horticulturae

Article

Sustainable Viticulture of Italian Grapevines: Environmental Evaluation and Societal Cost Estimation Using EU Farm Accountancy Data Network Data

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Abstract: Since the agriculture sector, such as Italian grapevine production, exert a pressure on the environment to some extent, this research aims to evaluate the environmental impacts and estimate the societal costs of four current grapevine production systems (i.e., vine grapes cultivated to produce common or quality wine using organic and non-organic agricultural practices), based on the Italian Farm Accountancy Network Data. For these purposes, the Life Cycle Analysis and Shadow Price techniques have been used. The results revealed that the levels of environmental impacts differed considerably between every cultivation system. Hence, the agricultural land occupation indicator induced the highest external costs, followed by climate change, terrestrial acidification, and freshwater eutrophication among the four grapevine cultivation systems. Accordingly, the assessment offers valuable insights into organic and non-organic viticulture practices to produce consistent and high-quality wine, as well as helping farmers make informed decisions that may improve environmental and societal impacts, leading to cost-effective management of their vineyards. We conclude that organic vineyard farming represents a promising sustainable viticulture production but is also important in exploring consumer perceptions and behavior towards this kind of grapevine production.

Keywords: Farm Accountancy Data Network; global warming; grapevine production; life cycle analysis; shadow price; sustainability costs; sustainable viticulture; vineyard management

Citation: Frem, M.; Petrontino, A.; Fucilli, V.; Sansiviero, C.; Bozzo, F. Sustainable Viticulture of Italian Grapevines: Environmental Evaluation and Societal Cost Estimation Using EU Farm Accountancy Data Network Data. *Horticulturae* **2023**, *9*, 1239. https://doi.org/10.3390/horticulturae9111239

Academic Editor: Nikolaus Merkt

Received: 12 October 2023
Revised: 6 November 2023
Accepted: 16 November 2023
Published: 17 November 2023

1. Introduction

1.1. Context and Importance

Grapevine production is an important sector in Italy, where it represents around 10% of the total production value of the Italian agricultural sector [1]. With an export market of around EUR 7 billion [2], Italy has the fourth-most significant vineyards in the European Union (EU) in terms of hectares (EU: 3,194,614 ha; Italy: 688,958 ha, representing 21.56% of the total EU area under vineyards) and holdings (EU: 3,194,614; Italy: 302,686, representing 13.58% of the EU vineyard holdings), in which the average area under grapevines is around 2.3 ha per holding [3]. Among the 20 Italian regions, Apulia (southern Italy) and Veneto (northern Italy) generate almost the highest production of grapevines (1.4 million tons), followed by Emilia-Romagna (0.8 million tons) and Sicily (0.7 million tons), as depicted in Figure 1.

On the one hand, Italian grapevine production exerts pressure on the environment to some extent, aiming to increase crop yield and profitability and contributing significantly to climate change, water and soil pollution, soil erosion, biodiversity loss, natural resource decline [4], such as land, water, fossil phosphorus, and energy, and the production of CO_2 emissions and waste [4,5]. Sustainability issues relevant for an agricultural sector, such as Italian grapevines, are economically competitive [6], ecologically sound, and socially acceptable [7]. When addressing these sustainability dimensions, it is crucial to comprehend which methodological tool(s) can be used to assess farm sustainability. In this direction, numerous studies have assessed this phenomenon by conducting field farmer surveys. Zham et al. [8], Dantsis et al. [9], and Marchand et al. [10] are only a few examples of survey applications. However, to assess farm sustainability for economic, social, and environmental issues, the EU Farm Accountancy Data Network (FADN) has been widely used [11].

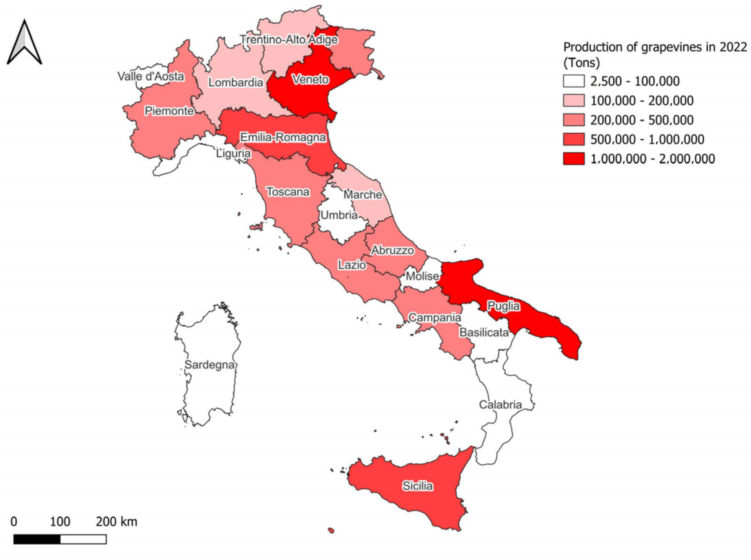

Figure 1. Production of grapevines among Italian regions in 2022. Source: Istat [1].

