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# Economic and environmental outcomes of a sustainable and circular approach: Case study of an Italian wine-producing firm

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## 1. Introduction

Small- and medium-sized enterprises (SMEs) play a crucial role in the European economy. They represent 99% of all businesses in the EU and they employ around 100 million people (European Commission, 2020). Unsurprisingly, SMEs are also the backbone of the Italian economy. They constitute 99.9% of the total number of active companies (4.4 million SMEs), providing around 80% of Italian employment and 70 % of gross value added. Micro-enterprises make up 94.9 % of all SMEs (these have less than 10 employees and less than €2 million in turnover) (European Commission - European Investment Bank, 2021).

In Italy, SMEs are the most widespread entities in the agri-food industry and their small size is a characteristic feature – as is the case in France and Spain (Gilinsky et al., 2016; Gilinsky et al., 2015; Hussain et al., 2008). In particular, in the Italian wine industry only 32 businesses are 'larger firms' with turnover over €50 million, and only 3 of these posted turnover in excess of €200 million (Mediobanca, 2021). The wine industry's supply chain is quite multifaceted due to the presence of different players in the production process. There are 310,000 farms involved in the wine business (many agricultural companies make wine and sell bulk wine directly or organize themselves into cooperatives), and 46,000 winemakers, including 518 cooperatives, account for one half of total domestic wine production; the remaining share of domestic wine production comes from industrial wineries. In Italy, the wine sector is a key activity both in terms of revenue and exports (ISMEA, 2022). The industry generates approximately €13 billion, which corresponds to 10% of the entire turnover in the agrifood sector (ISMEA, 2022), and at the international level Italy is the biggest world producer and the second biggest exporter (Pomarici et al., 2021). The organization of activities involving the production, transformation and distribution of wine at these firms is mainly based on one of two supply chain models (ISMEA, 2018):

- Integrated supply chains, in which a single company (usually an SME) produces and interfaces with distribution channels – from growing the grapes to selling the bottled wine (the kind of supply chain which this study focuses on).
- Extended supply chains, where consortia, cooperatives and associations (made up of many SMEs) operate in accordance with a logic of cooperation and organization regarding their distribution channels.

The importance of the wine industry at the national and international level highlights how imperative it is to make this industry sustainable throughout both of the supply chain models mentioned above (Bandinelli et al., 2020). The wine industry is a major contributor to environmental issues like climate change, wastage, natural resource depletion, and water and air pollution (Kraus et al, 2020). These multiple impacts on the environment are primarily related to the use of fertilizers and plant protection products in vineyards (Serio et al., 2018), as well as bottling (Gabzdylova et al., 2009; Villanueva-Rey et al., 2014). Around the world, the wine sector produces about 0.3% of annual global greenhouse gas (GHG) emissions from anthropogenic activities (Rugani et al., 2013), and this constitutes about 2% of the agriculture sector's contribution, which is estimated to be 14% of the total (IPCC, 2014). Unfortunately, comprehensive data on environmental pollution in the Italian wine industry is not available and little specific information (i.e., water consumption) can be inferred from the academic literature. For instance, agricultural production in Italy is responsible for 85% of the country's freshwater appropriation (Aivazidou & Tsolakis, 2020) and, in the case of the winemaking sector, the average water footprint of Italian grapes is 488 L per kg of fresh fruit (Mekonnen & Hoekstra, 2011).

Developing a sustainable wine supply chain means firms need to manage sustainability issues in relation to each phase of the production, transformation and distribution process. Accordingly, it is crucial for firms to be aware of the strategies they can implement throughout the

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whole wine supply chain in order to respect the environment. Incorporating solutions for environmental concerns into concrete strategic actions in business management can be more difficult for small- and medium-sized enterprises than for larger companies, since SMEs tend to have greater strategic constraints in terms of resources and capabilities than their bigger counterparts (Del Brìo & Junquera, 2003). Nevertheless, it is imperative that SMEs fit their business models into a sustainable and circular approach in order to transform environmental requirements into opportunities to drive market competition.

The implementation of the circular economy (hereafter, CE) at a firm level can improve business sustainability, as recently argued by Geissdoerfer et al. (2017) and Pieroni et al. (2019). Specifically, a regenerative system such as this requires firms to gradually adopt eco-efficient production models with a view to optimizing resource exploitation and minimizing waste and emissions. When they do this, the CE is not their final goal but rather it is part of “an ongoing process to achieve greater resource efficiency and effectiveness” (Lüdeke-Freund et al., 2019, p.37), which may favorably impact firm performance through corporate sustainability. The implementation of such practices and strategies does not always come easily for companies. Adding new environmental concerns to existing organizational activities may require supplementary capabilities that provide firms with the necessary leverage to gain a competitive advantage (Annunziata et al., 2018).

The existing literature on this theme is fragmented. While, on the one hand, there is a stream of research focusing on the circular economy and the evolution of related business models (Parida et al., 2019; Fehrer & Wieland, 2020; Mostaghel & Chirumalla, 2021), on the other hand there are managerial theories that investigate the circular economy from different perspectives, including the following: human resource management (HRM) and the ‘human side’ of the CE (Chiappetta Jabbour et al, 2019); consumer values (Cherrier and Türe, 2020); digital technology (Kristoffersen et al., 2020); and the CE in emerging economies (Patwa et al., 2020). However, none of these have provided a clearcut view of how a firm could implement different CE strategies in its business. According to the Natural Resource-Based View (hereafter, NRBV), firm strategy is “rooted in capabilities that facilitate environmentally sustainable economic activity by achieving the competitive advantage” (Hart, 1995; p. 992). Therefore, the central idea in this paper is to combine the literature on the circular economy and the NRBV with an approach that provides a more comprehensive framework that will allow SMEs to manage their new environmental challenges by focusing on their internal resources.

Taking these considerations into account, this paper investigates the implementation of sustainable and circular strategies at the micro level by addressing the following research questions: *R1 – How can sustainability be measured in SMEs using both economic and environmental indicators? R2 – How can the circular economy facilitate environmental and economic sustainability in SMEs?* By addressing these issues, the study contributes to a conceptual and empirical definition of the importance of the CE and sustainability practices in SMEs, since these businesses often feature “unique characteristics, contexts, and logics” (Mayson, 2011).

In this vein, our paper aims to evaluate circular and sustainable approaches in wine-making SMEs using the “Life Cycle Thinking” (UNEP/SETAC, 2017) approach. This method aims to manage the entire life cycle of the products and services of an organization in order to move towards more sustainable consumption and production systems. Recent contributions (Calicchio Berardi, 2019; Esposito et al., 2020) recognize this method as relevant when investigating and measuring sustainable and circular economy strategies in the wine industry, by overcoming the shortcomings of research that provides only partial views of the wine supply chain (Broccardo & Zicari, 2020). Furthermore, this paper aims to quantify the benefits arising from sustainable practices applied to the grape-to-wine system in Italian SMEs using a circular economy approach.

The paper is structured as follows. The next section provides an overview of the available literature on sustainability and the circular economy. The section that follows it describes the research methods we applied to an Italian wine-making SME with a sustainable business model and organic production (according to Reg. (EU) 2020/464). For each phase of production (from growing the grapes to bottling the wine), the study calculated both the economic costs of the life cycle (Life Cycle Costing – LCC) in the last five years and the carbon footprint of annual production through an environmental Life Cycle Assessment (LCA). In addition, the study assesses the reduction of economic and environmental costs achievable through the implementation of strategies aiming to transform a traditional linear business into a circular one (through the re-use of organic waste transformed into compost for on-farm fertilization, weed control and soil erosion prevention). The main findings and results are presented in the third part, followed by a discussion of the research findings, limitations and concluding remarks.

## 2. Theoretical lens and framework

The NRBV appears to be a suitable framework to include the natural and socio-economic environment in strategic management and a useful theory to explore the paths taken by firms that pursue environmental strategies to achieve a significant and sustainable competitive advantage over time (Atkin et al., 2012). The NRBV considers three interconnected environmental strategies: pollution prevention, product stewardship, and sustainable development (Hart, 1995). Pollution prevention aims to encourage environmental sustainability while simultaneously decreasing costs and maximizing efficiency throughout internal operations (Hart & Dowell, 2011). Pollution prevention may be related to process-based modifications (Graham, 2018) which are connected to adaptations that lessen environmental impact during different phases of the process, from the acquisition of raw materials to production (Hoque & Clarke, 2013). Despite the huge amount of research on pollution prevention, there is still a lack of clarity in the definition of pollution prevention and how it should be applied. Consistent with Hart’s (1995) classification of pollution prevention, this study focuses on the analysis of the internal production process and the prevention of pollution through both the reduction of internal resources (inputs) in life cycle production (such as raw materials, energy, fuel, labor, etc.) and waste reuse. Although some studies have considered the influence that energy and waste reduction practices have on environmental and operational performance (Rao & Holt, 2005; Pullman et al., 2009), they have not classified these practices as pollution prevention or considered the relationships between them.

