Planning the Integrated Management of Organic Waste Flows and Agricultural Residues for a Circular Economy

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Abstract

In the recent years, the production, management and disposal of both organic waste and agricultural residues has become significantly difficult in Italy, due to the lack of suitable facilities. Very often, indeed, within the different regions, there are no treatment plants for the organic fraction of municipal solid waste or agricultural residues treatment centres, so as to give them a second life in the perspective of a circular economy. The lack of proximity treatment centres, forces local administrations to send these flows to plants outside their territorial area, with a consequent increase for transport and treatment costs.

This paper, with reference to the study area of the Matera municipality (Basilicata region - Southern Italy), taking into consideration the organic waste flows of non-domestic users from separate collection and agricultural residues - especially those coming from the wine production chain - provides a state-of-the-art analysis of the problems related to their collection, management and disposal. Subsequently, an alternative model feasibility study - called "*proximity composting*", aimed at a more sustainable management of these flows based on their "zero-kilometers treatment" – has been implemented.

The results obtained have demonstrated that the proposed scenario is much more sustainable when compared to the current situation, both from an economic and environmental point of view. Indeed, thanks to the use of calculation tools, the economic (€/year) and environmental (Kg CO_2 avoided/year) advantages, due to the save of transport and disposal of flows outside the region, have been quantified, with consequent reduction of waste tax for citizens (€/year). In addition, the implementation of maps using a Geographical Information System (GIS) has demonstrated a better optimization of the system. Finally, it was highlighted the social utility of the proposed model, because citizens become an active part in the process and self-produce soil fertilisers.

Keywords: Wine production chain, Proximity composting, CO_2, Waste tax, Geographical Information Systems.

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1. Introduction

The concept of *circular economy* is based on the idea that the value of materials and products is kept as high as possible for as long as possible, in order to minimize the need to introduce new materials and energy, thus reducing the environmental pressure related to their use (European Environment Agency, 2017).

The urgent need to transform the linear model into a circular one is particularly important in the case of agriculture by-products and urban waste.

The improvement of agricultural *co-products*, *by-products* and *waste* is indeed fundamental for the production of renewable biological resources and the conversion of these resources and waste streams into added-value products, such as food, feed, bio-based products and bioenergy (Carus and Dammer, 2018).

Agricultural and agro-industrial activities generate significant quantities of product residuals and organic waste of different types, potentially usable not only as an alternative fuel in energy plants for the production of energy (Statuto et al., 2018), but also for the restoration of soil fertility, as added-value components in other industrial sectors (nutraceutical, cosmetic, etc.), or in the building sector - as a natural additive that could be incorporated into clay bricks to increase their technical performance (Statuto et al.,2018/a).

Subsequently, there are other secondary options that could be exploited, offered in same the agricultural sector, which can contribute to its sustainable development (Statuto and Picuno, 2016). Indeed, mostly in case of residual biomass coming from the wine production chain, there are currently different possibilities of reuse of residues which, depending on the relevant industrial process, may have a very different environmental impact. So, they could find a second life in different areas, e.g.: the pomace as a substrate for plants growth (Diaz et al., 2002; Nogales et al., 2005; Bustamante et al., 2009; Paradelo et al., 2010) or as dyes for the food industry and as antioxidants due to its high percentage of polyphenols (Ping. et al., 2011; Thorngate and Singleton, 1994; Karleskind, 1992); as a raw material for the production of tartaric acid (vinification dregs) (Versari et al., 2001; Braga et al., 2002); stalks as fuel for the electricity and the production of heat (Università Politecnica delle Marche, 2013) or as potent adsorbents for heavy metal removal (Tripathi and Ranjan, 2015); finally, as a raw material for the production of oil and flour (grape seeds) (Bail et al., 2008).

Considering, instead, the activity of management and recovery of *municipal solid waste*, through separate collection, it is possible to obtain interesting by-products to be reused in the circular economy. From the process of aerobic or anaerobic transformation of the organic fraction of municipal solid waste, two products of particular interest can be obtained: biogas, further transformed into biomethane; and quality compost, that is reusable in agriculture.

The organic fraction of municipal solid waste, or bio-waste, is composed mainly of food waste of plant or animal origin and green waste, in an amount that depends on the area under consideration (Eurostat, 2013). According to European recommendations and environmental considerations, this waste must be collected separately at home, to be then biologically treated by composting or anaerobic digestion to ensure the production of high-quality compost, in accordance with new European regulations (European Union, 2008).

