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Rethinking Sustainability within the Viticulture Realities Integrating Economy, Landscape and Energy

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Abstract: Sustainability is often explained through three dimensions (society, economy and environment). However, such a definition currently appears to be restricted. Sustainable development often includes the energy issue. An example of realities founded on bioenergy are agro-energy districts. These realities involve all the three dimensions of sustainability, integrating also the energy dimension and fueling a potential circular economy. Based on these premises, the most affluent rural subdivision in Italy is that of wine. The wine sector has experienced a recent growth of its economic market, diverging from other agricultural activities and enlarging its cultivated surface areas. In this sense, the local landscape has also changed. Owing to the strong inclination of the wine sector in adopting sustainable strategies and measures, agro-energy districts can be the following future phase in viticulture realities as a cutting-edge business in the modern agricultural sector, implementing new strategies and opportunities.

Keywords: sustainability; viticulture; agro-energy districts; circular economy; landscape; energy

1. Introduction

Sustainability is often explained through three dimensions: society, economy and environment [1–4]. However, such a definition currently appears to be restricted [3,5–7]. Sustainable development often includes the energy dimension, e.g., to guarantee a suitable energy efficiency [8–11]. Though energetic sustainability considers both energy required to achieve a task and that can be retained by the power supplied from the environment [12,13]. In literature, several contributions aimed at explaining why sustainability does not include the energy dimension, stressing on economic processes that do not take energy into consideration [14,15]. In this sense, new theories were born. For instance, bio-economy assumed a meaning in recent years that binds energy and economy, strengthening and comprehending environmental and sustainability issues [15,16].

In this framework, bio-economy assumes a decisive role in the development of local rural realities [17], combining economic growth and respect for the environment [18]. In countryside areas, the energy component can be merged with sustainable development [10,11,13] by creating agro-energetic districts [19]. The global energy state is generally characterized by agricultural residues, a dependence on firewood, animal power and manure to cover primarily subsistence energy needs. Therefore, rural areas can offer a large energy contribution in the form of biomass [20]. Biomass constitutes the main global energy source for almost 50% [21]; for instance, wood biomass is a current key renewable energy source, on behalf of a relevant amount of rural energy supply [22].

As a solution for socioeconomic, environmental and political issues [23], bioenergy is based on the sustainable use of renewable resources (e.g., solar plants) and biomass (e.g., agricultural wastes), taking up a real choice for the supply of energy services [24]. For instance, various benefits derive from it, ranging from the simple energy provision to opportunities for regional growth [25].

Working as a network of local agricultural firms, agro-energy districts can be an example of realities founded on bioenergy [19]. Achieving energy self-sufficiency, such local network attempts to guarantee simultaneously zero impact energy compared to fossil fuels, rural development, food security, local self-sufficiency, sustainable agricultural management, biodiversity, conservation and climate change mitigation [26]. Agro-energy chains can provide innovative local solutions, both in terms of advanced technology, management and economy in the primary sector using local and regional biomass supply [19,27–29].

Even if agro-energy districts are defined as highly sustainable systems, some research activities also addressed that an increasing expansion of these realities can cause over-exploitation of soil fertility, undesirable changes and conflicts among different land-use choices [3,19,30–32]. This assumption derives from often speculative actions cause unsuitable manipulation. For instance, in the last decades, solar plants have had a strong expansion in Italy. While they offer energy from renewable sources, a large amount of agricultural land has been occupied by solar plants, turning out negative processes of soil degradation [33].

The identification of energy districts in rural areas highlights the lack of appropriate tools for decision making and planning at the different scales. Planners must apply an interdisciplinary approach to select the most appropriate method of analysis. Identifying and applying an effective planning methodology to be applied throughout the European community is essential [34].