### 2.1. Pollution prevention and economic performance

Some empirical studies have adopted the concept of competitive advantage in different dimensions of performance (e.g., environmental and financial) (Rao & Holt, 2005; Ronnenberg et al., 2011). However, there is no broad consensus regarding the relationship between environmental practices and economic performance, and this calls for further investigation (Wu & Pagell, 2011). This lack of consensus regarding the relationship between environmental practices and economic performance might be related to the different ways in which economic performance has been assessed across studies (Graham & McAdams, 2016). Some of the studies that have examined the relationship between environmental strategies and economic performance have found that while these efforts are connected with improvements in environmental performance, a direct link to economic costs is not supported in the case of some environmental practices (Pullman et al., 2009; Graham & Potter, 2015). Other studies (Green et al., 2012; Graham & McAdam, 2016), in contrast, support a direct relationship between environmental and economic performance. Other scholars (Graham & McAdam, 2016) speculate that when companies strengthen their environmental performance by implementing environmental strategies, such an approach may lead to additional progress regarding other performance dimensions (such as cost). The NRBV does not identify a specific association between environmental efforts and economic performance, but rather it aims to highlight the broader economic benefits for companies that engage in environmentally friendly practices (Hart & Dowell, 2011).

### 2.2. *The CE and pollution prevention*

The functioning of the CE implies that resources will be integrated into the economy of the production process in accordance with the concept of reduction, reuse, and recycling. As the ultimate aim of such an approach is to prevent pollution, it is clear that the core concepts of the CE and the NRBV are closely connected (Kusumowardani et al, 2020).

Research is currently continuing to determine a standardized method for measuring the effects that the CE has, and there is thus a lack of CE indicators at the micro-level (Linder et al., 2017; Pauliuk, 2018). In this study, we addressed the CE in terms of resource recovery, specifically assessing the economic and environmental effects generated by the collection of organic waste (Beres et al., 2017) that is composted and then reused at vineyards as organic compost. The on-farm reuse of compost from organic waste has positive effects in terms of fertilization, weed control, and soil erosion reduction (Cirigliano et al., 2017). Organic compost reuse likely translates into savings because it eliminates the purchase of other fertilizers and weed control products, and at the same time it is environmentally beneficial in terms of soil protection and biodiversity conservation. Consequently, we argue that the CE positively influences economic and environmental performance through resource reuse practices.

### 2.3. *The circular economy and sustainability in winemaking SMEs*

The CE is a central concept in sustainability and sustainable development (Ghisellini et al., 2016; Korhonen et al., 2018; Suarez-Eiroa et al., 2019). The relationship between sustainability and the CE has been explored by many scholars (e.g. Millar et al., 2019; Sauvé et al., 2016; Suarez-Eiroa et al., 2019), but there has been no debate regarding the (conceptual) relationship between the CE and sustainability. The key differences arise in terms of the nature of this relationship. For example, Geissdoerfer et al. (2017) show that the academic literature has validated the relationship between the two concepts (sustainability and the CE). Firstly, the CE is a requirement of sustainability; secondly, there is a beneficial relationship between the CE and sustainability; and thirdly, there is a compensatory relationship between the CE and sustainability (Kristensen & Mosgaard, 2020). In general, the CE is broadly presented as an alternative management model which has economic and environmental benefits (Blomsma & Brennan, 2017; Geissdoerfer et al., 2017).

Notwithstanding the relevance of the CE in the sustainability paradigm, most studies focus almost exclusively on large organizations (Kumar et al., 2019; Parida et al., 2019; Zhu et al., 2010), and empirical studies regarding the CE in SMEs continue to be scant (Dey et al., 2020). Some scholars (Katz-Gerro & López Sintas, 2019) have focused their attention on CE strategies in European SMEs, highlighting activities in the areas of waste minimization, energy consumption reduction, products and services remodeling, renewable energy, and water usage. Another stream of research (Prieto-Sandoval et al., 2018) has analyzed challenges and opportunities for adopting the CE in Spanish SMEs, showing that the main driver of CE implementation was cost savings rather than concerns over image building and regulatory pressure. Furthermore, Rizos et al. (2016), in defining the business models for adopting the CE within SMEs, have brought to light the barriers that hinder the implementation of the CE approach. Ünal et al. (2019) have studied the managerial practices for CE design in the case of an Italian office supply SME. The shortage of academic studies on the CE and SMEs is especially noticeable in the wine industry. In their review of the CE in the agrifood sector, Esposito et al. (2020) pointed out the need for further research on the potential opportunities that can arise with a circular economy perspective and identified the importance of wine as a sub-category. Sehnem et al. (2020), after exploring the CE in wine production chains, called for further studies of circular economy practices and business models (Lewandowski, 2016; Merli et al., 2018). There is an increasing interest in the sustainable practices that can lead to reduced environmental impact in wine-producing SMEs (Singh et al., 2020), especially considering not only the role they play in the economy but also their deep-rooted presence in their local communities and the consequent part they play as drivers of job creation (Broccardo & Zicari, 2020; Baumann-Pauly et al., 2013). This paper thus responds to recent calls for studies on the CE and SMEs with a specific focus on the wine sector.

## 3. Methods

Using a life cycle approach, this study evaluates both the economic and environmental aspects of a small winemaking company (a wholly owned family business) located in the northern part of the Lazio Region, in the Province of Viterbo (central Italy). The average annual turnover of this firm was approximately €230,000 and the average number of employees in the 2015–2019 period was seven. The firm is managed using a sustainable business model based on organic farming criteria (according to EU Regulation 2020/464) and it applies a circular economy approach by collecting and transforming its agricultural waste into fresh reusable resources for the farm. This wine firm's business model had already been partly analyzed from a climate change mitigation perspective by Chiriacò et al. (2019), who showed that the sustainable management of the vineyard had achieved carbon neutrality, producing no impact in terms of GHG (greenhouse gas) emissions. Based on these findings and seeking to perform a more comprehensive economic and environmental assessment of the entire wine production cycle, we assessed the following in this study:

1) The Life Cycle Cost (LCC) – using the Activity-Based Costing (ABC) method – and the carbon footprint – through a Life Cycle Assessment (LCA) – of annual production in this firm's grape-to-wine system over a five-year period (2015–2019). According to many scholars, when applied together, LCC and LCA can be considered a combined and integrated assessment method (Miah et al., 2017; Hong et al., 2014; Yu-rong et al., 2009) that can provide a holistic assessment of the annual economic and environmental costs (Kendal et al., 2008).
2) Variations in economic and environmental costs as a consequence of the implementation of strategies seeking to transform traditional linear business processes (make, use and dispose) into circular ones (take, make, distribute, use and recover).

### 3.1. *Sample*

Our sample case applies a sustainable business model. The firm's most significant sustainable management practices include reduced use of chemicals (limited amounts of copper and sulfur allowed, as permitted under current organic farming criteria, Reg. (EU) 2020/464) (Ghisellini et al., 2016; The Ellen MacArthur Foundation, 2012); no tilling and the maintenance of grass cover; and the removal of shredded pruning materials in order to avoid the spread of pests and diseases and to reduce treatments. Sustainable practices applied in the cellar include the reduced use of chemical inputs during vinification (in accordance with organic wine production process Regulation (EU) No 203/2012); energy savings thanks to the natural maintenance of temperatures in a cellar that is dug out of natural rock; and the use of sustainable packaging solutions, including ultralight glass bottles with 10% less weight compared to standard bottles (Chiriacò et al., 2019).

Moreover, this firm applies a CE approach in its reuse of organic winemaking residues (i.e. pruning materials from the vineyard and stalks, grape skins and grape seeds from vinification) and their transformation into organic compost (Askarany & Franklin-Smith, 2014; Boldrin et al., 2009; Coker, 2010) that is then reused on the farm (waste-as-a-resource) for soil organic fertilization (Blomsma & Brennan, 2017; Li et al., 2010; Murray et al., 2017; Preston, 2012), along with the relevant secondary effects of weed control and soil erosion reduction (Cirigliano et al., 2017).

