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Economic and Environmental Sustainability Assessment of an Innovative Organic Broccoli Production Pattern

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Abstract: Organic farming nowadays is held up as a model of sustainability; however, this is not always an economic advantage for farmers due to the reduced yields compared to the conventional regime. The aim of the study is therefore to provide an environmental and economic analysis of the innovative organic model proposed by the Bresov project to assess its sustainability. The study is therefore based on a Life Cycle Assessment methodology and the economic evaluation, through the calculation of the gross income of innovative organic and conventional broccoli cultivation in Sicily. The impact categories analysed reported a 60–100% reduction in impact in the case of innovative organic compared to conventional. From an economic point of view, although there is a minimal reduction in yield in organic compared to conventional, there is an increase in production costs that translates into a reduction in the gross income of approximately 61%. These gaps are filled when the organic product is granted a premium price and thanks to aid from the Common Agricultural Policy. The innovative organic approach, characterised by new products and soil management methods, confirms it as an alternative to conventional. This approach contrasts with the mere substitution of synthetic products.

Keywords: gross income; horticulture; Italy; LCA; vegetable

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1. Introduction

Climate change, defined by the IPCC (Intergovernmental Panel on Climate Change) as one of the most serious threats to life on the planet [1], is leading to imbalances in both human and natural systems. Mitigating its effects, as well as reducing world hunger and increasing the resilience of socio-ecological systems, are some of the highlights of the UN 2030 Sustainable Development Goals (SDGs). Access to food and thus the stability of food security is threatened by climate change. They directly affect yields, reducing them by between 3.1 and 7.4% for every degree Celsius increase in global temperature [2]. Furthermore, world population growth by 2050 will require an increase in agricultural production of around 25–70% [3]. The world's population is currently growing by about 1.1% per year, and if current trends continue, it will reach 9.7 billion by 2050 [4]. This scenario is aggravated by the current European situation characterised by the Russian–Ukrainian war, which has led to a reconsideration of raw materials with increasing values due to lack of availability and to a process of revision of the CAP (Common Agricultural Policy) by the European Union. The link between climate change and the agricultural sector is characterised by its generating 16–27% of all anthropogenic emissions [5]. These are distributed throughout the production cycle, from seed preparation to harvesting and storage of end products. The ambitious goal of achieving climate neutrality by 2050 to meet the above challenges requires a reduction in the use of non-renewable resources [6]. They are largely used by the agricultural sector for fertiliser production, nitrogen products, the operation of machinery and the transport of products [6]. In this context, within the agricultural sector, the use of energy and non-renewable fossil fuels is particularly high in the horticultural one [7]. Vegetable growing is a type of production associated with extremely intensive use of production factors such as land, water and energy [7]. These topics underline that meeting the needs of the growing population requires adapting production systems towards environmental, economic and social sustainability [8]. In this context, it is necessary to find cultivation methods producing sufficient quantities and quality food, combined with environmentally friendly practices. Classical organic farming is considered a sustainable model, although does not always guarantee an adequate yield to meet food demand [7]. The main principles of the organic method are to maintain optimum soil health through the use of cover crops, crop rotations and organic soil amendments. This approach represents a long-term commitment to improving soil quality and increasing soil organic matter, thus sequestering more carbon per unit area than conventional agriculture [9]. Hence, the benefit and possibility of achieving climate neutrality through environmentally friendly practices that reduce soil, water and air pollution, making organic farming an instrument of environmental protection and a promoter of sustainable development [10]. The elimination of synthetic chemical products makes it necessary to replace them with environmentally friendly products which makes the application of organic farming principles possible in the horticultural sector as well [11]. While beneficial to the environment, organic farming often does not offer farmers the possibility of achieving adequate yields to cover production costs and obtain adequate remuneration from farming. Consequentially, new practices and protocols to increase organic production yields require careful scientific analysis to ensure their economic and environmental validity [9]. The aim must therefore be to formulate an innovative model of organic farming, evolved from the classic model, respectful of the environment and combining productivity and quality.

Future trends in population, land use and harvests vary according to different socio-economic and climatic conditions [12]. To improve the resilience of agricultural systems to climate damage, profound changes in the sector are required, which are only possible through a detailed analysis of input/output conversion to environmental effects [13]. Agricultural modifications to counter climate change also require an adaptation of societies in terms of behaviour, understanding and values [14]. Agricultural production is determined by market demands, political implications and in the case of organic products also by the preferences of consumers who, appreciating their quality, are willing to pay a premium price [9]. Providing an agricultural product respectful of the environment and human health results in increased consumer confidence in products that incorporate ethical and environmental values.