The current organizational model of management, treatment and valorisation of organic waste is very complicated and expensive due to the lack of proximity treatment plants. This problem forces local administrations to send these flows to plants outside their territorial area, with a consequent increase for treatment and transport costs.

The imbalance between the various areas of the country, indeed, forces the centre and south of Italy to transfer their organic waste (from separate collection) in other regions, with great economic disadvantages and air pollution for emissions due to the frequent and constant movement of vehicles.

The flows that are not treated but are transferred to landfill, instead, have a high disposal cost, due to the difficulty of finding suitable landfills, with an increase in expenditure on citizens. Even the separate collection itself and in particular the "door to door" model (more widely used) has significant criticalities, such as traffic due to vehicles (especially in narrow streets or, on the contrary, in very crowded and busy streets) with consequent excessive consumption of the road surface as well as emission of CO_2 into the atmosphere; the exposure of the bins on the street subject to bad weather, or the presence of animals; the withdrawal concentrated in narrow time slots; etc.

The same problems concern the management and valorisation of *wine by-products*, currently also complicated by strict regulations and bad practices. They represent a real problem for producers, because they are produced in considerable quantities but concentrated in short periods of the year (September-October, generally).

Indeed, very often they are disposed without respecting the law, reused without relevant results or sent to distilleries, also outside the region, with considerable economic and environmental disadvantages. Therefore, in both cases, at present, both for organic waste and wine by-products, there are problems that weigh on the strategies of the various municipalities and are complicated to manage.

Table 1 shows the main residual materials classifiable as by-products and the processing yields of grapes (Università Politecnica delle Marche, 2013).

Table 1. Wine production and relevant by-products from the transformation of 100 kg of grape.

Entrance (kg)	Exit (kg)	Residues Classifiable as by-Products (%)	
Grapes (100 Kg)	Wine (77 Kg)	Virgin (5.4) and exhausted pomace (4.6)	10
		Grapeseeds	5
		Stalks	3
		Dregs	5

From each one of the winemaking phases, different types of by-products are generated. The stalks are the first to be released. They correspond to the woody part of the bunch and are eliminated during de-stemming. The vinification dreg is the muddy residue that is deposited in the containers, after fermentation, during storage or after authorized treatments, as well as the residues obtained by filtration or centrifugation of this product. This consists mainly of yeast cells produced during alcoholic fermentation, bacteria, tartaric salts, plant cell residues and ethanol (Bai et al.,2008; Naziri et al.,2012).

The main by-product of the supply chain is the pomace, which represents about 10%–30% of the mass of grapes crushed. It is composed of grape seeds, grape skins and stems residues and it consists mainly of unfermented sugars, alcohol, polyphenols, tannins, pigments and other valuable products. The size of the winery and the winemaking methods used directly influence its quantity and quality (Muhlack et al.,2018). Together with the residual sugars, it has other physical (e.g., pH, moisture, etc.) and chemical (e.g., lignocellulose, polyphenols, ash, etc.) characteristics, which are important to consider when pomace is used as raw material (Table 2).

Table 2. Physical and chemical properties of grape pomace and other by-products.

Parameter	Stalks	Pomace	Dregs	Reference
pH	4.4	3.8	4	(Bustamante et al.,2008)
Organic Substance (g/kg)	920	915	759	
Oxidizable organic carbon (g/kg)	316	280	300	
Water soluble carbon (g/kg)	74.5	37.4	87.8	
Total nitrogen (g/kg)	12.4	20.3	35.2	
P (g/kg)	0.94	1.15	4.94	
K (g/kg)	30	24.2	72.8	
Ca (g/kg)	9.5	9.4	9.2	
Mg (g/kg)	2.1	1.2	1.6	
Fe (mg/kg)	128	136	357	
Mn (mg/kg)	25	12	12	
Cu (mg/kg)	22	28	189	
Zn (mg/kg)	26	24	46	

2. Materials and Methods

The study area is the total territory of the municipality of Matera (Basilicata region - Southern Italy) (Figure 1). It has a population of 60,341 inhabitants (Istat, 2019). With a total geographical area of 392,09 Km^2 (Urbistat, 2019) it is the second largest municipality of Basilicata region *(*after Potenza*)* and it is predominantly covered by rural land, with a quite low regional population medium density, equal to 153,9 inhabitants/km^2 (RSDI, 2019). The territory of Matera (403 meters a.s.l.) is characterised by a warm and temperate climate, with an average temperature of 15.4 °C and an average annual rainfall of 593 mm (climate-data.org, 2020). The total agricultural area is 195,596.14 ha (accounting for 19.56% of the regional surface area); 164,300.75 ha are actually used for agricultural production (RSDI,2019).