The entire wine production is directly carried out within the firm, from vine cultivation to winemaking and bottling. Three main sets of activities were identified:

1) *Grape production*. This includes all on-field activities, from vines and soil management to grape harvesting. The vineyards are spread across an area of 9.36 ha and include five grape varieties (Grechetto, Incrocio Manzoni, Aleatico, Sangiovese, and Violone). In late summer-early autumn, the grapes are manually harvested and transported to the cellar, which is located on the farm premises, by tractor and trailer. The initial field operations after the grape harvest involve the manual pruning and binding of the grape vines. The material removed during pruning is shredded and collected to be composted on the farm, along with the grape residues (stalks, grape skins and grape seeds) that are by-products of vinification. Subsequently, in early spring, the compost produced on-farm is spread under the vine rows as fertilizer, used for weed and soil erosion control (DeVetter et al., 2015; Cirigliano et al., 2017), or, alternatively, applied in a series of tractor-operated mowing operations for under-row weed control. Moreover, inter-row mowing for weed control is also carried out with the use of the tractor. Weed residues from mowing are shredded and left on the soil. No irrigation occurs and no chemicals for fertilization or weed control are applied, except for limited amounts of copper oxide and sulfur for disease control, as allowed by organic farming criteria.
2) *Transformation (vinification)*. This takes place in the cellar and starts immediately after the grape harvest. It includes all operations ranging from the destemming and crushing of the grapes to must production and wine fermentation in tanks, depending on the desired output, grape quality and oenological preferences (Gonzales-Gomez & Morini, 2006). The wine is then aged in stainless steel tanks or in wooden barrels, which may last less than a year, especially for white wines, or up to three or four years for aged red wines. Organic wine production involves reducing chemical inputs to a minimum (Reg (UE) No 203/2012). It should be noted that in this cellar, which is exposed in a north-westerly direction and is dug into the rock, a natural damping down of the outside temperature occurs, which translates into a lower level of electricity consumption (Chiriacò et al., 2019) than would normally be required to maintain constant temperatures during wine fermentation and aging (Ribereau-Gayon et al., 2006). The grape residues from vinification (stalks, grape skins and grape seeds), along with the vine prunings, are collected and composted on the farm to be reused as organic fertilizer for the soil.
3) *Bottling and packaging*. This includes bottling and packaging operations for the twelve types of finished wine which are bottled in eight different types of packaging.

### 3.2. *Data collection*

Data was collected and processed with different analytical techniques for both the economic and environmental assessments. Primary data was either internally produced by the firm or gathered from direct observation (from 2015 to 2019). When primary data was not available, we used secondary data from the relevant literature. The five-year timeframe was considered appropriate to cover the annual variability which can occur in agricultural production and to reflect increasing inter-annual human-induced climate variability more clearly (IPCC, 2019; CMCC, 2020), as well as the consequent frequency and quantity of inputs (and therefore costs and GHG emissions) used in the field and in the cellar.

Since the LCC and LCA approaches were applied in consideration of the entire life cycle of the wine production process, input and output items were selected for each group of activities (Table 1). Grape production inputs include plant protection products, human labor, fuel for field operations, and the depreciation and maintenance costs of agricultural machinery. Output items are the total amount of grapes produced each year and part of the total compost derived from pruned materials, considering an average amount of 3.1 tons (fresh weight) per hectare per year and 46% humidity content (directly measured by Chiriacò et al., 2019). During vinification, inputs include labor, the consumption of energy and water in the cellar, oenological products (yeast, nutrients for the yeast and sulfur dioxide), and the depreciation and maintenance costs of winemaking machinery. The outputs are the total amount of wine produced in a year and the portion of total compost arising from grape residues during the vinification process (stalks, grape skins and grape seeds), which totaled, on average, 36% of the weight of the harvested grape (as directly observed by Chiriacò et al., 2019), with 80% humidity content (Marras et al., 2015). In bottling and packaging, the inputs are the labor, energy and water consumption required during bottling, the raw materials used for packaging (glass bottles, corks, labels, cap seals and cardboard boxes; see Table 3 for detailed information), and the depreciation and maintenance costs of the bottling equipment. The outputs are the wine bottles and other products (e.g. bag-in-box wines), reported in Table 1, depending on their eight different types of packaged wine. Since some wines can take several years before they are ready for bottling, for our assessment of the annual economic and environmental costs we considered the amount of wine bottled during a year, which may include one or more previous years of grape production and harvesting (especially for aged red wines). Selling, distribution and marketing activities were intentionally not included as they do not directly contribute to the production of wine.

### 3.3. *Economic data analysis*

In line with other scholars (Gonzales-Gomez & Morini, 2006; Biondi et al., 2017), for the purposes of this paper we adjusted the general ABC method to handle cost calculations in the LCC of winemaking SMEs. The LCC-ABC method was applied to the whole production process and calculated the cost of each activity and the final production cost of a liter of wine (the cost object). Process costing includes the following steps: 1) choice of the key activities in the production process (grape production, transformation, bottling and packaging); 2) cost allocation for each activity with the attribution of direct costs and the assignment of indirect costs using cost drivers; 3) transfer of costs allocated to each activity for semi-finished products (i.e. tons of grapes, liters of wine for transformation and bottling, and packaging activities) so as to be able to define an activity cost per unit; and 4) calculation of the full cost of the product (liter of wine) as the sum of all manufacturing costs (Biondi et al., 2017).

We classified direct costs (labor, raw materials, fuel, and depreciation) and indirect costs (energy, water, and the maintenance costs of field and cellar machinery) for each phase. Direct costs were allocated to each activity by considering the nature of the cost (e.g. yeast is a direct cost in the transformation phase), followed by the allocation of indirect costs (Table 2).

As for labor, the cost driver was represented by the hours dedicated to each activity (at an average cost of €10.62 per hour, in accordance with the collective bargaining agreement). For the depreciation of field and cellar machinery, we relied on the register of depreciable property to understand the link between assets and activities (assets directly and indirectly ascribable to specific activities). As for machinery maintenance, we assumed a level of 1% depreciation (on a yearly basis) of the value of acquisition cost. The unitary costs of all raw materials (plant protection, oenological products, and packaging) derive from annual incomes. In addition, an in-depth cost analysis was carried out in

**Table 1**
Inventory of data needed for the economic and environmental analysis of a wine-producing firm.

| Process | Inputs/outputs | 2015 | 2016 | 2017 | 2018 | 2019 |
|---|---|---|---|---|---|---|
| Grape production | Copper oxide (kg ha$^{-1}$) | 2.2 | 4.6 | 1.9 | 3.6 | 4.1 |
| | Sulfur (kg ha$^{-1}$) | 1.5 | 5.8 | 5.4 | 13.5 | 6.5 |
| | Orange tree essential oil (L ha$^{-1}$) | – | – | 0.5 | – | – |
| | Zeolite (kg ha$^{-1}$) | – | – | – | 3.2 | 1.1 |
| | Vinegar (L ha$^{-1}$) | – | – | – | – | 0.2 |
| | Chestnut tannin (kg ha$^{-1}$) | – | – | – | – | 0.1 |
| | Labor (hours ha$^{-1}$) | 168 | 195 | 122 | 116 | 184 |
| | Fuel consumption (L ha$^{-1}$) | 394 | 260 | 301 | 247 | 355 |
| | Depreciation for field machinery (€ ha$^{-1}$) | 255.2 | 451.3 | 451.3 | 451.3 | 526.9 |
| | Maintenance of field machinery (€ ha$^{-1}$)[a] | 69.4 | 69.4 | 69.4 | 69.4 | 77 |
| | Grape production (ton ha$^{-1}$) | 5.0 | 6.4 | 2.7 | 2.9 | 6.5 |
| | Compost from pruning material (ton d.m. ha$^{-1}$) | 0.17 | 0.17 | 0.17 | 0.17 | 0.17 |
| Transformation | Labor (hours L$^{-1}$)[b] | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 |
| | Electricity (IT energy mix) (kWh L$^{-1}$)[c] | 0.50 | 0.52 | 0.51 | 0.50 | 0.42 |
| | Water (L L wine$^{-1}$)[d] | 5.4 | 5.4 | 5.4 | 5.4 | 5.4 |
| | Yeast and nutrients for the yeast (g L wine$^{-1}$) | 0.4 | 0.4 | 0.4 | 0.4 | 0.4 |
| | Sulfur dioxide (g L wine$^{-1}$) | 0.2 | 0.2 | 0.2 | 0.2 | 0.2 |
| | Depreciation for transformation machinery (€ L$^{-1}$) | 0.11 | 0.17 | 0.42 | 0.38 | 0.15 |
| | Maintenance of transformation machinery (€ L$^{-1}$)[a] | 0.01 | 0.02 | 0.06 | 0.05 | 0.02 |
| | Wine production (L ha$^{-1}$) | 3,162 | 3,910 | 1,698 | 1,870 | 4,913 |
| | Compost from grape residues (ton d.m. ha$^{-1}$) | 0.42 | 0.52 | 0.26 | 0.27 | 0.53 |
| Bottling and packaging | Labor (hours L$^{-1}$)[b] | 0.02 | 0.01 | 0.03 | 0.02 | 0.02 |
| | Electricity (IT energy mix) (kWh L$^{-1}$)[c] | 0.13 | 0.13 | 0.13 | 0.12 | 0.11 |
| | Water (L L wine$^{-1}$)[d] | 0.6 | 0.6 | 0.6 | 0.6 | 0.6 |
| | Depreciation for bottling equipment (€ L$^{-1}$) | 0 | 0 | 0 | 0 | 0.01 |
| | Maintenance of bottling equipment (€ L$^{-1}$)[a] | 0 | 0 | 0 | 0 | 0.001 |
| | Bottled wine (number of 0.75 L bottles)[e] | 16,199 | 14,132 | 22,180 | 18,999 | 18,194 |
| | *Type A* | *12,545* | *11,574* | *15,188* | *12,700* | *9,470* |
| | *Type B* | *1,784* | *1,200* | *2,731* | *981* | *3,865* |
| | *Type C* | *1,870* | *800* | *3,228* | *5,318* | *4,859* |
| | *Type D* | – | *558* | *1033* | – | – |
| | Bottled wine (number of magnum 1.5 L bottles)[e] | – | – | – | 100 | 151 |
| | Bottled wine (number of 0.375 L bottles)[e] | 705 | 480 | – | 1,440 | 430 |
| | Wine in 10*L* bag-in-box (number of items)[e] | 416 | 323 | 320 | 600 | 527 |
| | Wine in 3L bag-in-box (number of items)[e] | 27 | – | 186 | 476 | 566 |

