Potential biogas production from agricultural by-products in Sicily. A case study of citrus pulp and olive pomace

Francesca Valenti, Simona M.C. Porto, Giovanni Cascone, Claudia Arcidiacono

Building and Land Engineering Section, Department of Agriculture, Food and Environment, University of Catania, Italy

Abstract

Renewable energy sources represent a suitable alternative to conventional fossil fuels, due to the possible advantages in terms of environmental impact reduction. Anaerobic digestion of biomasses could be considered an environmental friendly way to treat and revalorise large amounts of by-products from farming industries because it ensures both pollution control and energy recovery. Therefore, the objective of this study was to define a methodology for evaluating the potential biogas production available from citrus pulp and olive pomace, which are suitable agricultural by-products for biogas production. In the first phase of the study, the spatial distribution of both olive and citrus-producing areas was analysed in Sicily, a geographical area of the Mediterranean basin highly representative of these types of cultivation. Then, a GIS-based model, which had been previously defined and utilised to evaluate the amount of citrus pulp and olive pomace production, was applied to this case study. Based on the results obtained for the different provinces of Sicily, the province of Catania was chosen as the study area of this work since it showed the highest production of both citrus pulp and olive pomace. Therefore, a further analysis regarded the quantification of olive pomace and citrus pulp at municipal level. The results of this analysis showed that the total amount of available citrus pulp and olive pomace corresponded theoretically to about 11,102,469 Nm^3/year biogas. Finally, the methodology adopted in this study made it possible to identify suitable areas for the development of new biogas plants by considering both the spatial distribution of the olive and citrus growing areas and the locations of the existing processing industries.

Correspondence: Simona M.C. Porto, Building and Land Engineering Section, Department of Agriculture, Food and Environment, University of Catania, via S. Sofia 100, 95123 Catania, Italy.
E-mail: siporto@unict.it

Key words: Olive pomace; citrus pulp; by-products; anaerobic digestion; biogas; GIS; spatial analysis.

Acknowledgements: this study was carried out within the research project of Dr. Eng. Francesca Valenti, PhD student of the *Doctorate in Agricultural, Food, and Environmental Science (XXX Ciclo)* of the University of Catania (Advisor: Dr. Eng. Simona M.C. Porto, Co-Advisor: Prof. Eng. Wei Liao).

Contributions: the authors contributed equally.

Ethical standards: the experiment carried out in this study complied with the current Italian laws.

Received for publication: 22 May 2017.
Accepted for publication: 4 July 2017.

Journal of Agricultural Engineering 2017; XLVIII:727
doi:10.4081/jae.2017.727

Introduction

The production of climate-altering gases is strictly related to the increasing demand for energy consumption due to several causes such as the rapid growth of the world's population, the accelerating industrialisation as well as the expanding urbanisation. This condition arises public concern on global warming, which is likely to grow based on the forecasts of increased emissions (Commission of the European Communities, 2007). Since fossil fuels used for energy production are highly responsible for greenhouse gas emissions, renewable energy technologies must be implemented to balance and reduce fossil energy use (De Montis, 2014) and sustainably satisfy energy demand. Among many renewable energy alternatives (*i.e.*, solar, wind, hydro, geothermal, and biomass), which have been intensively studied and developed in the past decades, the production of biogas from biomass by anaerobic digestion has developed significantly worldwide in the last twenty years (Molari *et al*., 2014).

A growing number of biogas plants have been built in Italy, which became the third world biogas producer after China and Germany, and most part of the investments in this field have been made in Northern Italy (Piccinini *et al*., 2010; Fabbri *et al*., 2013; Sgroi *et al*., 2015).

However, in most Italian regions, especially in North-Central Italy, the biogas is produced by using dedicated energy crops (*e.g.*, beetroot, sugar cane, sorghum, and corn and wheat), which arise environmental, social and economic concerns related to the competition between food and no-food products (Boscaro *et al*., 2015). As a consequence, there is the necessity to analyse the possibility of using alternative biomass sources for the production of methane by anaerobic digestion (Thompson and Meyer, 2013). Therefore, in more recent years, an innovative concept to produce biogas, based on a system of sustainable intensification of crop rotation and the use of agro-industrial wastes, was developed (Dale *et al*., 2016). The adoption of this new system of production would reduce the environmental, economic and social impacts generated by both the cultivation of dedicated energy crops and the presence of waste generated by agro-industrial activities (Dell'Antonia *et al*., 2013).

To date, the development of biogas plants in Sicily is still very limited, despite the importance of the agricultural sector for the island. However, this situation of delay with respect to North Italy could be an advantage for the biogas sector, as the development of biogas production plants still has the potential to be planned according to environmental, economic and social criteria of sustainability.

