sustainability

MDPI

Article

Continuous Improvement of VIVA-Certified Wines: Analysis and Perspective of Greenhouse Gas Emissions

Nicola Casolani [1], Emilio Chiodo [2,*] and Lolita Liberatore [1]

[1] Department of Economic Studies, University "G. d'Annunzio" of Chieti-Pescara, Viale Pindaro 42, 65127 Pescara, Italy
[2] Department of Bioscience and Technology for Food, Agriculture and Environment, University of Teramo, Via Balzarini 1, 64100 Teramo, Italy
* Correspondence: echiodo@unite.it; Tel.: +39-0861-266898

Abstract: The agri-food sector is one of the major contributors of Greenhouse Gas (GHG) emissions responsible for global climate change. The suitability of world areas for viticulture is evolving due to climate change, with new challenges linked to the sustainability of production. Viticulture and the wine sector in general are, at the same time, impactful sectors associated with negative environmental externalities. The VIVA certification program is focused on the sustainability performance of the vine–wine supply chain in Italy. It comprehends four scientific indicators, called "Air", "Water", "Vineyard", and "Territory". The Air indicator expresses the impact that the production of a specific wine and / or the company activities have on climate change. This paper analyzes and compares GHG emissions of 45 wines certified VIVA 2.0 (or the subsequent 2.1 update). Results showed that the most impactful phase is the bottling phase (average values of 0.58 kg CO_2-eq/bottle), which accounts for 41.1% of total emissions, followed by the industrial phase (about 19.9%). The total values of GHG emissions for each wine profile ranged between 0.81 and 2.52 kg CO_2-eq/bottle. A coefficient of performances of GHG emissions was calculated to show the weak phase for each wine, a useful tool with a view to continuous improvement.

Keywords: wine sustainability; VIVA certification; greenhouse gas emissions; life-cycle thinking

check for updates

Citation: Casolani, N.; Chiodo, E.; Liberatore, L. Continuous Improvement of VIVA-Certified Wines: Analysis and Perspective of Greenhouse Gas Emissions. *Sustainability* **2023**, *15*, 2349. https://doi.org/10.3390/su15032349

Academic Editors: Barbara Campisi, Gianluigi Gallenti and Federico Nassivera

Received: 8 November 2022
Revised: 20 January 2023
Accepted: 23 January 2023
Published: 27 January 2023

1. Introduction

Sustainable agricultural and food processing are considered effective strategies to adapt the food system to climate change and mitigate its effects [1]. Agriculture, Forestry and Other Land Use (AFOLU) sectors are prominent contributors of GHG emissions that cause global climate change, accounting for around a quarter of global emissions [2]. At the same time, climate change is directly affecting the agricultural sector, and viticulture production is one of the most challenged, due to the need to combine grape quality and grapevine cultivar adaptation [3].

Viticulture is a relevant agricultural activity that covers about 7,3 million of hectares worldwide; vineyard cultivation has gradually gone beyond the traditional producing areas and concerns a wide range of Northern and Southern hemisphere countries (including China, India, and Brazil) [4]. Suitability for viticulture is changing due to climate change, and potential new areas (i.e., Northern Europe countries) are becoming appropriate for viticulture [1], while traditional producing areas—such as the Mediterranean areas—are threatened by global warming because of reduced rainfall, intensification of extreme weather phenomena, rise in temperatures, and heat shocks [3,5,6].

Although so dependent on the quality of the environment, viticulture and, in general, the wine sector is, at the same time, an impactful sector, associated with many environmental issues [7] which provoke negative externalities to the environment [8], for example, through the intensive use of pesticide and other chemicals [9].

The awareness of the environmental impact of viticulture and wine production has increased over the last years, together with consumers' consciousness and institutional attention. Even though there is not a unique conclusion in the literature about consumer propensity to buy sustainable wines, especially when there is a trade-off with organoleptic or sensory aspects [8,10,11], it is worth noting that sustainability issues play an important role in consumers' buying choices [12], and a growing demand for products with environmental certification in the years ahead can be expected [13,14].

An increasing number of producers are oriented towards sustainable viticulture and perceive the implementation of sustainability strategies as a competitive advantage [15]. The reasons can be different: as a means of market differentiation; to increase the management and organizational efficiency [16,17]; for personal environmental consciousness and responsibility [18–20]; and to leave the company in better condition for future generations [21].

The certification of sustainable practices is gaining ever-increasing importance to guarantee the environmental and social engagement of wine companies, used as a marketing and a communication tool [16,18]. Furthermore, the communication of sustainable products through carbon footprint labels is a factor that is positively associated with consumers' willingness to pay [22]. In this wider context, special attention should be paid to the environmental aspects of sustainability and to the calculation of GHG emissions [23].

2. Literature Review

Numerous programs have been proposed at national or regional level for the certification of sustainable practices. They highlight different tools (guidelines, indicators, labels, protocols), methodologies (self-assessment, third-party validation, third-party certification), boundaries (the product, the company, the whole chain), and different aspects of sustainability, such as environmental, social, and economic issues.

On the one hand, the presence of different criteria can represent a way of adapting to the different territorial specificities and emphasizing specific aims. On the other hand, this aspect represents a weak point in communication towards stakeholders and in the general path of the sector towards sustainability. A unique and comparable approach could reduce the information asymmetry and improve the effectiveness of the communication [8,18,19,24].

Various papers carried out an observation of different methodologies and tried to identify common ground able to allow an easier comparison among the companies' results. Flores [16] proposes an analysis of certification schemes in six wine producing countries mainly of the new wine world (South Africa, New Zealand, Australia, Chile, USA, France), classified on the basis of, among others, the presence of guidelines, indicators, or parameters. Merli et al. [8] analyze numerous sustainability programs in the new world (USA, New Zealand, South Africa, Chile) and in Europe (France, Germany, Austria, Spain). Corbo et al. [18] and Merli et al. [8] compare different programs in the Italian wine sector concerning issues on sustainability.

The International Organisation of Vine and Wine (OIV) produced the "General principles of sustainable vitiviniculture-environmental-social-economic and cultural aspects" (Resolution OIV-CST 518-2016) [25], in which, in the framework of the broader concept of sustainability, environmental aspects, namely, the protection of soils, water, air, biodiversity, and landscapes, are considered.

If the social, economic, and cultural aspects of sustainability are still underconsidered [16], there seems to be a wider consensus on the environmental aspects, which are of major interest for climate-change mitigation. The calculation of GHG emissions, in this context, gains the highest importance.

The food system is estimated to be responsible for one-third of total global GHG emissions, with three quarters generated at the farm gate or in pre- and post-production activities [26]. In the agri-food field, the wine sector is one of the major contributors to global greenhouse gas emissions [13,27] and consequently to climate change and global warming [28,29]. Therefore, it is very important to study tools that allow quantification of climate-altering emissions in viticulture and enology [23,30,31].

The International Organization for Standardization (ISO) produced standard methodologies for the calculation of GHG emissions based on the Life-Cycle Assessment (LCA) approach: ISO 14067:2018 (Greenhouse gases–CF of Products–Requirements and guidelines for quantification); ISO 14044:2006 (Environmental management–Life cycle assessment–Principles and framework); and ISO 14026:2017 (Environmental Labels and declarations–Principles, requirements and guidelines for communication of footprint information).

The "General principles of the OIV greenhouse gas accounting protocol (GHGAP) for the vine and wine sector" (Resolution OIV-CST 431-2011) are guidelines based on ISO standards and other international protocols, aiming at providing the specifications proper to the vine and wine sector [32]. The OIV provides a consistent method for identifying areas of emission reductions associated with vine and wine firms' activities [33].

