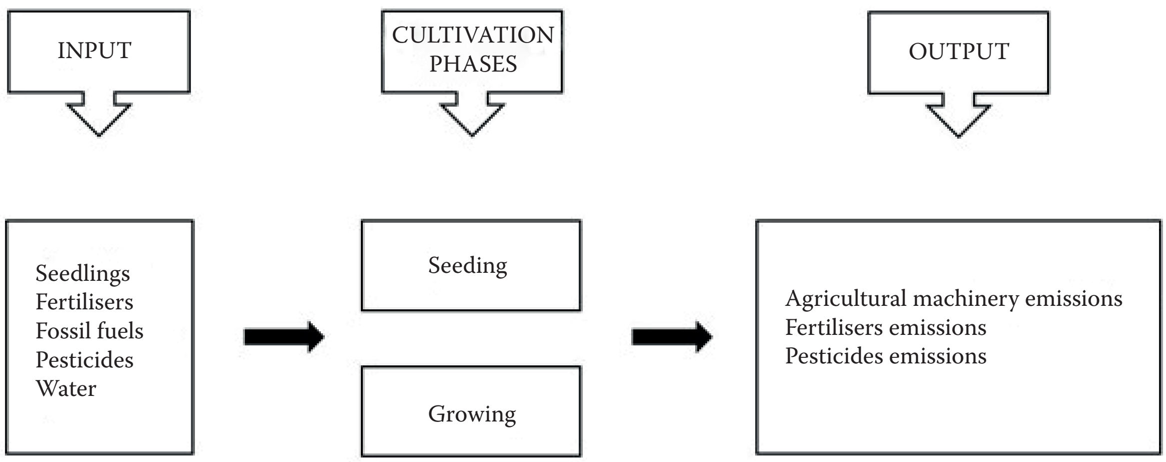

Figure 2. System boundaries for tomato cultivation

Source: own elaboration

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types of data: primary data collected directly on the farms with ad hoc questionnaires covering all stages of tomato cultivation; background data relating to the production of fertilisers, pesticides, and fuels for which the Ecoinvent 3.6 database was used, and tertiary data, found in the literature, relating to emissions generated by fertiliser and pesticide distribution and fuel combustion. According to Page et al. (2012), the foreground data are of high quality because collected through direct conversations with farmers. Table 2 shows in detail all input used with the relative quantities in the conventional and organic cultivation process.

As mentioned above, the calculation of emissions related to fertiliser distribution and machinery use was carried out according to the suggestions of Nemecek and Kägi (2007). With regard to the calculation of pesticide distribution emissions, the Ecoinvent approach was used in which 'all pesticides applied for crop production are considered as emissions into the soil. The quantities of pesticides used as inputs were then simultaneously calculated as outputs (emissions into the agricultural soil). The substances specified in the inventories were used as references to correlate the corresponding emissions' (Falcone et al. 2019).

Methods of impact assessment. The Life Cycle Impact Assessment (LCIA) deals with the quantification of potential impacts through the identification of impact categories, it allows emissions and resource extractions to be translated into a limited number of environmental impact scores (Hauschild and Huijbregts 2015). To carry out the environmental impact assessment, the SimaPro 9.1 software was used, within which the method IPPC 2013GWP 100a developed by the International Panel on Climate Change was selected. This method lists the IPCC climate change factors with a time horizon of 100 years (IPCC 2013). The IPCC characterisation factors for the direct global warming potential (except CH_4) of atmospheric emissions do not take into account: the indirect formation of dinitrogen monoxide from nitrogen emissions; the radiative forcing from emissions of NOx, water, sulphate, etc. in the lower stratosphere and upper troposphere; the formation of CO_2 from CO emissions (IPCC 2013).

RESULTS AND DISCUSSION

Results. The quantification of GWP through LCA is done per unit area (1 ha) and per fresh mass (1 kg of tomato) because the environmental impact of crop production is linked to both, the area of land occupation and yield. Overall the GWP of agricultural production is determined by nitrogen oxide emissions from N-fertilisation, combustion of fossil fuels in agricultural machinery and irrigation (Nemecek et al. 2011a). GWP per hectare represents the intensity of agricultural input use. Based on the IPCC calculation method (IPCC 2013), the results are shown in Table 3. In this case, conventional cultivation reported a higher impact of about 51% compared to organic cultivation. This is primarily due to the application of mineral fertilisers and synthetic products for crop protection. The best result was achieved by the organic method thanks to the use of organic fertilisers and plant protection products in accordance with the cultivation method used.

