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Assessment of Fruit and Vegetable Residues Suitable for Renewable Energy Production: GIS-Based Model for Developing New Frontiers within the Context of Circular Economy

Roberta Selvaggi and Francesca Valenti *

Department of Agriculture, Food and Environment, University of Catania, Via Santa Sofia, 95123 Catania, Italy; roberta.selvaggi@unict.it
* Correspondence: francesca.valenti@unict.it

Abstract: Due to the necessity of developing renewable energy sources, the anaerobic digestion for producing biomethane has developed significantly in the last years, since it allows to both reduce disposal treatment and produce green energy. In this field, fruit and vegetable wastes have been recently put forward, since they could represent a suitable resource for producing biomethane as a new frontier within the context of a circular economy. This study aims at filling the gap in the knowledge of the production, quantities and biogas potential production of these residues. On this basis, a GIS-based model was developed and applied to the Sicily region by investigating the specific regulatory framework as well as by analysing descriptive statistics. The results of the GIS analyses enabled the localisation of the highest productive territorial areas and highlighted where fruit and vegetable wastes are abundantly located. In this regard, about 7 million Nm^3 of biogas could be produced by reusing only the fruit and vegetable residues coming from the three most representative Sicilian wholesale markets among those considered. Finally, the regulatory framework is of crucial importance in inhibiting or supporting the use of the selected biomass in a specific sector, with regard to the case study considered.

Keywords: renewable energy; agricultural waste; recycling; biomethane; GIS; circular economy

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1. Introduction

Nowadays, climate change is the most imminent environmental issue facing the world. Rising global temperatures will have major effects on human life, on food chains, ecosystems and wildlife. It is well known that global warming is due to the large-scale anthropogenic emission of greenhouse gases (GHG). The usage of renewable energy sources to produce electricity and heat could reduce the negative impact of fossil fuels on GHG released into the atmosphere [1,2]. So renewable resources could play a key role in current CO_2-mitigation policies [3]. In this context, biomasses are one of the most important renewable energy sources, also because they can guarantee a continuous power generation, unlike other discontinuous energy sources (i.e., wind or solar energy). To contribute to reaching the 2020 EU goals, among the different technologies and processes anaerobic digestion (AD) could be a suitable way to produce renewable energy [4,5]. In fact, in accordance with the environmental and sustainability policies adopted by European Member States, recently there has been an increase in the spread of this technological process.

AD is a biochemical degradation process that presents a double benefit, as it produces biogas and meanwhile treats biomass, especially agricultural residues, and agro-industrial by-products, reducing their disposal in landfills [6,7].

Currently, AD plants are encouraged by the Indirect Land Use Change (ILUC) policy to produce advanced biofuels from feedstock that do not compete directly with food and feed crops, such as wastes and agricultural residues, non-food crops and algae. In detail, waste materials like sewage sludge, livestock manure, crop residues, the OFMSW (organic fraction of municipal solid waste) and fruit and vegetable waste are very important since they do not compete with food and feed crops as biomasses for the AD process [3,8]. In this regard, there are several types of waste creation areas in societies, for instance, farm-level waste [9], waste in construction sites [10], household-level solid waste [11], OFMSW [12] and vegetable and fruit waste [13]. Among these, fruit and vegetable wastes (FVWs) are a very important category of biomasses because they are produced in considerable quantities at the end of all agricultural, supermarket and wholesale market activites, and their landfill disposal is quite difficult due to their very high perishability [14,15].

Fruit and vegetable wastes contain a high percentage of organic matter that can be converted into biogas with a high yield. The presence of key micro, macro and trace elements allows the process to proceed without the addition of additives or other organic materials such as co-substrates [16,17]. It is important that fruits and vegetables are mixed in appropriate proportions to balance the excess or deficiency of nutrients and other inhibiting substances, or to limit the input of undesirable substances such as sulfur [18].

According to the estimation of the United Nations Food and Agriculture Organization (FAO), the waste generated by the fruit and vegetable sector is estimated to represent up to 60% of the food waste generated yearly in the world [19,20], and this estimation was reported to be much higher in Italy (about 87%) [21].

FVW generation increases the operating costs of markets due to the reduction of revenue and the increase of disposal costs [22]. In detail, FVWs represent a significant economic issue for companies and pose environmental problems due to their high moisture content and biodegradability [23]. According to the Goal 12.3 of the Sustainable Development Goals (SDGs) identified in 2015 by ONU, sustainable production and consumption is one advantage of reducing food wastes. Many governments and organisations around the world have committed to reducing food loss and waste. The valorisation of reusing them as renewable energy source meets the indication of Directive 2008/98/EC of the European Parliament, which establishes, following a hierarchy of residues, that the residues must be sent to disposal in sanitary landfills if they cannot be reused, recycled or recovered [24,25].

For these reasons, in recent years, large efforts have been dedicated to the development of actions and policies for FVW management [26]. So FVW valorisation processes concerning value-added derivatives have been deeply analysed in recent years. Despite the intense research activities, the current main destination of FVWs is still landfill disposal, although researchers agree that they can be use as feedstocks to produce renewable energy and fertilisers. Moreover, this could represent a suitable and more interesting alternative to both reduce environmental impact and produce clean energy within a green economy perspective [27]. In this regard, the valorisation of FVW is at an initial stage of development and more essential elements must still be assessed to verify its feasibility [28,29]. Firstly, data on the exact amount of both wastes obtained by agro-industrial companies, food processing and fruit and vegetable residues form markets is nowadays very limited. In fact, no official information is provided by the EU, given the commercial sensitivity of this data for all the producers.