The objective of the present article is to examine the notion of 'sustainability', adding a fourth dimension, which is that of energy. In Italy, the only driving subdivision in the agricultural sector is the wine industry [35]. Wine products experienced a strong interest in the last years, especially due to its economic market. Furthermore, thanks to the reform concerning the common wine market organization (CMO) [36], a lot of rural abandoned lands have been reconverted for viticulture practices in Italy. Since the European Commission published the expenses for the national support plan at the European level in recent years, Italy is the country that has economically invested more (€11,700 for 28,000 hectares under renovation for a total of €325 million) than other countries, as France (€4300 for 51,000 hectares) and Spain (€3700 for 47,000 hectares). The expansion of the wine market has brought landscape changes and/or homogenization, particularly in areas where this crop can be most suitable. The establishment of agro-energy districts can become a cutting-edge business in the modern agricultural sector, implementing new strategies, even of a sustainable nature, by several networks actors. Following previous works (e.g., [32]), the present work evaluated how the Italian landscape has changed in just over a decade (2000–2012), estimating how much biomass from the wine industry can be obtained.

1.1. Sustainability and Energy Dynamics in Local Economies

Stressing on an innovative economic growth of rural contexts, arose the need to take environmental measures [37], the concept of sustainability has taken on a broader meaning [38]. Sustainable development policies and strategies must achieve a reliable equilibrium between economy and ecosystem protection, (i) reconciling production and environmental requirements and (ii) ensuring competitiveness and local attractiveness [39]. Nevertheless, quantitative methods to support local sustainability are lacking [40] since the complexity of the notion of sustainability makes it difficult to predict which policy can better integrate human needs, economic growth and environmental quality [41]. In this framework, emerging renewable energies (such as biomass) have become an essential element for encouraging and supporting the development of rural areas [42]. Taking operative actions and restricting negative effects on the local environment, several studies proposed modelling techniques for economic, energy and environmental analysis concerning agro-energy supply chains and their locations [43]. The sustainability existing in agro-energy supply chains involves not only (i) energy and the use of renewable energies, but also embraces (ii) environmental issues, by improving the socio-economic sphere such as (iii) the level of different farmers and (iv) the local income [38,41,43–47].

2. Materials and Methods

The methodology followed various steps. Firstly, a descriptive stage of the wine sector was applied in Italy, in terms of production data concerning both offer and foreign trade. Secondly, a spatial exploration was performed by observing landscape changes and land-use dynamics. In this respect, the Italian regions that have witnessed a greater growth for the wine sector in the last years emerged. Veneto region was one of these contexts and therefore was investigated in the present study. An estimation of the amount of biomass that can be obtained from the contexts considered allowed an assessment of energy and potential mechanization processes, as well as an economic evaluation.

2.1. The Viticulture Sector in Italy

Despite an incessant decline of the primary sector, mainly in peri-urban areas [48], Italy experienced a growth rate in the wine sector. The Italian country embodies the second largest wine producer recording a world market share of 16.4% and a turnover of €10.5 billion [49–51]. The rising demand, even foreign, of Italian wine resulted into a strong increase in recent decades [35]. The growing devotion that wine sector dedicates on quality allowed to create a reference point for data and analysis of the Italian wine heritage [52,53], which boasts 523 protected products with designation of origin (PDO) and protected geographical indication (PGI) (Figure 1 and Table 1).