Table 4 shows the results per unit of fresh mass produced (kg of harvested tomato). Organic cultivation reported a lower GWP, which makes organic tomatoes more sustainable than their conventional counterparts. The latter reported in this case a 35% higher impact than organic.

In general, crops with high N requirements and high pesticide use are expected to have a greater impact than crops using products and fertilisers allowed under organic legislation.

To give more detail on the impact generated by the two cultivation methods, Figure 3 shows the percentage of GWP achieved during transplanting and seedling growth. 60.1% of the impact generated by conventional cultivation is concentrated during the growing phase when the greatest amount of fertilisers and protective products are applied. In contrast, organic cultivation generates 57.5% of the total CO_2-eq kg during the transplanting phase. In this case, manure application takes place before planting the seedlings. This implies that most of the impact is concentrated at this stage. The results obtained per cultivation stage are furthermore consistent both per ha of cultivated area and per kg of tomato.

Table 3. Carbon footprint (CF) per unit area (ha)

Impact category	Unit	Conventional tomato	Organic tomato
IPCC GWP 100a	kg CO_2-eq	4 035.90	1 988.80

Source: own elaboration

Table 4. Carbon footprint (CF) per fresh mass produced (kg)

Impact category	Unit	Conventional tomato	Organic tomato
IPCC GWP 100a	kg CO_2-eq	0.02	0.01

Source: own elaboration

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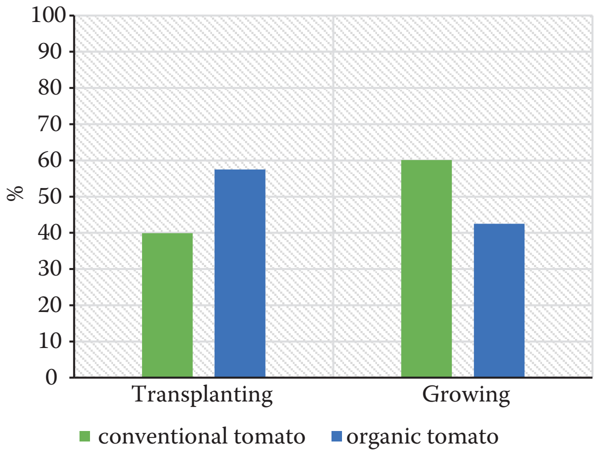

Figure 3. Percentage distribution of impact during cultivation phases per ha and kg

Source: own elaboration

Discussion. The study is based on LCA to quantify the global warming potential of open field tomatoes. The available literature on the analysis of the environmental impact of tomatoes using LCA methodology is very heterogeneous with regard to the details of the inventory and the objectives of the studies (Torres Pineda et al. 2021). In this regard, a reliable comparison of the literature metadata is not possible (Urbano et al. 2022). The results obtained from the impact assessment vary depending on the production system, agronomic practices, LCI and system boundaries considered (Urbano et al. 2022). In the existing literature, there is a lack of studies on open-field tomatoes comparing organic and conventional methods. This represents a strength of the present work, which would be an important contribution to the literature in this field. Authors dealing with tomatoes in the open field under a conventional regime, such as Urbano et al. (2022), obtained a result of 0.120 kg CO_2-eq for GWP. The higher impact compared to our result can mainly be explained by the higher amounts of mineral fertilisers administered to the crop compared to the situation we analysed. Given the lack of papers on the crop under consideration that deals with the comparison between organic and conventional, the authors decided to analyse the comparison of the two cultivation methods carried out on other crops. Chatzisymeon et al. (2017), analysed pepper cultivation in open field and again for the Climate Change category, expressed in CO_2-eq, the conventional method was found to be more impactful due to fertilisation and irrigation. Similarly, Foteinis et al. (2021) found a higher GWP for the conventional method than the organic one, in the cultivation of eggplant in open fields. Foteinis and Chatzisymeon (2016), analysed the cultivation of lettuce. They report that the CO_2-eq emissions of organic lettuce cultivation are about 15 % lower than conventional ones per cultivated area. On the other hand, they note that when expressing results per unit of product, organic lettuce emits 1 282 kg CO_2-eq per tonne of harvested product, while in conventional 631 kg CO_2-eq·t^{-1}, which is largely reduced due to the high yield of conventional cultivation. The listed studies show both an interest in quantifying GWP based on the comparison between organic and conventional, and an increased benefit of applying organic practices to reduce the environmental impact of the agricultural sector. In particular, the last one analysed (Foteinis and Chatzisymeon 2016), confirms the importance of focusing the study on the dual functional unit to provide the reader with a detailed overview.