This lack of official data related to the amount of waste, in terms of volume, and to the spatial localisation of the sites where these wastes are produced, is an important factor that has limited the reuse, exploitation, and valorisation of the wastes for sustainable processes.

Moreover, the demand for renewable and sustainable resources (e.g., green energy, water, investment for equipment and workforce) and for innovative valorisation strategies as compared to that of traditional waste management options should be evaluated. In fact, as reported by Valenti et al. [30] the implementation of new strategies is viable only if it brings economic (e.g., reduction of disposal costs and increase of incomes from the valorisation of the by-products/waste) and environmental advantages (e.g., reduction of waste amount for the landfill and of emission) as compared to conventional disposal strategies.

Nonetheless, logistic-related problems make these residues difficult to valorise [31]. In this regard, geographical information system (GIS) tools have been intensively used to perform analyses of feedstock supply and logistics [32–35]. While fruit and vegetable processing side streams generated from agro-industrial chains have been evaluated for the production of enzymes, organic acids (e.g., succinic and lactic acid) and renewable energy [36,37], whole fruit and vegetables from open markets have not been considered as potential feedstocks by evaluating the high amounts disposed of in landfill as waste, as reported by Liakou et al. [38].

Given the uncertainty of data relating to biomass amounts, this research aims, by using GIS tools, to fill the gap in the knowledge of the production, localisation and yield of fruit and vegetable residues to support producers in waste valorisation actions, i.e., for energy uses [22,32,39,40]; to revisit regulations to facilitate their use is urgently needed.

This study investigates the suitability of using FVWs as a possible feedstock of the blend for the diet of the anaerobic digestion plants where the biogas sector is still developing and biomethane is a real and viable possibility. The production of energy is only one of the possible destinations of these wastes, but it represents the most reasonable. In fact, in the study area there are no farms or other possible outlets for these by-products, if not landfills.

Therefore, the collected data influenced the actual and real possibility of recycling fruit and vegetable residues. This explorative study is important for planning the valorisation of new biomasses that could be used as feedstock for the existing biogas plants or for developing new ones in a sustainable way. In fact, their use can have a positive impact with regard to environmental protection, and especially in terms of reduction of both GHG emissions from these biomasses logistic supplies and soil consumption for dedicated energy crops.

2. Materials and Methods

A methodology for assessing the suitability of using new biomasses suitable as a feedstock to produce biogas is described. In this regard, statistical tools were adopted, and a GIS analysis was carried out. In detail, the QGis software (ver. 3.10.11), an open-source GIS software, was used since it is a decision support tool appropriate for collecting, organising, analysing and localising geographical data.

Firstly, by adopting statistical tools, the agricultural sector and the production were analysed in order to find the trend of production and the cultivated area for the Sicilian horticultural sector from 2015 to 2019. Data were acquired from the national surveys database [41]. Then, by using spatial analysis GIS tools, the production areas were localised in the study area, and the most productive areas were considered in order to deeply investigate the wholesale market flows. A specific methodology was developed in order to quantify the processed fruit and vegetables, the obtained waste production and, therefore, the potential biogas production. In detail, FVW production was computed by using specific face-to-face surveys at the wholesale markets and data available from annual statistic tools. After obtaining specific authorisation to process the data, from the managers of the food markets, for each selected market (Catania, Ragusa and Palermo) eight pit owners were interviewed. They represent about 30% of the total pit owners for each considered wholesale market. This quantity was imposed on us by the wholesale market managers, due to the Covid-19 emergency that made further pit visits impossible. The questionnaire was very simple, with only one section. We noted the amount in transit through the pits in the various years (from 2015 to 2019) in terms of product input and biomass disposed of (net of plastics and other packaging). So we obtained an index related to the quantities of wastes and we used this index referring to the total amount of biomass disposed of by the wholesale market (data collected by interviewing the wholesale manager).

Finally, the amount of potential biogas producible was estimated according to the quantity of FVWs. In the following subsections are detailed the methodological approach and the materials utilised.

2.1. Case Study

Sicily is an autonomous region of Italy and the largest island in the Mediterranean Sea (Figure 1), covering approximately 26,000 km^2. It has a unique climate pattern characterised by hot/dry summers and mild/wet winters. These conditions are beneficial to renewable energy production using agro-ingustrial residues obtained from typical activities: Cultivation first of all of citrus, and grape, olive oil, wheat and other products, and sheep and cattle breeding. Therefore, it was chosen as the study area.

Figure 1. Geographic position of the study area.

In Sicily, agriculture has a decisive position in the regional economy. Like in the other parts of southern Italy, employees in agriculture are plentiful but they have low wages.

Furthermore, in Sicily, about 3.9 million metric tons of matrix are yearly produced by agro-industrial activities and are available and potentially reusable in biogas plants. These biomasses include byproducts from the agro-industrial chains (i.e., whey, citrus pulps, olive pomace residues and others), wastes from livestock (i.e., cattle manure), agricultural crop residues (i.e., cereal straw and others field and process residues) and some dedicated feedstocks obtained from energy crops. Among them, agro-industrial biomasses and livestock manure represent more than 60% of the total biomasses produced [42].

Sicily is the Italian region with the greatest extension of agricultural land [42]. Considering the area dedicated to agriculture, Sicily excels in cereal production and is the first Italian producer of oranges with half (52%) of the entire national output.