On this basis, the objective of this study was to evaluate the potential availability of two main by-products of the Sicilian agro-industrial sector, *i.e.*, citrus pulp and olive pomace, obtained from the citrus and olive oil processing industries. Since they are suitable agricultural by-products for biogas production, their quantification and localisation in Sicily could contribute to build an information base suitable for multi-criteria analysis aimed at finding optimal locations for biogas plants in view of increasing them in number.

Materials and methods

The GIS-based model for the computation of olive pomace and citrus pulp availability

Previous research studies (Valenti *et al*., 2017a, 2017b, 2017c) have demonstrated how citrus and olive crops have maintained a decisive position for the regional economy of Sicily and have confirmed the Sicily's key role in the Italian production. In fact, by considering the Italian citrus production, Sicily contributes with 56% of the total, and in the Italian olive oil sector, the data analysis confirms that South Italy, particularly Apulia, Calabria and Sicily produce 70% of the total olive production (Inea, 2014a, 2014b).

To evaluate the potential biogas production from citrus pulp and olive pomace, which are the main by-products of citrus and olive oil industries, the methodology proposed by Valenti *et al*. (2016) and Valenti *et al*. (2017a, 2017b) was applied to compute the index i_{ocp_n}, which describes the level of availability of olive pomace and citrus pulp for biogas production at provincial level:

$$i_{ocp\_n} = \frac{Cp_n}{Cp_{tot}} + \frac{Op_n}{Op_{tot}} \quad (1)$$

where n=1 to 9 is the number of the Sicilian provinces, the terms $C_{p\ tot}$ and $O_{p\ tot}$ are the amounts (expressed in tons) of citrus pulp and olive pomace, respectively, which are produced in Sicily, and $C_{p\ n}$ and $O_{p\ n}$ are the amounts of citrus pulp and olive pomace produced in each province.

The greater is the index, the highest is the potential availability of those two by-products. Therefore, the computation of the index i_{ocp_n} allowed the selection of the province with the highest potential availability of these two by-products. This province, chosen as the study area, was then sub-divided into a number of zones (i=*1 to m*), corresponding to the territorial boundaries of each municipality (m).

Olive and citrus cultivation areas, S_{olive_i} and S_{citrus_i}

The computation of the olive cultivation area (S_{olive_i}) and the citrus cultivation area (S_{citrus_i}) at municipal level was carried out in the study area by utilising the data obtained from the 6th Agricultural Census 2010 (Istat, 2010). The 6th Agricultural Census is the last available and provides a complete information base with fine territorial details and a complete data framework on the structure of agriculture and animal husbandry system at a national, regional, and local level.

The computed values of S_{citrus_i} and S_{olive_i} were used to perform GIS analyses, by using the regional technical map related to the year 2008 (RTM 2008) as base map. The RTM 2008 is a numerical map produced at a 1:10,000 nominal scale and includes the projections of the most relevant geographical features. Among the different layers included in the RTM 2008, the olive layer (layer G1) and citrus layer (layer G0_A), which are two of the vegetation layers (layer G) and include the polygons of olive producing areas, were chosen. This last information was compared with that coming from the 6th Agricultural Census in order to validate the database used for the GIS-based analyses. This validation could be carried out also when the considered land use coverage was not available in the adopted base map, by performing the automated classification of agricultural cultivation within remote sensing images (Arcidiacono and Porto, 2010, 2008; Modica *et al*., 2016a, 2016b).

Olive pomace and citrus pulp potential production, O_{p_i} and C_{p_i}

In order to acquire information about the amount of citrus pulp (C_{p_i}) and olive pomace (O_{p_i}) potentially available in each municipality of the study area, the model proposed by Valenti *et al*. (2016, 2017a) was applied. The average percentage of olive pomace ($O_{pav\ \%}$) and citrus pulp ($C_{pav\ \%}$), produced by the processing industries were obtained by utilising a specific questionnaire for surveying each company of the study area. These indices were used to compute O_{p_i} and C_{p_i}, by applying the following relations:

$$O_{p\_i} = O_{pav\%} \times Ca_{olive} \times Y_{olive} \times S_{olive\_i} \quad (2)$$

$$C_{p\_i} = C_{pav\%} \times Ca_{citrus} \times Y_{citrus} \times S_{citrus\_i} \quad (3)$$