The aim of the current study is to provide a new paradigm for organic farming based on the quantification of environmental impact and economic analysis. For this purpose, it is proposed the quantification of the environmental impact of broccoli (Brassica oleracea L.) cultivation in Sicily (Italy), according to the innovative organic approach proposed by Bresov as opposed to the conventional method. The economic evaluation of the two cultivation processes is also of fundamental importance to define which of the two is more sustainable in monetary terms [15]. The comparison of the two agricultural systems makes it possible to highlight the virtuous practices to be applied in order to reduce the horticultural footprint, contrast climate change and guarantee the food supply [16]. For this purpose, the reference method is Life Cycle Assessment (LCA), which is used for quantifying environmental impacts along the supply chain, comparing different production systems and assessing sustainability [17]. LCA makes possible the accounting of environmental impacts from the sourcing of raw materials to the disposal of the product itself (cradle-to-grave approach). It allows the formulation of mitigation strategies focused on primary sources and emissions. The methodology has received considerable attention from policymakers, thanks to scientific evidence from academic research, to reduce the environmental burden of food and farming systems. It is also used in monitoring the achievement of the SDGs, as it is a standardised ISO 14040:2006 guideline [18–20]. Several authors have used LCA to assess the environmental impact of horticultural products, such as tomatoes [21], cauliflower [22] and lettuce [23], as well as to compare seasonal and off-season products [24]. Others [25,26], have shown instead a reduction in the horticultural footprint by switching from conventional to organic farming methods. In our study, the application of LCA is used to quantify, for the first time, the environmental impact of growing broccoli in Sicily (Italy) according to two different cultivation methods. The choice of this production area was made because Sicily is particularly suited to the production of broccoli, which is one of the main vegetable crops produced. Moreover, the study can be replicated in other pedoclimatic contexts and at the same time, Sicily has similar characteristics to other contexts where this type of cultivation is grown. The analysis was conducted from different perspectives: global warming potential, resource depletion, water and land use, human toxicity and other impact categories detailed below, in order to determine the most efficient cultivation method for the following compartments: air, soil, water and human health.

2. Materials and Methods

2.1. Innovative Organic Protocol

Innovative organic cultivation was carried out as part of the BRESOV H2020 Euro-pean project "Breeding for Resilient, Efficient and Sustainable Organic Vegetable Production" (https://bresov.eu/ (accessed on 1 October 2022)); while conventional one was analysed by considering a specialised farm present in the same area (Sicily), in order to make the comparison. Brassica oleracea L., which originated in the Eastern Mediterranean region, has undergone a long process of diversification in Italy. Thanks to its plasticity, crossbreeding and domestication process, it is characterised by numerous cultivated forms [27]. Southern Italy, in particular Sicily, is considered the main centre of domestication for broccoli; in fact, production in Italy is mainly concentrated in the south and on the islands [28]. Brassica oleracea var. italica (cultivar Sparacello) was used for the current study, this crop is particularly suited to different growing areas (due to its resistance to biotic and abiotic stresses) and is therefore one of the reference crops in the Bresov project [29]. The latter, funded by the European Union's Horizon 2020 research and innovation programme, involves 22 countries in which farmers, research institutes and stakeholders in the value chain work together, following a collaborative and participatory approach. The overall objective of the project is to improve the competitiveness of three of the most important families of vegetable crops (Brassicaceae, Fabaceae, Solanaceae) when grown in an organic production system, in order to obtain sustainable production through the selection of resistant genotypes [29]. The Bresov approach aims to change the classical organic method into a more innovative one aimed at achieving sustainability in its three dimensions: environmental, economic and social, improving the competitiveness of these three crop families and guaranteeing farmers a sustainable yield. The long-term goal of applying the innovative organic method will be to gradually introduce changes in established organic farming systems and practices, using the selection of appropriate germplasm to enhance response to stress factors and human health benefits.

The study was conducted under experimental conditions for which two fields, one hectare each, were chosen with the same characteristics. The comparison of the farms examined was carried out taking into account the principle of equal conditions, therefore the same cultivation area was chosen, thus reducing climatic and environmental diversity, and farmers with the same professional skills had farms with the same technical managerial characteristics. The main differences between innovative organic and conventional cultivation concern the type of products used, their combination and application period. The innovative organic protocol involves the application of pellet manure to increase the organic matter content of the soil, before transplanting the seedlings in a quantity of 3500 kg/ha. Once the seedlings have been planted, the Bresov protocol includes the application of mycorrhizal fungi and microorganisms at a dose of 3.3 kg/ha useful for sustaining the plant in the different phenological phases. The application of mycorrhizal fungi and microorganism increase the content of nutrients such as nitrogen, phosphorus, potassium, zinc and copper in the soil, decreasing the intake of these elements through fertilisation [30]. At the same time, the use of these products favours the response of horticultural plants to stress and the activation of defence mechanisms promoted by the accumulation of phytochemicals [31]. Crop protection is achieved through the application of copper and Bacillus Thuringensis, with three applications from transplanting to the end of the crop cycle and with a total quantity of 2 kg/ha for each product, according to the innovative organic method. On the other hand, conventional cultivation is characterised by the use of nitrogenous fertilisers, herbicides and synthetic pesticides, which are not permitted in organic farming. In the conventional method, the first application of mineral fertiliser is localised and manual, while the next 3 applications are made by fertigation. Crop protection against pests is carried out using Spinosad-based products while weed control involves the application of Oxifluorfen. The quantities of all products used in the two cultivation methods are summarised in Table 1. Another important difference concerns the number of seedlings used per hectare, as well as the amount of water and diesel used in the cultivation process. In the case of organic cultivation, Bresov's innovative protocol involves the use of 41,000 seedlings, with a smaller distance between rows to reduce the incidence of weeds and achieve good productivity. This results in an increase in plants per hectare of around double the conventional method. It is also an advantage in maintaining a high productivity per hectare, which makes the crop economically sustainable, based on obtaining more but smaller inflorescences. In the case of conventional cultivation, just over half, i.e., 20,833 seedlings, as weed control is carried out chemically. In relation to cultivation operations, the Bresov protocol is based on the implementation of surface tillage carried out with rotary disc harrows and vibrocultivators to maintain a good soil structure and adequate organic matter content. In addition, contributing to good soil fertility are efficient crop rotations, also applied to control weeds. In the conventional method, instead, the soil is tilled by deep ploughing and then, before transplanting, other tillage is carried out such as milling and harrowing.