By elaborating on data from the Italian National Statistical Institute (Istat) database it was found that, in the last five years (from 2015 to 2019), with reference to the horticultural production area (both horticultural open field crops and greenhouses), in Italy an average of 356,089 ha/year were cultivated, while in Sicily about 58,357 ha/year (about 16%) were cultivated [41]. Table 1 shows the trend of the analysed period and the mean values, subdivided for the specific cultivation of horticultural open field crops and greenhouses ones, for the nine provinces of the study area.

Within the selected interval, overall, as shown in Table 1, the areas cultivated with horticultural crops registered a slight increase (+1.9%) by rising from 57,949 ha to 59,069 ha.

Instead of, by considering greenhouse horticulture, leaving out the data for the provinces of Catania and Messina, which are outliers, there is a common trend across the region: Greenhouse horticulture areas decreased from 2015 to 2019. Only the province of Trapani recorded a slight increase in greenhouse cultivated areas: From 1104 ha in 2015 to 1114 ha in 2019.

Table 1. Sicilian cultivated area for horticultural crops (ha) and trend of evolution (%).

	Cultivated Area (ha)					Mean (ha)
	2015	**2016**	**2017**	**2018**	**2019**	
Agrigento						
- Horticultural open field crops	17,519 100.0	17,449 99.6	17,358 99.1	17,898 102.2	18,557 105.9	17,756
- Horticultural greenhouses	346 100.0	342 98.9	329 95.1	329 95.0	329 95.1	335
Caltanissetta						
- Horticultural open field crops	10,102 100.0	10,331 102.3	9978 98.8	9107 90.2	9019 89.3	9707
- Horticultural greenhouses	830 100.0	830 100.0	829 99.9	829 99.9	829 99.9	829
Catania						
- Horticultural open field crops	3846 100.0	3847 100.0	3232 84.0	3847 100.0	3849 100.1	3724
- Horticultural greenhouses	15 100.0	0.2 1.0	0.2 1.0	0.2 1.0	0.2 1.0	3
Enna						
- Horticultural open field crops	560 100.0	560 100.0	560 100.0	560 100.0	560 100.0	560
- Horticultural greenhouses	11 100.0	9.0 85.7	9.0 85.7	9.0 85.7	9.0 85.7	9
Messina						
- Horticultural open field crops	1243 100.0	1703 137.0	1706 137.2	1717 138.1	1781 143.3	1630
- Horticultural greenhouses	55 100.0	0.9 1.6	0.9 1.6	0.9 1.6	0.9 1.6	12
Palermo						
- Horticultural open field crops	7185 100.0	7143 99.4	7663 106.7	7794 108.5	8015 111.6	7560
- Horticultural greenhouses	61 100.0	58.3 96.3	58.3 96.3	57.8 95.5	58.9 97.4	59
Ragusa						
- Horticultural open field crops	1835 100.0	1985 108.2	2095 114.2	2225 121.3	2170 118.3	2062
- Horticultural greenhouses	4470 100.0	4380.0 98.0	3970.0 88.8	3960.0 88.6	3925.0 87.8	4141
Syracuse						
- Horticultural open field crops	4943 100.0	5425 109.8	5453 110.3	5662 114.5	5802 117.4	5457
- Horticultural greenhouses	1135 100.0	1124.0 99.0	1108.5 97.7	1093.0 96.3	1083.1 95.4	1109
Trapani						
- Horticultural open field crops	2690 100.0	2315 86.1	2305 85.7	2195 81.6	1965 73.0	2294
- Horticultural greenhouses	1104 100.0	1094.0 99.1	1094.0 99.1	1134.0 102.7	1114.0 100.9	1108

Regarding open field horticultural areas, however, there is no common generalised trend: Some provinces have recorded a contraction of areas while others have recorded a marked increase (first of all Messina).

Greenhouse cultivation is mainly concentrated in the province of Ragusa, in the coastal area. More than 56% of the Sicilian greenhouse surface is located in this territorial area.

As regards greenhouse cultivation, the most common species are, in this order: Tomato, zucchini, bell pepper, eggplant and watermelon; whereas, for open field production, the most cultivated species are, in this order: Artichoke, tomato, melon, cauliflower and lettuce.

In Table 2 the production obtained in these cultivated areas, detailed for each Sicilian province, is shown. The trend for the period from 2015 to 2019 and the average values, by providing the detail of greenhouse and field crops, were reported.

Table 2. Sicilian production of horticultural crops (t) and trend of evolution (%).