1.2. Review of the Farm Sustainability Assessment Based on FADN Data

In the last two decades, a great deal of studies have used the FADN data, as depicted in Table S1. To explore the trade-off between economic and environmental sustainability and the influence of dairy farming characteristics on this relation, Thomassen et al. [12], Jan et al. [13], and Van der Meulen et al. [14] have used FADN data in the Netherlands, Switzerland, and Germany, respectively. In their paper, Dolman et al. [7] explored the variation in sustainability performance among fattening pig farms in the Dutch FADN network to identify the characteristics of the best-performing farms. In 2014, the same authors quantified the economic viability, the societal acceptance, and the environmental performance of internal nutrient cycling dairy farming in the Netherlands and compared it with a benchmark (standard) group. Also, Smedzik-Ambrozy et al. [15] have used the FADN database to assess the direct payment (subsidies as drivers) on the economic and environmental sustainability performance of Polish farms. The aim of this paper was to develop representative environmental sustainability indicators (i.e., the use of nitrogen and phosphorus) as benchmarks for assessing their balance of inputs and outputs (in kg per ha) and use efficiency (in %) across a range of six livestock farming systems. As such, nutrient balances and use efficiencies were used as the main agronomic efficiency and environmental performance indicators to assess the performance of a farm and, consequently, to enhance improvement in nutrient management. In their research, Mastronardi et al. [16] elucidated the environmental performance of an Italian agritourism farm based on FADN data. Koloszko-Chomentowska et al. [17] assessed the environmental sustainability of family-owned holdings (field crops, dairy cattle, and mixed) using FADN data. In their study, Vitunskiene and Dabkiene [18] assessed the relative sustainability index of family farms based on 23 sustainability indicators, covering the three dimensions of sustainability. In addition, O'Donoghue et al. [19] undertook a pilot study to enhance understanding of the economic sustainability of European family farms through the measurement of viability and vulnerability levels among eight EU countries. Vrolijk et al. [20] suggested an extension of the scope of the FADN data collection with sustainability data by integrating further environmental and social issues or by creating a separate sustainability farm database. Further, Martino et al. [21] assessed the efficiency and sustainability of fertilization programs for wheat production in the Umbria region (Central Italy). Brenann et al. [22] demonstrated that measuring sustainability allowed for comparisons between farmers who use extension services and those who do not among eight EU countries. Basing their paper on the FADN network, Koloszko-Chomentowska and Zukovskis [23] explored the sustainability of organic farming versus conventional farming in Poland. Reidla and Nurmet [24] examined dairy farms' economic, social, and environmental dimensions of sustainability and compared them between the Baltic States using the FADN database. Martinho et al. [25] investigated economic, social, and environmental sustainability in farms of the European Union regions, in which a nonparametric analysis from a sustainable perspective (for the economic, social, and environmental dimensions) identified total production as the output and the labour, total assets (capital), fertilizers, crop protection consumption (environment), and the wages paid (social) as the inputs. Other sustainability assessment studies focused on the calculation and comparison of environmental impacts of current apple production practices based on FADN data [26], in which the impacts were compared between conventional, integrated, and organic producers and, when possible, converted into external costs. The research investigated whether the shift to integrated apple production is an improvement in terms of environmental impacts compared to conventional production. Bazzani et al. [27] simulated the abatement costs of CO_2 emissions over a short time horizon, considering different arable systems in Italy based on the Italian FADN database. To reflect the heterogeneity of farms in terms of GHG emissions, Balezentis et al. [28] estimated the eco-efficiency, shadow price, and marginal abatement costs of dairy farms in Lithuania based on the FADN data for 2015, 2017, and 2019, for which herd size, labour, feed costs, agricultural land, and capital were considered inputs, whereas milk production and greenhouse gas emissions were used as the desirable output and undesirable output, respectively; farm-specific emission parameters were also calculated.

1.3. Purpose, Justification, and Significance

In this instance, the present research was carried out to explore simultaneously the diversity in environmental and societal sustainability performances among Italian grapevine farming. Precisely, this research aimed to evaluate environmental impacts and estimate the societal costs of four current grapevine production systems (i.e., VCWNO: vine grapes cultivated for common wine production based on non-organic agricultural practices; VCWO: vine grapes cultivated for common wine production based on organic agricultural practices; VQWNO: vine grapes cultivated for quality wine production based on non-organic agricultural practices; VQWO: vine grapes cultivated for quality wine production based on organic agricultural practices), based on the FADN data. In other words, this study explored if the switch to an organic cultivation system would induce an improvement in terms of environmental impacts by addressing two interlinked research foci: (i) What are the environmental impacts of Italian vineyard farms on the concerned cultivation systems to produce wine? And (ii) what are the societal/external costs of these vineyard cultivation systems? By exploring these issues, this study contributes to the scientific literature in different ways. First, there is a paucity of research assessing vineyard cultivation systems over the whole of Italy, as supported by the literature review (Section 1.2). Second, the existing farm sustainability assessment has never been focused simultaneously on the environmental impacts and societal costs of vineyard cultivation systems for wine production. As such, the present paper is the first to explore the diversity and variation in environmental and societal performance among Italian vineyard farms. Third, the current farm sustainability assessment study is essential to support farmers' decisions for the development and promotion of appropriate sustainable vineyard systems and, consequently, enhance their environmental and societal performances and cost-effective management. Fourth, assessing environmental and societal farms' sustainability performances also has public implications in terms of supporting policy analyses, raising awareness among vineyard farms about sustainable production, and disseminating results to interested stakeholders in terms of the adoption of organic and/or non-organic agricultural practices at the farm level. For these purposes, we used a Life Cycle Analysis (LCA) that constitutes a methodological approach to calculate the environmental performances of such vine grape production, giving the farmers substantial insights to prosperously accomplish sustainability and cleaner production [29–31]. Moreover, we based our assessment on the Italian FADN data because they present the potential to (i) explore simultaneously the environmental impacts and societal costs of vineyard cultivation systems for a relatively large number of grapevine farms and (ii) use detailed and precise financial economic data collected annually by the "Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria" (CREA) on a large national sample of farms in Italy. Once the environmental impacts were calculated by the LCA, we used the shadow price technique [26,32] to convert them into monetary units, indicating the societal/external costs and, consequently, showing how the different Italian vineyard systems are currently performing. By selecting these two methods, we proceeded in a similar manner to Annaert et al. [26], who assessed the environmental impact of current apple cultivation practices in Flanders, Belgium, using the FADN data. The following section addresses how these two techniques were implemented in this study.

