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Assessment of Citrus Pulp Availability for Biogas Production by Using a GIS-based Model: the Case Study of an Area in Southern Italy

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In literature, anaerobic digestion of biomasses is commonly considered an environmental friendly way to treat and revalorise large amounts of by-products from farm industries because it could ensure both pollution control and energy recovery. This process is defined as the biological conversion of organic material to a variety of end products including 'biogas', the main constituents of which are methane (65–70%) and carbon dioxide.
Citrus pulp is the main by-product of citrus processing industries and is composed of variable quantities of peel, pulp, and seeds. Recently, citrus pulp has been object of research studies because of its possible conversion from an ordinary by-product to an energy resource through an anaerobic digestion process. This possibility is of relevant importance also for reducing the environmental burden caused by disposal processes of the residues of citrus processing industries.
At present, the lack of official data related to citrus pulp availability and spatial localisation has limited the reuse, exploitation, and valorisation of this by-product. Therefore, with the aim to fill this gap the objective of this study was to analyse the spatial distribution of the citrus producing areas and the amount of processed citrus in order to quantify the availability of citrus pulp for biogas production at a provincial level. To this aim a GIS-based model, previously defined and applied to evaluate the amount of citrus pulp production at a regional level, was applied to the case study of Catania province (Sicily, Italy).
The results obtained in this study could constitute a valuable support for providing potential solutions to issues related to the environmental burden of citrus pulp disposal. Moreover, they could contribute to build an information base aimed at improving the sustainability of biogas sector, by helping to identify the best location for new biogas plants through the optimization of the logistics of biomasses supply in geographical areas where biogas sector is still developing.

1. Introduction

Among the renewable energy sources, the production of biogas from biomass by anaerobic digestion has developed significantly in the last twenty years with a growing number of biogas plants making Italy the third world producer after China and Germany, even though investment has been above all in Northern Italy (Fabbri et al., 2010; Fabbri et al., 2013; Sgroi et al., 2015).
In most Italian regions, especially in North-Central Italy, the biogas is produced by dedicated energy crops (e.g., beetroot, sugar cane, sorghum, and corn and wheat), but in recent years, an innovative system to produce biogas was developed (Dale et al., 2016). This concept involves the development of double cropping as well as the reduction, or complete replacement, of chemical fertilisers required for cultivation. These features, could be used to build new biogas plants, by running on a significant proportion of fuels from

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agriculture and agro-industrial by-products (CRPA, 2008), especially in those areas where the biogas sector is still not developed, such as in South Italy.

Among the by-products used to extract biogas (Valenti et al., 2017a), the re-use of the residual biomass coming from the citrus processing industry, such as citrus pulp, has been recently put forward (Tamburino and Zema, 2009). Initially, this involves hydrolysing the pectin, cellulose and hemicellulose contained into simple sugars. Then, the their alcoholic fermentation generates ethanol and carbon dioxide by way of glycolysis, pyruvate dehydrogenase, and alcohol dehydrogenase (Wilkins et al., 2007).

Citrus cultivation plays a key role for the economy in the USA, Brazil, Mexico, China, India, Iran, and many Mediterranean countries, including Spain, Italy, and Greece (Martín et al., 2010, Valenti et al., 2017b). However, the processing of citrus fruits produces a huge amount of citrus pulp, which is often disposed in landfills or used as animal feed in small quantities. Since EU directive 2008/98/EC establishes that food waste cannot be disposed of in a landfill without a previous valorisation, the re-use of citrus pulp for energy purpose could be an advantage with regard to environmental and economic concerns (EU, 2014).

Since there is a general uncertainty of data relating to biomass quantities, this research aims at investigating the amount of available citrus pulp at provincial level in order to estimate the potential biogas production. This aim is relevant for the planning of the development of new biogas plants in a sustainable way with regard to environmental protection, i.e, reduction of both land use for dedicated energy crop and GHG emissions derived from feedstock supply and logistics, and the re-use of agro-industrial wastes. On this basis, the case study of the province of Catania and its municipalities was analysed by using GIS tools and descriptive statistics as well as by investigating the specific regulatory framework.

2. Materials and methods

2.1 The study area

In Italy citrus production is relevant since it covers an area of 142,011 ha with a production of 2.7 million tons, according to the most recent official statistical data (Kale et al., 1995). Valenti et al. (2016) analysed citrus producing areas in Sicily, a region in South Italy, and discovered that the provinces of Catania and Syracuse have the highest citrus production. Particularly, the computation of an index, which describes the level of availability of citrus pulp obtained at regional level (Figure 1), highlighted that the province of Catania has the highest potential production of citrus pulp.