Source: Farm registry.
[a] The cost of maintenance was assumed to be 1% of the agriculture machinery's purchase price.
[b] Labor in the cellar was assumed to be 50% for transformation and 50% for bottling and packaging.
[c] The energy consumption of electricity was assumed to be 80% for transformation and 20% for bottling and packaging.
[d] Water consumption was assumed to be 90% for transformation and 10% for bottling and packaging.
[e] Wine bottled during the year but from grapes harvested and vinified in previous years.

**Table 2**
Direct and indirect costs classified by activity.

| | Grape production | Transformation | Bottling and packaging |
|---|---|---|---|
| *Direct costs* | Labor (wages and salaries), diesel for farming (fuel), plant protection (e.g. copper oxide, sulfur, etc.), depreciation for field machinery | Labor (wages and salaries), yeast and other oenological products, depreciation for transformation machinery | Labor (wages and salaries), packaging raw materials (bottles, labels, corks, etc), depreciation for bottling machinery |
| *Indirect costs* | Maintenance costs of specific field machinery | Electricity (IT energy mix) , water, maintenance costs of transformation machinery | Electricity (IT energy mix) , water, maintenance costs of bottling machinery |

relation to packaging. Our economic analysis considered all cost items for eight different wine categories (Table 3).

Having determined the direct and indirect costs of each activity, our economic analysis assigned each cost to its relative semi-finished product (grapes, and bulk and bottled wine). By distributing the activity cost by product units, it was possible to calculate the cost of activity performance per liter of finished wine.

### 3.4. Environmental data analysis

All winemaking process operations imply the production of a certain amount of anthropogenic GHG emissions, which are the main cause of human-induced climate change (IPCC, 2019). Measuring the GHG emissions of each phase of the production process is paramount in order to detect the main hotspots and define possible business management strategies to reduce climatic impact. The anthropogenic GHG emissions throughout the overall life cycle of the wine firm investigated, also known as its carbon footprint, were assessed via an LCA applied using a "cradle-to-gate" approach (Finkbeiner et al., 2006) in which all wine production inputs (from grape cultivation to packaged bottles of wine) are included within the boundary of the system. Only emissions from the transport and packaging of raw materials were not included, as they were shown to be negligible (Chiriacò et al., 2019).

The LCA methodology follows the ISO 14,040 standard on "LCA – Principles and procedures" and the ISO 14,044 on "LCA – Requirements and guidelines" (Finkbeiner et al., 2006). However, as the LCA considers the whole life cycle of the wine production process, which in many cases can last for a number of years, in this study we used data on a yearly basis so as to provide a holistic assessment of the annual environmental impact in terms of GHG emissions.

The data used to perform the LCA was collected from the firm's registers or directly measured (Table 1). More detailed primary data for the wine packaging is reported in Table 4. Total GHG emissions were calculated using the LCA software SimaPro 7.3.3, multiplying primary

**Table 3**
Primary costs of wine packaging.

| | | Glass bottle (€ bottle$^{-1}$) | Label (€ bottle$^{-1}$) | Cork (€ bottle$^{-1}$) | Cap seal (g bottle$^{-1}$) | Bag (€ unit$^{-1}$) | Other |
|---|---|---|---|---|---|---|---|
| 0.75 L bottle | Type A | 0.16 | 0.11 | 0.20 | 0.03 | – | – |
| | Type B | 0.48 | 0.35 | 0.20 | 0.08 | – | 0.10 |
| | Type C | 0.26 | 0.20 | 0.20 | 0.03 | – | 0.03 |
| | Type D | 0.81 | 0.45 | 0.24 | 0.02 | – | 3.27 |
| Magnum 1.5 L bottle | | 1.08 | 0.70 | 0.88 | – | – | 0.19 |
| 0.375 L bottle | | 0.58 | 0.31 | 0.20 | – | – | – |
| 10 L bag-in-box | | – | 0.35 | – | – | 1.20 | – |
| 3 L bag-in-box | | – | 0.10 | – | – | 0.88 | – |

**Table 4**
Primary data of the wine packaging.

| | | Glass bottle (g bottle$^{-1}$) | Label (g bottle$^{-1}$) | Cork (g bottle$^{-1}$) | Cap seal (g bottle-1) | Cardboard *6-bottle* box (g item$^{-1}$) | Aluminum bag (g item$^{-1}$) | Plastic valve (g item$^{-1}$) |
|---|---|---|---|---|---|---|---|---|
| 0.75 L bottle | Type A | 360 | 1.1 (rp) | 4.5 | 0.8 (pvc) | 46 | – | – |
| | Type B | 500 | 0.5 (rp), 7 (c) | 4.5 | 5 (sh) | 46 | – | – |
| | Type C | 400 | 9 (rp), 2 (sh) | 4.5 | 0.5 (rp) | 46 | – | – |
| | Type D | 850 | 9 (rp), 2 (sh) | 9 | 5 (a) | 150* | – | – |
| 1.5 L magnum bottle | | 1,000 | 1 (rp), 14 (c) | 9 | 10 (sh) | 46 | – | – |
| 0.375 L bottle | | 500 | 1.1 (rp) | 4.5 | 0.8 (pvc) | 46 | – | – |
| 10*L* bag-in-box | | – | 1.1 (rp) | – | – | 300* | 25 | 5 |
| 3L bag-in-box | | – | 1.1 (rp) | – | – | 120* | 15 | 5 |

rp = recycled paper, c = cotton, a = aluminum, sh = shellac, pvc = polyvinyl chloride.
* single cardboard box.

data by emission factors (Table 5) derived from the literature and international databases (i.e. Ecoinvent database). Final GHG emissions are expressed in $CO_2$ equivalent ($CO_2$eq) dependent on the global warming potential (GWP) with a time horizon of 100 years, which was assigned 1 GWP to 1 kg of $CO_2$, 28 GWP to 1 kg of $CH_4$, and 265 GWP to 1 kg of $N_2O$.

**Table 5**
Emission factors.

| | Unit | Emission factor (kg CO2eq) | Data source |
|---|---|---|---|
| Copper oxide | kg | 1.94 | Althaus et al., 2007 |
| Sulfur | kg | 1.39 | Althaus et al., 2007 |
| Orange tree essential oil | l | 2.25 | Jungbluth et al., 2011 |
| Zeolite | kg | 1 | Frischknecht et al., 2005 |
| Vinegar | l | 1 | Frischknecht et al., 2005 |
| Chestnut tannin | kg | 1.89 | Jungbluth et al., 2011 |
| Diesel for farming (fuel combustion) | kg | 3.1 | Nemecek and Kagi, 2007 |
| Specific weight of diesel | kh/L | 0.84 | Nemecek and Kagi, 2007 |
| Italian energetic mix | kWh | 0.65 | Dones et al., 2007 |
| Yeast and nutrients for the yeast | g | 0.001 | Jungbluth, 2007 |
| Sulfur dioxide | g | 0.0004 | Althaus et al., 2007 |
| Glass bottle | kg | 0.67 | Hischier, 2007 |
| Cork | g | 0.001 | Kellenberger et al., 2007 |
| Polyvinyl chloride (PVC) | g | 0.003 | Plastics Europe, 2005 |
| Recycled paper, with de-inking | g | 0.002 | Hischier, 2007 |
| Recycled corrugated board | g | 0.001 | Hischier, 2007 |
| Aluminum | kg | 0.84 | Classen et al., 2009 |
| Kraft paper bleached | kg | 0.84 | Hischier, 2007 |
| Plastic – High-Density-Polyethylene (HDPE) | kg | 1.93 | Hischier, 2007 |
| Cotton | kg | 27.1 | Frischknecht et al., 2005 |
| Shellac | kg | 2.65 | Frischknecht et al., 2005 |

(Insert Table 4 and Table 5).