	Production (t)					**Mean (t)**
	2015	**2016**	**2017**	**2018**	**2019**	
Agrigento						
- Horticultural open field crops	322,937 100.0	302,870 93.8	300,227 93.0	307,831 95.3	316,093 97.9	309,991
- Horticultural greenhouses	21,932 100.0	14,449 65.9	12,826 58.5	13,017 59.4	13,093 59.7	15,064
Caltanissetta						
- Horticultural open field crops	99,284 100.0	114,852 115.7	115,566 116.4	85,641 86.3	71,303 71.8	97,329
- Horticultural greenhouses	41,725 100.0	41,725 100.0	41,698 99.9	41,696 99.9	41,696 99.9	41,708
Catania						
- Horticultural open field crops	59,667 100.0	59,685 100.0	47,401 79.4	59,846 100.3	60,039 100.6	57,328
- Horticultural greenhouses	750 100.0	750 100.0	750 100.0	750 100.0	750 100.0	750
Enna						
- Horticultural open field crops	7265 100.0	7970 109.7	8550 117.7	7750 106.7	7535 103.7	7814
- Horticultural greenhouses	695 100.0	1265 182.1	1265 182.1	1265 182.1	1265 182.1	1151
Messina						
- Horticultural open field crops	18,290 100.0	36,379 198.9	36,555 199.9	37,055 202.6	37,445 204.7	33,145
- Horticultural greenhouses	3181 100.0	1705 5.4	1818 5.7	1818 5.7	1818 5.7	7794
Palermo						
- Horticultural open field crops	85,253 100.0	84,611 99.2	106,318 124.7	106,939 125.4	109,989 129.0	98,622
- Horticultural greenhouses	20,173 100.0	19,664 97.5	19,666 97.5	19,736 97.8	20,051 99.4	19,858
Ragusa						
- Horticultural open field crops	52,057 100.0	52,640 101.1	71,350 137.1	82,100 157.7	83,300 160.0	68,289
- Horticultural greenhouses	239,300 100.0	232,300 97.1	209,250 87.4	220,300 92.1	243,000 101.5	228,830
Syracuse						
- Horticultural open field crops	111,035 100.0	122,614 110.4	123,920 111.6	124,616 112.2	125,591 113.1	121,555
- Horticultural greenhouses	45,240 100.0	44,224 97.8	45,320 100.2	44,815 99.1	45,412 100.4	45,002
Trapani						
- Horticultural open field crops	32,458 100.0	27,120 83.6	25,380 78.2	24,390 75.1	21,900 67.5	26,250
- Horticultural greenhouses	9704 100.0	9704 100.0	9754 100.5	10,474 107.9	10,434 107.5	10,014

Concerning open field horticultural areas, and also horticultural greenhouse production, Messina data are outliers and cannot be considered.

In the selected time interval, overall, the production of horticultural crops registered a slight increase (+3.3%), despite a decrease in the quantities produced in greenhouses (−1.7%).

Regarding horticultural greenhouse production, there is a common trend across the region: Greenhouse horticulture productions are constant from 2015 to 2019. Only the province of Enna recorded a doubled production: From 695 t in 2015 to 1265 t in 2019, with the same cultivated area of about 10 ha (as shown in Table 1).

Regarding open field horticultural production, however, there is no common generalised trend: Trapani, Caltanissetta and Agrigento have recorded a contraction of areas, while others have recorded a marked increase (first of all Messina and Ragusa). In these areas there has been an intensification of cultivation processes and a birth of numerous new companies.

Furthermore, by analysing the available data from the ISTAT database, it was found that the most productive horticultural greenhouse species are, in order, tomato, zucchini, eggplant, bell pepper and watermelon, while the most productive horticultural open field crop species are, in order, tomato, melon, artichoke, cauliflower and lettuce.

As for the surface area, Ragusa is also the province in which there is the greatest production (about 60.9% of total Sicilian production).

2.2. Data Analysis

In this study, an extensive database was improved according to statistical sources, i.e., ISTAT (years 2015–2019), to quantify horticultural production by GIS analysis.

The base maps used in the GIS included the Regional Technical Map (RTM 2008) as the base map for producing thematic maps. RTM 2008 is an upgrade of previous versions of the RTM 2005 numerical edition (sites CDE), the 2001 edition (sites 7-8-9), the 2004 edition (site B) and the 2003 edition (site A). RTM 2008 was created by using the digital colour ortho-photos ATA0708 with a geometrical resolution of 25 cm × 25 cm. All administrative boundaries adopted for map elaboration were taken from RTM 2008—layer I.

By analysing available data on the agricultural sector, the provinces with the highest volumes produced were identified and localised on GIS software. Then, by using QGIS software v.3.10.11, the overlay of data contained in the base maps and the use of the Jenks tool in the QGIS software produced an arrangement of the selected horticultural producing areas based on the maximisation of variance among the classes. The next step of the methodology was the analysis of the quantity of FVWs produced from the selected wholesale market.

In detail the amount of the produced waste was analysed to identify and to survey local wholesale markets located in the study area.

To quantify the production and obtain the residual amount, which could be considered waste production, the biggest markets sited in the study area were sampled. A questionnaire was given to each pit manager involved in the research to find out the production targets, the quantity of the products entering the pit and the amount of residual products coming out of the pit, especially for those wastes usable for the energy process.

The collected data was anonymously elaborated to specifically estimate the amounts of residual products and where they are available (spatial location) in the study area.

The last step of the study was to assess the potential production of biogas obtainable by the amount of estimated residual products. The theoretical biogas potential (Btot) was computed by using the formula (Equation (1)):

$$B_{\text{tot}} = A \cdot Y \tag{1}$$

where A is the amount of FVWs (expressed as tons of fresh matter) and Y is the FVW biogas potential yield, which was considered equal to 158.1 ± 18.7 Nm^3/t of fresh matter, as reported by Adani et al. [43], who adopted the simple and fast tests to predict potential biogas developed by Schievano et al. [44].

3. Results

Horticultural producing areas acquired by the ISTAT database were deeply analyzed for the different provinces by providing a GIS map to show their territorial distribution. In detail, ISTAT data were used to localise, on a territorial level, the distribution of cultivated areas dedicated to horticultural production. By adopting the Jenks tool, available in the QGis software, the Sicilian provinces were grouped in three different classes in order to maximise the differences in the cultivated areas. As a result, the areas that showed the highest horticultural surface areas were the provinces of Palermo, Agrigento and Caltanissetta, as shown in Figure 2.