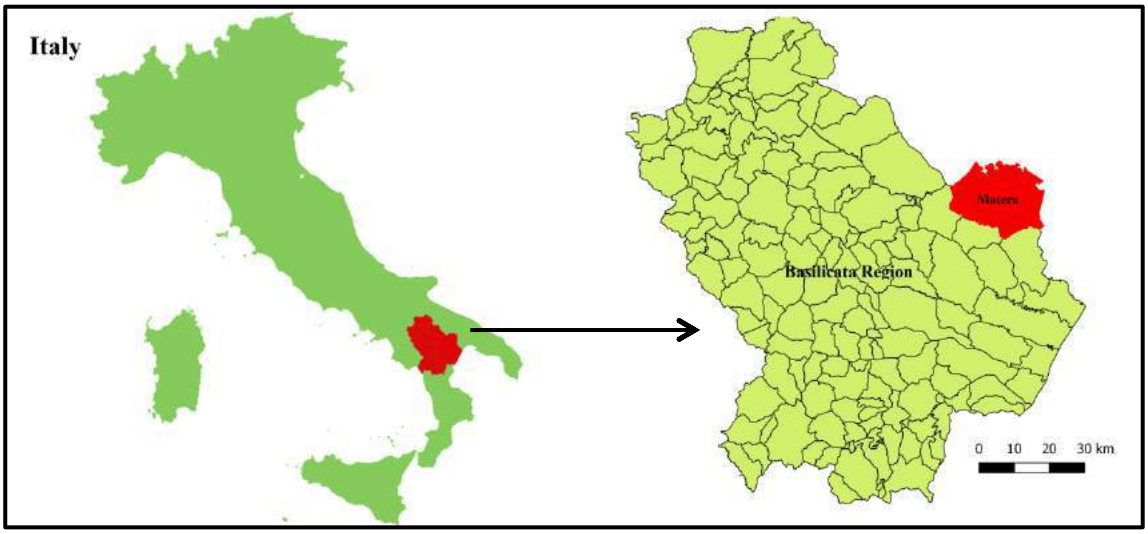

Figure 1. Location of the study area.

Considering the area of the municipality of Matera potentially producing D.O.C. (Denominazione di Origine Controllata – Product of a Controlled Origin) wines, equal to 32% of the total area covered with grapes (25.08 hectares), assuming an annual production of 8 tons/ha of grapes, and calculating the territory dedicated to the whole amount of wine grapes production, the amount of the pomace usable, equal to 200.64 tons, has been determined (Statuto et al., 2018). Moreover, the percentage of the total amount of the ***pomace*** considered in this case is the 10% of wine grapes production, which means a production of about 20.06 tons/year.

Regarding the **organic waste**, with reference to the study area, considering the main non-domestic users most relevant to waste production such as refectories, hospitals, restaurants etc., their urban waste production (t/year) which depends on surface area and on the relative production coefficient (Dipartimento delle Finanze,2018), and taking into account the waste composition in Basilicata region according to which the organic fraction corresponds to 40% of the total production, the total amount of organic waste has been also determined (Table 3).

Table 3. Organic waste production for non domestic users considered.

Category	Urban waste production (t/year)	Organic fraction (%)
Museums, libraries, schools, associations, worship places	313.06	40
Hotels with restaurant	8.64	
Nursing and retirement home	186.40	
Hospital	525.91	
Offices, agencies and professional offices	2,108.6	
Restaurants, inns, taverns, pubs	444.49	
Refectories, breweries	13.21	
Bar, coffee shop, bakeries	120.26	
Fruit and vegetables, fishmongers, flowers and plants	80.93	
Bed and Breakfast	22.27	
Agritourisms	14.21	
Total Organic waste production 1,535.19 t/year		

2.1 Economic and environmental feasibility study of the proposed model

In order to prevent some of the main problems, previously described, regarding the current organizational model of collection, management and disposal of organic waste (from separate collection) and wine by-products, a new integrated model of collection and management of both organic waste of non-domestic users (from separate collection), and wine by-products has been hypothesized, studied and proposed called "*proximity composting*".