## 4. Results

### 4.1. Life cycle costing and life cycle assessment results

The activity-based costs of each key activity were, on average, the following: €550.0 per ton of grapes (Min €402.0 in 2019; Max €769.8 in 2017) during grape production activity (Table 6); €0.64 per liter of wine (Min €0.44 in 2016 and 2019; Max €0.98 in 2017) during transformation activity (Table 7); and €1.00 (Min €0.90 in 2017 and 2018; Max €1.20 in 2019) as the average value per unit of packaged wine (i.e. average of eight types of packaging) during bottling and packaging activity (Table 8). Cost efficiency was higher during transformation activity (€0.64 per liter), followed by bottling and packaging (€0.70 per liter of packaged wine) and grape production (€0.90 per liter). Direct costs had a greater impact on grape production (covering 96.9% of the total costs of this activity), mainly due to labor costs (68% of total costs), and on bottling and packaging (covering 95.2% of the total costs of this activity), mainly due to the top-quality, high-priced materials used for packaging (68% of total costs). During transformation activity, the economic impact of direct costs was lower (72.9% of the total costs of this activity) (Table 9). During this activity, the highest direct cost (38%) was related to labor, followed by the depreciation of cellar machinery (33%). The full cost was calculated by summing up the costs of the three key activities. The average full cost for a liter of wine was €2.20.

The average GHG emissions resulting from the LCA analysis of the entire wine making process were 25.91 (Min 20.51 in 2018; Max 32.06 in 2019) Mg $CO_2$eq year$^{-1}$ (Table 10), including the sustainable grape production, which was responsible for an average emission of 7.7 (Min 6.3 in 2018; Max 9.7 in 2015) Mg $CO_2$eq year$^{-1}$, the process of transforming grapes into wine, which generated an average emission of 9.1 (Min 5.3 in 2017; Max12.7 in 2019) Mg $CO_2$eq year$^{-1}$, and the bottling and packaging process, which released an average emission of 9 (Min 8.2 in 2016; Max 10.5 in 2019) Mg $CO_2$eq year$^{-1}$.

In grape production, the main driver of GHG emissions was fuel consumption for field operations, which was responsible for nearly the entirety of emissions for this activity (29% of total emissions; Table 10).

**Table 6**
Grape production activity cost.

| | 2015 | 2016 | 2017 | 2018 | 2019 | Average | Avg % |
|---|---|---|---|---|---|---|---|
| Labor (€) | 15,823.2 | 18,101.3 | 12,037.4 | 11,367.7 | 16,124.6 | 14,690.9 | 68% |
| Diesel for farming (€) | 2,582.8 | 1,701.4 | 1,970.2 | 1,620.6 | 2,327.5 | 2,040.5 | 9% |
| Plant protection (€) | 415.9 | 97.1 | 565.2 | 965.1 | 352.1 | 479.1 | 2% |
| Direct depreciation (€) | 2,388.8 | 4,225.0 | 4,225.0 | 4,225.0 | 4,932,2 | 3,999.2 | 18% |
| Maintenance (€) | 650.0 | 650.0 | 650.0 | 650.0 | 720.7 | 664.1 | 2% |
| Total (€) | 21,860.7 | 24,774.8 | 19,447.8 | 18,828.3 | 24,457,2 | 21,873.8 | 100% |
| Grape production Activity Cost (€ ton$^{-1}$) | 468.1 | 415.7 | 769.8 | 694.4 | 402.0 | 550.0 | |
| Grape production Activity Cost (€ L$^{-1}$) | 0.7 | 0.7 | 1.2 | 1.1 | 0.5 | 0.9 | |
| Grape production Activity Cost (€ ha$^{-1}$) | 2,335.5 | 2,646.9 | 2,077.8 | 2,011.6 | 2,612.9 | 2,336.9 | |

**Table 7**
Transformation activity cost.

| | 2015 | 2016 | 2017 | 2018 | 2019 | Average | Avg % |
|---|---|---|---|---|---|---|---|
| Labor (€) | 5,148.2 | 4,726.5 | 5,205.7 | 4,271.2 | 7,517.3 | 5,373.8 | 33% |
| Electricity (€) | 4,497.6 | 3,071.7 | 2,015.1 | 2,626.3 | 3,147.8 | 3,071.7 | 19% |
| Water (€) | 351.6 | 434.8 | 188.8 | 208.0 | 546.4 | 345.9 | 2% |
| Oenological products (€) | 306.0 | 310.2 | 297.8 | 298.7 | 315.8 | 305.7 | 2% |
| Direct depreciation (€) | 3,412.5 | 6,555.0 | 6,825.0 | 6,825.0 | 7,640.5 | 6,251.6 | 38% |
| Maintenance (€) | 350.0 | 1,050.0 | 1,050.0 | 1,125.4 | 1,082.4 | 931.6 | 6% |
| Total (€) | 14,066.0 | 16,149.0 | 15,582.4 | 15,354.6 | 20,250.2 | 16,280.3 | 100% |
| Transformation activity cost (€ L$^{-1}$) | 0.48 | 0.44 | 0.98 | 0.88 | 0.44 | 0.64 | |
| Transformation activity cost (€ ha$^{-1}$) | 1,502.8 | 1,725.2 | 1,664.8 | 1,640.5 | 2,163.5 | 1,739.3 | |

**Table 8**
Bottling and packaging activity costs.

| | 2015 | 2016 | 2017 | 2018 | 2019 | Average | Avg % |
|---|---|---|---|---|---|---|---|
| Labor (€) | 5,148.2 | 4,726.5 | 5,205.7 | 4,271.2 | 7,517.3 | 5,373.8 | 27% |
| Electricity (€) | 1,124.4 | 767.9 | 503.8 | 656.6 | 786.9 | 767.9 | 4% |
| Water (€) | 39.1 | 48.3 | 21.0 | 23.1 | 60.7 | 38.4 | 0,2% |
| Packaging (€) | 10,981.6 | 11,352.8 | 15,225.3 | 14,520.1 | 14,880.5 | 13,392.1 | 68% |
| Direct depreciation (€) | – | – | – | – | 322.5 | 322.5 | 2% |
| Maintenance (€) | – | – | – | – | 743.0 | 743.0 | 4% |
| Total (€) | 17,293.3 | 16,895.5 | 20,955.8 | 19,471.0 | 24,310.9 | 19,785.3 | 100% |
| Bottling and packaging Activity cost (€ unit$^{-1}$) | 1.0 | 1.1 | 0.9 | 0.9 | 1.2 | 1.0 | |
| Bottling and packaging Activity cost (€ L-1) | 0.6 | 0.5 | 1.3 | 1.1 | 0.5 | 0.7 | |
| Bottling and packaging Activity cost (€ ha$^{-1}$) | 1,847.6 | 1,805.1 | 2,238.9 | 2,080.2 | 2,597.4 | 2,113.8 | |

**Table 9**
Distribution of direct and indirect costs.

| | | 2015 | 2016 | 2017 | 2018 | 2019 | Avg |
|---|---|---|---|---|---|---|---|
| *Grape production* | *Direct costs* | 97.0% | 97.4% | 96.7% | 96.5% | 97.1% | 96.9% |
| | *Indirect costs* | 3.0% | 2.6% | 3.3% | 2.7% | 2.9% | 2.9% |
| *Transformation* | *Direct costs* | 63.0% | 71.8% | 79.1% | 74.2% | 76.4% | 72.9% |
| | *Indirect costs* | 37.0% | 28.2% | 20.9% | 25.8% | 23.6% | 27.1% |
| *Bottling and Packaging* | *Direct costs* | 93.3% | 95.2% | 97.5% | 96.5% | 93.5% | 95.2% |
| | *Indirect costs* | 6.7% | 4.8% | 2.5% | 3.5% | 3.5% | 4.8% |

Energy consumption was the main driver of emissions in transformation activity, again covering approximately the totality of emissions for this activity (35% of total emissions; Table 10). Indeed, GHG emissions from this activity might have been even higher had it not been for savings on electricity costs thanks to the natural cooling and insulating properties of the rock cellar, which keeps temperatures constant (see section 3.1). The main drivers of GHG emissions during bottling and packaging activity were the raw materials used to package the wine (glass bottles above all), which were about 26% of total emissions, and energy consumption, which was 9% of total emissions (Table 10). Indeed, in this case as well, GHG emissions from this activity would have been even higher had it not been for the application of sustainable packaging solutions, including ultralight glass bottles (360 g) with 10% less weight compared to standard bottles (see section 3.1).