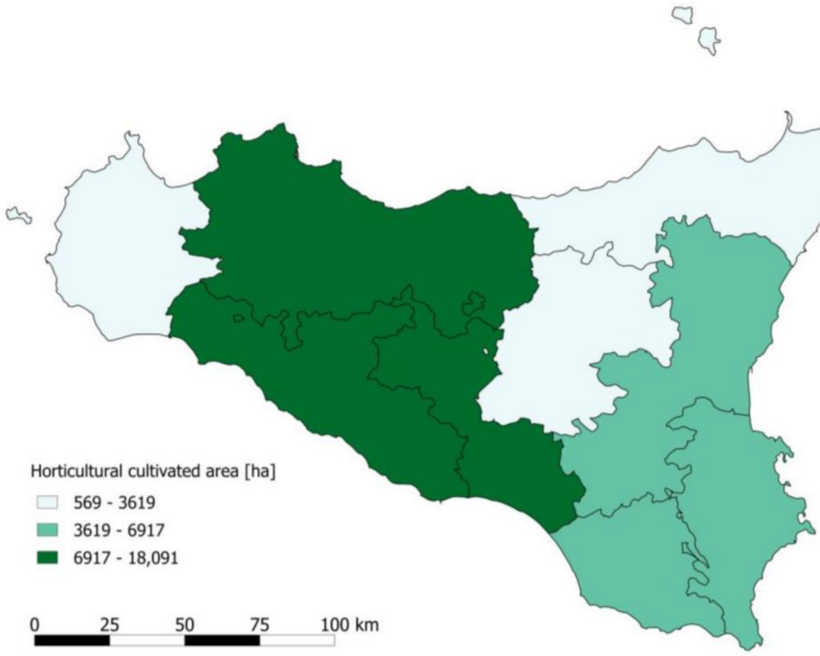


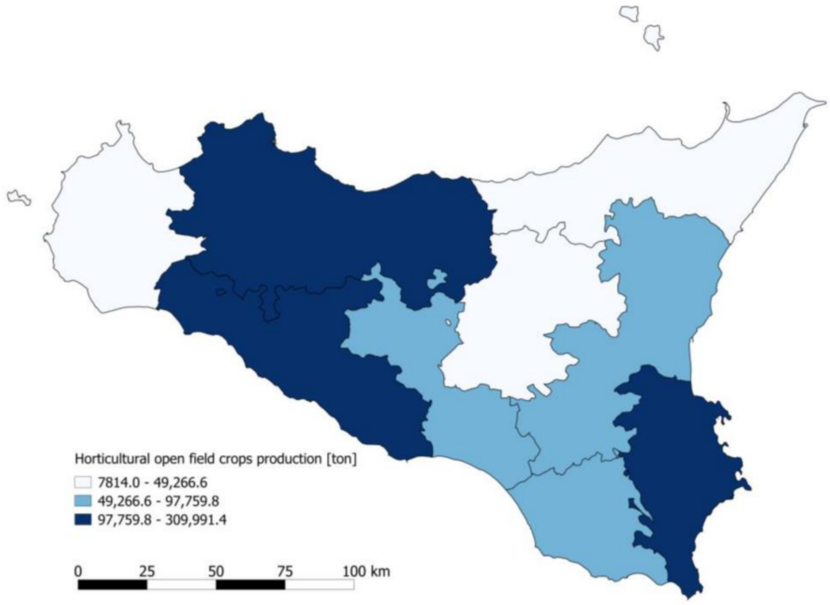
Figure 2. Distribution of horticultural cultivated area within the Sicily region (ISTAT, from 2015 to 2019).

Then, the horticultural cultivated areas were subdivided into horticultural open field crops and horticultural greenhouses (Table 1) by showing different distributions within the Sicilian provinces, as reported in Figure 3a,b.

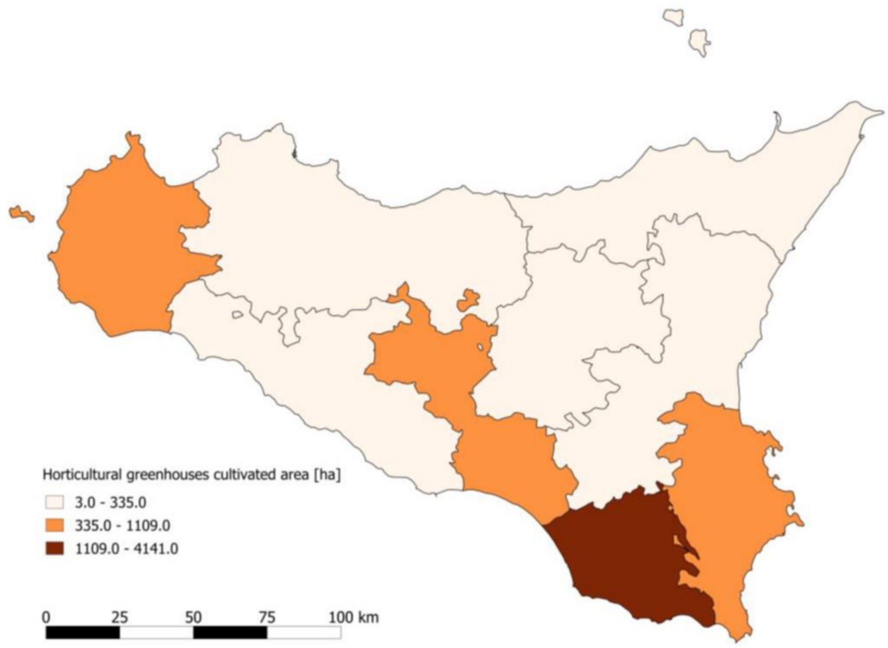
The distribution of the horticultural cultivated areas allows the identification of two different areas for horticultural production located in the south-west and in the south-east of the island, respectively, for open field crops and greenhouses.