Table 1. Inputs used in innovative organic and conventional broccoli cultivation (*).

Input	Unit	Innovative Organic Broccoli	Conventional Broccoli
Plants	n./ha	41,000	20,833
Fertiliser NP (18–46)	kg/ha	-	400
Fertiliser NH_4NO_3	kg/ha	-	100
Organic fertiliser (pallet manure)	kg/ha	3500	-
Herbicides (Oxifluorfen)	kg/ha	-	0.12
Pesticide (Spinosad)	kg/ha	-	0.12
Organic pesticides: Copper Bacillus Thuringensis	 kg/ha kg/ha	 1 2	 - -
Organic compounds: mycorrhizal fungi and microorganisms	kg/ha	3.3	-
Diesel	L/ha	10.5	34.5
Water	m^3/ha	2493	9000

(*) Our elaboration.

With regard to the amount of water used, the innovative organic protocol provides for a significant reduction compared to the conventional method (Table 1). In the former, the reduced quantity stipulated in the protocol is due to the lower vegetative vigour of the plants, while in the latter, the higher quantity results from the greater amount of water used and the fertiliser distribution by fertigation. The innovative aspect of the Bresov protocol also translates into better water management, resulting in significant water savings. The same applies to the amount of fuel used, which is significantly higher in conventional cultivation due to more tillage before transplanting. Finally, the latter and harvesting practices are carried out manually by both farms surveyed.

2.2. Life Cycle Assessment

The ISO guidelines define LCA as an iterative process consisting of four steps: goal and scope definition, inventory analysis, impact assessment and interpretation [20]. It is a collection of data representing input flows (materials and energy) and output flows consisting of related emissions [32].

2.2.1. Goal and Scope Definition

The aim of the current research is the comparative evaluation of innovative organic and conventional broccoli growing, using the LCA methodology. It takes into account the processing and inputs used in the cultivation process. The dual objective of the study is therefore:

- The quantification of mass and energy inputs and outputs, considering the in-direct impact linked to the production of raw materials and the generation of energy sources;
- The assessment of environmental impacts in broccoli cultivation to highlight hot spots and suggest improvements.

The impact assessment was carried out with the Recipe midpoint method, developed through cooperation between RIVM (National Institute of Public Health and the Environment), Radboud University Nijmegen, Leiden University and PRé Sustainability [33]. The impact category indicators considered in the study were: global warming; stratospheric ozone depletion; ionizing radiation; ozone formation, human health; fine particulate matter formation; ozone formation, terrestrial ecosystems; terrestrial acidification; freshwater eutrophication; marine eutrophication; terrestrial ecotoxicity; freshwater ecotoxicity; marine ecotoxicity; human carcinogenic toxicity; human non-carcinogenic toxicity; land use; mineral resource scarcity; fossil resource scarcity; water consumption.

Another important concept in LCA is the functional unit, the unit of measurement to which all input and output data are referred [34]. Specifically, it was defined as 1 ha of cultivated area in order to study the ecological function of the cultivation process [35] and 1 kg of harvested product in order to study the production function. The comparison between organic and conventional methods is then carried out by means of a UF of land and a UF of mass.

With regard to the system boundaries (Figure 1), in accordance with ISO 14040:2006, these were set from cradle to farm gate. It includes preliminary tillage for field preparation, fertilisation, crop protection and herbicide application. Harvesting operations were left out of the system boundary as they were performed manually in both cases.

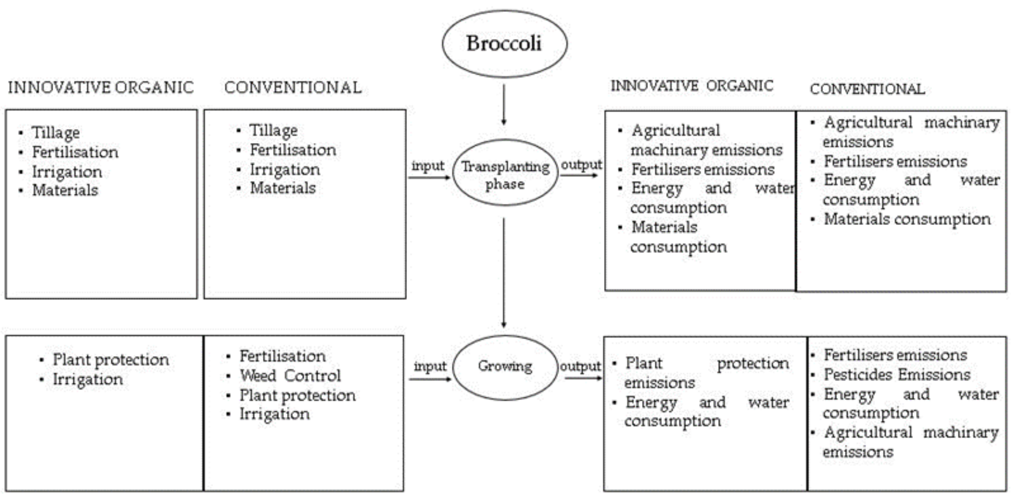

Figure 1. System boundary in the evaluation of broccoli LCA. (*). (*) Our elaboration.