where Ca_{citrus} and Ca_{olive} are the coefficients of processing availability for citrus and olive respectively, obtained by literature, and Y_{citrus} and Y_{olive} were the yields ($t \cdot ha^{-1}$) of citrus and olive producing areas, respectively. The coefficient Ca_{citrus} was fixed to 0.3 (Inea, 2014a, 2014b), because only 30% of the citrus production is currently processed by the agro-industrial sector, and the coefficient Ca_{olive} was fixed to 1 since the amount of olive production considered in this study was entirely used for olive oil production (Istat, 2010). The yields of citrus and olive producing areas (Y_{citrus} and Y_{olive}, respectively) were computed by the following equations:

$$Y_{olive} = \frac{P_{olive\_prov}}{S_{olive\_prov}} \quad (4)$$

$$Y_{citrus} = \frac{P_{citrus\_prov}}{S_{citrus\_prov}} \quad (5)$$

where P_{olive_prov} and P_{citrus_prov} are the amounts (expressed in tons) of olives and citrus produced in the province, respectively, related to year 2010 and recorded by 6th Agricultural Census; and S_{olive_prov} and S_{citrus_prov} are the surfaces of olive and citrus producing areas of the province, respectively, in the same time interval considered for $P_{olive\ prov}$ and P_{citrus_prov}.

Biogas potential production, B_{tot_i}

The evaluation of biogas potential production (B_{tot_i}) associated to the estimated citrus pulp C_{p_i} and olive pomace O_{p_i} was calculated by using the following relation:

$$B_{tot\_i} = C_{p\_i} \times Y_{citrus\_pulp} + O_{p\_i} \times Y_{olive\_pomace} \quad (6)$$

where Y_{citrus_pulp} and Y_{olive_pomace} are the biogas potential of citrus pulp and olive pomace obtained from literature, respectively. The value equal to 89.3 Nmc/ttq was used for citrus pulp as it was reported by Cerruto *et al*. (2016) which analysed the potential biogas production from by-products of citrus processing industries in Sicily; while the value equal to 131.00 Nmc/ttq was used for olive pomace as it was reported by Reale *et al*. (2009) in a wider research where the biogas availability of different biomasses at regional scale was investigated.

Suitable areas for the development of new biogas plants

The municipalities of the considered province were grouped into classes related to the surface area (S_{mun}) of their territorial boundaries. This criterion was chosen in order to compare the densities of the citrus and olive growing areas among the classes by using descriptive statistic tools. The categorisation of the municipalities into classes was obtained by using a data clustering method designed to determine the best arrangement of values into different classes. Among the different algorithms available in QGIS software, the Jenks Natural Breaks classification method was used. This algorithm aims at finding natural groupings of data to create classes by maximising the variance between individual classes and minimising the variance within each class.

After the definition of the classes, the territorial boundaries of the municipalities belonging to the classes having a density of citrus and olive growing areas higher than that of the whole province were selected to be overlaid with the feature class containing the localisation of the citrus processing industries. This operation allowed the selection of the municipalities where planning the development of new biogas plants was most suitable. Further improvements for a more precise location of biogas plants within each municipality should be achieved by using more detailed information acquired at local level.

Results and discussion

The computation of the index i_{ocp_n} and its spatial distribution within the Sicilian region showed that the province of Catania had the highest potential production of citrus pulp and olive pomace (Figure 1). Therefore, this province was chosen as the study area and was subset into 58 zones, which corresponded to the municipalities within the territorial boundary of the province.

The olive and citrus processing industries, previously identified in Valenti *et al*. (2017a, 2017b), respectively, were located by using their geographical coordinates in order to produce a feature class of the distribution of citrus and olive processing industries in the considered province (Figure 2). Twenty-nine olive processing industries and six citrus processing industries were located and, by applying specific questionnaires, data were elaborated to compute the average percentages of olive pomace ($O_{pav\%}$) and citrus pulp ($C_{pav\%}$) processed, which amounted to approximately 45% and 57.5%, respectively (Valenti *et al*., 2017a, 2017b).

To calculate P_{olive_i} and P_{citrus_i}, which are the amounts (expressed in tons) of olive and citrus production at municipal level, the data related to citrus and olive producing area, obtained from 6th Agricultural Census, were elaborated and reported in Table 1. Although only 36 out of the 58 municipalities contributed to citrus fruit production, about 190,000 t per year of citrus fruits were produced. This production was very high if compared with olive for oil production, which was about 33,000 tons per year and was obtained from almost all municipalities.

In Table 1, the citrus and olive producing areas, S_{citrus_i} and S_{olive_i}, of each municipality within the study area, were also reported as they were used for the next computations.