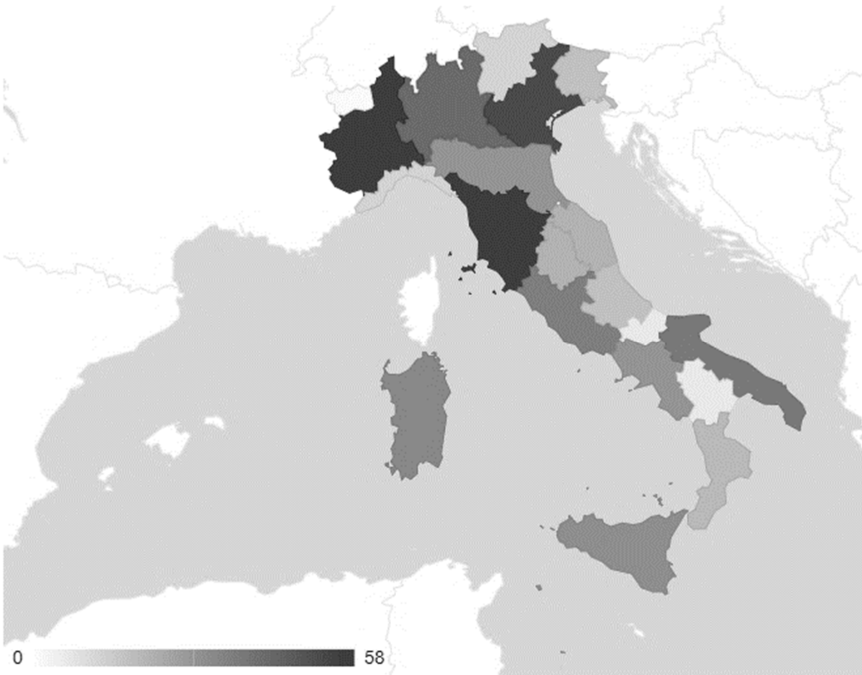

Figure 1. The list of denominations: ratio between PDO and PGI products.

As in other European countries, numerous sustainable practices have already been implemented by many firms in the wine industry during the last years, based on voluntary standards, management systems and specific agendas [35,50,54,55]. Compared to other agricultural activities, the wine industry as an evolving economic activity resulted to be very inclined to achieve a rich set of tasks through its specific organizational capacities and resources [50].

Table 1. Summary Framework of Wine Industry (2011–2013).

Offer	2011	2012	2013	V%	μm	Foreign Trade	2011	2012	2013	V%	μm
Production (*)	42,705	41,070	48,161	11%	thousands hl	Import (*)	298	306	321	7%	millions of €
Weight of denominations (Doc/Docg) (*)	33.1	33.0	36.1	8%	% q.	Import/ consumption	7.7	11.6	12.9	40%	% q.
Production/ consumption	223.6	190.1	238.4	6%	% q.	Weight on the tot. Agribusiness	0.74	0.77	0.79	6%	% v.
Industry turnover (***)	11,235	12,010	12,587	11%	millions of €	Export (*)	4405	4695	5039	13%	millions of €
Weight on sales ind. Agroal. (***)	8.8	8.0	8.0	−10%	% v.	Weight on the tot. Agribusiness	14.6	14.7	15.1	3%	% v.
DEMAND	2011	2012	2013	V%	udm						
Total apparent consumption (***)	19,100	21,600	20,200	5%	thousands hl						
Apparent per capita consumption (***)	32	36	34	6%	Liters						

Source: (*) Istat, (**) Agea, (***) Ismea.

The effects of recent trends in the wine sector are visible on the local landscape [35]. Using Corine Land Cover maps, vineyard realities and landscape changes can be observed during three-time periods (2000, 2006 and 2012). The growing hectares for vineyards have been supported by a profitable market, noticeable in many Italian regions [51]. The spatial elaboration was implemented through a Geographic Information Systems (GIS) [56,57], extracting only the class of vineyards. Specifically, economically relevant areas such as in Tuscany and Veneto regions recorded an increasing cultivated surface area (Figure 2), allowing an improved production of their typical wines (e.g., Chianti and Prosecco) [51,58].