2. Materials and Methods

2.1. Environmental Sustainability Evaluation: LCA Methodology

We implemented here a well-established LCA method, as stated in the ISO 14040 and ISO 14044 standards [29,30,33–35], for which its implementation stages involved the following: (i) the goals and scope of the analysis (that includes the aims, functional/operational unit, frontier systems, and interpretation of data); (ii) an inventory of resource use and emissions; (iii) impact category evaluation; and (iv) the interpretation of data. Regarding the goals and scope statements, this study aimed to assess Italian vineyards with 4 cultivation systems, as described above, with the adoption of organic and non-organic agricultural practices at the farm level. Table 1 depicts the farm-level sustainability indicators of each cultivation system used in this research. The selection of vine grape crops was based on their relative economic importance in the Italian agricultural sector and their relative abundance in the twenty Italian regions.

Table 1. Farm-level sustainability indicators (data inputs) used in the LCA analysis (based on yearly average in the period of 2017–2021).

Variable	Unit	Description	
Irrigation	m^3/ha	Yearly average volume of water distributed	
Fertilizers (Inorganic and Organic)	kg/ha	Yearly average quantity of fertilizers, applied as ì	
		Conventional: inorganic fertilizer as N, P_2O_5, K_2O, manure, and compost.	Organic: organic, organo-mineral, manure, and compost
Phytosanitary products *	kg/ha	Yearly average quantity of pesticides sprayed as Insecticides (as 100% emissions in the soil) Fungicides (as 100% emissions in the soil) Herbicides (as 100% emissions in the soil) Other pesticides (as 100% emissions in the soil)	
Energy and fuel	kwh/ha	Yearly average volume of energy and fuel consumed (i.e., diesel and other fuels for tractors and other machinery)	

* Based on Nemecek and Schnetzer (p. 21, [31]), in which "all pesticides applied for crop production were assumed to end up as emissions to the soil".

The scenarios we explored involve the use of the following: (i) water (expressed in m^3/ha), (ii) fertilizers (in terms of inorganic and organic, expressed in kg/ha), (iii) phytosanitary products (in terms of pesticides, insecticides, and herbicides, expressed in kg/ha), energy (expressed in kwh/ha), and fuel (expressed in kwh/ha). In such scenarios, the functional unit used was the surface unit of 1 hectare of vine grapes. For each cultivation system, we analyzed data/variables (Table 1) related to the five most recent growing seasons (2017–2021) available in the data set. The final sample consisted of 14,825 farms, including 6024, 1373, 7259, and 1696 for VCWNO, VCWO, VQWNO, and VQWO grapevine farms, respectively. The classification into conventional or organic cultivation was carried out according to the Italian FADN monitoring unit, for which vine grape farms are classified as organic if they are organically certified according to European regulations. Moreover, we exclude young, unproductive vineyards younger than two years [35,36]. This was carried out to exclude the impact that non-productive plants may have on the results [26]. Furthermore, we used the functional surface unit (1 ha) instead of the product unit due to the heterogeneity the of cultivation system in terms of organic and non-organic cultural practices. Moreover, the boundary systems were limited to the production phase of vine grapes, as presented in Figure 2.