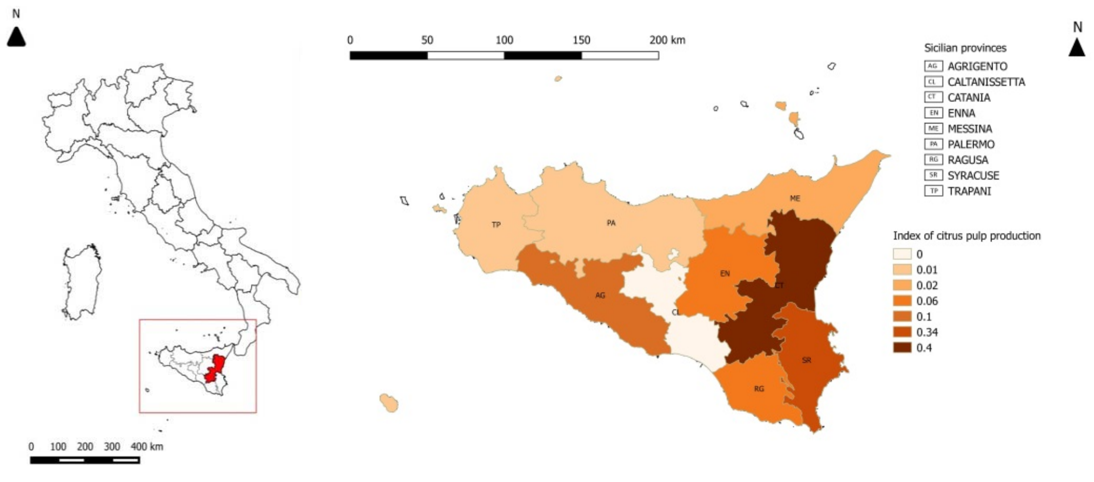

Figure 1: Geographic position of the study area and the index of citrus pulp availability at the regional level.

2.2 The GIS-based model for the computation of citrus pulp availability at provincial level

The model proposed by Valenti et al. (2016), previously applied at regional level in Sicily, was used in this study to compute the index that describes the level of citrus pulp availability at provincial level in Catania. To this aim, the study area was subdivided into 58 zones, which are the municipalities composing the province of Catania. Then, citrus producing areas S_{citrus_i} and citrus pulp production P_{citrus_i} , were computed. For S_{citrus_i} data, the 6th Agricultural Census 2010 (ISTAT, 2013) was used. The data gathered by the Agricultural General Census provides a complete information base about the structure of the agricultural and livestock system on a national, regional, and local level. Therefore, the data has a strong impact on the development of the national agricultural policy and, since the survey is conducted according to the rules drawn up on a European level, it also represents a fundamental tool for EU agricultural policymakers. It was conducted with the main objective to outline a statistical information framework, update and detail the structure of agricultural and livestock farms operating in Italy and the agricultural production methods adopted. Although the information contained in 6th Agricultural Census 2010 database is more accurate than that included in the ISTAT database, which was used in the previous research (Valenti et al., 2016), some basic data are still missing, such as the yield of the cultivated areas. Therefore, since data about the amount of produced citrus fruits were not available at the municipal level, some preliminary elaborations were carried out for the computation of P_{citrus_i}. Firstly, the yield of citrus producing areas (Y_{citrus}) was computed at the provincial level, then it was applied to obtain the citrus production at the municipal level according to the following relation:

$$P_{citrus\_i} = Y_{citrus} \times S_{citrus\_i} \quad (1)$$

The values of S_{citrus_i} and P_{citrus_i} were used to perform GIS analyses, by using the Regional Technical Map related to the year 2008 as base map. Image processing for the classification of high-resolution satellite images could also be used for this purpose if RTMs were not available (Arcidiacono et., 2008; Arcidiacono et al. 2010).

The amount of the citrus fruits processed by the citrus processing industry, for each municipality, was obtained by the equation 2 where the coefficient of availability (*Ca*) obtained by literature was fixed to 30% (Inea 2014a; 2014b).

$$P_{processed\_citrus\_i} = Ca \times P_{citrus\_i} \quad (2)$$

The average percentage of citrus pulp $Cp_{av\%}$ was obtained by surveying all the citrus processing industries of the province of Catania. The identification of the citrus processing industries in the study area and their localisation by using the GPS coordinates made it possible to produce a feature class in the GIS. The data, which were obtained from each industry for two different citrus producing campaigns, were elaborated in anonymous form by using the descriptive statistics. The ratios between the produced citrus pulp and the amount of citrus fruit processed, for each industry, were computed and averaged to obtain $Cp_{average\%}$.