In our research, the crop was analysed according to both conventional and organic cultivation methods to highlight practices for reducing the impact. As the results highlight, the organic method of tomato cultivation shows undoubted advantages. The use of organic fertilisers such as manure and natural crop protection products has resulted in a reduced impact both per ha of cultivated area and per kg of fresh mass harvested. The organic method analysed in this study reverses previous LCA studies that compared agricultural products from conventional and organic systems where, per quantity of products, the impacts are often higher in the case of organic (Meier et al. 2015; Foteinis and Chatzisymeon 2016). The combination of inputs used for organic tomatoes also resulted in a slightly lower yield than conventional tomatoes. This translates into a concrete result for farmers who often abandon the organic method because of the low yields, often preferring quantity over quality and respect for the environment. Manure application before seeding and limited doses of mineral fertilisers and natural pesticides during the crop's growth phase increases the fertility potential for managing tomatoes in open fields. This leads the crop to become resilient and to slightly lower yields than conventional ones. The lower yield gap in organic cultivation is overcome by a higher price compared to conventional tomatoes. The former is 1.08 EUR·kg^{-1} compared to 0.97 EUR·kg^{-1} for conventional tomatoes in Italy for the year 2021 (Sinab 2022), while in the reference area, the average prices recorded are 1.30 EUR·kg^{-1} for organic and 1.10 EUR·kg^{-1} for conventional tomatoes. The recognition of a premium price for the implementation of a more sustainable

https://doi.org/10.17221/104/2023-AGRICECON

cultivation process should encourage Sicilian farmers to adopt these practices. Farmers' lack of confidence in adopting organic farming practices lies in the uncertainty associated with this cultivation method. The organic farmers interviewed stated that they had encountered sub-optimal years, in which physiopathology was difficult to combat with the products permitted in organic farming. The conventional method, thanks to synthetic products, provides farmers with a guarantee of the yields that will be obtained in the various production cycles. In addition to an advantage for farmers, the quantification of the GWP of tomatoes and its communication to the consumer through the label, represents greater safety and protection for human health, at a time in history when the consumer is much more careful in his purchases than in the past and willing to pay a higher price for a healthier and more environmentally friendly product.

The quantification of CO_2-eq emissions in Mediterranean crops is also a potential benefit for the inclusion of carbon offset strategies in farm sustainability plans. Once the carbon sequestration from the atmosphere, carried out by the plant for its vital functions, has been calculated, the emitted quantities measured by CO_2-eq allow a balance between carbon sequestered and emitted to establish the tons actually stored in the soil. Future lines of research will focus on the calculation of carbon credits. They, in relation to the carbon stored in the soil, would both encourage sustainable practices and allow bigger companies to offset their emissions by purchasing credits from virtuous farms. This opens up a further possibility of income differentiation for farmers who adopt sustainable cultivation methods and who would consequently be driven to adopt the organic cultivation method.

CONCLUSION

The future of agricultural production according to the demands of a growing world population must be steered towards a path of efficiency and sustainability. These needs must also be met by conventional production systems, in order to make them more environmentally and health-friendly. The application of organic production models certainly represents the sustainable future of our production systems but implementing improvements to conventional methods such as reducing the amount of fertilisers and pesticides used to a minimum threshold could be a viable alternative for farmers. Achieving the SDGs of reducing world hunger, preserving biodiversity, and combating climate change are reflected in the application of organic farming. A 25% reduction in the quantity produced compared to the conventional method is combined with the undoubted advantage of higher-quality production. The study carried out on table tomatoes in the central area of the Mediterranean basin is a demonstration of this. The market for agricultural products, today more than in the past, is characterised by environmentally and health-conscious consumers (Sturiale and Studeri 2011), so the farmer should be rewarded for his environmentally friendly production and transition to a circular economy aimed at waste reduction. This means creating an active market for carbon credits that allows for an exchange between less virtuous companies and sustainable ones, and a willingness on the part of consumers to pay a slightly higher price to find on their table a product that respects the environment and human health. Future research lines will focus on quantifying the carbon credits to be awarded to farmers and assessing consumers' willingness to pay for sustainable food products.

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