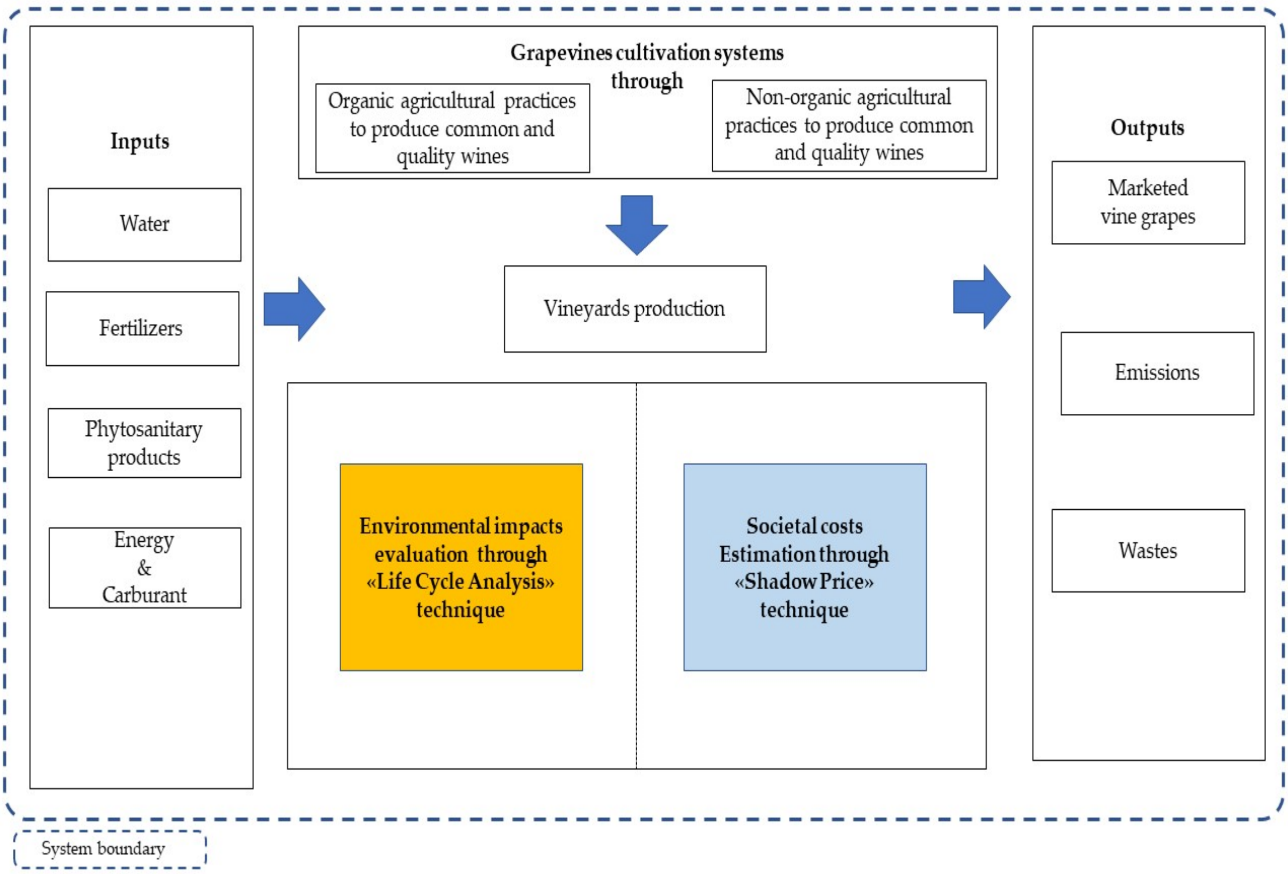

Figure 2. Overview of the categories of inputs and outputs that were considered in our grapevine cultivation system analysis.

With respect to the inventory of resources used and emissions, in the second stage of the LCA approach, we retrieved data categories and converted them into input (i.e., all emissions obtained from the environment) and output data (i.e., all emissions delivered into the environment) for each vine grape cultivation system in this second phase of the LCA, as depicted in Figure 2. Therefore, the inventory was initiated to gather data on the characteristics of water irrigation, organic and inorganic fertilizers, phytosanitary products, and energy and fuel (Table 1). Direct emissions related to the use of these inputs were estimated and modeled based on Open LCA software using the Eco-invent 3.7.1 database. In terms of the impact category evaluation, the third stage of the LCA approach, we converted the data inputs (Table 1) of each vine grape cultivation system into environmental impacts into a limited number of indicator scores at two hierarchical levels, 17 midpoint indicators and 3 endpoint indicators, based on the ReCiPe Midpoint Hierarchist method [37–40], as depicted in Table 2.

Table 2. ReCiPe midpoint and endpoint indicators used in the LCA analysis.

Midpoint Indicator	Unit	Endpoint Indicator
Agricultural land occupation—ALOP	m^2	Ecosystem quality
Climate change—GWP100	kg CO_2-Eq	
Freshwater ecotoxicity—FETPinf	kg 1,4-DCB-Eq	
Freshwater eutrophication—FEP	kg P-Eq	
Marine ecotoxicity—METPinf	kg 1,4-DCB-Eq	
Natural land transformation—NLTP	m^2	
Terrestrial acidification—TAP100	kg SO_2-Eq	
Terrestrial ecotoxicity—TETPinf	kg 1,4-DCB-Eq	
Urban land occupation—ULOP	m^2	
Human toxicity—HTPinf	kg 1,4-DCB-Eq	
Ionizing radiation—IRP_HE	kg U235-Eq	
Ozone depletion—ODPinf	kg CFC-11-Eq	
Particulate matter formation—PMFP	kg PM10-Eq	
Photochemical oxidant formation—POFP	kg NMVOC	
Fossil depletion—FDP	kg oil-Eq	Resources
Metal depletion—MDP	kg Fe-Eq	

2.2. Societal Costs Estimation: Shadow Price Methodology

To quantify the societal costs of the four concerned vine grape productions, a wide range of monetization references exist for almost all the environmental impacts, but these vary largely in terms of geographical scale, location, and time. In this direction, we assessed the organic and non-organic cultivation systems from a societal point of view through the estimation of the costs of the most relevant impact categories that aligned with our contextual research, such as agricultural land occupation (expressed in EUR per m^2), climate change (expressed in EUR per emission of kg CO_2-Eq), terrestrial acidification potential (expressed in EUR per emission of kg SO_2-Eq), and freshwater eutrophication potential (expressed in EUR per emission of kg P-Eq), based on the shadow price method (De Bryun et al. 2010) and as set out in the study by Annaert et al. in 2017, as depicted in Table 3.