The second step was the analysis of the horticultural production, since the most productive areas could not correspond to the most cultivated areas.

The next step was focussed on wholesale market localisation. After a direct interview with the regional coordinator of wholesales market activities, the Sicilian active wholesale markets were located within Sicily region by considering their GPS coordinates, and a GIS map was made as shown in Figure 4.



(**a**)



(**b**)

Figure 3. (**a**) Distribution of horticultural open field crop cultivated areas. (**b**) Distribution of horticultural greenhouse cultivated areas (ISTAT from 2015 to 2019).

In order to quantify wholesale market residues and waste production, firstly all the wholesale market data (i.e., production flows) were analysed based on the available database, and by using the GIS tool (i.e., Heatmap plugin) a heat map of their production was made (Figure 5).

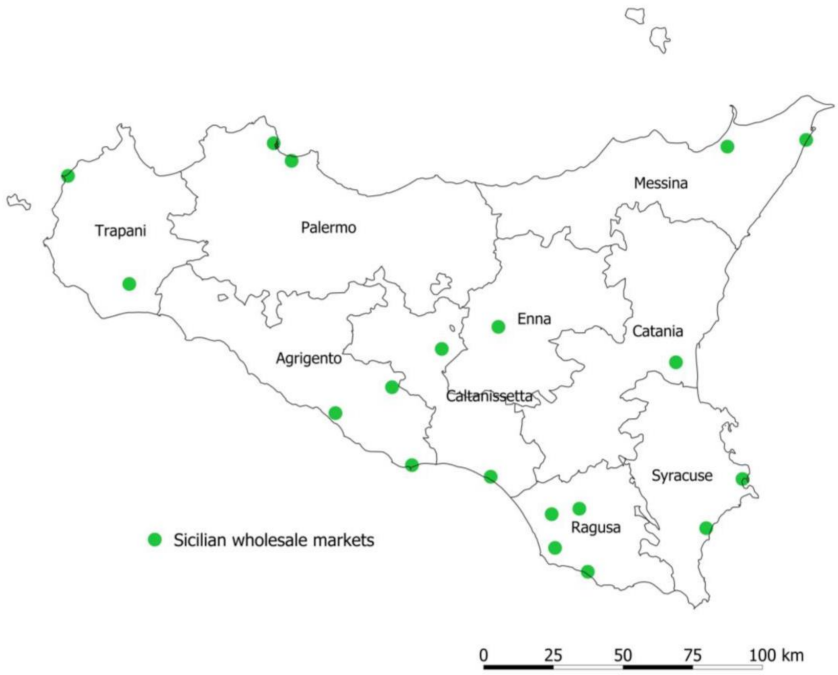


Figure 4. Wholesale market localisation within Sicily region (data obtained by direct interviews).

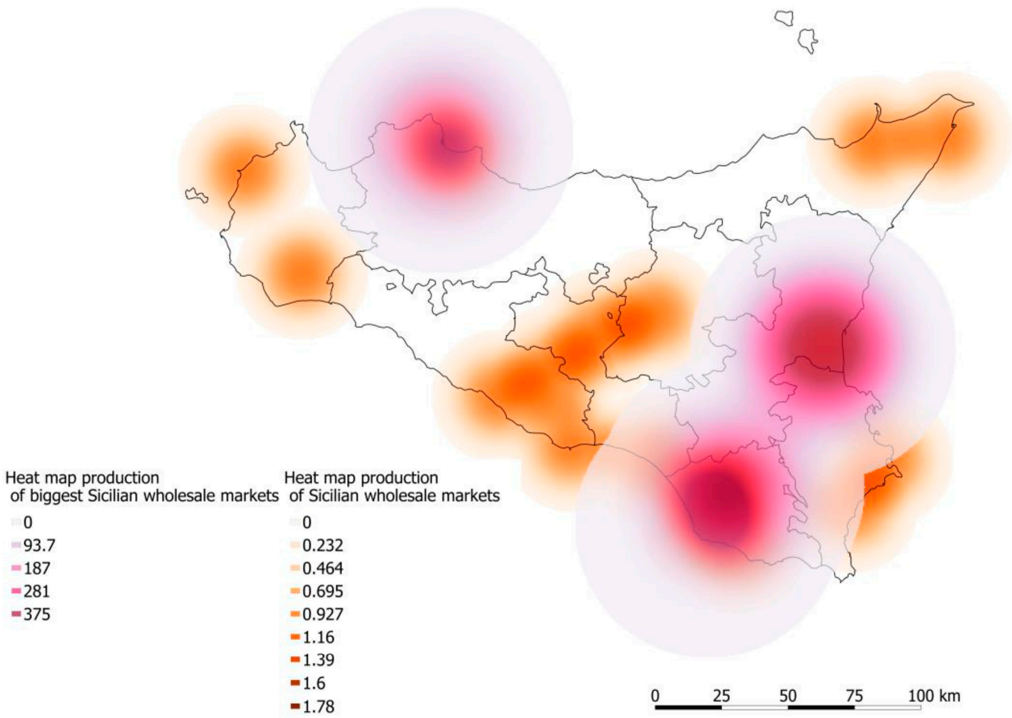


Figure 5. Wholesale markets heat map distribution based on their flow production.