Carbon Footprint (CF) is a generally accepted indicator of GHG emissions for measuring the impact of human activities in terms of quantity of greenhouse gases produced, expressed as "units of carbon dioxide equivalent (CO_2-eq)" [34–36]. In detail, this indicator is useful to understand the contribution to the Global Warming Potential (GWP), the total amount of CO_2 and the other greenhouse gases coming from the product's life cycle.

Typical inputs that have an impact on GHG emissions coming from wine production are: soil preparation, fertilization, application of phytosanitary products, fuel/electricity for agricultural activities, harvesting of grapes, and their transportation to the winery; electricity required in the wine-making process, storage, and refrigeration; the production of glass bottles, bottle closers, and other packaging materials; and the distribution of wines in the market [37–41].

CF ratings of wine production have only appeared in recent years. Several studies have been published [42–46], but the comparison of the results is hindered by the different methodological approaches used [23].

Due to different calculation procedures and diversity in the results, efforts have been made to increase the consistency of the methodologies, and the LCA approach has become the most complete and used approach [7,8].

LCA has proved to be a suitable method to analyze the environmental impacts of the different life-cycle stages of wine [8,47], because of its holism and comprehensiveness. Although CF represents a partial aspect of the more complex and comprehensive LCA approach, it has been accepted as a valid indicator for communicating the LCA environmental results because of its focus on causes of global warming and its capacity to be representative of wider environmental impacts [13]. CF is thus assumed as a basic element in the LCA methodology for the calculation of GHG emissions.

However, some elements remain under discussion, such as the system boundaries of the LCA methodology to be applied in the analysis (from "cradle to gate" to a "cradle to grave" approach) [13], the use of generic information versus the use of site-specific information [48], as well as the aspect of the high variation in the CF results, even under the same methodological assumptions [49].

The four major steps usually identified in wine production for the CF calculation are viticulture, wine making, distribution, and bottle disposal [50].

Ponstein et al. [51], in a study conducted in Germany, found that 19% of emissions related to wine production came from grape production, while 81% related to wine-making (industrial phase), were mainly related to packaging materials (57%). Litskas et al. [52], in a French study of 38 wine-producing companies in Bordeaux, show higher impacts (more than double) related to the use of fuel comparing with the management of pesticides and fertilizers. Soil fertilization practices provide for the administration of nitrogen, phosphorus, potassium, and other microelements (Mg, Fe, Bo, Zn, Cu), in order to guarantee production levels adequate to the needs of the winery based on the characteristics of the soil; fertilization represents a very important phase in terms of GHG emissions [53].

Ferrara and De Feo [54], in their literature review on the applications of LCA in the wine sector, showed that the CF values of red and white wine are very similar.

Italy plays an important role concerning sustainable viticulture. In 2014, the Wine Sustainability Forum was launched and 15 major projects for sustainability were identified and analyzed [55], emphasizing environmental sustainability indicators, emissions of greenhouse gases, and the use of LCA [8]. However, a database regarding inventory data in the wine sector is missing or limited to the Italian context [56].

Nowadays, two standards seem to attract higher attention at national level, namely, the Equalitas standard for environmental, economic, and social certification of the wine chain, promoted by Federdoc (the National Federation of the Consortia for the protection of designation of origin in the wine sector) in 2015, and the VIVA standard "Sustainability in viticulture in Italy", launched by the Italian Ministry of the Environment for measuring the sustainability performance of the vine–wine chain in 2011.

Both programs are based, for the environmental aspects of sustainability, on the LCA methodologies defined by international standards. The Equalitas calculation of the CF of a product (CFP) is based on the principles and requirements of UNI EN ISO 14064-1:2019 (Greenhouse gases-Part 1: Specification with guidance at the organization level for quantification and reporting of greenhouse gas emissions and removals) and UNI EN ISO 14067:2018 [57].

The VIVA program aims to assess sustainability in its three dimensions, environmental, economic, and social [18]. It applies to the vine–wine supply chain a series of indicators based on international standards and guidelines [23,58]. The certification is based on four indicators: Air (climate footprint), Water (water footprint), Vineyard (impact of agronomic management practices), and Territory (socio–economic–cultural impact). The Air indicator, based on the disciplinary VIVA, follows the line of ISO 14067:2018 and ISO 14044:2006 [59].

D'Ammaro et al. [23], in a recent study, analyzed the main factors that contribute to the CFP of 33 Italian wines certified by VIVA and compared and evaluated the results obtained. The CFP indicator is used for the quantification of GHG emissions and removals using the LCA approach.

3. Materials and Methods

The sample is represented by 45 VIVA 2.0/2.1-certified Italian wines produced by a winery on the date 23 February 2022 (the full list of the products is detailed in Appendix A, Table A1). The VIVA methodology framework for the Air indicator was reported by D'Ammaro et al. [23].

In this study, GHG emissions are referred to as the results of the Air indicator of VIVA-certified companies. For each wine that obtained the VIVA certification, the reports relating to the Air indicator were downloaded and the values related to GHG emissions were analyzed. The reports are publicly available on the official VIVA website (https://viticolturasostenibile.org/, accessed on 23 February 2022) and contain information such as wine typology (sparkling, red, white), wine category (the designation of origin, if present), company name, region of production, the amount of CO_2 equivalent emissions per bottle for each phase (agricultural, industrial, bottling, distribution, and disposal), and the name of the organization which approved the certification after the audit.

The calculation of GHG emissions for the Air indicator takes into account various inputs, such as: consumptions of pesticides, herbicides, organic, and synthetic fertilizers in vineyards; combustion of fossil fuels; electricity consumption; farming practices; consumption of materials in the industrial phase (e.g., enzymes and other auxiliary materials); packaging; and waste transport and treatment (for a more detailed description, see: Merli et al.; D'Ammaro et al.) [8,23].

All the following phases in the VIVA framework have been considered:

- Agricultural phase, concerning all the work conducted in the field including pruning, harvesting, treatments, irrigation, and fertilization.
- Industrial phase, which includes all operations in industrial phases.

- Bottling phase, which deals with bottling, labeling, corks, pallets, and more (packaging).
- Distribution phase of the products, which includes transport.
- Disposal phase, where the greenhouse gases emitted after consumption were evaluated.

Given the fact that all the wines are certified under the VIVA framework, we can assume that all the parameters that have been analyzed are fully comparable among the different products. The functional unit refers to a 0.75 L bottle of wine.

Figure 1 represents the geographic location of the sample; most of the wines are located in Tuscany (13) and in Emilia-Romagna (9) regions.

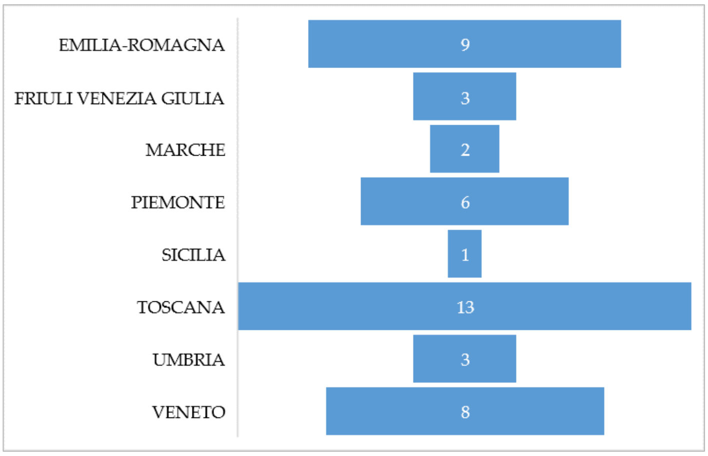

Figure 1. Geographic location of the wines sample (Italian regions).

A general explorative analysis of all certified VIVA wines (e.g., mean, standard deviation, variance) was performed.