For each municipality, O_{p_i} and C_{p_i}, which described the potential olive pomace and citrus pulp production, respectively, were calculated by using the Eqs. 2 and 3 and were reported in Table 1. With regard to the citrus pulp production, only five munic-

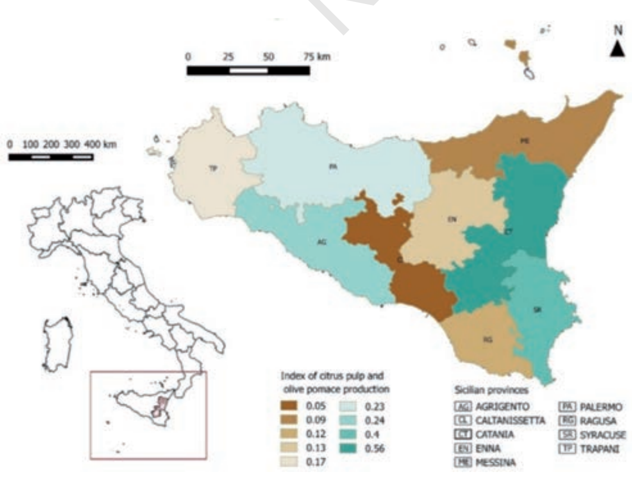

Figure 1. The level of olive pomace and citrus pulp production at provincial level.

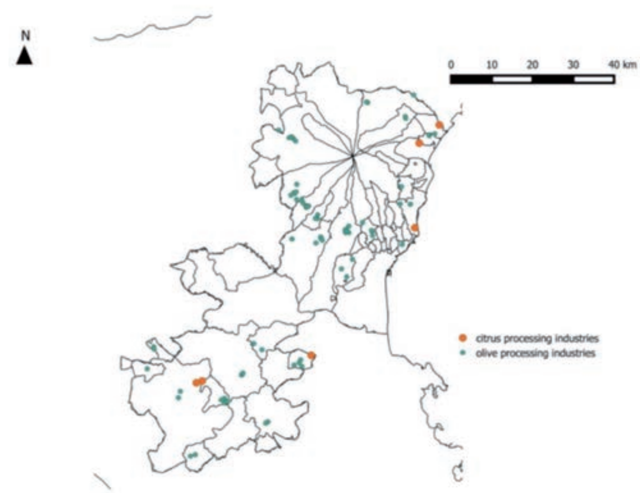

Figure 2. Localisation of citrus and olive processing industries in the province of Catania.

Table 1. Olive pomace $Op_{\_i}$, citrus pulp $Cp_{\_i}$ and biogas potential B_{tot} production for each municipality.