As reported in Figure 5, firstly (in orange) all the wholesale markets data were elaborated for the production of a heat map; then, among them, the wholesale markets with the biggest flow production were selected (in pink), and their data were elaborated by adopting again the heat map tool. An overlay of the two produced heat maps was carried out in order to show the high difference of flow production (Figure 5).

In detail, the largest and most important wholesale markets, sited in the provinces of Catania, Ragusa, and Palermo, were selected as a sample for carrying out a face-to-face survey analysis with the aim of estimating the quantity of FVWs.

The surveyed data are summarised in Table 3 in order to define an average percentage of potential horticultural wastes in the period between 2015 and 2019.

Table 3. Quantities of estimated fruit and vegetable wastes (t).

Site of the Wholesale Market	Incoming Products (Vegetables and Fruit)	Wastes	
	(t)	(t)	(%)
Catania	308,579	21,376	6.9%
Vittoria	261,901	13,357	5.1%
Palermo	183,500	11,744	6.4%

As shown in Figure 6, by considering all the horticultural products, the provinces of Syracuse, Ragusa, Agrigento, Catania, Palermo and Caltanissetta were highlighted as the most productive ones. Furthermore, the results of the analysis of the production of the three selected biggest wholesale markets confirmed the results obtained with the ISTAT database on the horticultural production by highlighting three different areas (Figure 6).

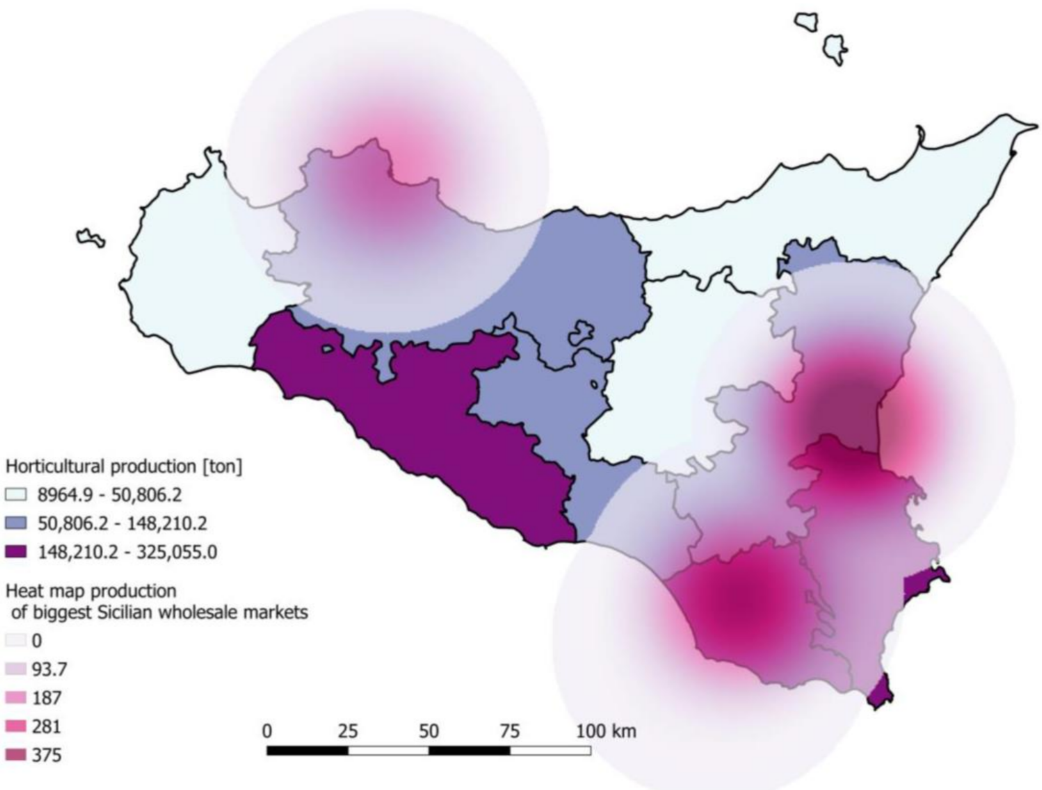


Figure 6. Overlay result of the selected biggest wholesale markets and the horticultural production areas.

The last step of the study was the computation of the potential biogas production by recycling FVWs. As reported in Table 3, the FVWs were computed, and by using Equation (1) the potential biogas was estimated to be about 7 million of Nm^3 [44]. In detail, as reported in Figure 7, the heat map with potential biogas production obtainable by the three selected wholesale markets was produced. Moreover, the potential production from each considered wholesale market amounts to about 3.3 million Nm^3, 2.1 million Nm^3 and 1.8 million Nm^3, respectively, for the wholesale markets located in the municipalities of Catania, Vittoria and Palermo. As shown in Figure 7 the wholesale market located in Catania province is the biggest one, with the highest flow production and potential biogas production.