Nearest Neighbor Analysis [60] was applied to the GHG emission values in the production phases (all phases excluding distribution and disposal) of VIVA-certified wines with the aim of understanding if the spatial distribution of wines grouped for typology (red, white, sparkling) reveals differences.

Then, data dispersion was calculated through the coefficient of variation (CV) [61]. CV was performed for GHG emissions considering the values of all phases of all wines. It was calculated as the ratio of the standard deviation to the mean. The aim was to understand the data variability for each wine profile.

Finally, a performance coefficient (PC) was calculated for each phase considering the GHG emissions of each wine profile, as follows:

$$\text{PC} = \text{GHG emission values of wine}_n \text{ in phase}_a / \text{average value of GHG emissions of all wines in phase}_a \quad (1)$$

Here, wine_n indicates each wine profile, and phase_a indicates the phase evaluated (e.g., vineyard industry, packaging, distribution, disposal). PC was also rendered as a heat map, useful for understanding whether, for each wine profile, the performance was better/worse than the mean values of all the certified wines.

4. Results and Discussion

Table 1 shows the analysis of the data of GHG emissions at different stages of production. With regard to the vineyard phase, the average value of GHG emissions is 0.25 kg CO_2-eq/bottle; this phase is characterized by a high range of values (0.05–0.80 kg CO_2-eq/bottle). In this stage, various inputs contribute to GHG emissions, such as the fossil fuel consumption of machinery in field operations [39,45], as well as the use of fertilizers and pesticides [40,62,63]. Ferrara and De Feo [54] showed that these factors contribute to various degrees depending on the studies considered and the type of input. In viticultural activities, they report that the use of fertilizers gives a contribution ranging from 30 to 85%

in terms of CF and fuel consumption from 20 to 40%. Furthermore, environmental impacts are largely influenced by the geographical location of production [64,65], especially in the vine-growing sector, which is a field strongly correlated with pedo-climatic conditions that also have an influence on the use of fertilizers and pesticides, both inputs affecting the CF [30,41].

Table 1. GHG emissions of VIVA 2.0/2.1-certified wines in different stages of production (kg CO_2-eq/bottle).

Phases	Range	Minimum	Maximum	Mean	Std. Deviation	Variance
Agricultural	0.75	0.05	0.80	0.25	0.18	0.03
Industrial	1.00	0.03	1.03	0.28	0.20	0.04
Bottling	0.64	0.30	0.94	0.58	0.12	0.02
Distribution	0.51	0.01	0.52	0.26	0.14	0.02
Disposal	0.10	0.00	0.10	0.04	0.03	0.00
All phases	1.71	0.81	2.52	1.41	0.33	0.11

In industrial production, the values are slightly higher than in the agricultural phase (0.28 kg CO_2-eq/bottle) and the standard deviation is the highest (0.20).

The bottling phase is the most impactful, with average values around 0.58 kg CO_2-eq/bottle; furthermore, the standard deviation has lower values than the vineyard and industrial phases, which means a lower variability in the data. The distribution and disposal phase have mean values of 0.26 kg CO_2-eq/bottle and 0.04 kg CO_2-eq/bottle.

The average value for the entire vine–wine life cycle (sum of GHG emissions of all phases) is 1.41 kg CO_2-eq/bottle; this result aligns with the main international studies. Tsalidis et al. [66] analyzed CF of red and white wine production located in South European countries; the results showed that the CF ranged between 1.02 and 1.62 CO_2-eq for a bottle of wine.

Scrucca et al. [67] reported the results related to typical Italian wineries and show a CF between 0.9 and 2.0 kg CO_2-eq/bottle. Litskas et al. [52], in 20 vineyards in Cyprus, found an average CF of 1.31 kg CO_2-eq/bottle, while Benedetto [39] reported a value of CF of 1.64 kg CO_2-eq/bottle for a typical Sardinian white wine in her study.

The average impact of each phase on the total in terms of GHGs is reported in Figure 2. The disposal phase is the least impactful phase (2.6%), while the most impactful is represented by the bottling phase (41.1%).

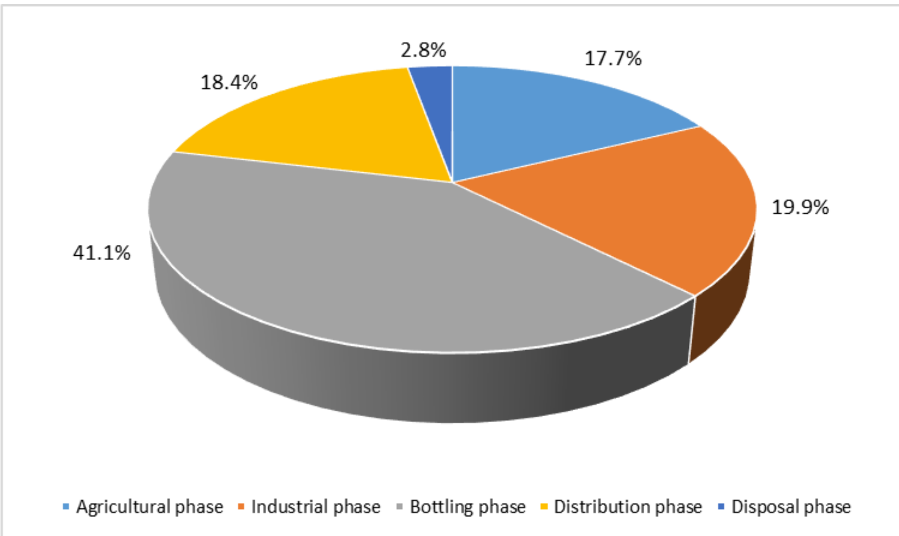

Figure 2. Average impact of each phase on total in terms of GHGs.

These results align with previous studies in which packaging was found to be very impactful in the wine chain [41,42,49,51,68]. Amienyo et al. [27] highlighted the importance of recycled glass content in bottles as a strategy to reduce GWP.

In Figure 3, the distributions of GHG emission values in the different phases are reported. The frequency distributions of values highlight the variability of GHG emissions in each phase. The variability of the profiles in the whole process seems to be normally distributed (see Figure 3, letter F), contrary to the frequency distributions in some different production stages. In the agricultural phase, values equal to or greater than 0.6 kg CO_2-eq/bottle are infrequent (6.7%). In this phase, the values ranged around 0.10–0.21 kg CO_2-eq/bottle in 40% of cases. The lower average impact of the agricultural phase is the result of the presence of a high number of very-low-impact wineries. In this phase, pesticide, fertilizers, and fossil fuels are the important contributors to carbon emissions [30,47,54].