Table 3. Shadow prices used in the societal cost estimation.

Impact Category	Shadow Price
Agricultural land occupation—ALOP	EUR 0.48 per m^2
Climate change—GWP100	EUR 0.402 per kg CO_2-Eq
Terrestrial acidification—TAP100	EUR 0.237 per kg SO_2-Eq
Freshwater eutrophication—FEP	EUR 0.60 per kg oil-Eq

Source: based on and Annaert et al. [26] and De Bryun et al. 2010 [32].

3. Results

3.1. Inputs Used and Outputs among Vineyards

Table 4 depicts the yearly average amount of agricultural inputs that were used to produce vine grapes among the four concerned cultivation systems. As such, organic vine grape farmers used, on average per year, the lowest amount of water to irrigate their vineyards for quality wine production. As expected, the conventional farmers applied, on average, the highest quantity of mineral fertilizers in terms of azote (312 kg/ha), phosphorous (236 kg/ha), and potassium (213 kg/ha) to produce vine grapes for common wine production. However, the VCWO had lowest results, except for phosphorous. Regarding the use of pesticides, the results revealed that the VQWO farmers applied the relatively highest dose of pesticides at around 34 kg/ha compared to the other three vine grape production systems, and they also used a relative high volume of fungicides on their vineyards. This result may appear to be abnormal and surprising because they have environmental restrictions on the use of phytosanitary products in organic vineyards. Concerning the use of fuel and energy, the results showed that the organic farmers used more energy and fuel than the non-organic ones, for which the highest average fuel was found for the VQWO production system at 1019 Kwh/ha.

Table 4. Inputs used among the considered vineyard cultivation systems (based on yearly average in the period of 2017–2021).

Variable	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Irrigation	m^3/ha	1016	974	631	609
Fertilizers:					
Inorganic as N, P_2O_5, K_2O	kg/ha	760	-	483	-
Organic		-	626	-	388
Organo-mineral		-	108	-	138
Compost		17	88	22	105
Swine manure		29	630	54	133
Cattle manure		72	413	544	711
Poultry manure		0.01	0.42	3	20
Phytosanitary products:					
Pesticides	kg/ha	14.48	17.02	27.23	33.69
Insecticides (50% emissions in the soil)		0.60	1.07	5.10	5.40
Fungicides (50% emissions in the soil)		5.75	6.94	7.59	10.92
Herbicides (50% emissions in the soil)		0.49	0.17	0.50	0.20
Other pesticides (50% emissions in the soil)		0.39	0.32	0.43	0.33
Energy and fuel	Kwh/ha	858	873	742	1019
Yield	Tons/ha	12.47	10.20	10.64	9.27
Farmers	Number	6024	1373	7259	1696
	%	40.63	9.26	48.96	1.13

Source: Italian FADN [41].

In terms of output, the VQWO has, on average per year, the lowest yield of around 9 Tons/ha compared to a yield of 12.5 Tons/ha for the VCWO and almost 11 Tons/ha for the VQWNO cultivation systems.

3.2. Environmental Sustainability Impacts: LCA Results

The environmental impacts associated with the VCWNO, VCWO, VQWNO, and VQWO, expressed by one hectare as a functional unit and to the production of 10 tons of vine grapes, are shown in Tables 5 and 6, respectively. As such, the levels of environmental impacts differed considerably between every cultivation system. The adoption of organic cultural practices to produce common wine induced an overall potential reduction impact for all the environmental categories across the four modes of grapevine production, except for water depletion, for which the VQWO mode of production generated the lowest environmental impact.

Table 5. Environmental impacts per hectare among the considered vineyard cultivation systems.

Receipe Midpoint Indicator	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Agricultural land occupation—ALOP	m^2 per year	10,198.40	10,117.30	10,157.50	10,144.30
Climate change—GWP100	kg CO2-Eq	3383.41	1282.81	2464.45	1630.70
Fossil depletion—FDP	kg oil-Eq	1342.10	422.11	963.86	540.42
Freshwater ecotoxicity—FETPinf	kg 1,4-DCB-Eq	151.45	52.64	107.53	62.48
Freshwater eutrophication—FEP	kg P-Eq	0.92	0.34	0.71	0.47
Human toxicity—HTPinf	kg 1,4-DCB-Eq	926.12	382.37	715.88	516.21
Ionising radiation—IRP_HE	kg U235-Eq	306.88	92.93	230.11	122.01
Marine ecotoxicity—METPinf	kg 1,4-DCB-Eq	124.09	45.27	88.02	53.07
Marine eutrophication—MEP	kg N-Eq	5.46	2.85	4.33	3.54
Metal depletion—MDP	kg Fe-Eq	335.69	123.75	248.86	158.89
Natural land transformation—NLTP	m^2	0.95	0.30	0.67	0.36
Ozone depletion—ODPinf	kg CFC-11-Eq	0.00	0.00	0.00	0.00
Particulate matter formation—PMFP	kg PM10-Eq	7.57	3.48	5.80	4.32
Photochemical oxidant formation—POFP	kg NMVOC	12.88	7.85	10.36	9.39
Terrestrial acidification—TAP100	kg SO2-Eq	20.27	7.37	15.29	9.73
Terrestrial ecotoxicity—TETPinf	kg 1,4-DCB-Eq	0.83	0.22	0.61	0.31
Urban land occupation—ULOP	m^2 per year	138.97	33.68	95.74	40.86
Water depletion—WDP	m^3	1030.18	978.54	640.54	613.55

Table 6. Environmental impacts per 10 Tons among the considered vineyards cultivation systems.