2.2.2. Life Cycle Inventory

Assembling the inventory analysis involves collecting data on the entire production process. In this case, foreground data on field operations for broccoli production and background data on the production of fuels, pesticides, fertilisers and electricity generation were used. The first was collected directly in the field, while the latter were obtained from the Ecoinvent V 3.6 database, available on the SimaPro 9.1, software used for the analysis. Emissions from the distribution of fertilisers, pesticides and the use of all machinery were calculated according to the suggestions of Nemecek and Kägi [36]; while the Ecoinvent approach was used to calculate emissions from crop protection and weed control substances, in which "all pesticides applied for crop production were assumed to end up as emissions to the soil. The amounts of pesticides used as inputs were thus simultaneously calculated as outputs (emissions to agricultural soil). The substances specified in the inventories were used as references to correlate the corresponding emissions" [37]. In order to provide more information, Table 1 contains the quantities and units of all inputs used in the cultivation process of innovative organic and conventional broccoli.

2.2.3. Impact Assessment

Impact assessment involves quantifying potential environmental impacts through the selection of impact categories, indicators and characterisation models [37]. Life cycle impact assessment (LCIA) makes it possible to translate emissions into limited environmental impact scores. For this study, the impact method selected within the software is Recipe midpoint [33]. It consists of eighteen impact categories at midpoint level, which is a problem-oriented approach that translates the impacts into eighteen environmental themes [26] to highlight the damages associated with organic and conventional broccoli cultivation. Characterisation factors at midpoint level are located along the impact pathway, generally at the point after which the mechanism is the same for all environmental flows assigned to that impact category [38]. This provides a stronger relationship with environmental flows and a low level of uncertainty. The characteristic impact categories of the selected method and their results are shown in Table 2.

Table 2. Characterisation factors and environmental impact per hectare in innovative organic and conventional broccoli cultivation (*).

Impact Category	Unit	IOB	CB
Global warming	kg CO_2 eq	2187.77	8304.40
Stratospheric ozone depletion	kg CFC11 eq	0.00	0.13
Ionizing radiation	kBq Co-60 eq	54.03	249.92
Ozone formation, human health	kg NOx eq	2.82	16.85
Fine particulate matter formation	kg $PM_{2.5}$ eq	1.99	13.67
Ozone formation, terrestrial ecosystems	kg NOx eq	2.88	17.12
Terrestrial acidification	kg SO_2 eq	3.89	44.44
Freshwater eutrophication	kg P eq	0.34	2.19
Marine eutrophication	kg N eq	0.03	0.19
Terrestrial ecotoxicity	kg 1,4-DCB	6946.09	40,197.32
Freshwater ecotoxicity	kg 1,4-DCB	179.79	916.96
Marine ecotoxicity	kg 1,4-DCB	226.05	1160.19
Human carcinogenic toxicity	kg 1,4-DCB	37.02	199.92
Human non-carcinogenic toxicity	kg 1,4-DCB	1784.33	10,838.79
Land use	m^2a crop eq	366.22	280.45
Mineral resource scarcity	kg Cu eq	7.02	65.33
Fossil resource scarcity	kg oil eq	637.43	1599.60
Water consumption	m^3	2527.91	9973.59

(*) Our elaboration.

2.3. Economic Assessment Method

The purpose of the study is to provide a comparison between the economic evaluation of innovative organic and conventional methods. In this way, farmers can become aware of the competitiveness they can obtain on the market. In spite of the different methodologies used in the literature to calculate agricultural income, the definition of gross income was chosen in order to achieve prefixed objective [39].

Gross income (GI) is calculated according to the relation:

$$GI = GSPVC \tag{1}$$

where:

GSP = gross saleable production

VC = variable costs

GSP is obtained by multiplying the yield of each cultivation method by the selling price of the product, whereas VC are the sum of costs incurred for materials used in the cultivation process, labour and the share of materials with total wear and tear [40]. Input prices derive from direct surveys of raw material suppliers, while product prices refer to average quotations (weighted average of quantities and prices over the entire production cycle) provided by horticultural operators in the area of interest for both conventional and organic crops.