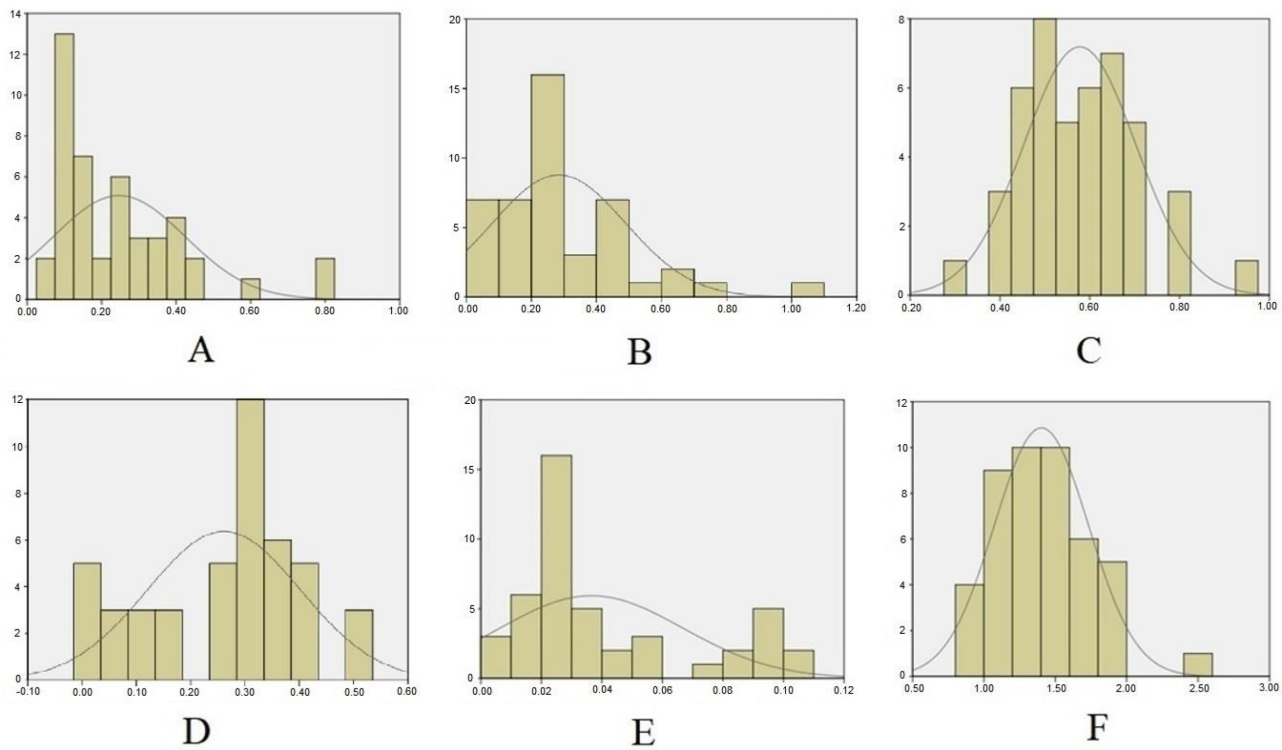

Figure 3. Distribution of wine profiles per GHG emissions values (kg CO_2-eq/bottle) in different stages of production (**A**) = agricultural phase; (**B**) = industrial phase; (**C**) = bottling phase; (**D**) = distribution phase; (**E**) = disposal phase; (**F**) = total.

On the contrary, in the bottling phase, most companies are distributed around the average. However, even in the bottling stage there are cases of more virtuous companies, given that the lowest value is less than one-third compared to the highest value (values between 0.30 and 0.94 kg CO_2-eq/bottle). The glass bottle weight gives an important contribution to GHG emissions and represents a critical factor for intervention [41,69,70]. For example, the use of 32% lighter bottles can reduce GHG emissions per bottle of wine by 14% [23].

In the industrial phase, 35.5% of the sample ranged between 0.20 and 0.29 kg CO_2-eq/bottle, while 33.3% of values in the bottling phase cover the interval 0.51–0.61 kg CO_2-eq/bottle. The results in this phase are influenced by wine typology and the specific production cycle [43,44,51].

Finally, 62% of the values in the distribution phase ranged between 0.27 and 0.40 kg CO_2-eq/bottle and 51.1% cover the interval 0.02–0.04 kg CO_2-eq/bottle in the disposal phase.

Nearest Neighbor Analysis (Table 2) was applied to the production phases (vineyard, industry, bottling phases). The results (presented in Figure 4) show that the distribution of GHG emission values over the three dimensions cannot be classified according to the type of wine (red, white, sparkling) and, consequently, they do not represent a functional criterion of distinction among groups.

Table 2. Case-Processing Summary of Nearest Neighbor Analysis.

		N°	Percent
Sample	Training	36	80%
	Holdout	9	20%
Valid		45	100%
Excluded		8	
Total		53	

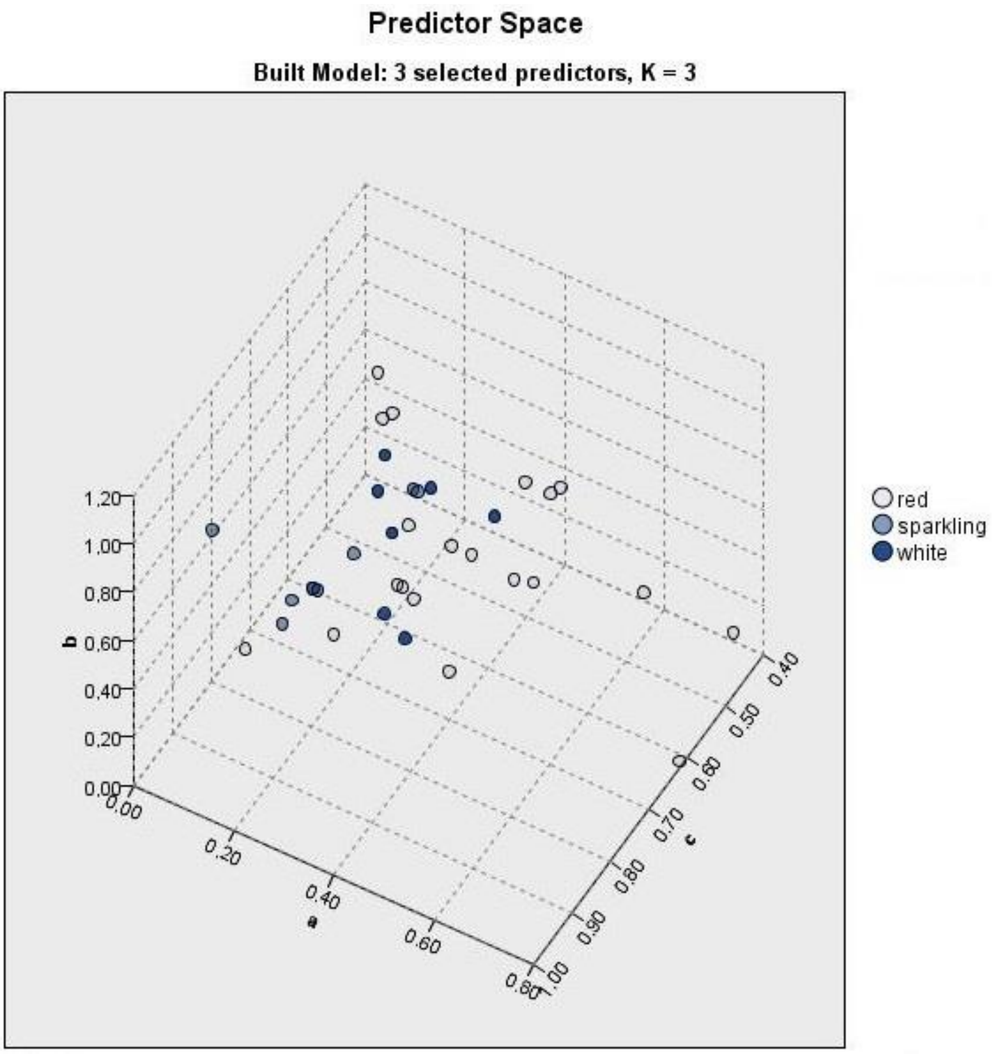

Figure 4. Nearest Neighbor Analysis of GHG emissions (kg CO_2-eq/bottle) considering production phases (vineyard, industry, bottling phases) for red, white, and sparkling wine.

In Figure 5, the CV and the total GHG emissions of all the different wine profiles are reported, while a heat map (Table 3) shows the PC in the different phases for each profile.