This last model, based on "zero-kilometres treatment" of the considered flows, different from the current one (composting in very distant industrial plants), not very sustainable, very expensive and disadvantageous, on the one hand aims to improve the separate collection in individual municipalities, and consequently reduce the amount of organic waste to be treated, on the other hand to give a second life, more sustainable, to wine by-products in the perspective of the circular economy.

The basic organizational idea includes the deposit of organic waste produced by non-domestic users and by-products coming from the wine supply-chain, at a temporary collection centre, located within the municipality itself, that host mini-composting plants (composter) for the production of biological fertilizer, that each user or producer will be able to reuse in their own land, to close the circle of circular economy and restore the level of soil fertility.

In recent decades, indeed, a persisting inadequate substitution of soil nutrients has led to the lack of organic matter (Manniello et al., 2020) and consequent low level of soil fertility (Manniello et al., 2020/a), only partly balanced by the reuse of agricultural residues (Manniello et al., 2020/b).

After analysing the costs referred to the current scenario (Table 4), the area for the processing of such flows has been localised (Figure 2). The geographical localisation of the area has been performed using a GIS (QGIS - v. 3.4) in which the municipality has been considered as reference unit and it has been carried out taking into account particular constraints such as areas at landslides risk, or proximity to polluted sites (and therefore sites reported and to be reclaimed) or to industrial areas, nature reserves or areas with landscape and archaeological constraints, sites of community interest (Sci) and Special protection areas (Spa).

Preferential factors such as, for example, the multiplicity of access roads, accessibility not conditioned by atmospheric events (snow, ice), barycentrality to waste production, the financial cost of the areas and the absence of industrial plants with a strong environmental impact in the proximity have been also considered.

Thanks to the direct interviews with experts in the sector, all the initial costs of the proposed model, supported by the municipality, such as the investment cost of the composter (about 600 euros for each ton of organic waste to be treated), the various costs for the purchase and video surveillance of the area, staff training, informatisation of the collection center and the entire process, have been also estimated. Moreover, the annual fixed costs including cost of personnel, the electricity consumption of the machinery and the related maintenance costs (obtained directly from the technical data sheet of the machinery) have been also added (Table 5).

Table 4. State of the art data for the collection and disposal of organic waste and winery-by products.

Current scenario		Reference
Organic waste collection cost (€/tons)	200	Direct interviews with operators
Organic waste disposal cost (€/tons)	150	Direct interviews with operators
Distance from the nearest composting plant (Laterza-Taranto) (Km)	22	
Fuel yield (Km/l)	2,8	Ministero dello Sviluppo Economico, 2018 (vehicles with a mass greater than 26 tons)
Fuel cost (€/l)	1,5	Ministero della Transizione Ecologica, 2020
Average transportable quantity (tons)	30	Direct interviews with operators
Winery by-products disposal cost (€/tons)	0.22	Novello, 2015
Distance from the nearest distillery (Km)	500	Direct interviews with operators