	S_{mun}# [ha]	S_{olive_i}* [ha]	P_{olive_i}° [t]	O_{p_i} [t]	S_{citrus_i}* [ha]	P_{citrus_i}° [t]	C_{p_i} [t]	B_{tot_i} [Nm^3]
Aci Bonaccorsi	171.00	1.00	3.11	1.40	-	-	-	183.01
Aci Castello	878.00	16.64	51.75	23.25	118.06	575.54	330.94	32,597.93
Aci Catena	846.00	2.66	8.27	3.72	-	-	-	486.80
Aci Sant'antonio	1424.00	5.95	18.50	8.31	-	-	-	1088.90
Acireale	4037.00	56.29	175.06	78.64	-	-	-	10,301.55
Adrano	8266.00	477.83	1486.05	667.53	-	-	-	87,446.99
Belpasso	16,521.00	884.51	2750.83	1235.67	4230.19	20,622.18	11,857.75	1,220,770.11
Biancavilla	6981.00	331.14	1029.85	462.61	-	-	-	60,601.46
Bronte	24,912.00	663.49	2063.45	926.90	64.92	316.49	181.98	137,675.07
Calatabiano	2632.00	112.99	351.40	157.85	34.43	167.85	96.51	29,296.62
Caltagirone	38,114.00	1393.33	4333.26	1946.50	649.03	3164.02	1819.31	417,455.91
Camporotondo Etneo	651.00	43.39	134.94	60.62	-	-	-	7940.74
Castel di Iudica	10,257.00	249.26	775.20	348.22	475.00	2315.63	1331.48	164,518.27
Castiglione di Sicilia	11,812.00	417.10	1297.18	582.69	-	-	-	76,332.88
Catania	18,163.00	261.19	812.30	364.89	4549.99	22,181.20	12,754.19	1,186,749.24
Fiumefreddo di Sicilia	1207.00	12.59	39.15	17.59	583.71	2845.59	1636.21	148,417.82
Giarre	2711.00	21.06	65.50	29.42	1290.64	6291.87	3617.83	326,925.96
Grammichele	3083.00	106.40	330.90	148.64	482.70	2353.16	1353.07	140,301.12
Gravina di Catania	513.00	-	-	-	-	-	-	-
Licodia Eubea	11,174.00	227.31	706.93	317.55	97.22	473.95	272.52	65,935.70
Linguaglossa	5982.00	115.64	359.64	161.55	3.16	15.41	8.86	21,954.12
Maletto	4069.00	52.02	161.78	72.67	6.39	31.15	17.91	11,119.64
Maniace	3758.00	218.75	680.31	305.60	2.27	11.07	6.36	40,601.35
Mascali	3751.00	30.50	94.86	42.61	1407.02	6859.22	3944.05	357,785.69
Mascalucia	1617.00	17.75	55.20	24.80	-	-	-	3248.40
Mazzarrone	3457.00	154.86	481.61	216.34	49.96	243.56	140.04	40,846.65
Militello in Val di Catania	6207.00	245.82	764.50	343.41	840.14	4095.68	2355.02	255,290.22
Milo	1655.00	4.42	13.75	6.17	42.18	205.63	118.24	11,367.36
Mineo	24,482.00	892.62	2776.05	1247.00	3676.34	17,922.16	10,305.24	1,083,615.09
Mirabella Imbaccari	1521.00	119.78	372.52	167.33	-	-	-	21,920.77
Misterbianco	3742.00	101.27	314.95	141.48	1514.12	7381.34	4244.27	397,546.38
Motta Sant'anastasia	3547.00	204.42	635.75	285.58	1149.83	5605.42	3223.12	325,234.98
Nicolosi	4236.00	14.40	44.78	20.12	-	-	-	2635.32
Palagonia	5742.00	121.37	377.46	169.56	3838.33	18,711.86	10,759.32	983,018.92
Paternò	14,374.00	620.10	1928.51	866.29	3402.79	16,588.60	9538.45	965,266.82
Pedara	1910.00	3.22	10.01	4.50	-	-	-	589.29
Piedimonte Etneo	2635.00	90.78	282.33	126.82	211.80	1032.53	593.70	69,631.10
Raddusa	2325.00	44.61	138.74	62.32	3.99	19.45	11.18	9162.79
Ragalna	3928.00	145.93	453.84	203.87	-	-	-	26,706.44
Ramacca	30,453.00	692.84	2154.73	967.91	8282.72	40,378.26	23,217.50	2,200,118.36
Randazzo	20,426.00	329.57	1024.96	460.41	-	-	-	60,314.14
Riposto	1309.00	5.15	16.02	7.19	556.55	2713.18	1560.08	140,257.57
San Cono	659.00	16.77	52.15	23.43	-	-	-	3069.05
San Giovanni la Punta	1077.00	16.13	50.16	22.53	3.04	14.82	8.52	3712.90
San Gregorio di Catania	561.00	3.29	10.23	4.60	31.78	154.93	89.08	8557.24
San Michele di Ganzaria	2567.00	164.85	512.68	230.30	8.70	42.41	24.39	32,346.74
San Pietro Clarenza	623.00	20.86	64.87	29.14	-	-	-	3817.56
Santa Maria di Licodia	2608.00	383.57	1192.90	535.85	-	-	-	70,196.60
Santa Venerina	1889.00	44.83	139.42	62.63	119.58	582.95	335.20	38,137.43
Sant'agata Li Battiati	309.00	2.00	6.22	2.79	13.97	68.10	39.16	3862.97
Sant'alfio	2567.00	14.61	45.44	20.41	284.08	1384.89	796.31	73,784.39
Scordia	2415.00	99.02	307.95	138.33	771.86	3762.82	2163.62	211,332.78
Trecastagni	1902.00	8.73	27.15	12.20	-	-	-	1597.66
Tremestieri Etneo	647.00	3.61	11.23	5.04	-	-	-	660.66
Valverde	548.00	3.64	11.32	5.09	-	-	-	666.15
Viagrande	1002.00	18.45	57.38	25.77	-	-	-	3376.51
Vizzini	12,594.00	289.44	900.16	404.35	23.44	114.27	65.71	58,837.48
Zafferana Etnea	7631.00	43.24	134.48	60.41	2.75	13.41	7.71	8601.67
Total	**355,078.00**	**10,642.99**	**33,099.70**	**14,868.38**	**38,822.68**	**189,260.57**	**108,824.82**	**11,665,815.26**
Minimum	171.00	-	-	-	-	-	-	-
Maximum	38,114.00	1393.33	4333.26	1946.50	8282.72	40,378.26	23,217.50	2,200,118.36
Mean	6122.03	183.50	570.68	256.35	669.36	3263.11	1876.29	201,134.75
Standard deviation	8044.39	272.76	848.30	381.06	1517.78	7399.17	4254.53	406,293.70