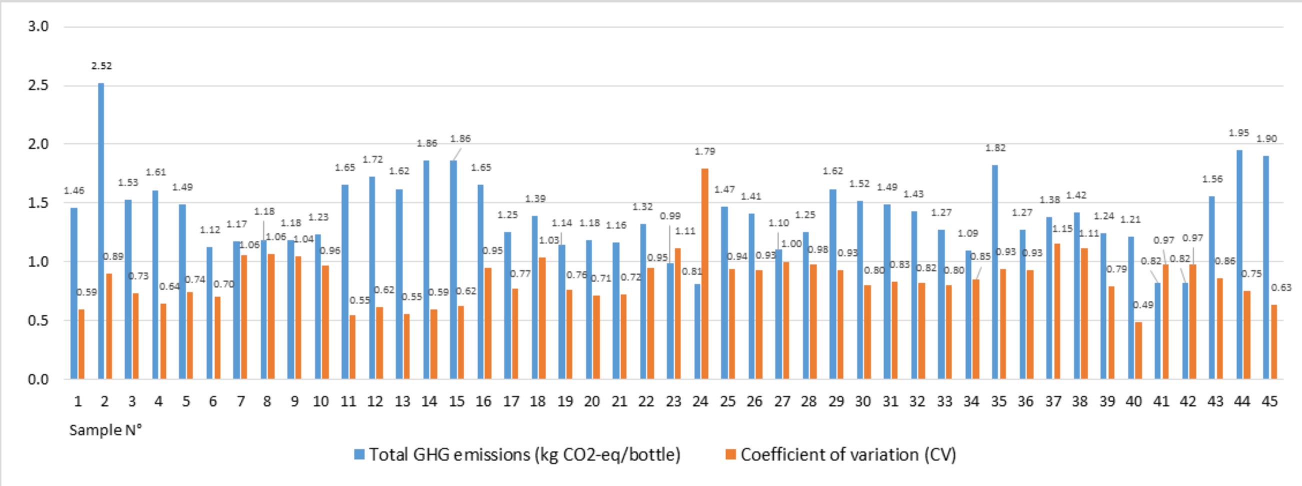

Figure 5. CV and total GHG emissions for each wine profile.

Table 3. Heat map on PC of GHG emissions for each wine profile in each phase.

Wine Profile N°	Agricultural Phase	Industrial Phase	Bottling Phase	Distribution Phase	Disposal Phase
1	0.85	0.97	1.16	1.07	2.46
2	0.45	1.63	3.62	1.30	2.74
3	1.01	1.11	1.02	1.22	0.55
4	1.17	1.13	1.02	1.22	1.92
5	1.05	1.11	1.02	1.07	0.55
6	0.69	0.78	0.74	1.03	0.55
7	0.32	1.11	0.42	1.19	0.82
8	0.32	1.11	0.42	1.15	0.82
9	0.36	1.11	0.42	1.19	0.82
10	0.81	1.06	0.21	1.22	0.82
11	1.66	0.78	1.44	1.42	0.27
12	1.29	1.02	1.44	1.49	0.27
13	1.46	0.78	1.44	1.53	0.27
14	1.46	1.02	1.44	1.88	0.27
15	1.58	1.14	1.44	1.49	0.27
16	1.50	1.42	0.32	1.38	0.55
17	0.45	0.88	0.95	1.30	0.55
18	1.62	1.21	0.70	0.27	0.00
19	0.49	0.81	0.81	1.11	0.55
20	0.65	0.81	0.81	1.11	0.55
21	0.61	0.81	0.81	1.11	0.55
22	1.13	1.00	1.48	0.04	0.55
23	0.69	0.95	0.84	0.04	0.55
24	0.20	1.18	0.11	0.08	0.82
25	0.40	1.25	0.91	1.38	0.55
26	0.40	1.18	0.91	1.22	0.55
27	0.40	0.97	0.39	1.11	0.55
28	0.57	0.92	1.72	0.11	1.37
29	0.45	0.88	2.67	0.54	2.46
30	0.49	0.88	2.18	0.69	2.46
31	0.57	0.88	2.18	0.50	2.46
32	0.49	0.88	2.04	0.54	2.46
33	1.74	0.99	1.16	0.42	0.05
34	1.74	0.90	0.74	0.42	0.05
35	3.24	1.07	0.10	1.07	2.19
36	1.01	1.07	0.09	1.07	2.19
37	0.36	1.37	0.35	1.49	0.55
38	0.24	1.37	0.60	1.45	0.55
39	1.62	0.71	1.20	0.11	1.09
40	0.97	0.52	0.95	1.26	1.09
41	1.05	0.69	0.25	0.15	1.37
42	1.05	0.69	0.25	0.15	1.37
43	0.65	1.19	0.39	1.91	2.74
44	3.24	0.83	0.91	1.49	0.27
45	2.51	0.83	0.91	1.99	0.55

The total values of GHG emissions for each wine profile ranged between 0.81 and 2.52 kg CO_2-eq/bottle, while the CV ranged in the interval 0.49–1.79. This expresses the data variability for each wine profile, revealing those with higher levels (e.g., N° 2, 44, 45).

The heat map shows that some wine profiles (i.e., profiles N° 28, 29, 30, 31, 32 in Table 3) present values that are higher than average (equal to 1) for some phases (vineyard, industry, distribution phases) but not for others (bottling and disposal phases). Only wine profile N° 23 presents values less than 1 for all the phases, which means under the mean value, while only the wine profile N° 4 has values more than 1 for all the phases. The other wine profiles present values of GHG emissions higher than the average for some phases, while lower for others.

In this context, performances are evaluated by comparing the results among wine profiles. Each wine profile is associated with a type of wine produced by a winery in a particular geographical context. Strategies of GHG emissions reduction need to consider these specificities in line with the principle of continuous improvement of the environmental management standards [71].

While the presented tools constitute a first explorative analysis, further internal analysis by each firm is needed to understand the best strategies for carbon emission reduction and to establish the margins of intervention on the various stages of production, considering the specific structure/assets of the company. Strategies aiming at reducing carbon emissions comprehend lowering inputs in vineyard management and optimizing the winemaking and transportation processes. Fertilization, application of phytosanitary products, fuel/electricity for agricultural machinery, and harvesting of grapes and their transportation represent inputs that should be take into account for GHG emission reduction in the viticulture phase. Electricity required for wine production, storage and refrigeration, yeasts and enzymes, wine additives and oenological products, and waste management and sanitation products are the inputs that impact on carbon emissions in the industrial phase, as well glass wine bottles, closures, packaging, and storing materials [37–41,47].

These environmental management strategies should be considered in strict balance with economic issues [72]. Rugani et al. [13] estimate a worldwide impact of the wine sector on CF of 0.3% of human activities. Consequently, strategies for reducing companies' carbon emissions seem to play an important role in agri-food system sustainability.

5. Conclusions

The wine sector is characterized by a variety of approaches aimed at improving sustainability. VIVA is the Italian sustainability program that has been analyzed in this study referring to GHG emission reduction, described by the Air indicator. VIVA certification represents, at the same time, both a tool for determining environmental performance and a marketing tool, performing the important function of communicating the companies' environmental and socio–economic achievements to consumers. In this view, the continuous reduction in gas emissions constitutes a real marketing advantage for the companies that improve their performance.

In this study, the variability in GHG emissions of different wines was analyzed for each wine profile that adheres to VIVA certification, and statistical tools for monitoring performances were applied. If the results presented by the scientific literature show relevant discrepancies due to the different methodologies adopted, the results of this study are fully comparable because the products belong to the same certification scheme. The comparison, both at phase and at company levels, allows identification of the most impactful phases and the relative position of each company in the whole producing process and in each specific phase.

The methodological framework of this study constitutes a starting point for a benchmarking strategy of wine companies aimed at evaluating and reducing their carbon emissions. Within the perspective of strategic business management, wine firms can acquire a competitive advantage towards competitors by reducing carbon emissions in the critical phases.

Considering the more general aspects, the analysis highlighted the higher impact of some production stages on the whole process, which consequently need priority political and institutional interventions. In general, GHG emissions differ considerably according to the production phase and the most impactful, on average, is by far the bottling one. Consequently, the examination of the mitigation potential of bottle weight reduction, and glass bottle reuse or recycling, should deserve special attention from wine producers and their collective organizations.