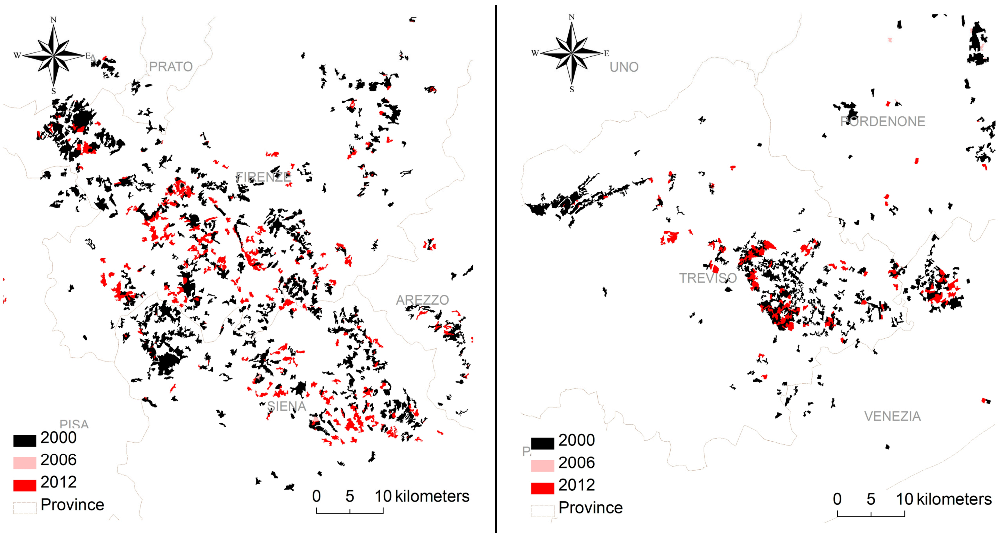

Figure 2. Land-use trends concerning vineyards in Tuscany (**left**) and Veneto regions (**right**).

2.2. Local Case Study

Performing all the operations required for data collection, 16 Italian vineyards were analyzed. They are in the provinces of Treviso, Pordenone and Udine, in the northern area of Italy. This territorial context was assumed as a local case study since it is strongly devoted to the wine production. The examined vineyards cover a surface area of 30 hectares. They were selected according the type of harvesting site and the extension of the plot (width > 1 hectare). Operations were carried out providing a reliable data source on a real working situation. Each vineyard was scheduled according to several characteristics (statistics for each firm, relating to the management techniques and/or mechanization processes). A set of specific data identifies each context in analysis such as: the name of the firm; geographical localization (e.g., province, municipality, location, address); the collector as the firm that carried out the collection; and the distance from the transfer center (expressed in kilometers). Time references specify each stage of the process (e.g., date). The structure of each vineyard was described by specifying its surface area (expressed in hectares), spatial position and detailed measurements (e.g., inter-row line and distance between wine rows in meters, number of homogeneous rows). The features on the pruning management were stated according to: year of planting of the vineyard; variety of cultivated wine crops; vineyard breeding system; type of pruning (manual or mechanical); and ratio between the number of rows and that of bands (Figure 3).

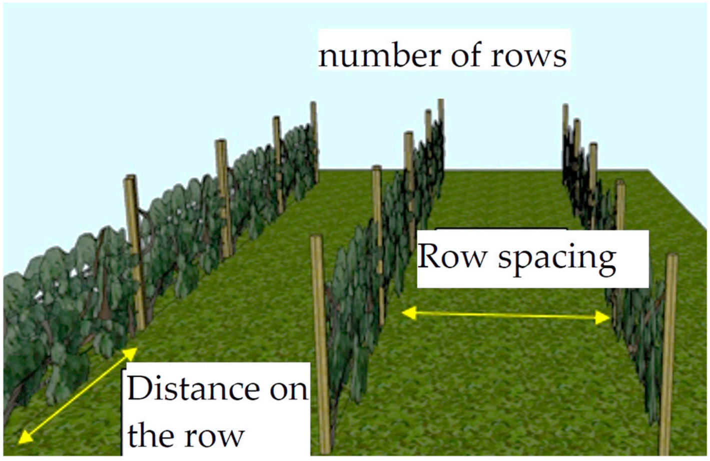

Figure 3. Graphic processing of parameters detected in each vineyard.

2.3. Field Sampling Tests

Field sampling tests essentially involved the collection, the weighing of the resulting pruning material (aimed at estimating the residual biomass production) and the timing collection. An estimation system (called "grid") was used. The availability of the resulting biomass depends on many factors [59,60]. For weighing operations, a data acquisition method was drawn up, following the UNI EN 14778/2011. This normative directs which methods applied for the preparation of plans and certificates and for the taking samples of solid biofuels (e.g., cultivated areas). After weighing operations, a representative sample was collected and subsequently analyzed in the laboratory. The instrumentation used for sampling tests was variegated, e.g., georeferenced camera, adhesive labels for the classification of samples etc.