3. Results

3.1. Environmental Impacts of Innovative Organic and Conventional Broccoli

The results of the impact characterisation (Tables 2 and 3) refer to 1 hectare of cultivated area and 1 kg of broccoli, respectively, for the conventional cultivation process (CO) and innovative organic broccoli (IOB). These refer to the impact generated during the cultivation processes in which the inputs in Table 1 were used. The impact categories shown are grouped according to the protected area on which they have an adverse effect. Therefore, the characterisation factors: global warming; stratospheric ozone depletion; ionizing radiation; ozone formation; human health; fine particulate matter formation; human carcinogenic toxicity and human non-carcinogenic toxicity, refer to the human health protection area. The others relate to ecosystem damage; the global warming category falls into both protected areas because of the combined damage it causes to the environment and human health.

Starting from the global warming impact category, expressed in kg of CO_2 eq, the results show a reduction in impact of 74% per ha of cultivated area and 73% per kg of harvested broccoli in the innovative organic method compared to the conventional one. This demonstrates an advantage in the application of the former method in relation to rising temperatures and climate change. With regard to stratospheric ozone depletion, whose unit of measurement is kg CFC11 eq, the difference between the two cultivation methods is 100% for both FUs, again in favour of IOB cultivation. Concerning ionizing radiation and ozone formation, human health, the former expressed in kBq Co-60 eq and the latter in kg NOx eq, growing 1 ha of innovative organic broccoli has a 78% and 83% reduced impact, respectively, compared to conventional ones. For the mass unit, the results are also consistent, having the same percentages, confirming the double benefit for the environment and production. The same applies to the fine particulate matter formation category, expressed in kg $PM_{2.5}$ eq, where the IOB was less impactful than CB by just 85%, per ha of cultivated area and per kg of product. The organic regime again achieved an 83% impact reduction (for both FUs) compared to conventional in the category ozone formation, terrestrial ecosystems, measured in kg NOx eq. In the terrestrial acidification category, expressed in kg SO_2 eq, organic cultivation achieved an impact decrease of 91%, compared to CB, consistently for both ecological and production functions. The impact categories freshwater eutrophication, in kg P eq, and marine eutrophication, in kg N eq, accounted for 84% and 85% less environmental impact in innovative organic cultivation than conventional one per functional unit of area, while the impact reduction per kg of product is 84% in both categories. Moving on to the terrestrial ecotoxicity category, expressed in kg 1.4-DCB, 1 ha of IOB cultivation results in an environmental benefit characterised by an 83% reduced impact compared to the conventional method, whereas per kg of harvested broccoli, the impact reduction is 82%. The benefit of innovative organic is also confirmed in the categories: freshwater ecotoxicity, kg 1,4-DCB, and marine ecotoxicity, kg 1,4-DCB, where the impact reduction compared to conventional is 80% and 81% per ha of cultivated area and 80%, in both categories, per kg of broccoli. The other two impact categories belonging to the human health protection area, together with the first five analysed, are human carcinogenic toxicity and human non-carcinogenic toxicity, both expressed in kg 1,4-DCB, where IOB obtained a lower value than CB, 81% and 84% per ha and 81% and 83% per kg, respectively. Moving on to the land use category, whose unit of measurement is m^2a crop eq, the organic method showed a greater impact than the conventional method, with an increase in impact of 31% per ha of cultivated area and 33% per kg of harvested broccoli. IOB has also proven to be more sustainable in the mineral resource scarcity category, kg Cu eq, where the impact reduction compared to conventional is 89% in both FUs. The last two categories analysed: fossil resource scarcity, kg oil eq and water consumption, in m^3, showed a reduced impact in the organic case of 60% and 75% per ha and 60% and 74% per kg, respectively.

Table 3. Characterisation factors and environmental impact per kg of innovative organic and conventional broccoli harvested (*).

Impact Category	Unit	IOB	CB
Global warming	kg CO_2 eq	0.10672	0.39867
Stratospheric ozone depletion	kg CFC11 eq	0.00000	0.00001
Ionizing radiation	kBq Co-60 eq	0.00264	0.01200
Ozone formation, human health	kg NOx eq	0.00014	0.00081
Fine particulate matter formation	kg $PM_{2.5}$ eq	0.00010	0.00066
Ozone formation, terrestrial ecosystems	kg NOx eq	0.00014	0.00082
Terrestrial acidification	kg SO_2 eq	0.00019	0.00213
Freshwater eutrophication	kg P eq	0.00002	0.00010
Marine eutrophication	kg N eq	0.00000	0.00001
Terrestrial ecotoxicity	kg 1,4-DCB	0.33883	1.92978
Freshwater ecotoxicity	kg 1,4-DCB	0.00877	0.04402
Marine ecotoxicity	kg 1,4-DCB	0.01103	0.05570
Human carcinogenic toxicity	kg 1,4-DCB	0.00181	0.00960
Human non-carcinogenic toxicity	kg 1,4-DCB	0.08704	0.52035
Land use	m^2a crop eq	0.01786	0.01346
Mineral resource scarcity	kg Cu eq	0.00034	0.00314
Fossil resource scarcity	kg oil eq	0.03109	0.07679
Water consumption	m^3	0.12331	0.47881

(*) Our elaboration.

In order to provide an overview of the different impact categories considered, Figures 2 and 3 show graphs comparing innovative organic and conventional broccoli per ha of cultivated area and per kg of harvested broccoli.