Agricultural and industrial transformation phases, which have similar impact values and similar data variability, comprehend various inputs that are relevant for GHG emissions. In a benchmarking perspective, an analysis of the best management practices could be useful for a reduction in carbon emissions, mainly for the profiles with higher impact.

The strategies for reducing carbon emissions need to be applied "tailor-made", considering the company's structure and the real possibility of improvement, but also taking into consideration economic sustainability.

The analysis of GHG emissions confirms great variability in the results, even within the same certification scheme. This element, in turn, calls for a great opportunity of improvement in many companies. Furthermore, the company that reduces carbon emissions could take advantage by an appropriate communication activity within the certification scheme.

Definitively, these methodological frameworks could stimulate a virtuous competitive environment within companies which adhere to VIVA, adding value to the certification scheme, and could be extended to similar networks, creating the conditions for the improvement of the sustainability of the whole production system.

Author Contributions: Conceptualization, E.C., L.L. and N.C.; methodology, L.L. and N.C.; formal analysis, E.C., L.L. and N.C.; investigation, L.L. and N.C.; data curation, L.L. and N.C.; writing—original draft preparation, E.C. and N.C.; writing—review and editing, E.C., L.L. and N.C. All authors have read and agreed to the published version of the manuscript.

Funding: This research received no external funding.

Data Availability Statement: The data presented in this study are available upon request from the corresponding author.

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

Appendix A

Table A1. Profiles of VIVA-certified wines.

Wine Profile N°	Type of Wine	Classification *	Region
1	RED	DOCG	PIEMONTE
2	SPARKLING	DOCG	PIEMONTE
3	RED	DOCG	TOSCANA
4	RED	DOCG	TOSCANA
5	RED	DOC	TOSCANA
6	WHITE	IGT	TOSCANA
7	SPARKLING	DOC	EMILIA-ROMAGNA
8	SPARKLING	DOC	EMILIA-ROMAGNA
9	SPARKLING	DOC	EMILIA-ROMAGNA
10	WHITE	DOC	FRIULI VENEZIA GIULIA
11	RED	IGT	TOSCANA
12	RED	DOCG	TOSCANA
13	RED	DOCG	TOSCANA
14	RED	IGT	TOSCANA
15	WHITE	IGT	TOSCANA
16	SPARKLING	-	TOSCANA
17	WHITE	DOC	VENETO
18	RED	DOCG	TOSCANA
19	SPARKLING	DOC	EMILIA-ROMAGNA
20	SPARKLING	DOC	EMILIA-ROMAGNA
21	SPARKLING	DOC	EMILIA-ROMAGNA

Table A1. *Cont.*

Wine Profile N°	Type of Wine	Classification *	Region
22	RED	DOCG	VENETO
23	WHITE	DOC	VENETO
24	SPARKLING	DOC	VENETO
25	SPARKLING	DOC	EMILIA-ROMAGNA
26	SPARKLING	DOC	EMILIA-ROMAGNA
27	SPARKLING	DOC	EMILIA-ROMAGNA
28	WHITE	IGT	UMBRIA
29	RED	DOCG	PIEMONTE
30	RED	DOCG	PIEMONTE
31	RED	DOCG	PIEMONTE
32	RED	DOCG	PIEMONTE
33	RED	IGT	TOSCANA
34	RED	IGT	TOSCANA
35	RED	DOC	MARCHE
36	WHITE	DOC	MARCHE
37	RED	DOC	VENETO
38	RED	DOCG	VENETO
39	RED	IGT	UMBRIA
40	RED	DOC	UMBRIA
41	WHITE	DOC	FRIULI VENEZIA GIULIA
42	WHITE	DOC	FRIULI VENEZIA GIULIA
43	RED	DOC	SICILIA
44	RED	DOCG	VENETO
45	RED	DOC	VENETO

* DOC and DOCG refer to the Italian classification of PDO wines; IGT refers to PGI wines (Italian Law 238/2016). Available online: https://www.politicheagricole.it/flex/cm/pages/ServeBLOB.php/L/IT/IDPagina/12012 (accessed on 21 October 2022).

References

1. Chiriacò, M.V.; Belli, C.; Chiti, T.; Trotta, C.; Sabbatini, S. The potential carbon neutrality of sustainable viticulture showed through a comprehensive assessment of the greenhouse gas (GHG) budget of wine production. *J. Clean. Prod.* **2019**, *225*, 435–450. [CrossRef]
2. Intergovernmental Panel on Climate Change (IPCC). *Climate Change 2014: Mitigation of Climate Change. Contribution of Working Group III to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change*; Cambridge University Press: Cambridge, UK; New York, NY, USA, 2014; p. 24.
3. Bonfante, A.; Monaco, E.; Langella, G.; Mercogliano, P.; Bucchignani, E.; Manna, P.; Terribile, F. A dynamic viticultural zoning to explore the resilience of terroir concept under climate change. *Sci. Total Environ.* **2018**, *624*, 294–308. [CrossRef]
4. OIV—International Organisation of Vine and Wine. *State of the Vitivinicultural World in 2020*; OIV: Dijon, France, 2021; Available online: https://www.oiv.int/public/medias/7909/oiv-state-of-the-world-vitivinicultural-sector-in-2020.pdf (accessed on 21 October 2022).
5. Mozell, M.R.; Thach, L. The impact of climate change on the global wine industry: Challenges & solutions. *Wine Econ. Policy* **2014**, *3*, 81–89.
6. Palliotti, A.; Tombesi, S.; Silvestroni, O.; Lanari, V.; Gatti, M.; Poni, S. Changes in vineyard establishment and canopy management urged by earlier climate-related grape ripening: A review. *Sci. Hortic.* **2014**, *178*, 43–54. [CrossRef]
7. Christ, K.L.; Burritt, R.L. Critical environmental concerns in wine production: An integrative review. *J. Clean. Prod.* **2013**, *53*, 232–242. [CrossRef]
8. Merli, R.; Preziosi, M.; Acampora, A. Sustainability experiences in the wine sector: Toward the development of an international indicators system. *J. Clean. Prod.* **2018**, *172*, 3791–3805. [CrossRef]
9. Escribano-Viana, R.; López-Alfaro, I.; López, R.; Santamaría, P.; Gutiérrez, A.R.; González-Arenzana, L. Impact of chemical and biological fungicides applied to grapevine on grape biofilm, must, and wine microbial diversity. *Front. Microbiol.* **2018**, *9*, 59. [CrossRef]
10. Palmieri, N.; Perito, M.A. Consumers' willingness to consume sustainable and local wine in Italy. *Ital. J. Food Sci.* **2020**, *32*, 222–233.
11. Sogari, G.; Pucci, T.; Aquilani, B.; Zanni, L. Millennial Generation and Environmental Sustainability: The Role of Social Media in the Consumer Purchasing Behavior for Wine. *Sustainability* **2017**, *9*, 1911. [CrossRef]