3. Results

3.1. Landscape Changes

Using elaborations maps from Corine Land Cover dataset, vineyard expansion has risen to landscape changes. Due to the profitability of wine production, especially if of high quality, spatial transformations concerned a land conversion towards viticulture uses, leading to a homogenization of the local landscape. This phenomenon occurred in areas owing a consolidate commercial system based on wine, which results to be a chief product for their local economy.

The economic realities analyzed in the present study are placed in some municipalities in Northern Italy given the recent and exponential development of the wine sector in this context. Especially, the work focused on the provinces of Pordenone, Treviso and Udine, which recorded a growing surface area designed for vineyards with positive rates, respectively of 9%, 21% and 23%. As detected in Figure 4, a rapid expansion of vineyard-grown areas in 2012 was witnessed in these contexts, where their wine products are even marked with PDO and PGI labels.

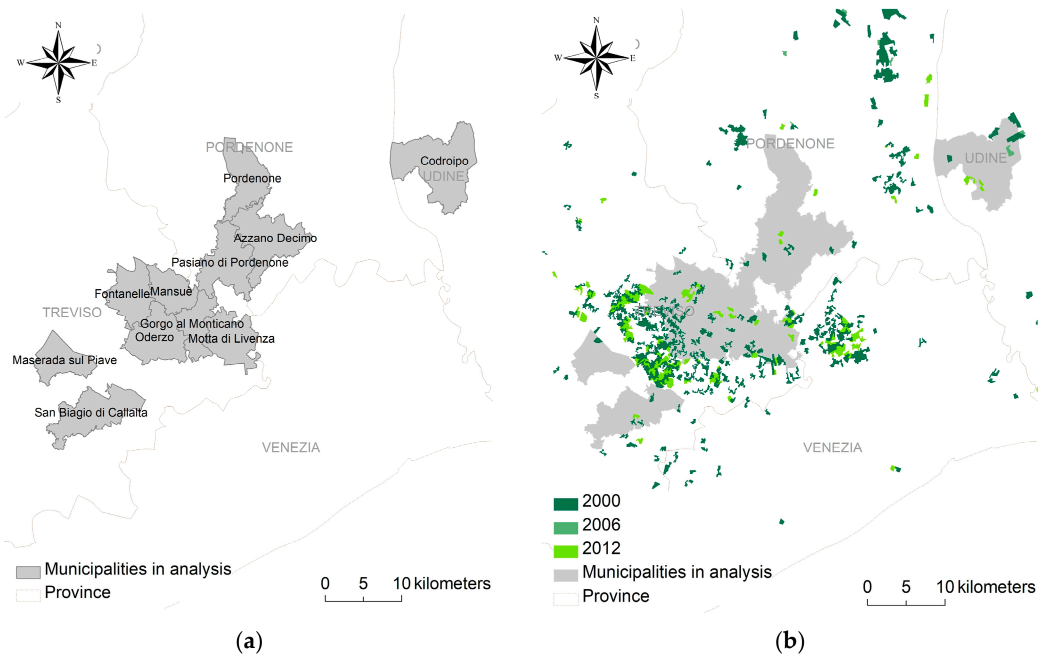

Figure 4. Municipalities where are located the economic realities analyzed (**a**) and the expansion of vineyards over time (2000–2012) (**b**).

356 homogeneous rows were detected at the local scale, occupying about 4140 m of wine rows. Furthermore, the distance between the work sites considered and the supply centers for the harvested product was evaluated. Looking for energetic and economic sustenance, an optimal distance from the supply centers was fixed at 30 km. The nearest distances were 1.5 km away while the furthest one was 37.5 km away.

3.2. Energy and Mechanization Assessment

Results confirmed that around 2 tons of biomass/year can be obtained from viniculture activities. A production of about 1,540,000 tons/ha/year (water content of 50%) can be estimated in Italy. Referring to dry matter, the vine wood has a lower calorific value (19.8 MJ/Kg), higher than spruce (18.8 MJ/Kg) and beech (18.4 MJ/Kg); then, it has an ash content between 3% and 4% with a melting point higher than 1400 °C. Considering the calorific value (water content of 50%), it amounts to 2.4 kWh/kg, producing 3,141,600 MWh/year of thermal energy (energy obtainable from about 273,182 tons of diesel). Assuming an annual activeness of boilers for heating of 1500 h, it reaches a total thermal output of 2094 MW. Producing cogeneration, it could get 628,320,000 kWh of electricity and 2,513,280,000 kWh of thermal energy.