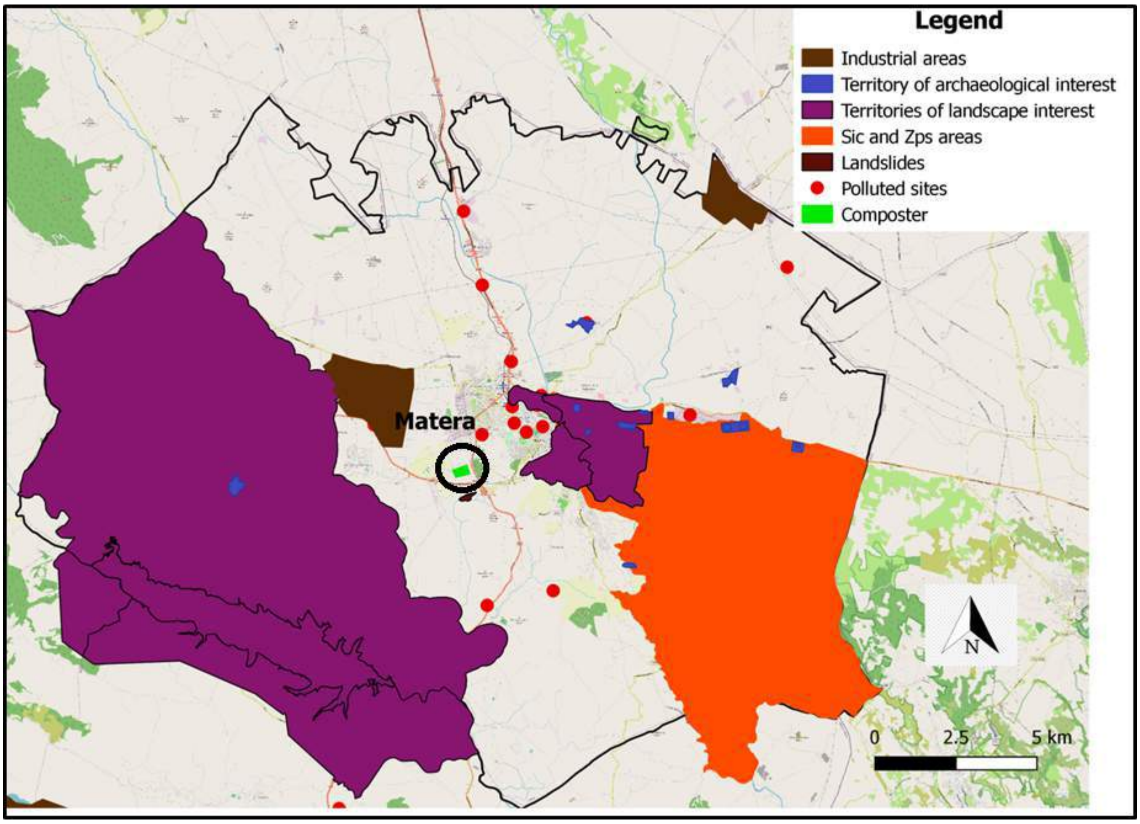

Figure 2. Geographical localisation of the area for "proximity composting".

Table 5. Initial and annual fixed costs for the electro-mechanical composter

Composter Investment Cost (€)	900,000
Various costs (Videos, Bureaucracy, Area) (€)	10,000
Staff Training (€)	1,500
Collection Center and Processing Informatisation (€)	25,000
Municipal Initial Costs (€)	**936,500**
Personnel costs (€/year)	50,000
Electricity consumption (€/year)	500
Composter maintenance (€/year)	3,500
Municipality Fixed Costs (€/year)	**54,000**

Finally, the avoided costs related to the transport (equation 1) and disposal (equation 2) of organic waste, and disposal of winery by-products (equation 3) has been calculated.

$$\textbf{Organic Waste} - \textbf{Avoided Transport Cost}\left(\frac{€}{\textbf{year}}\right) = \frac{D}{R} * 2 * C * \left(\frac{Qt}{Qm}\right) \quad (1)$$

where "D" is the distance from the nearest composting plant considered (Puglia region – Southern Italy); "R" is the average fuel yield for vehicles transporting waste (Table 4); "C" is the fuel cost calculated in table 4; "Factor 2", because the round trip has been considered; "Q_m" is the average transportable quantity (Table 4); "Q_t" is the total organic waste production (Table 3).

$$\textbf{Organic Waste} - \textbf{Avoided Disposal Cost}\left(\frac{€}{\textbf{year}}\right) = \text{Disposal cost}\left(\frac{€}{t}\right) * Qt\,(t) \quad (2)$$

where "Disposal cost" represents the disposal cost per ton of waste (Table 4); "Q_t" is the total organic waste production (Table 3).

$$\textbf{Winery By} - \textbf{products Avoided Disposal Cost}\left(\frac{€}{\textbf{year}}\right) = \text{Disposal cost}\left(\frac{€}{t}\right) * Qt\,(t) \quad (3)$$

where "Disposal cost" represents the disposal cost for wine by-products in distillery (Table 4); "Qt" is the total winery by-products production, previously calculated.

2.2 Calculation of economic and environmental saving

Following the adoption of the hypothesized model, the economic and environmental savings, compared to the current scenario, both for organic waste and wine by-products has been calculated as follows:

$$\boldsymbol{Organic\ Waste\ Economic\ saving}\left(\frac{€}{year}\right) = \left[\left(\frac{Ci}{5}\right) + Cf\right]\left(\frac{€}{year}\right) - [Avoided\ \ Transport\ Cost + Avoided\ Disposal\ Cost]\left(\frac{€}{year}\right) \quad (4)$$

where "Ci" are initial costs of the municipality (spread over 5 years); "C_f" are the fixed costs of the municipality; "Avoided Transport Cost + Avoided Disposal Cost" are the economic savings due to the lack of movement of flows to the composting plant, because in the hypothesised model they remain within the municipality of production (so-called, "proximity" composting).

$$\boldsymbol{Wine\ By - products\ Economic\ saving}\left(\frac{€}{year}\right) = Avoided\ disposal\ cost\ in\ distillery\left(\frac{€}{year}\right) \quad (5)$$

For wine by-products, the economic saving is essentially due to the failed disposal to distillery, because in the hypothesized model they are valued within the municipality itself.