3.2. Economic Results of Innovative Organic and Conventional Broccoli

Variable costs were determined by taking into account all the operations carried out by the surveyed farms, for the innovative organic and conventional methods. The activity level, expressed in h/ha (hours/hectare), is given in Table 3. It shows a high degree of variability between the two cultivation methods, in particular, the innovative organic process is characterised by 591.5 h/ha compared to 373.5 h/ha for the conventional one, with a higher effort in terms of time and labour of 218 h/ha for IOB. The main differences are attributable to the transplanting phase which requires 40 h/ha for IOB due to the double quantity of seedlings used; for weeding which in the organic method is completed manually and several times during the crop cycle amounting to 112 h/ha against 26 h/ha for CB; and for crop protection treatments which, being carried out with products permitted in organic farming, require a greater number of interventions than chemical ones, thus counting an effort of 18 h/ha per IOB. Regarding other operations such as tillage, fertilisation and irrigation IOB is characterised by a reduction in working hours compared to the conventional process, with the exception of harvesting which for the innovative organic method requires 400 h/ha due to the larger number of corymbs to be harvested which are smaller in size and often require more time to harvest.

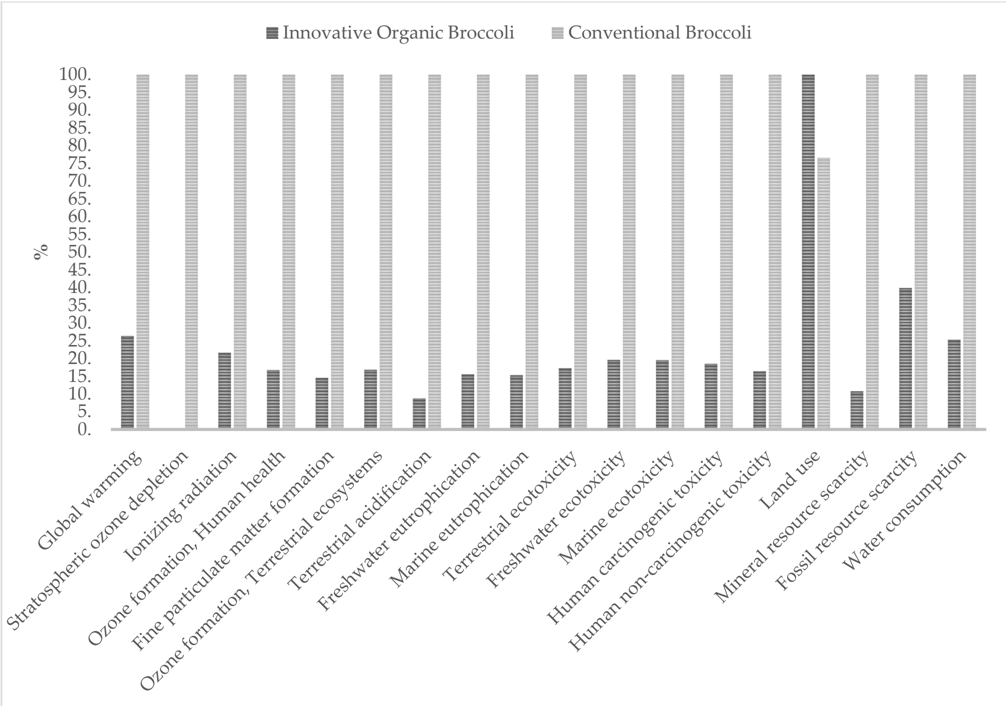

Figure 2. Impact comparison of innovative organic and conventional broccoli per ha of cultivated area (% of average value for each category). (Our elaboration on SimaPro 9.1 software).

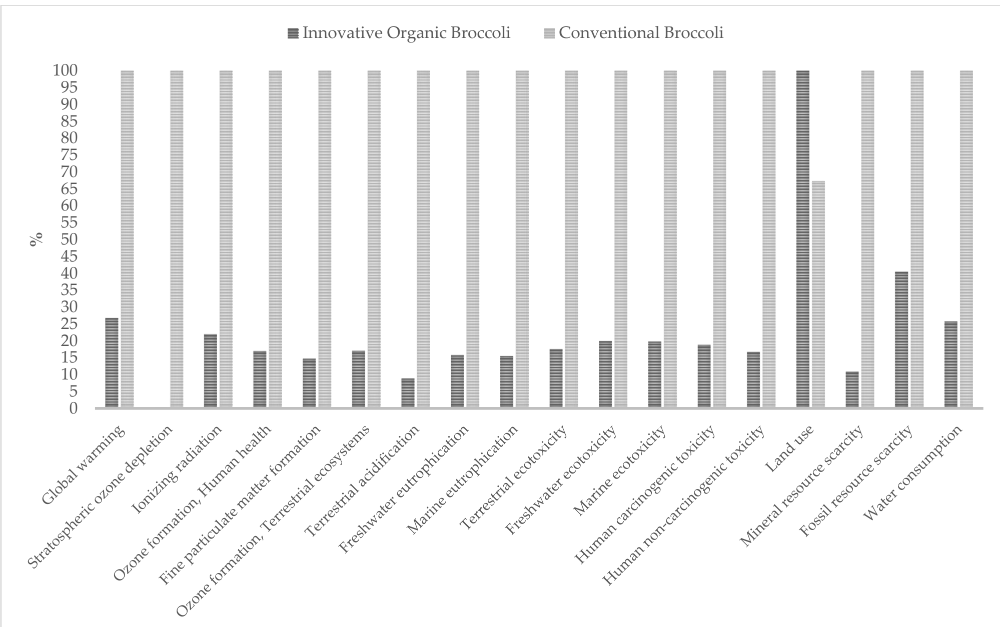

Figure 3. Impact comparison of innovative organic and conventional broccoli per kg of product (% of average value for each category). (Our elaboration on SimaPro 9.1 software).