Sources: *Censimento Istat, 2010; °Istat, 2008; #RTM 2008.

ipalities out of 58 (Belpasso, Catania, Mineo, Palagonia, and Ramacca) contributed with more than 60% of the total production, which was equal to about 108,824 tons. The olive pomace production was equally distributed in each municipality, except for three municipalities (Belpasso, Caltagirone, and Mineo), which produced the 30% of the total olive pomace, which was about 14,868 tons. For the whole province of Catania, the total biogas production was estimated to be about 11,665,815 Nm^3. For each municipality, the values of the estimated B_{tot_i}, computed by applying Eq. 6 were also reported in the Table 1 and mapped in Figure 3.

In order to select suitable areas for the location of new biogas plants, the municipalities were grouped into the five classes reported in Table 2 and for each of them the main statistic parameters of S_{citrus_i} and S_{olive_i} were showed in Table 3.

In the municipalities belonging to the first class, which has an average value of S_{mun} equal to about 1158 ha, the 8% of the whole surface is for olive and citrus cultivation, which are the 3% e 5% of the whole S_{mun} respectively, corresponding to 26.28 ha of olive groves and 61.73 ha of citrus growing areas on average.

In the municipalities having S_{mun} between about 2414 ha and 6981 ha, with an average value of S_{mun} of about 3904 ha, the citrus growing areas increased. In fact, the density of the olive growing areas remains unchanged, equal to the 3% of the whole surface and equivalent to about 128 ha, whereas the surface area of the citrus growing areas reached the 19% of the entire surface, which was equal to about 729 ha on average.

Table 2. Classification of municipalities based on municipality surface area.

Class	S_{mun} [ha]	S_{mun}_mean [ha]	B_{tot_i}_mean [Nm^3]
1st	<2414.9	1158.8	20,261.7
2nd	2414.9-6981.2	3904.3	206,169.9
3rd	6981.2-14,374.0	10,872.36	203,848.5
4th	14,374.0-24,912.4	20,900.70	737,824.6
5th	>24,912.4	34,283.19	1,308,787.4

The third class of municipalities, having an average value of S_{mun} equal to about 10,872 ha, shows an overall density of the citrus and olive growing areas equal to 8% of the whole surface. Compared to the second class, a reduction in the density of the citrus growing areas was encountered, which were equal to the 5% of the whole surface that corresponds to about 571 ha. With regard to the percentage of the olive growing areas, they kept unchanged to 3%, which is equivalent to about 332 ha.

The analysis of the fourth class of municipalities, having an average value of S_{mun} of about 20,900 ha, revealed an increase in the percentage of the density of the citrus growing areas compared to the third class, whereas the distribution of the olive growing areas remained unchanged. In fact, about 606 ha are cultivated with olive groves (3% of S_{mun}) and 2504 ha are citrus growing areas (12% of S_{mun}).

In the class of municipalities with S_{mun} higher than 24,912 ha, which has an average value of S_{mun} of about 34,283 ha, a slight increase of the citrus growing areas to 13% of S_{mun}, which corresponds to about 4465 ha, was found whereas the percentage of the olive growing areas kept unchanged to 3%, which corresponds to about 1043 ha.

These data analyses showed that, for all the considered classes, the density variation in percentage of the citrus growing areas ranged between 5% (first and third classes) and 19% (second class) while the olive growing areas always occupied a surface area equal to about 3% of S_{mun}.

Since the olive growing areas are equally distributed in percentage in all the classes, these results induce to affirm that the potential biogas production could be mainly affected by the density of the citrus growing areas, which showed to have densities higher than that of the whole province (about 10%) in the second class (about 19%), fourth class (about 12%), and fifth class (about 13%). In addition, the highest values of B_{tot} mean (Table 2), which were found for the same classes above mentioned, drive to the same conclusion.

In the GIS model, the polygons of the 21 municipalities belonging to these three selected classes (Acireale, Biancavilla, Grammichele, Linguaglossa, Maletto, Mascali, Militello in Val di Catania, Misterbianco, Motta Sant'Anastasia, Nicolosi, Palagonia,

Table 3. S_{olive_i} and S_{citrus_i} distribution for each municipalities group.