Receipe Midpoint Indicator	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Agricultural land occupation—ALOP	m^2 per year	81,795	99,200	95,423	109,480
Climate change—GWP100	kg CO2-Eq	27,136	12,578	23,152	17,599
Fossil depletion—FDP	kg oil-Eq	10,764	4139	9055	5832
Freshwater ecotoxicity—FETPinf	kg 1,4-DCB-Eq	1215	0.516	1010	0.674
Freshwater eutrophication—FEP	kg P-Eq	0.007	0.003	0.007	0.005
Human toxicity—HTPinf	kg 1,4-DCB-Eq	7428	3749	6725	5571
Ionising radiation—IRP_HE	kg U235-Eq	2461	0.911	2162	1317
Marine ecotoxicity—METPinf	kg 1,4-DCB-Eq	0.995	0.444	0.827	0.573
Marine eutrophication—MEP	kg N-Eq	0.044	0.028	0.041	0,038
Metal depletion—MDP	kg Fe-Eq	2692	1213	2338	1715
Natural land transformation—NLTP	m^2	0.008	0.003	0.006	0.004
Ozone depletion—ODPinf	kg CFC-11-Eq	0.000005	0.000004	0.000007	0.000008
Particulate matter formation—PMFP	kg PM10-Eq	0.061	0.034	0.055	0.047
Photochemical oxidant formation—POFP	kg NMVOC	0.103	0.077	0.097	0.101
Terrestrial acidification—TAP100	kg SO2-Eq	0.163	0.072	0.144	0.105
Terrestrial ecotoxicity—TETPinf	kg 1,4-DCB-Eq	0.007	0.002	0.006	0.003
Urban land occupation—ULOP	m^2 per year	1115	0.330	0.899	0.441
Water depletion—WDP	m^3	8262	9595	6017	6622

Moreover, among these cultivation systems, agricultural organic practices, having a relative low use of chemical pesticides and fertilizers, showed a relatively low decrease in environmental impacts for all the concerned indicators, as depicted in Table 7. In addition,

Figure 3 revealed the aggregation of the midpoint indicators in three impact categories (ecosystem quality, human health, and resources) expressed in points among the four vine grape cultivation systems. In this direction, the overall environmental impacts were 782, 518, 670, and 560 for VCWNO, VCWO, VQWNO, and VQWO, respectively. Further, the total environmental impact on ecosystem quality was the main category contributor and widely different from the rest of the two other environmental categories: human health and resources. With respect to each indicator category's implications, the main endpoint contributors were agricultural land occupation, climate change, and fossil depletion for the ecosystem quality, human health, and resources impact categories, respectively.

Table 7. Midpoint environmental impacts per hectare among the considered vineyard cultivation systems.

Receipe Midpoint Indicator	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Ecosystem quality—agricultural land occupation	points	366.66	363.96	365.26	364.93
Ecosystem quality—climate change	points	59.27	22.48	43.18	28.57
Ecosystem quality—freshwater ecotoxicity	points	0.07	0.02	0.05	0.03
Ecosystem quality—freshwater eutrophication	points	0.09	0.03	0.07	0.05
Ecosystem quality—marine ecotoxicity	points	0.01	0.00	0.01	0.01
Ecosystem quality—natural land transformation	points	3.03	1.13	2.15	1.36
Ecosystem quality—terrestrial acidification	points	0.26	0.09	0.20	0.12
Ecosystem quality—terrestrial ecotoxicity	points	0.27	0.07	0.20	0.10
Ecosystem quality—urban land occupation	points	6.36	1.54	4.38	1.87
Human health—climate chnage, human health	points	93.78	35.56	68.31	45.21
Human health—human toxicity		12.67	5.23	9.80	7.07
Human health—ionising radiation	points	0.10	0.03	0.07	0.04
Human health—ozone depletion	points	0.04	0.03	0.05	0.05
Human health—particulate matter formation—PMFP	points	39.80	18.31	30.64	22.89
Human health—photochemical oxidant formation	points	1.91	0.87	1.80	1.47
Resources—fossil depletion	points	160.94	50.62	115.58	64.80
Resources—metal depletion	points	36.55	18.06	27.91	21.65