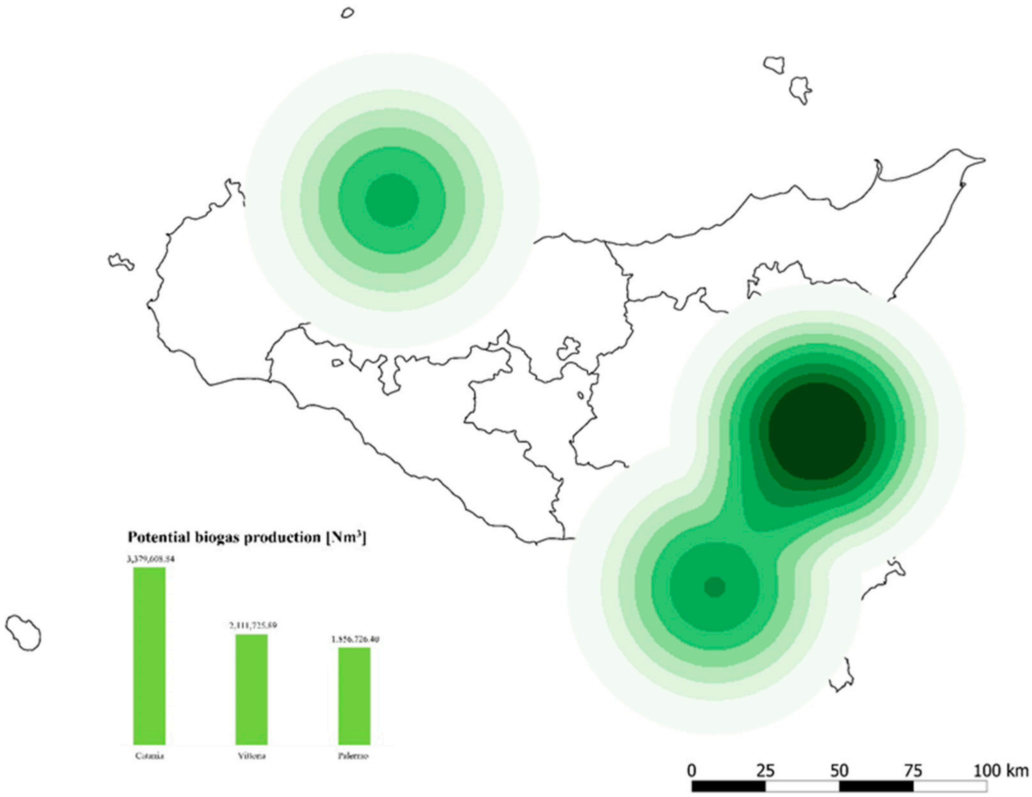


Figure 7. Estimation of biogas availability.

4. Discussion

Sicily and other southern Italian regions are well behind the rest of the country in terms of anaerobic digestion plants and the agro-energy chain in general [45]. The production potential of bio-methane in many parts of southern Italy is undeveloped and even unknown despite being potentially very high [46].

Furthermore, there is a great number of agro-industrial processing plants which could provide large quantities of "integrated biomasses" like citrus pulp and olive pomace, the last being absolutely appropriate for producing advanced biofuels [32–34]. In this context of green energy management, the possibility to reduce the wastes obtained by the wholesale market of fruits and vegetables is also a concrete option.

FVWs are produced in huge quantities by wholesale markets and represent an important category of residues that are difficult to dispose of because of their high perishability. They are easily degraded by the microbial bacteria with a speed dependent on the presence of mechanical damage or excessive ripening. This leads to significant environmental complications and high costs for fruit and vegetable markets both for disposal and for economic losses due to the lack of product sales. Anaerobic digestion may be the most appropriate technology for the disposal and energy valorisation of these residues [47].

Therefore, it would be preferable that the future policies of development of the biomethane sector take into account the availability and distribution at a territorial level of other agro-industrial biomasses [48], in order to find the optimal location of new anaerobic digestion plants [42–49].

The amount of FVWs estimated to be sent to anaerobic digestion plants is just under 46 thousand tons of biomasses. This means that this biomass could make a net contribution to the production of biomethane. However, there is a limit imposed by the Italian law about disposal and reuse. In particular, the by-products produced by the wholesale market are classified as "waste" (in accordance with art. n° 10 of Legislative Decree 205/2010 [50]) because the wholesale market is the final step of the chain before the sale: If the products are not suitable for sale, they are waste. Instead, they can be classified as "by-products" (in accordance with art. n° 12 of Legislative Decree 205/2010 [50]) if they are produced by a farm that sells to the wholesale market. So, if the anaerobic digestion plant is authorised only for the utilisation of by-products and if its manager wants to use digestate as an organic soil improver for agricultural soil, wholesale market FVWs cannot be used as feedstocks.

This is nonsense because the product at the market does not undergo manipulation or alteration. It is the same product that is considered differently only because its holder (wholesale market or farmer) is different.

If these biomasses were treated as by-products and not as wastes, producers would avoid landfill disposal costs and could only pay for the delivery to biogas plants. Even more, biogas plant owners might be willing to pay for having these biomasses. Therefore, a virtuous economic circle could be generated: From waste to by-product.

5. Conclusions

The study carried out on collected data and GIS-based maps fulfilled the objectives of the research proposed by providing both the spatial localisation of horticultural production in Sicily and the estimation of the amount of FVW production by both investigating the flow production of all the wholesale markets located in Sicily and face-to-face interviewing the selected three biggest ones. Then, these results allowed the assessment of the potential biogas production from FVW reuse.

Therefore, since anaerobic digestion plants need a blend of different biomasses for the diet, new biogas plants could be located as near as possible to where biomasses are produced. This condition is relevant to reducing the transport costs of these materials. Therefore, a further study, which is in progress, is necessary in order to assess the effective biogas production by BMP and AD tests with the aim of finding a suitable mix for the digesters and promoting among local authorities the use of these wastes as new biomasses. So, it will be possible to reduce the significant environmental impact of the wholesale market residues and increase bioenergy production within the context of a green and circular economy.

Finally, the importance of the regulatory framework to support or to inhibit the use of theses biomasses was highlighted with regard to the considered case study.

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