	S_{olive_i}* [ha] Classes				
	1st	2nd	3rd	4th	5th
Minimum	-	5.95	43.24	261.19	692.84
Maximum	164.85	383.57	620.10	892.62	1393.33
Mean	26.28	128.98	332.04	606.28	1043.09
Standard deviation	39.70	104.42	189.08	299.30	495.32
	S_{citrus_i}* [ha] Classes				
	1st	2nd	3rd	4th	5th
Minimum	-	-	-	-	649.03
Maximum	583.71	4107.02	3402.79	4549.99	8282.72
Mean	61.73	729.33	571.60	2504.29	4465.88
Standard deviation	160.21	1211.92	1260.13	2278.12	5397.83

*Source: Censimento Istat, 2010.

Mazzarrone, Maniace e Ragalna, Randazzo, Belpasso, Bronte, Mineo, Catania, Ramacca, Caltagirone) were overlaid with the current location of the citrus processing industries. Figure 4 shows the outcomes of this analysis. The geographical areas of the five municipalities (Acireale, Calatabiano, Caltagirone, Mascali, and Scordia) obtained by the GIS analysis could be considered the most suitable location for planning the sustainable development of new biogas plants with regard to the minimisation of transportation costs for feedstock supply and logistics, in terms of economic, social and environmental impacts. Information on other biomasses required for the anaerobic digestion within each municipality of the considered classes could be useful for a more precise localisation of new biogas plants based on their potential availability.

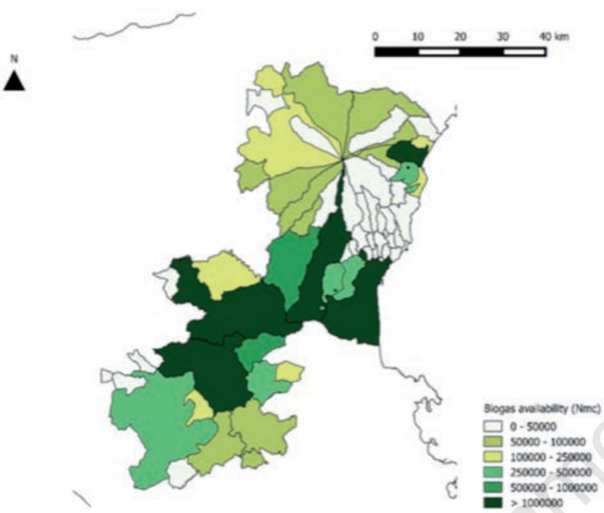

Figure 3. Estimation of biogas availability at municipal level.

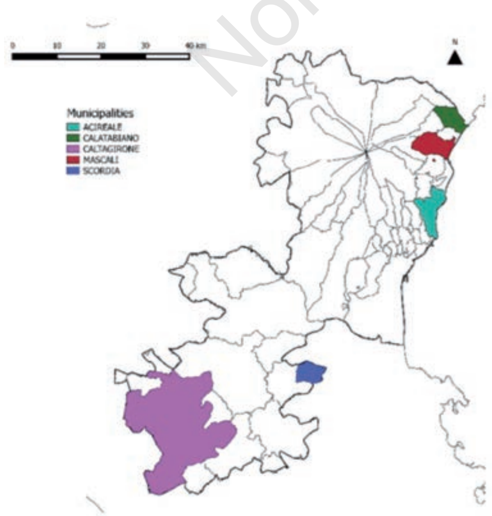

Figure 4. Suitable areas to locate new biogas plants in the province of Catania.

Conclusions

The application of the proposed methodology allowed the identification of the major citrus and olive producing areas with the final aim of estimating potential biogas production. Based on the obtained results, the olive pomace and citrus pulp obtained from those producing areas could constitute a promising combination of biomass resources because of their potential utilisation for energy purposes. At the same time, they could offer a solution to the management problems connected to the disposal of these by-products.

The results lay the basis for future studies aimed at finding a more detailed localisation of new biogas plants within each municipality of the considered province. In the study, the selection of the areas eligible for biogas plants location was mainly influenced by the density of the citrus producing areas, which ranged from 5% to 19% among the classes of municipalities analysed. In fact, the density of the olive producing areas resulted always equal to about 3% among the same classes. Further analyses should carried out to obtain information about other biomasses required for a suitable diet of the anaerobic digesters to be located.

References

Arcidiacono C., Porto S.M.C. 2008. Image processing for the classification of crop shelters. Acta Hortic. 801:309-16.

Arcidiacono C., Porto S.M.C. 2010. A model to manage crop-shelter spatial development by multi-temporal coverage analysis and spatial indicators. Biosyst. Eng. 107:107-22.

Boscaro D., Pezzuolo A., Grigolato S., Cavalli R., Marinello F., Sartori L. 2015. Preliminary analysis on mowing and harvesting grass along riverbanks for the supply of anaerobic digestion plants in north-eastern Italy. J. Agr. Eng. 46:100-4.