### 4.2. *The economic and environmental impact of CE activities*

With a view to assessing the economic and environmental impact of the CE practices applied in this firm, we calculated the costs avoided (adopting financial proxies) and the GHG emissions avoided through the implementation of the CE approach. As previously explained, the CE approach applied in the firm we investigated included the collection of the organic waste materials from pruning and vinification in order to compost them on the farm and then reuse them in the vineyards as organic compost for fertilization and weed control purposes. Notably, the total amount of compost, ranging from 4 to 6.5 tons of dry matter (d. m.) ha$^{-1}$ year$^{-1}$ (Table 11), was produced annually by the winemaking firm in question, from the reuse of pruning materials and grape residues from vinification (stalks, grape skins and grape seeds).

The on-farm production and use of compost was investigated by

**Table 10**
GHG emissions assessed via LCA from the vineyard to the bottled wine.

| | Inputs | GHG emissions kg $CO_2$eq | | | | | Average | Avg % | |
|---|---|---|---|---|---|---|---|---|---|
| | | **2015** | **2016** | **2017** | **2018** | **2019** | **kg $CO_2$eq** | | |
| Grape production | Copper oxide | 40.74 | 82.94 | 33.61 | 65.48 | 73.91 | 59.33 | <1% | |
| | Sulfur | 20.02 | 76.06 | 70.72 | 175.70 | 84.51 | 85.40 | <1% | |
| | Orange tree essential oil | – | – | 11.25 | – | – | 11.25 | <1% | |
| | Zeolite | – | – | – | 30.00 | 10.00 | 20.00 | <1% | |
| | Vinegar | – | – | – | – | 1.60 | 1.60 | <1% | |
| | Chestnut tannin | – | – | – | – | 1.89 | 1.89 | <1% | |
| | Fuel consumption | 9,608 | 6,329 | 7,329 | 6,028 | 8,658 | 7,591 | 29% | |
| **Total kg $CO_2$eq** | | **9,669** | **6,488** | **7,445** | **6,300** | **8,830** | **7,746** | **30%** | |
| *kg $CO_2$eq $ha^{-1}$* | | *1,033* | *693* | *795* | *673* | *943* | *828* | | |
| *kg $CO_2$eq $L^{-1}$* | | *0.33* | *0.18* | *0.47* | *0.36* | *0.19* | *0.30* | | |
| Transformation | Electricity (IT energy mix) | 9,714 | 12,397 | 5,255 | 5,640 | 12,652 | 9,131 | 35% | |
| | Yeast and nutrients | 11.84 | 14.64 | 6.36 | 7.00 | 18.40 | 11.65 | <1% | |
| | Sulfur dioxide | 2.37 | 2.93 | 1.27 | 1.40 | 1.27 | 1,85 | <1% | |
| **Total kg $CO_2$eq** | | **9,728** | **12,414** | **5,262** | **5,648** | **12,671** | **9,145** | **35%** | |
| *kg $CO_2$eq $ha^{-1}$* | | *1,039* | *1,326* | *562* | *603* | *1,354* | *977* | | |
| *kg $CO_2$eq $L^{-1}$* | | *0.33* | *0.34* | *0.33* | *0.32* | *0.28* | *0,32* | | |
| Bottling and packaging | Electricity (IT energy mix) | 2,428 | 3,099 | 1,314 | 1,410 | 3,163 | 2,283 | 9% | *kg $CO_2$eq $bottle^{-1}$* |
| | 0.75 L bottle *Type A* | 3,717 | 3,429 | 4,500 | 3,763 | 2,806 | 3,643 | 14% | *0.296* |
| | *TType B* | 1,052 | 707 | 1,610 | 578 | 2,278 | 1,245 | 5% | *0.589* |
| | *TType C* | 641 | 274 | 1,107 | 1,823 | 1,666 | 1,102 | 4% | *0.343* |
| | *TType D* | – | 422 | 781 | – | – | 601 | <1% | *0.756* |
| | 1.5 L magnum bottle | – | – | – | 113 | 171 | 142 | <1% | *1.13* |
| | 0.375 L bottle | 275 | 187 | – | 562 | 168 | 298 | <1% | *0.390* |
| | 10*L* bag-in-box | 161 | 125 | 124 | 232 | 204 | 169 | <1% | *0.387* |
| | 3L bag-in-box | 5 | – | 33 | 84 | 100 | 55 | <1% | *0.177* |
| **Total kg $CO_2$eq** | | **8,279** | **8,244** | **9,468** | **8,566** | **10,556** | **9,022** | **35%** | |
| *kg $CO_2$eq $ha^{-1}$* | | *884* | *881* | *1,012* | *915* | *1,128* | *964* | | |
| *kg $CO_2$eq $L^{-1}$* | | *0.50* | *0.59* | *0.46* | *0.38* | *0.50* | *0.49* | | |
| **TOTAL GHG emissions Mg $CO_2$eq** | | **27.68** | **27.15** | **22.18** | **20.51** | **32.06** | **25.91** | **100%** | |
| **GHG emissions Mg $CO_2$eq $ha^{-1}$** | | **2.96** | **2.90** | **2.37** | **2.19** | **3.42** | **2.77** | | |
| **GHG emissions kg $CO_2$eq $L^{-1}$** | | **1.15** | **1.10** | **1.26** | **1.07** | **0.97** | **1.11** | | |

**Table 11**
Effects of on-farm compost application.

| | 2015 | 2016 | 2017 | 2018 | 2019 | Avg |
|---|---|---|---|---|---|---|
| Total vineyard area (ha) | 9.36 | 9.36 | 9.36 | 9.36 | 9.36 | |
| On-farm compost produced (tons d.m.) | 5.5 | 6.4 | 4.0 | 4.1 | 6.5 | 5.3 |
| Alternative organic fertilizer to replace the on-farm compost (tons) | 7.7 | 9.0 | 5.6 | 5.7 | 9.1 | 7.4 |
| Vineyard area coverable by the annual compost (ha) | 0.92 | 1.07 | 0.66 | 0.68 | 1.09 | 0.88 |
| *(% of the total area)* | *10%* | *11%* | *7%* | *7%* | *12%* | *9%* |
| Fuel saved by avoiding mowing under the row (L) | 402 | 315 | 214 | 183 | 438 | 310 |
| Labor (hours) saved | 11.4 | 12.9 | 7.9 | 8.2 | 2.1 | 8.5 |

observing its effect on labor and fuel costs as well as on GHG emissions, through field weed control operations. Since the optimal under-row compost distribution should cover a width of 0.5 m, with a thickness of 0.05 m, and that the average planting layout in the investigated vineyard is 2.5 × 0.8 m, which corresponds to about 4,000 linear meters per hectare, and since the specific weight of the on-farm produced compost was 0.6 tons $m^{-3}$ (directly measured), it became apparent that the optimal amount of compost would be 6 tons d.m. $ha^{-1}$ $year^{-1}$. Therefore, the total amount of compost annually produced at this winemaking firm (ranging from 4 to 6.5 tons d.m. $ha^{-1}$ $year^{-1}$, Table 11) would be enough to cover about one-tenth (7–12%, Table 11) of the entire vineyard area of the farm (9.36 ha). Each year the compost was then distributed by tractor over approximately-one-tenth of the vineyard area, stimulating natural weed control and avoiding springtime mowing operations, which consequently saved on labor and fuel costs and consequent GHG emissions.

From the economic point of view, we calculated the amount of annual labor hours and fuel saved by not conducting weed control operations on the under-rows in the portion of the vineyard area (approximately 10%) covered by the compost (Table 11), multiplied by the hourly labor cost (an average €10.62 per hour in accordance with the collective bargaining agreement, as mentioned earlier) and by the average fuel cost (which was €0.70 per liter, calculated as the average cost for the invoices from the prior five years). Results showed total average annual savings in labor costs of €90.0 (Min €23.2; Max €137.3) and total average savings in fuel costs of €217.2 (Min €127.8; Max €306.4) (Table 12).

With regard to the GHG emissions avoided thanks to the reduced use of fuel for under-row mowing operations, the emissions saved were calculated by multiplying the fuel saved (Table 11) by the relative emission factor (Table 4). Results indicated an average amount of GHG emissions avoided of 808 (Min 476 in 2018; Max 1,140 in 2019) kg $CO_2$eq per year (Table 12). This allowed the firm to save an extra + 3% of GHG emissions that would have occurred due to field operations for under-row weed control operations without the application of the on-farm compost.