12. Pomarici, E.; Vecchio, R. Millennial generation attitudes to sustainable wine: An exploratory study on Italian consumers. *J. Clean. Prod.* **2014**, *66*, 537–545. [CrossRef]
13. Rugani, B.; Vázquez-Rowe, I.; Benedetto, G.; Benetto, E. A comprehensive review of carbon footprint analysis as an extended environmental indicator in the wine sector. *J. Clean. Prod.* **2013**, *54*, 61–77. [CrossRef]
14. Schultz, K.; Williamson, P. Gaining Competitive Advantage in a Carbon-constrained World: Strategies for European Business. *Eur. Manag. J.* **2005**, *23*, 383–391. [CrossRef]
15. Gilinsky, A., Jr.; Newton, S.K.; Atkin, T.S.; Santini, C.; Cavicchi, A.; Casas, A.R.; Huertas, R. Perceived efficacy of sustainability strategies in the US, Italian, and Spanish wine industries: A comparative study. *Int. J. Wine Bus. Res.* **2015**, *27*, 164–181. [CrossRef]
16. Flores, S.S. What is sustainability in the wine world? A cross-country analysis of wine sustainability frameworks. *J. Clean. Prod.* **2018**, *172*, 2301–2312. [CrossRef]
17. Giacomarra, M.; Galati, A.; Crescimanno, M.; Tinervia, S. The integration of quality and safety concerns in the wine industry: The role of third-party voluntary certifications. *J. Clean. Prod.* **2016**, *112*, 267–274. [CrossRef]
18. Corbo, C.; Lamastra, L.; Capri, E. From Environmental to Sustainability Programs: A Review of Sustainability Initiatives in the Italian Wine Sector. *Sustainability* **2014**, *6*, 2133–2159. [CrossRef]
19. Szolnoki, G. A cross-national comparison of sustainability in the wine industry. *J. Clean. Prod.* **2013**, *53*, 243–251. [CrossRef]
20. Gabzdylova, B.; Raffensperger, J.F.; Castka, P. Sustainability in the New Zealand wine industry: Drivers, stakeholders and practices. *J. Clean. Prod.* **2009**, *17*, 992–998. [CrossRef]
21. Gilinsky, A., Jr.; Newton, S.K.; Vega, R.F. Sustainability in the global wine industry: Concepts and cases. *Agric. Agric. Sci. Procedia* **2016**, *8*, 37–49. [CrossRef]
22. Grebitus, C.; Steiner, B.; Veeman, M.M. Paying for sustainability: A cross-cultural analysis of consumers' valuations of food and non-food products labeled for carbon and water footprints. *J. Behav. Exp. Econ.* **2016**, *63*, 50–58. [CrossRef]
23. D'Ammaro, D.; Capri, E.; Valentino, F.; Grillo, S.; Fiorini, E.; Lamastra, L. Benchmarking of carbon footprint data from the Italian wine sector: A comprehensive and extended analysis. *Sci. Total Environ.* **2021**, *779*, 146416. [CrossRef]
24. Santiago-Brown, I.; Metcalfe, A.; Jerram, C.; Collins, C. Sustainability assessment in wine-grape growing in the new world: Economic, environmental, and social indicators for agricultural businesses. *Sustainability* **2015**, *7*, 8178–8204. [CrossRef]
25. OIV—International Organisation of Vine and Wine. *Resolution OIV-CST 518-2016*; General Principles of Sustainable Vitiviniculture—Environmental—Social—Economic and Cultural Aspects; OIV: Dijon, France, 2016; Available online: https://www.oiv.int/public/medias/5766/oiv-cst-518-2016-en.pdf (accessed on 21 October 2022).
26. Tubiello, F.N.; Rosenzweig, C.; Conchedda, G.; Karl, K.; Gütschow, J.; Xueyao, P.; Obli-Laryea, G.; Wanner, N.; Qiu, S.Y.; De Barros, J.; et al. Greenhouse gas emissions from food systems: Building the evidence base. *Environ. Res. Lett.* **2021**, *16*, 065007. [CrossRef]
27. Amienyo, D.; Camilleri, C.; Azapagic, A. Environmental impacts of consumption of Australian red wine in the UK. *J. Clean. Prod.* **2014**, *72*, 110–119. [CrossRef]
28. Galbreath, J. *On the Relevancy of Climate Change to Business: Evidence from the Margaret River Wineregion of Australia*; Working Paper No. 107; American Association of Wine Economists: New York, NY, USA, 2012; Available online: https://wine-economics.org/working-papers/ (accessed on 21 October 2022).
29. Hannah, L.; Roehrdanz, P.R.; Ikegami, M.; Shepard, A.V.; Shaw, M.R.; Tabor, G.; Zhi, L.; Marquet, P.A.; Hijmans, R.J. Climate change, wine, and conservation. *Proc. Natl. Acad. Sci. USA* **2012**, *17*, 6907–6912. [CrossRef]
30. Jradi, S.; Chameeva, T.B.; Delhomme, B.; Jaegler, A. Tracking carbon footprint in French vineyards: A DEA performance assessment. *J. Clean. Prod.* **2018**, *192*, 43–54. [CrossRef]
31. Vázquez-Rowe, I.; Villanueva-Rey, P.; Iribarren, D.; Moreira, M.T.; Feijoo, G. Joint life cycle assessment and data envelopment analysis of grape production for vinification in the Rías Baixas appellation (NW Spain). *J. Clean. Prod.* **2012**, *27*, 92–102. [CrossRef]
32. OIV—International Organisation of Vine and Wine. *Resolution OIV-CST 431-2011: General Principles of the OIV Greenhouse Gas Accounting Protocol (GHGAP) for the Vine and Wine Sector*; OIV: Dijon, France, 2011. Available online: https://www.oiv.int/public/medias/2107/oiv-cst-431-2011-en.pdf (accessed on 21 October 2022).
33. Galletto, L.; Barisan, L. Carbon footprint as a lever for sustained competitive strategy in developing a smart oenology: Evidence from an exploratory study in Italy. *Sustainability* **2019**, *11*, 1483. [CrossRef]
34. Karwacka, M.; Ciurzyńska, A.; Lenart, A.; Janowicz, M. Sustainable development in the agri-food sector in terms of the carbon footprint: A Review. *Sustainability* **2020**, *12*, 6463. [CrossRef]
35. Röös, E.; Sundberg, C.; Tidåker, P.; Strid, I.; Hansson, P.A. Can carbon footprint serve as an indicator of the environmental impact of meat production? *Ecol. Indic.* **2013**, *24*, 573–581. [CrossRef]
36. Weidema, B.P.; Thrane, M.; Christensen, P.; Schmidt, J.; Løkke, S. Carbon footprint: A catalyst for life cycle assessment? *J. Ind. Ecol.* **2008**, *12*, 3–6. [CrossRef]
37. Martins, A.A.; Costa, M.C.; Araújo, A.R.; Morgado, A.; Pereira, J.M.; Fontes, N.; Graça, A.; Caetano, N.S.; Mata, T.M. Sustainability evaluation of a Portuguese "terroir" wine. In Proceedings of the 41st World Congress of Vine and Wine, BIO Web of Conferences, Punta del Este, Uruguay, 19–23 November 2018; EDP Sciences: Les Ulis, France, 2019. 12/03017.
38. Martins, A.A.; Araújo, A.R.; Graça, A.; Caetano, N.S.; Mata, T.S. Toward sustainable wine: Comparison of two Portuguese wines. *J. Clean. Prod.* **2018**, *183*, 662–676. [CrossRef]
39. Benedetto, G. The environmental impact of a Sardinian wine by partial life cycle assessment. *Wine Econ. Policy* **2013**, *2*, 33–41. [CrossRef]