Results established that the quantity of shoots per hectare fluctuates from 1.7 to 3.9 tons; while, considering the dry weight, it varies from 1.0 to 2.5 tons per hectare (Figure 5). The average water content diverges from 37.3 to 47.6% (Figure 6).

Evaluating these contexts in energy terms, four work sites were analyzed during the biomass harvest: shredding of wine shoots (i) with and (ii) without harvesting; (iii) packing of bales of 1.2 m × 1.5 m; and (iv) packing of bales of 0.6 m × 0.4 m. The work sites all work in commune. A preliminary step allows the turning of wine shoots, usually accumulated in alternate rows, an easier turning maneuver and an optimization, in terms of time, of the subsequent processing.

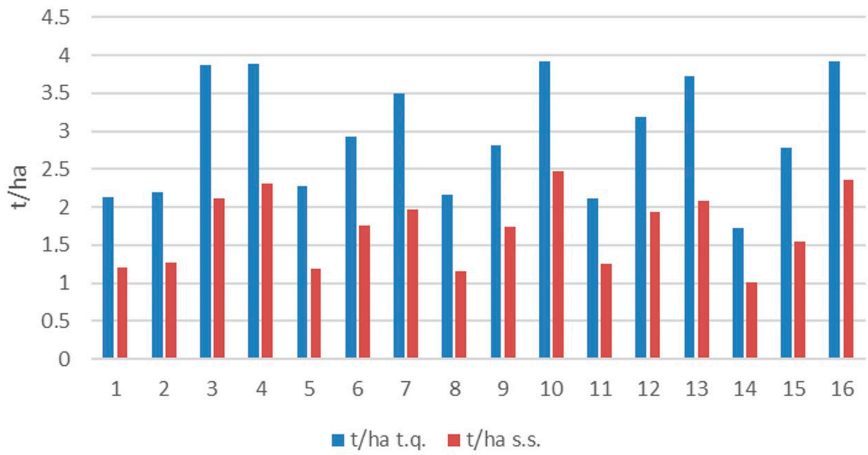

Figure 5. Number of shoots on the ground in each case study.

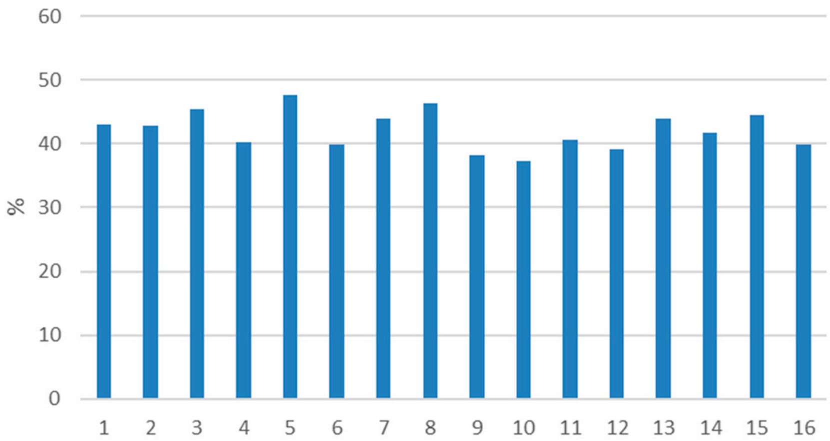

Figure 6. Average water content of shoots in each case study.

Excluding the number of shoots per hectare remained on the ground after mechanization processes (0.08 to 0.52 tons per hectare with an average water content from 33.6% to 46.3%), results from gasification test showed that vineyard pellets are a biofuel with homogeneous characteristics. The syngas composition is suitable for motor power supply, where process conditions were stable and highly repeatable. The formation of ash and tar with wine pellets is slightly higher than wood pellets, but not critical. Furthermore, no fusion slag formation was observed in the reactor. The filter must be replaced a bit earlier than normal: with a used filter the pressure rises to a rate of 5 mbar/h, with a new filter at 1.5 mbar/h (therefore in the standard). The experimental test has therefore had a positive outcome since wine pellet therefore seems potentially usable in micro cogeneration units based on the gasification process.