Moreover, another important benefit provided by the use of the on-farm compost produced was avoiding the purchase of alternative organic fertilizer for the vineyard area where the compost was distributed. The most common organic fertilizers allowed in organic farming are on average 55% organic matter, compared to values of approximately 75% when directly measuring the on-farm compost produced. Therefore, in comparison to the on-farm compost produced, an amount 1.4 times higher of alternative organic fertilizer would have been needed to achieve a comparable effect (i.e. 7.7 tons in 2015, 9 tons in 2016, 5.6 tons in 2017, 5.7 tons in 2018, and 9.1 tons in 2019; see Table 10). Considering the average price of €600 per ton (value directly taken from a supplier's quote), the average cost saved was €4,452 (Min

**Table 12**
Economic and environmental impacts of circular economy strategies.

| Impact | Economic and environmental proxies | Activity involved | 2015 | 2016 | 2017 | 2018 | 2019 | Avg |
|---|---|---|---|---|---|---|---|---|
| Economic | Labor costs saved on field operations for weed control (€) | Grape production | 117.6 | 137.3 | 84.6 | 87.5 | 23.2 | 90.0 |
| Economic | Fuel costs saved on field operations for weed control (€) | Grape production | 281.3 | 220.6 | 150.0 | 127.8 | 306.4 | 217.2 |
| Economic | Cost saved on purchase of organic fertilizers as alternative to on-farm produced compost (€) | Grape production | 4,20 | 5,400 | 3,360 | 3,420 | 5,460 | 4,452 |
| Environmental | GHG emissions avoided thanks to compost used for weed control (kg $CO_2$eq) | Grape production | 1,047 | 821 | 558 | 476 | 1,140 | 808 |

€3,360; Max €5,460) per year (Table 12).(See Fig. 1).

### 4.3. Comparative results

Fig. 2 shows a comparative analysis of economic and environmental costs by sets of activities assessed at the firm investigated, including the economic and environmental effects achievable with CE practices. The LCC and LCA results showed a rather balanced environmental impact in terms of GHG emissions across the three activities of grape production, transformation, bottling and packaging, covering an average share of 30%, 35% and 35%, respectively, and a slightly imbalanced economic impact, with higher costs for grape production and lower ones for transformation, with an average share of 38%, 28% and 34%, respectively, for grape production, transformation, and bottling and packaging.

While the field operations for grape production were on average those with the lowest impact from a climatic point of view (responsible for 30% of total GHG emissions in wine production), they were, on the other hand, those with the highest cost on average (38% of the total costs of wine production). The opposite was true for the transformation process, which had considerable impact in terms of GHG emissions (on average 35% of total GHG emissions during wine production) and was the least expensive (on average 28% of the total costs of wine production).

Moreover, an interesting result is highlighted in the red portions of the columns, which show that the CE practices applied at this firm generated both economic and environmental advantages at the same time, producing savings of 3% in total annual GHG emissions and 8% in total annual costs. In particular, the slightly greater economic advantage compared to environmental benefits was due to the fact that the CE practices we investigated led to savings regarding both the labor and fuel used for field operations and both elements (labor and fuel) engendered a reduction in the financial costs, whereas the reduction in GHG emissions was only thanks to savings on fuel.

## 5. Discussion

The findings of this study have demonstrated that economic and environmental sustainability can be objectively measured in a winemaking Small Medium Enterprise (SME) and that a CE business model leads to better firm performance, both in environmental and economic terms. Specifically, in relation to the first research question, this study has shown how an integrated approach using LCC and LCA can simultaneously measure the economic and environmental sustainability of each phase of the production process using the amount of GHG emissions (in $CO_2$eq) as the main environmental indicator and unit costs (in euros) as the main economic indicator. In particular, the results of the LCC and LCA show a contradictory response regarding the positive association between costs and environmental performance. More specifically, our findings show grape production activity has a greater economic impact than the higher operating costs of other activities. Conversely, on-field grape production was, on average, the activity that, from a climate point of view, had less impact. In addition, the opposite was true for the transformation process, which, in contrast, had a higher impact in terms of GHG emissions, in addition to being the least expensive process. These contradictory findings regarding grape production activity could be explained by the strong impact that manual labor has (mainly for harvesting and pruning). In fact, to ensure high-quality wine, the firm relies heavily on manual work, opting to rely less on mechanical operations, even though the latter could contribute to cutting labor costs and improving profit margins (Tudisca et al., 2011), because this would be to the detriment of quality. While manual labor constitutes a high-cost driver, it is not linked to greater environmental impact (Hunkeler et al., 2008) since it does not generate GHG emissions. This result is explained well in Graham and McAdam’s (2016) analysis, in which the authors affirm that “it is not the practices

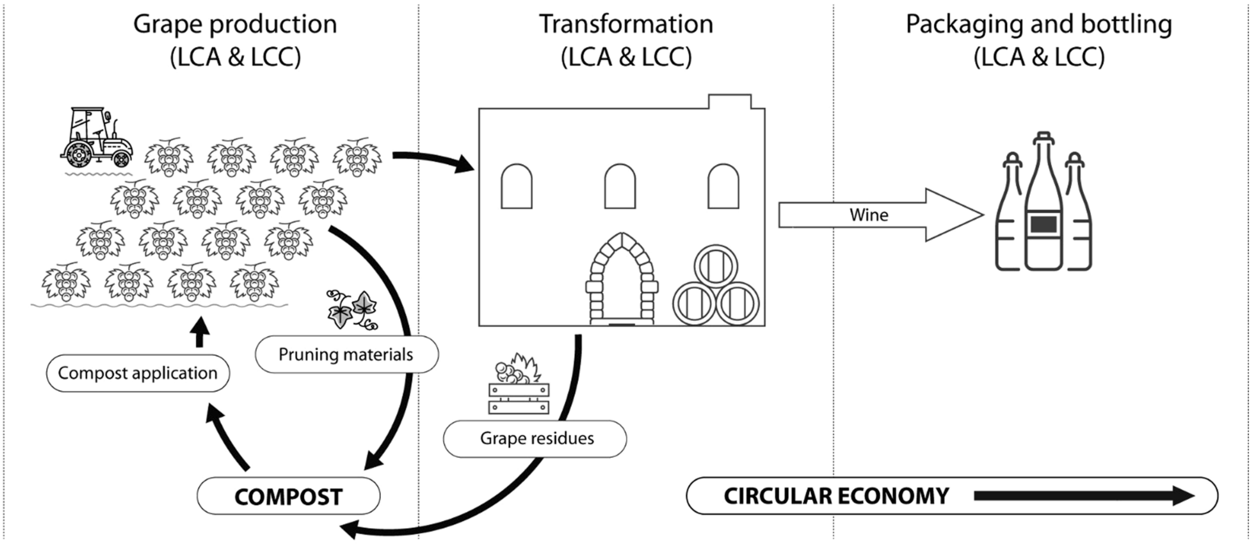

**Fig. 1.** Methodological approach followed to apply LCA and LCC in the SME supply chain and CE assessment.

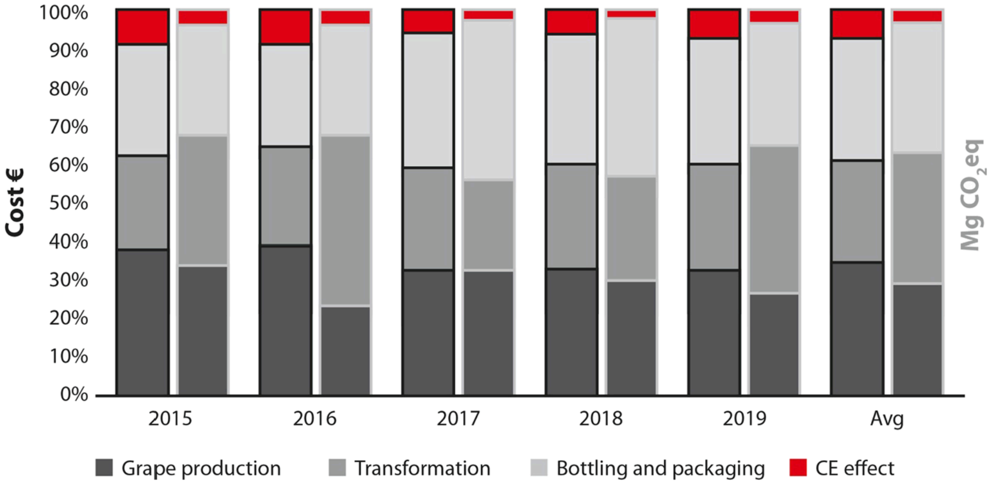

**Fig. 2.** Economic and environmental impact of three activities – grape production, transformation, bottling and packaging – and observed effects of the circular economy* **The effects of the circular economy activities are highlighted in red. Black columns represent the economic impact; gray columns show the environmental impact. Values are expressed as percentages of the total cost (in euros) and as total GHG emissions (in Mg $CO_2eq$).* (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

themselves that are directly influencing cost performance, but rather the improvements in environmental performance generated through these practices" (Graham & McAdam, 2016; p. 1350). However, if total annual GHG emissions were considered per ton of grape harvested, the trend for the climatic aspect would be similar to the economic one, with GHG emissions per unit of grapes (i.e. kg $CO_2$eq ton$^{-1}$) becoming higher in years with low productivity. Nevertheless, the recent literature (Chiriacò et al., 2017; Chiriacò & Valentini, 2021) has highlighted the relevance of assessing GHG emissions as total emissions per area rather than per unit of product, because the fluxes in climate-altering gases recorded in the atmosphere come from cultivated land in any given period, regardless of the amount of grapes produced and harvested.