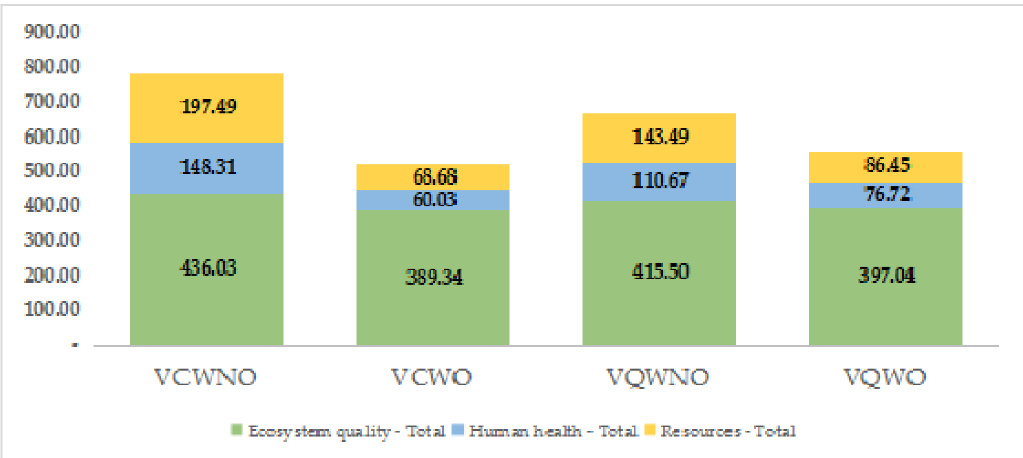

Figure 3. Endpoint environmental impacts per hectare among the considered vineyard cultivation systems.

3.3. External Costs Estimation: Shadow Price Results

The monetary conversion of the four environmental impact indicators into the societal costs associated with the VCWNO, VCWO, VQWNO, and VQWO, expressed by one hectare as a functional unit, is shown in Table 8. As a result, the ALOP induced the highest external costs, followed by GWP100, TAP100, and FEP among the four grapevine cultivation systems. Further, the conventional farmers (VCWNO and VQWNO), as expected, had a higher societal cost and a higher gross margin (Table 9) compared to the organic vineyard farmers (VCWO and VQWO), mainly due to higher yields per hectare (Table 4).

Table 8. Societal costs per hectare among the considered vineyard cultivation systems.

Receipe Midpoint Indicator	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Agricultural land occupation—ALOP	EUR per m^2	4895.23	4856.30	4875.60	4869.26
Climate change—GWP100	EUR per kg CO_2-Eq	1360.13	515.69	990.71	655.54
Terrestrial acidification—TAP100	EUR per kg SO_2-Eq	4.80	1.75	3.62	2.31
Freshwater eutrophication—FEP	EUR per kg P-Eq	0.55	0.20	0.43	0.28
Total	Per 1 ha	6260.72	5373.94	5870.36	5527.39

Table 9. Yearly average yields and costs per hectare associated to the considered vineyard cultivation systems.

Parameter	Unit	Vineyard Cultivation System			
		VCWNO	VCWO	VQWNO	VQWO
Yield	Tons/ha	12.47	10.20	10.64	9.27
Total gross production	EUR/ha	5389	4846	8432	7055
Variable costs	EUR/ha	1286	1106	1606	1615
Labor costs	EUR/ha	3142	3074	3591	3350
Machine labor costs	EUR/ha	2320	2462	2426	2261
Operative margin	EUR/ha	−1359	−1797	6827	5440
Gross margin	EUR/ha	4104	3704	809	−172

4. Discussion

This research aimed to calculate and compare the environmental impacts of four current grapevine production systems, based on Italian FADN data. In this direction, different cultural practices could be assessed for many farms. Grapevine input data on irrigation, fertilizers, phytosanitary products, energy, and fuel, as well as output data in terms of yields, were involved in this research to underline the variation in environmental sustainability performances and societal costs among Italian grapevine farming through the LCA and shadow price techniques, respectively. Therefore, grapevine agricultural practices induce an important impact on the environment.

In this study, due to the reduction in use associated with the cycle of grapevine production (Table 1), VCWO and VQWO were found to induce relatively low societal costs towards the four most relevant indicator categories: ALOP, GWP100, TAP100, and FEP (Table 7). In addition, organic cultural practices require (i) less consumption of groundwater that is not easily renewed, (ii) less use of chemical fertilizers, and (iii) less use of chemical pesticides. In contrast, the results reveal that the organic model requires relatively more fuel and energy for agricultural machinery to ensure a thermal regime for the planting and cultivation periods. Also, it attenuates the potential direct toxicity to ecosystem quality, human health, mainly for vineyards workers consumers, and resources.

Consequently, there are good opportunities to reduce external environmental costs by adopting an organic cultivation system. In contrast, the societal costs for ALOP were relatively high compared to the non-organic models. This is obvious, considering that organic viticulture requires a higher planting density. But the latter is considered useful to produce quality wine of high sanitary quality. Further, the moderate difference between common and quality wine does not induce a significant variation in external costs. In other words, the LCA results per functional unit of 1 ha revealed that the conversion from conventional to organic grapevine production may induce an improvement in the societal environmental dimension of sustainability, and this is in line with the findings of other research for which LCA has been greatly applied to assess the effects of viticulture on the environment and assist in implementing private and public strategies to improve the environmental performances of grapes during their entire life cycle.