Assessing energy sustainability exposed that both the production chains of the wood chips and the chains to produce pellets are energy-efficient. The chains with collection sites in small bales and large bales are the (energetically) less impacting ones, while the dies with the in-line and parallel forage harvester are slightly more energy-intensive. The comparison with fossil-based diesel also demonstrated the great convenience for the collection and use of wine pruning for energy purposes.

3.3. Economic Evaluation

To exhaustively evaluate economic advantage to turn out wood chips, pellets and briquettes, four wine's collecting and processing chains were analyzed by packing site in: forage harvester on line (TCL), parallel forage harvester (TCP); large bales (BG); and small bales (BP) (Table 2).

Table 2. Cost of different operations of collection and transformation of wine shoots.

Operation	Minimum Cost (€/tons)	Maximum Cost (€/tons)	Water Content *
Forage harvester on line	20	30	35
Parallel forage harvester	64.5	64.5	35
Large bales	25	30	35
Small bales	34	40	35
Chipping	25	33	25
Transport	10	15	25–35
Storage, natural drying and handling	7	10	25
Shredding pre-densification	5	10	10
Briquetting with plant amortization	75	85	10
Pelleting with plant amortization	85	110	10

* expressed as a percentage.

The economic data related to the various cost items refer to those in the AIEL database-Italian Society of Agroforestry Energy and other bibliography.

From the economic analysis of the production chains, the average production cost of wood chips from wine shoots ranges from 46 to 87 €/t. This supply chain is not as expensive. The average cost of total production of briquettes has a range between 133.5 and 174.5 €/t. The highest cost derives from the densification operation that normally equals (or even exceeds) the cost of all previous operations. The average total production cost of pellet from agricultural origin falls within a range between 151 and 192 €/tons, resulting the most expensive one.

Considering the average costs of products in the hypothetical economic market, which are around 80–110 €/tons for wood chips, 150–180 €/tons for briquettes and 185–220 €/tons for agricultural pellets (all VAT excluded), following the AIEL database, all chains appeared to be economically practicable.

Regarding transport costs, a maximum distance of 30 km from the transfer center was assumed. This value can be used as limit of cost-effectiveness of the supply chain. While bales are always transported on an agricultural trailer, pellet chips can be transported on an agricultural trailer towed by a tractor on shredder loading yards. Among additional costs, there is also the manpower of a tractor operator.

Finally, the construction sites that are on average less expensive from an economic viewpoint, such as forage harvesters, are the most impacting ones; while, the packing yards, which are more economically demanding, are energetically less expensive.

4. Discussion

Explaining (and achieving) sustainable development in local contexts, the typical three dimensions (economy, society and environment) may be restricted [3,5–7,13]. The notion of "sustainability" appears rather limited today since it is integrally normative, complex, subjective and vague [61]. Reflecting on the role of energy [9,10], landscape and land-use changes emphasizes an additional intrinsic value meant for sustainability. Additionally, sustainable development requests an acceptable supply of energy resources, available in the long term and at reasonable costs, deprived of undesirable social impacts [11].

Being the most damaged in recent decades, rural areas require a confident change based on the principles of multifunctionality [48,62]. In the present work, the wine sector has been used as an interesting economic reality in the Italian framework. The conversion of many hectares from abandoned farmland to vineyards has led to different land-use changes. The importance of managing territories starting from their land-use destination is essential to protect local identity, landscape and biodiversity [3,63–65]. Particularly specific areas, which founded their economy on wine products, have seen a homogenization of their landscapes. This fact often coincided with the presence of wines with PDO and PGI labels, as prosecco wine in Veneto region. Additionally, outcomes confirmed that the increase in the quality of the wine sector has involved the whole Italian country.