Cerruto E., Selvaggi R., Papa R. 2016. Potential biogas production from by-products of citrus industry in Sicily. Qual. Access Success Suppl. 17:251-8.

Commission of the European Communities. 2007. Communication from the Commission to the Council and the European Parliament. Renewable Energy Road Map Renewable energies in the 21st century: building a more sustainable future, COM 848, Brussels.

Dale B.E., Sibilla F., Fabbri C., Pezzaglia M., Pecorino B., Veggia E., Baronchelli A., Gattoni P., Bozzetto S. 2016. Biogasdoneright™: an innovative new system is commercialised in Italy. Biofuel Bioprod. Bioref. 10:341-5.

De Montis A. 2014. Strategic environmental assessment of energy planning tools: A study of Italian regions and provinces. Environ. Impact Assess. Rev. 46:32-42.

Dell'Antonia D., Cividino S.R.S., Carlino A., Gubiani R., Pergher G. 2013. Development perspectives for biogas production from agricultural waste in Friuli Venezia Giulia (Nord-East of Italy). J. Agr. Eng. 44(2s):569-72.

Fabbri C., Labartino N., Manfredi S., Piccinini S. 2013. Biogas, il settore è strutturato e continua a crescere. L'Inf. Agr. 11:11-6.

Inea. 2014a. Annuario dell'agricoltura italiana 2013, Vol. LXVII. Istituto Nazionale di Economia Agraria, Roma, Italy.

Inea. 2014b. L'agricoltura nella Sicilia in cifre. 2013. Istituto Nazionale di Economia Agraria, Roma, Italy.

Istat. 2010. 6° Censimento Generale dell'Agricoltura. Istituto nazionale di statistica, Roma, Italy.

Molari G., Milani M., Toscano A., Borin M., Taglioli G., Villani

G., Zema D.A. 2014. Energy characterisation of herbaceous biomasses irrigated with marginal waters. Biomass Bioener. 70:392-9.

Modica G., Pollino M., Lanucara S., La Porta L., Pellicone G., Di Fazio S., Fichera C.R. 2016a. Land suitability evaluation for agro-forestry: definition of a web-based multi-criteria spatial decision support system (MC-SDSS): preliminary results. Lecture Notes Comput. Sci. 9788:399-413.

Modica, G., Solano F., Merlino A., Di Fazio S., Barreca F., Laudari L., Fichera, C.R. 2016b. Using Landsat 8 imagery in detecting cork oak (Quercus suber L.) woodlands: a case study in Calabria (Italy). J. Agr. Eng. 5:205-15.

Piccinini S., Soldano M., Fabbri C., 2010. L'agricoltore crede nel biogas e i numeri lo confermano. L'Inf. Agr. 47:63-7.

Reale F., Stolica R., Gaeta M., Ferri M., Sarnataro M., Vitale V. 2009. Analisi e stima quantitativa della potenzialità di produzione energetica da biomassa digeribile a livello regionale. Studio e sviluppo di un modello per unità energetiche. Parte 1 - Metodologia. ENEA 2009, Report RSE/2009/RSE182. Available from: http://www.enea.it/it/Ricerca_sviluppo/documenti/ricerca-di-sistema-elettrico/celle-a-combustibile/rse182.pdf Accessed: 08/09/2014.

Sgroi F., Di Trapani A.M., Foderà M., Testa R., Tudisca S. 2015. Economic performance of biogas plant using giant reed silage biomass feedstock. Ecol. Engine. 81:481-7.

Thompson W., Meyer S., 2013. Second generation biofuels and food crops: co-products or competitors? Global Food Secur. 2:89-96.

Valenti F., Arcidiacono C., Chinnici G., Cascone G., Porto S.M.C. 2017a. Quantification of olive pomace availability for biogas production by using a GIS-based model. Biofuel. Bioprod. Bioref. 11:784-97

Valenti F., Porto S.M.C., Chinnici G., Cascone G., Arcidiacono C. 2016. A GIS-based model to estimate citrus pulp availability for biogas production: an application to a region of the Mediterranean Basin. Biofuel Bioprod. Bioref. 10:710-27.

Valenti F., Porto S.M.C., Cascone G., Arcidiacono C. 2017b. Assessment of citrus pulp availability for biogas production by using a GIS-based model: the case study of an area in southern Italy. Chem. Engine. Trans. 58:529-34.

Valenti F., Porto S.M.C., Chinnici G., Selvaggi R., Cascone G., Arcidiacono C., Pecorino B. 2017c. Use of citrus pulp for biogas production: a GIS analysis of citrus-growing areas and processing industries in South Italy. Land Use Policy 66:151-61.