Overall, variable costs for the innovative Bresov organic protocol and conventional methods (Table 4) amount to EUR 8894.15/ha and EUR 6958.86/ha, respectively, with a cost increase of 22% for the innovative organic method. Costs due to materials amount to EUR 3922.40/ha for IOB and EUR 3118.93/ha for CB and the increase for the innovative organic method is attributable to the purchase of broccoli seedlings to a greater extent and the higher cost of organic fertiliser and plant protection products. The category of labour and service costs for innovative organic broccoli cultivation amounts to EUR 4971.75/ha depending on the various degrees of activity and the weight of manual labour. For the conventional method, these costs are reduced by 27% compared to the previous case.

Table 4. The activity level of broccoli growing (*).

Activities	IOB (a)		CB (b)		Variations (a–b)	
	h/ha	%	h/ha	%	h/ha	%
Tillage	1.5	0.25	3.5	0.94	−2	−0.9
Transplanting	40	6.76	20	5.35	20	9.2
Fertilisation	2	0.34	8	2.14	−6	−2.8
Weeding	112	18.93	26	6.96	86	39.4
Pesticide treatments	18	3.04	6	1.61	12	5.5
Irrigation	18	3.04	30	8.03	−12	−5.5
Harvesting	400	67.62	280	74.97	120	55
Total	591.5	100	373.5	100	218	100

(*) Data collected through direct survey.

Table 5 shows the revenue analysis for the two cultivation methods analysed. The yields obtained vary from 20.50 t/ha for IOB to 20.83 for CB which, despite a lower number of plants per hectare, has a slightly higher yield due to the higher weight of corymbs obtained. Consequently, the gross saleable production is EUR 10250.00/ha for IOB and EUR 10415.00/ha for CB. Subtracting the variable costs from the gross production value gives the farmer's gross income (Table 6), which amounts to EUR 1355.85/ha for the innovative organic method and EUR 3456.14/ha for the conventional method. Overall, the economic analysis shows a reduction in profits for the innovative organic regime and an increase in production costs. This gap can easily be overcome by promoting organic products in the market, recognising them at a higher selling price than conventional ones and compensating for higher production costs against similar yields obtained [41].

Table 5. Variable costs of broccoli growing (*).

Indications	IOB (a)	CB (b)	Variation (a-b)	
	EUR/ha	EUR/ha	EUR/ha	%
Materials	**3922.40**	**3118.93**	**803.47**	**20**
Water	575.00	2083.00	−1508.00	−262
Plant	1107.00	562.49	544.51	49
Fertilisers	1820.00	418.00	1402.00	77
Pesticides	420.40	55.44	364.96	87
Others	196.12	155.95	40.17	20
Labour and services	**4971.75**	**3606.75**	**1365.00**	**27**
Cultivation-related operations	4735.00	3435.00	1300.00	27
Outsourcing service	236.75	171.75	65.00	27
Quotas and other attributes	**416.84**	**233.18**	**183.66**	**44**
Total average costs	**8894.15**	**6958.86**	**1935.29**	**22**

(*) Data collected through direct survey.

Table 6. Economic values of broccoli growing (*).

Indication	IOB (a)	CB (b)	Variation (a–b)
Yield (t/ha)	20.50	20.83	−0.33
Gross production value (EUR/ha)	10,250.00	10,415.00	−165.00
Variable costs (EUR/ha)	8894.15	6958.86	1935.29
Gross income (EUR/ha)	1355.85	3456.14	−2100.29

(*) Data collected through direct survey.

4. Discussion

The work aims to highlight the differences between the innovative organic cultivation method presented by the Bresov project and the conventional method for growing broccoli. The development of more efficient cultivation methods by researchers and policymakers requires data on the strengths and weaknesses of different agricultural systems [42]. Several studies have therefore focused on highlighting these differences with the LCA methodology. What emerges from the literature is that organic farming systems perform better in terms of energy input, which is mostly due to the elimination of synthetic fertilisers and pesticides [42,43]. Similarly, when it comes to pesticide emissions into surface and groundwater, better results were achieved in organic than in conventional methods due to the ban on artificial pesticides [42]. Soil biological activity is also improved by organic practices due to reduced erosive phenomena and increased organic matter content [44]. Studies in the literature, however, consider organic farming to be an inefficient system in terms of land use. Obtainable production yields are lower than those of conventional farming and this often requires the use of rotations with improving crops that are often not suitable for human consumption [45].