The wine sector can also strengthen the local identity and offer job opportunities [58], even in the form of seasonal work. In this context, it would be useful to deepen the role of job market and social influence on an economic reality, such as viniculture [66–69]. Increasing its social and employment backgrounds, a network of actors can be established through local districts that can integrally and spatially perform among different (socioeconomic) realities promoting a larger vision that also embraces the energy dimension [13]. Agro-energy chains within specific territorial areas might interrelate and advance synergies, while also lowering production costs [27]. In this regard, using biomass for energy as part of a sustainable development approach is deeply discussed since many concerns emerged about sustainability [3]. Bioenergy systems can be defined as complex systems having an impact on many kinds of scales (e.g., society) [32].

Establishing a spatial system based on circular economy [57], the benefits of an agro-energy district, compared with conventional systems, appears to integrate different dimensions (economic, society, environment and energy), increasing the denotation of sustainable development [13,19,27,70]. It may vary based on different crops, regions and technologies employed; particularly, certain damaging processes can be limited (or better avoided) in specific highly-sensitive areas to degradation processes such as soil erosion, also contributing to a real loss of biodiversity [3,63,71–73].

Agro-energy planning needs a complex investigation based on an integrated analysis of the local availability of biomass resources and the environmental impact of energy crops [32,74]. In this perspective, the present work also focused on energy and environmental viewpoint. Several studies have progressively assessed the combustion of pruning shears at different scales, confirming the environmental (and even energetic) sustainability of wine biomass [41,59,70]. The evaluation of the quality of atmospheric emissions from the combustion of pruning plants can confirm the degree of sustainability obtained from the combustion of biomasses. However, it is necessary to investigate this issue in greater depth to optimize the combustion methods of possible thermal plants and to ensure both a safe energy process and an emission level compatible with current regulations [59].

Furthermore, new technologies can assist in assessing agro-energy districts [32]. Multicriteria methods through Geographic Information Systems (GIS) are mainly suitable for both the spatial analysis of biomass supply systems and decision support in the bioenergy sector [56,57,75–78].

Sustainability has turn out to be a crucial matter for the wine industry [79] since the amounts of wine residues produced annually have grown in Italy. Following the existing literature, over 4 tons of biomass/year can be obtained from viniculture activities [59]. However, the results obtained confirmed that data around 2 tons/hectare/year are more reliable. From its pruning practices, a biomass production can be estimated equal to an average of 1.5–2.5 tons/hectare/year (water content of 50%). The results obtained recognized that the quantity of shoots per hectare fluctuates from 1.7 to 3.9 tons; while, considering the dry weight, it varies from 1.0 to 2.5 tons per hectare. The average water content diverges from 37.3% to 47.6%. This variability in the production of residues is linked to many factors, such as structure, geographical location and position of the vineyard [59,60].

From the economic investigation, different scenarios can be depicted. However, the reuse of rural residues brings about the cheapest strategy for local sustainable development as wood chips from wine shoots range from 46 to 87 €/tons.

By integrating the four dimensions (energy, economy, society and environment) that can lead to greater sustainable development, agro-energy districts applied to realities such as the wine-producing ones may be an emergent phenomenon that provides a new scenario of rural areas in the evolution towards a sustainable (energy) future. However, the present research suggests that further development of policies, strategies and networks of local actors must be structured and well managed to accomplish long-term positive consequences.

5. Conclusions

Exploring the concept of sustainability, current territorial systems dealt with innovative and complex development scenarios. In this sense, the energy dimension is integrated with the socioeconomic and environmental extents. Rural areas, being the most damaged in recent decades, require a confident change towards sustainable development based on the principles of multifunctionality. Viticulture realities can be an interesting study context in Italy given their current influence in the national and foreign economic market. It can be described as a cutting-edge business since it has implemented numerous development policies and opportunities. Owing to its strong predisposition in adopting sustainable strategies, agro-energy districts can be the following future phase in viticulture realities establishing a circular economy through the application of bioenergy and based on the respect of the local landscape and environment.

Author Contributions: A.C. and M.C. conceived and designed and performed the experiments; I.Z. analyzed the data; A.C., M.C. and E.M.M. contributed materials/analysis tools; I.Z. wrote the paper.

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