In this context, Ferrari et al. [35], Costanti and Barbetti [42], Smyth and Russel [43], Vazquez-Rowe et al. [44], Fusi et al. [45], Lamastra et al. [46], and Morelli et al. [47] are only a few relevant examples of LCA application to grapes, vine grapes, and wine production. In this context, to analyse the environmental performances of Spanish grape production for vinification, Vazquez-Rowe et al. [44] used a joint approach (LCA + DEA, known as Data Envelopment Analysis) that seemed more appropriate because it allowed grape vine farming to be better evaluated. Fusi et al. [45] quantified the environmental impacts of the wine life cycle stages (i.e., from vine planting to the final disposal of the glass bottle) in Sardinia (southern Italy), for which they demonstrated that the glass bottle production, the vine planting, and the grape production in terms of diesel fuel consumption contributed to a greater burden of environmental risk.

Previous research has also applied an LCA to assess the impacts of grape equality on the environmental profile of an Italina vineyard [35], for which the environmental emissions were mainly raised by the use of fertilizers and pesticides and agricultural land occupation. Further, Franco et al. [48] explored the environmental sustainability of wine production in Viterbo (central Italy), for which they demonstrated that the grape production stage was not sustainable. Other Italian studies focused on soil management (i.e., soil tillage, cover cropping, mulching with plant residues) as a tool for increasing sustainability in grape vine production [49]. Morelli et al. [47] revealed that organic management in a vineyard in northeast Italy constitutes a promising agricultural strategy for reducing the impact of viticulture on the environment. Perria et al. [50] provided evidence of the importance of the green trapes plant production strategy adopted in organic viticulture, inducing a low downy mildew pressure and, consequently, less phytosanitary treatments based on cupric products that may negatively affect the edaphic biodiversity of the soil. Consequently, viticulture farmers are encouraged to improve their conventional cultivation production techniques through the implementation of sustainable cultural practices, considering the environmental implications and societal costs of such best practices.

Moreover, different types of fertilizers and phytosanitary products (i.e., organic and non-organic) are applied by farmers, for which there is a lack of information on the period, frequency, and modes of application in the FADN data. This constrains the use of advanced life cycle assessment methods such PestLCI in our study. In addition, the FADN does not provide sufficient environmental and suitable social indicators (Dolman et al. 2012). As a result, this study does not assess social sustainability in terms of per surface unit function (i.e., hectare yield) per multiple viticulture planting systems in Italy.

In addition, well-known Italian geographical indications (i.e., PDO/Protected Designation of Origin and PGI/Protected Geographical Indications) are showing a growing production of wines with innovative production characteristics that go beyond the traditional standards. In this direction, the emergence of labels with claims like "artisanal wines", the use of indigenous yeasts harvested from the grapes, the presence of independent winemakers, and the production of orange wine are breathing new life into the industry. Accordingly, these innovations add a unique dimension to wine and lead to exceptional economic results. This is particularly true when such productions are organically certified, as there is a growing demand from consumers for sustainable products. Furthermore, looking at the results of common grapes for organic wine, the article emphasizes that these new practices can contribute to reducing the environmental impact of the wine industry, even in cases where wines do not fall under the PDO and PGI categories. This demonstrates how innovation and sustainability can go hand in hand, opening new opportunities for producers.

5. Conclusions

These evaluations have provided important information about organic and non-organic viticulture practices to produce common and quality wine, which is helpful for supporting farmers' decisions and, consequently, enhancing their environmental and societal performances and cost-effective management. Further investigations of these cultivation systems under different dimensions of economic and social viticulture sustainability are needed to constitute a promising source of knowledge and to set up strategies soon to better promote an appropriate sustainable vineyard system. Sustainability in grapevine production depends on several indicators. The results show that a high variability exists among vineyards cultivation systems in Italy. Our findings suggest that organic vineyard farming represents a promising and sustainable approach to viticulture production, but it is also important to explore consumer perceptions and behaviors towards sustainable and eco-friendly viticulture practices, and this will merit attention in the future to fully explore and assess this. Furthermore, the results explored here underassess the three dimensions of sustainability (economic, social, and environmental). Indeed, the findings represent a fraction of the sustainability evaluation of Italian grapevine cultivation systems. In other words, the important limits of this study include its assessment of the environmental dimension and the use of a monetization approach that covers certain impact categories while emitting the social impacts of the concerned cultivation systems. The main reason for these limitations is related to the fact that the FADN does not provide sufficient, suitable, or a wide range of social and environmental indicators, no certain technical data such as the active ingredients of the pesticides. Consequently, future research with more specific field surveys could be carried out to generate the requested information, and this would fully assess the sustainability of Italian wine grape cultivation systems.

Supplementary Materials: The following supporting information can be downloaded at https://www.mdpi.com/article/10.3390/horticulturae9111239/s1, Table S1: Literature review of the farm sustainability assessment based on FADN data.

Author Contributions: Conceptualization, M.F. and A.P.; methodology, M.F., A.P. and F.B.; software, A.P.; validation, V.F.; formal analysis, M.F. and A.P.; investigation, A.P. and M.F.; resources, F.B.; data curation, V.F.; writing—original draft preparation, M.F.; writing—review and editing, A.P.; visualization, A.P. and C.S.; supervision, V.F. and F.B.; project administration, F.B.; funding acquisition, V.F. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Data supporting reported results can be provided upon request.

Acknowledgments: Thanks are due to Enza Campanella for her administrative support and to Luca Cesaro, Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA), for sharing the concerned FADN-RICA data.

Conflicts of Interest: The authors declare no conflict of interest.

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