In general, the integrated LCC and LCA approach has proven to be a significant tool for simultaneously assessing the economic and environmental sustainability of a wine firm. In addition, this approach highlighted the main critical points in the production process in terms of economic and/or environmental costs, thereby suggesting which further actions could be carried out to increase efficiency and improve performance.

As regards the second research question, this study showed that a CE approach applied to the wine production process facilitates environmental and economic sustainability in SMEs. In fact, our findings suggest that the development of CE practices was positively associated with environmental and economic performance. In line with previous studies (Prieto-Sandoval et al., 2018), our findings highlighted the benefits and opportunities of adopting CE strategies in terms of reduced costs and avoided $CO_2$ emissions. Although specifically focused on the effects of organic waste reuse, our results showed average annual cost savings of €4,759 (corresponding to €508.46 per hectare) and 86 kg $CO_2$eq per hectare of GHG emissions avoided. However, the re-use of agricultural waste for the production of on-farm compost, as an example of the circular food economy, should be carefully considered and proposed only in organic agricultural systems, since glyphosate-based herbicides and other chemical residues in compost from the agricultural waste generated in intensive and conventional farming can lower crop yields (Muola et al., 2021) and pose serious risks to the environment and human health.

### 5.1. Theoretical implications

This study offers some important theoretical contributions. In line with other scholars (Kusumowardani et al, 2020), we connected the concept of the CE and the NRBV in terms of resource recovery through the collection of organic waste (Beres et al., 2017) that is composted and then reused. In this manner, our study has provided new insights into the debate surrounding sustainability and the circular economy in SMEs (Dey et al., 2020; Namagembe, 2021; Calicchio Berardi, 2019; Esposito et al., 2020; Beres et al., 2017) by adopting a pollution prevention approach as part of NRBV theory (Hart & Dowell, 2011). Compared to previous contributions mainly focused on large corporate organizations (Kumar et al., 2019; Parida et al., 2019; Zhu et al. 2010), we broadened knowledge of the role and effects of the CE by focusing on the micro level through an investigation of an Italian SME in the wine industry. Recent understanding of the CE is multilayered and conceptual, and theoretical consolidation is very welcome (De Angelis, 2022; Webster, 2021). Specifically, our analysis confirmed that CE practices can increase not only environmental sustainability but economic performance as well, by generating significant cost reductions (i.e. organic waste reuse for on-farm compost production and application saved the winemaker an annual amount of €4,759 and 86 kg $CO_2$eq per hectare of GHG emissions were avoided).

As with previous studies (Green et al., 2012), this paper confirmed that there is a relationship between economic and environmental performances in firms that implement a sustainable business model. Specifically, a combined LCC and LCA approach has proven to be a valuable tool to lay bare the link between the economic and environmental costs of the winemaking process, showing positive outcomes in terms of both GHG emissions and lower costs when sustainable and circular practices are applied (confirming previous results in SMEs, as in, for example, Selech et al., 2014). This result emphasizes the prevention of pollution by firms that pursue environmental strategies (Hart & Dowell, 2011) while they achieve a significant and sustainable competitive advantage over time (Atkin et al., 2012). It should be added that, according to some scholars (Kambanou & Sakao, 2020; Bierer et al., 2015; Rudenauer et al., 2005), the parallel use of LCA and LCC is a research topic that requires still more investigation. This study contributes to bridging the gap between LCA and LCC as sustainability assessment tools, providing a better understanding of how to integrate both methods to obtain an optimal assessment tool (Zhang et al., 2020). Our results confirm previous analyses (Hoogmartens et al., 2014) that highlighted the advantages of combining LCC and LCA (e.g., helping to improve supply chain efficiency and integration).

### 5.2. Practical implications

Our findings suggest practical implications for organizations and managers in relation to the implementation of pollution prevention strategies which focus on the reduction of organic waste within the internal production process. Our findings should provide convincing support for managers to implement (or improve) environmental strategies, namely CE strategies, regarding resource recovery (organic waste) (Beres et al., 2017), which can be composted and then reused in vineyards as organic compost. Firstly, we demonstrated that these resource recovery strategies – arising from the collection of organic waste from pruning and vinification and its reuse as compost on the farm – have the potential to improve environmental performance, which is an increasingly important requirement for organizations such as SMEs. In this vein, we recommend managers implement resource recovery measures that contribute to achieving a firm's environmental management goals, reducing GHG emissions and enhancing fertilization and weed control. For instance, to do so, managers should rethink the production process by equipping farms with appropriate machinery (such as pruning shredders, tractors with trailers, or facilities for compost fermentation and handling). Secondly, implementation of resource recovery strategies can also have a wider impact on financial dimensions, with cost reductions within the 'integrated' supply chain in which SMEs produce, transform and interfaces with their distribution channels. This offers some valuable insights for SMEs that may have so far been hesitant regarding the potential benefits of implementing environmental strategies because they have greater strategic constraints than larger companies regarding resources and capabilities (Del Brìo & Junquera, 2003).

In addition, our results have demonstrated that adopting LCC and LCA could become a key strategy for organizations, since this approach would allow them to closely monitor economic costs and GHG emissions in their supply chains. This integrated approach would also provide a key business management tool to assess the efficiency of the various production phases, identify weak points, and act accordingly by implementing appropriate and tailored solutions. Such an integrated approach could indeed be a valuable tool for managers and other stakeholders (policymakers, landowners and land planners, etc.) when designing more efficient management strategies not only at company level but also in consideration of the potential interoperability of firms in their own and other sectors.

## 6. Conclusions

The main contribution of this study is the adoption of a methodology based on the integration of the LCA and LCC approaches and the assessment of CE implementation strategies at a wine SME. The aim of this study was to use the lens of the NRBV to assess the relationship between the economic and environmental performance of a small Italian wine firm implementing sustainable management and the circular economy by simultaneously combining LCC and LCA. These methods were applied to each phase of the production process, using the amount of GHG emissions (in $CO_2$eq) as the main environmental indicator and unit costs (in euros) as the main economic indicator. The CE was assessed in terms of resource recovery, specifically measuring the economic and environmental effects of the collection of organic waste to be composted and then reused in vineyards as organic compost. The results of our study showed that the adoption of sustainable and circular approaches in this winemaking SME generated positive outcomes in terms of both environmental and economic sustainability, with a reduction in greenhouse gas (GHG) emissions and improved cost savings.

## 7. Limitations and orientation for future research

Carrying out a single case study is a leading research method that provides important insights in business studies (Leone et al., 2021). However, we need to be careful about generalizing our findings and conclusions to other sectors, especially those not based on agriculture. We assume that "the wine industry is comparable to many fragmented industries dominated by SMEs (Hamann et al., 2017), and thus, serves as an appropriate context for the objectives of this study" (Tyler et al, 2020; p. 456).

The main limitation of this study is related to the absence of an assessment of social impacts. Further studies could extend the joint LCC and LCA approach by including an assessment of the social impact in SMEs, integrating the three columns of sustainability (environmental, social, and economic) when CE strategies are analyzed (Alejandrino et al., 2022; Acerbi & Taisch, 2020; Moreau et al., 2017; Vinante et al., 2021). For instance, social assessments could be integrated into the methodology adopted in this paper by analyzing the social impact that CE strategies could produce on the firm's stakeholders (e.g., reducing workers' labor or improving supplier relationships) (Alejandrino et al., 2022).

In addition, this research focused on Italian winemaking SMEs, whereas future research could focus on and compare companies in other winemaking countries and territories – for instance, the so-called 'New World producers' (Pomarici et al., 2021) such as Chile, the Napa Valley or South Africa (Hussain et al., 2008). The significance of such a study would be the opportunity to discover new insights on sustainability, since a single and unified approach "is a little complicated due to the special environmental issues of different wine-growing regions" (Maicas & Mateo, 2020, p.1).

Additionally, it would be interesting to extend the research to the agri-food industry (Esposito et al., 2020), given that the circular food economy is at the core of the EU Green Deal and its Farm-to-Fork Strategy and Circular Economy Action Plan. In this vein, both economic and environmental performance could also be analyzed at the landscape level, where a number of firms can apply sustainable and CE strategies in a coordinated framework (Chiriacò & Valentini, 2021).

## CRediT authorship contribution statement

**Rita Mura:** Writing – review & editing, Writing – original draft, Supervision, Methodology, Data curation, Conceptualization, Formal analysis. **Francesca Vicentini:** Writing – review & editing, Writing – original draft, Conceptualization, Formal analysis. **Ludovico Maria Botti:** Data curation, Conceptualization. **Maria Vincenza Chiriacò:** Writing – review & editing, Writing – original draft, Methodology, Data curation, Conceptualization, Formal analysis.

## Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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