40. Neto, B.; Dias, A.C.; Machado, M. Life cycle assessment of the supply chain of a Portuguese wine: From viticulture to distribution. *Int. J. Life Cycle Assess.* **2013**, *18*, 590–602. [CrossRef]
41. Bosco, S.; Di Bene, C.; Galli, M.; Remorini, D.; Massai, R.; Bonari, E. Greenhouse gas emissions in the agricultural phase of wine production in the Maremma rural district in Tuscany, Italy. *Ital. J. Agron.* **2011**, *6*, e15. [CrossRef]
42. Navarro, A.; Puig, R.; Fullana-i-Palmer, P. Product vs. corporate carbon footprint: Some methodological issues. A case study and review on the wine sector. *Sci. Total Environ.* **2017**, *581*, 722–733. [CrossRef]
43. Bonamente, E.; Scrucca, F.; Rinaldi, S.; Merico, M.C.; Asdrubali, F.; Lamastra, L. Environmental impact of an Italian wine bottle: Carbon and water footprint assessment. *Sci. Total Environ.* **2016**, *560*, 274–283. [CrossRef]
44. Rinaldi, S.; Bonamente, E.; Scrucca, F.; Merico, M.C.; Asdrubali, F.; Cotana, F. Water and carbon footprint of wine: Methodology review and application to a case study. *Sustainability* **2016**, *8*, 621. [CrossRef]
45. Marras, S.; Masia, S.; Duce, P.; Spano, D.; Sirca, C. Carbon footprint assessment on a mature vineyard. *Agric. For. Meteorol.* **2015**, *214*, 350–356. [CrossRef]
46. Bosco, S.; Di Bene, C.; Galli, M.; Remorini, D.; Massai, R.; Bonari, E. Soil organic matter accounting in the carbon footprint analysis of the wine chain. *Int. J. Life Cycle Assess.* **2013**, *18*, 973–989. [CrossRef]
47. Casolani, N.; D'Eusanio, M.; Liberatore, L.; Raggi, A.; Petti, L. Life Cycle Assessment in the wine sector: A review on inventory phase. *J. Clean. Prod.* **2022**, *379*, 134404. [CrossRef]
48. Sinisterra-Solís, N.K.; Sanjuán, N.; Estruch, V.; Clemente, G. Assessing the environmental impact of Spanish vineyards in Utiel-Requena PDO: The influence of farm management and on-field emission modelling. *J. Environ. Manag.* **2020**, *262*, 110325. [CrossRef] [PubMed]
49. Vázquez-Rowe, I.; Rugani, B.; Benetto, E. Tapping carbon footprint variations in the European wine sector. *J. Clean. Prod.* **2013**, *43*, 146–155. [CrossRef]
50. Saxe, H. *LCA-Based Comparison of the Climate Footprint of Beer vs. Wine & Spirits*; Report No. 207; Institute of Food and Resource Economics: Copenhagen, Denmark, 2010.
51. Ponstein, H.J.; Meyer-Aurich, A.; Prochnow, A. Greenhouse gas emissions and mitigation options for German wine production. *J. Clean. Prod.* **2019**, *212*, 800–809. [CrossRef]
52. Litskas, V.D.; Tzortzakis, N.; Stavrinides, M.C. Determining the carbon footprint and emission hotspots for the wine produced in Cyprus. *Atmosphere* **2020**, *11*, 463. [CrossRef]
53. Pattara, C.; Giannantonio, L.; Lorito, V.; Vinciguerra, R.; Piscicelli, M.; Cichelli, A. Il contributo dei fertilizzanti all'effetto serra nella filiera vitivinicola. In Proceedings of the 38th World Congress of Vine and Wine (Part 2), Mainz, Germany, 5–10 July 2015; EDP Sciences: Les Ulis, France, 2015; Volume 5, p. 05001.
54. Ferrara, C.; De Feo, G. Life cycle assessment application to the wine sector: A critical review. *Sustainability* **2018**, *10*, 395. [CrossRef]
55. Forum per la Sostenibilità del Vino. *Primo Rapporto sulla Sostenibilità nel Vino*; Unione Italiana Vini: Milan, Italy, 2014; Available online: http://www.vinosostenibile.org/wp-content/uploads/2014/10/Primo-Rapporto-Sostenibilita-del-Vino-Ottobre-2014.pdf (accessed on 21 October 2022).
56. Notarnicola, B.; Tassielli, G.; Renzulli, P.A.; Di Capua, R.; Saija, G.; Salomone, R.; Primerano, P.; Petti, L.; Raggi, A.; Casolani, N.; et al. Life cycle inventory data for the Italian agri-food sector: Background, sources and methodological aspects. *Int. J. Life Cycle Assess.* **2022**. [CrossRef]
57. *REG_SOPD_002_20210801*; Regolamento Applicativo Dello Standard Sostenibilità Della Filiera Vitivinicola: Organizzazioni, Prodotti, Denominazioni di Origine (SOPD). Equalitas: Cagliari, Italy, 2021. Available online: https://www.equalitas.it/lo-standard/ (accessed on 21 October 2022).
58. Lamastra, L.; Balderacchi, M.; Di Guardo, A.; Monchiero, M.; Trevisan, M. A novel fuzzy expert system to assess the sustainability of the viticulture at the wine-estate scale. *Sci. Total Environ.* **2016**, *572*, 724–733. [CrossRef]
59. VIVA. Sustainability in the Italian Wine Sector. Available online: https://viticolturasostenibile.org/en/specifications-and-indicators/the-indicators/air/ (accessed on 21 October 2022).
60. Biau, G.; Devroye, L. *Lectures on the Nearest Neighbor Method*; Springer: Cham, Switzerland, 2015; pp. 154–196.
61. Lovie, P. *Coefficient of Variation. Encyclopedia of Statistics in Behavioral Science*; John Wiley & Sons, Inc.: Hoboken, NJ, USA, 2005; Volume 1, pp. 317–318.
62. Litskas, V.D.; Irakleous, T.; Tzortzakis, N.; Starvrinides, M.C. Determining the carbon footprint of indigenous and introduced grape varieties through Life Cycle Assessment using the island of Cyprus as a case study. *J. Clean. Prod.* **2017**, *156*, 418–425. [CrossRef]
63. Gazulla, C.; Raugei, M.; Fullana-i-Palmer, P. Taking a life cycle look at crianza wine production in Spain: Where are the bottlenecks? *Int. J. Life Cycle Assess.* **2010**, *15*, 330–337. [CrossRef]
64. Casolani, N.; Pattara, C.; Liberatore, L. Water and carbon footprint perspective in Italian durum wheat production. *Land Use Policy* **2016**, *58*, 394–402. [CrossRef]
65. Cartone, A.; Casolani, N.; Liberatore, L.; Postiglione, P. Spatial analysis of grey water in Italian cereal crops production. *Land Use Policy* **2017**, *68*, 97–106. [CrossRef]
66. Tsalidis, G.A.; Kryona, Z.P.; Tsirliganis, N. Selecting south European wine based on carbon footprint. *Resour. Environ. Sustain.* **2022**, *9*, 100066. [CrossRef]

67. Scrucca, F.; Bonamente, E.; Rinaldi, S. Carbon footprint in the wine industry. In *Environmental Carbon Footprints*; Muthu, S.S., Ed.; Butterworth-Heinemann: Oxford, UK, 2018; pp. 161–196.
68. Fusi, A.; Guidetti, R.; Benedetto, G. Delving into the environmental aspect of a Sardinian white wine: From partial to total life cycle assessment. *Sci. Total Environ.* **2014**, *472*, 989–1000. [CrossRef]
69. Meneses, M.; Torres, C.M.; Castells, F. Sensitivity analysis in a life cycle assessment of an aged red wine production from Catalonia, Spain. *Sci. Total Environ.* **2016**, *562*, 571–579. [CrossRef]
70. Gierling, F.; Blanke, M. Carbon reduction strategies for regionally produced and consumed wine: From farm to fork. *J. Environ. Manag.* **2021**, *278*, 111453. [CrossRef] [PubMed]
71. Murmura, F.; Liberatore, L.; Bravi, L.; Casolani, N. Evaluation of Italian companies' perception about ISO 14001 and Eco Management and Audit Scheme III: Motivations, benefits and barriers. *J. Clean. Prod.* **2018**, *174*, 691–700. [CrossRef]
72. Figge, F.; Hahn, T.; Schaltegger, S.; Wagner, M. The Sustainability Balanced Scorecard—Linking sustainability management to business strategy. *Bus. Strategy Environ.* **2002**, *11*, 269–284. [CrossRef]