Scientific findings in the field of comparative LCAs between organic and conventional results support the results of our study. Application of the Bresov protocol allows moving towards more sustainable cultivation. The comparison between the environmental impacts of innovative organic and conventional production highlighted higher sustainability in IOB than in CB. In the cultivation process within the human health protection area, the analysed categories reported a reduced impact on organic cultivation, as shown in the results section. The highest impact of CB in all categories analysed is due to the growth phase of the plant, which in the global warming category produces a significant environmental load compared to IOB due to higher water consumption for irrigation and nitrate-based fertilisation. In the stratospheric ozone depletion category, conventional fertilisation also contributed to CB's impact and to making the innovative organic process more sustainable. Moving on to the ionizing radiation category, the higher consumption of water, and therefore electricity, to run the pump that powers the irrigation system meant that CB had a greater impact than the innovative organic protocol. The same was true in all other impact categories where the environmental burden is attributable to irrigation and mineral fertilisation. The innovative organic protocol, however, showed a greater impact than the conventional method within the land use category, due to the production process of the seedlings used for transplanting, which, being more numerous than in CB, require a larger quantity of inputs, in terms of a substrate for seedling growth and water used. In the above light of the eighteen categories analysed, a negative result on one indicator seems a good compromise, in order to reduce the environmental burden caused by broccoli cultivation, achieved by innovative organic protocol. All results obtained by performing the analysis per ha of cultivated area are also consistent for the FU represented by 1 kg of harvested broccoli. What the results show allows us to consider the Bresov protocol as a model of sustainability; in fact, it achieved a slightly lower yield (1.6%) in organic cultivation than in conventional one. This makes the innovative method an important scientific finding allowing us to affirm that the synergy of factors such as a greater investment of plants/ha, the use of pelletised manure, the application of natural pesticides, mycorrhizal fungi and micro-organisms makes it possible to obtain a product respectful of the environment and human health and at the same time with an appreciable yield. Since this is a scientific protocol, we hope to test it on other vegetable crops to verify its real beneficial effect on both the environment and yields.

The application of the organic method is often driven by choices based on "specific relationships with nature, technology and social relations" rather than economic profit [46]. From an economic point of view, organic farming has several interesting implications: although its operating costs are not significantly different from the conventional method, it is characterised by labour costs that are around 10% higher and profits reduced by 20–30% [42]. It becomes 25–35% more profitable when organic premiums are considered [43]. Combining it with premium prices also reduces the risks for farmers [47]. In Europe, premium price and Common Agricultural Policy (CAP) subsidies have significantly increased the profitability of organic farmers [48].

The data presented, although limited in terms of statistical significance, assume scientific relevance both for their comparability and for the fact they concern the preliminary results of scientific research based on the analysis of experimental fields within the Bresov project.

The economic analysis of conventional and organic broccoli cultivation did not take into account CAP premiums in order to show what the profits would be net of aid. From an economic point of view, broccoli cultivation is an important source of livelihood for the area in question. Since the innovative organic method has shown a reduction in gross income and an increase in variable costs, it would require differentiation of the selling price in order to overcome these negative aspects since it is able to offer the consumer a product that is both healthier and more environmentally friendly at the same time [49]. Combining the environmental benefits of IOB with the willingness to pay a premium price, on the part of the consumer who is increasingly aware of buying environmentally friendly and healthy products, highlights the ability of the innovation of the Bresov protocol to pursue greater sustainability for farms that choose to adopt it. Several studies have shown that organic products contain a low amount of residues, which guarantees the consumer's health [50,51].

Changing to more sustainable and profitable cultivation involves the application of new practices and the substitution of inputs used in less virtuous production processes. The advantageous results of IOB are primarily due to the replacement of mineral fertilisers, used in the conventional method, with manure pellets. In fact, the application of organic fertilisers reduces N20 emissions from the soil as well as those caused during the production of the fertiliser itself, as demonstrated by several studies on the topic [52]. Furthermore, abandoning herbicides and replacing them with manual weed control interventions reduces the load of pollutants in the environment and risks to human and animal health [17].

5. Conclusions

The identification of a sustainable agricultural model requires comparative studies between conventional and organic methods. The implementation of the innovative organic method, belonging to the Bresov protocol, to broccoli cultivation has shown that applying new practices can benefit the environment and human health. They refer to the use of more plants per ha, organic fertilisers, natural crop protection products and the application of organic compounds based on mycorrhizal fungi and microorganisms. In addition, the use of surface tillage results in reduced impact and fuel savings. The non-use of synthetic fertilisers, pesticides and herbicides, as well as the reduced use of water and diesel for the cultivation process, reduced the environmental impact of innovative organic farming. In addition to an undoubted advantage in environmental and health terms, the Bresov protocol also represents an opportunity for farmers to increase production yields, which are generally reduced in the case of organic farming. The economic analysis showed an increase in production costs and a reduction in profitability for farmers, gaps that can be filled by taking into account CAP subsidies and the premium price granted to the more sustainably produced product. The cultivation of broccoli in Sicily represents a source of livelihood for farmers, as one of the main vegetable crops on the island. The study, therefore, aims to promote the transition from conventional to innovative organic methods, benefiting the environment and farmers in terms of profitability.

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