The related environmental savings are essentially due to CO_2 avoided due to non-movement vehicles to the composting plant (equation 6) or to the distillery (equation 7), since in the proposed model the flows are valorised within the municipality itself:

$$\boldsymbol{Avoided\ CO2\ emissions\ composting\ plant}\left(\frac{Kg}{year}\right) = CO2\ consumption\left(\frac{g}{Km}\right) * No\ of\ trips\ \left(\frac{Km}{year}\right) \quad (6)$$

$$\boldsymbol{Avoided\ CO2\ emissions\ distillery}\left(\frac{Kg}{year}\right) = CO2\ consumption\ \left(\frac{g}{Km}\right) * No\ of\ trips\ \left(\frac{Km}{year}\right) \quad (7)$$

The calculation, in addition to considering the number of trips per year, which is a function of the distance (round trip) to the composting plant or to the distillery (Table 4), of the average quantity transported by each vehicle and of the quantity of flows moved, also takes into consideration the parameter of CO_2 consumption (800 g/Km), obtained from personal processing by studying the registration books of the vehicles, their relative CO_2 consumption and considering an average value that is representative of the regional parameters.

3. Results and Discussion

Following the feasibility study conducted, table 6 shows the annual economic savings (€/year) with the relative payback period, due to the non-transfer of organic waste out of the region, while similarly the following table (Table 7) shows the economic savings associated with the non-transfer of wine by-products to the distillery. The environmental savings (CO_2 avoided) associated with the two processes is reported in table 8.

Table 6. Annual economic savings associated with “proximity composting model” regarding organic waste.

Organic Waste Economic saving	Costs (€)	Saving (€)	Final saving (€)
First Year	241,300	227,559.62	-13,740.38
Second Year	241,300	227,559.62	-27,480.76
Third Year	241,300	227,559.62	-41,221.15
Fourth Year	241,300	227,559.62	-54,961.53
Fifth Year	241,300	227,559.62	-68,701.91
Sixth Year	54,000	227,559.62	104,857.71
Investment return 6^0 YEAR			

Table 7. Annual economic savings associated with “proximity composting model” regarding winery by-products.

Winery By-products Economic saving (€/year)
458.48

Table 8. Annual environmental savings associated with “proximity composting model”.

Avoided CO_2 emissions (Kg/year) – composting plant	Avoided CO_2 emissions (Kg/year) - distillery
1,770.75	555.73

The obtained results shows that the proposed model is feasible above all from the economic point of view, most important aspect of both the municipality's management and planning strategies and the model's key players. The valorisation of the organic waste inside the municipality of Matera produces an economic benefit starting from the sixth year. Taking into account the useful life of the industrial plant used (20 years) the result appears satisfying. For wine by-products, on the other hand, the annual economic benefit is much lower, even if however interesting, because we are obviously dealing with a smaller flow than for organic waste, because they are not produced continuously, but only in certain months of the year.

There are also considerable quantities of CO_2 avoided due to the lack of movement of vehicles outside the region.

The results obtained are very interesting already at the municipal level but they obviously assume greater relevance in planning strategies at the regional level.

4. Conclusions

The current model of waste production and management and wine by-products represents an unsustainable model, both from an environmental and economic point of view. This type of organization is part of the so-called linear economy, based on the production of a good, its consumption and its subsequent disposal. It is essential to contrast this model with a new model, based on a circular economy concept. To achieve this objective, the collaboration of various players is fundamental: from legislators to producers, from environmental protection agencies to the infrastructures for the management of materials, from the personnel responsible for collection and disposal to the citizen, who must commit to a model of eco-sustainable living model.

The entire world is moving towards this new approach, facing numerous challenges and critical issues. One of these, perhaps the most serious, with regard to the management and disposal of organic waste and wine by-products is represented by the chronic lack of facilities: there are many municipalities that do not make (or make little) collection of these flows because there are no plants "on site" for their treatment and therefore high transportation costs must be sustained.

Currently, the most modern approaches to the issue suggest the treatment and recovery of waste and wine by-products near to the places of production, through small plants of negligible impact, responding to the targeted needs of many local realities contributing to use the compost on site produced.

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