The amount of citrus pulp potentially produced in each municipality ($Cp_{\_i}$) was calculated by using the follow equation:

$$Cp\_i = Cp_{av\%} \times P_{processed\_citrus\_i} \quad (3)$$

The last step of this study involved the evaluation of biogas potential production associated to the estimated citrus pulp in Catania province. Therefore, the theoretical biogas potential (B_{tot}) was calculated by using the following relation:

$$B_{tot} = Cp\ Y \quad (4)$$

Where *Cp* is the amount of citrus pulp and *Y* is the citrus pulp biogas potential. The biogas potential (*Y*) was 89.3 Nm^3/ttq for the feedstock material defined as "Citrus pulp of pigmented and yellow oranges sampled at the end of the whole process (extraction by means of in-line FMC juice extractors)', as reported in Cerruto et al. (2016).

3. Results and Discussion

To calculate S_{citrus_i} and P_{citrus_i} at the municipal scale, Agricultural Census 2010 data were elaborated and reported in Table 1. Data analyses regarded the amount of citrus growing areas, the amount of produced citrus fruits and, consequently, the amount of processed citrus fruits. Table 1 shows that the average amount of processed citrus fruits was about 3,263 t, with a standard deviation of about 7,399 t. The minimum value regarded 22 municipalities where citrus producing areas are not present.

Table 1: Minimum, maximum and mean values of S_{citrus_i}, P_{citrus_i}, and $P_{processed\_citrus\_i}$ obtained by elaborating the data related to 58 municipalities of the province of Catania.

	S_{citrus_i}* (ha)	P_{citrus_i} (t)	$P_{processed\_citrus\_i}$ (t)
Minimum	-	-	-
Maximum	8,282.7	134,594.2	40,378.3
Mean	669.4	10,877.0	3,263.1
Standard deviation	1,517.8	24,663.9	7,399.2

Source*: Data collected through direct survey.

Figure 3 shows the localisation of the six surveyed citrus processing industries in the province of Catania. This spatial analysis of data showed that the citrus processing industries in the territory are not equally located in the province. In fact, some of the industries are too close to each other.
The data collected by the surveys were elaborated by using descriptive statistical tools in order to highlight the main production aspects. The data elaborations, which were referred to the two last available campaigns (2012/2013 and 2013/2014) and reported in Table 2, provided minimum, maximum, and mean values of the productions of citrus fruits and citrus pulp, their standard deviation (SD), and the citrus pulp percentage $Cp_{av\%}$.

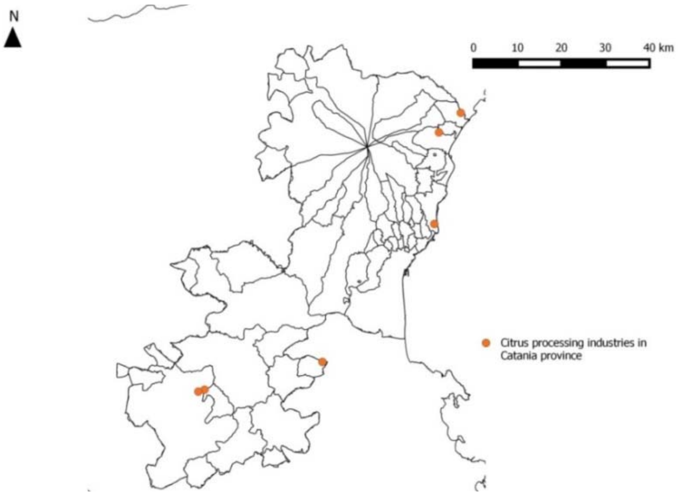

Figure 3: Localisation of citrus processing industries.

Table 2: Computation of the $Cp_{average\%}$ indicator.

	Campaigns						Averages		
	2012/2013			2013/2014					
	Processed citrus	Citrus pulp	$Cp_{av\%}$	Processed Citrus	Citrus pulp	$Cp_{av\%}$	Processed citrus	Citrus pulp	$Cp_{av\%}$
Minimum (t)	400.0	240.0	50.0	400.0	240.0	50.0	400.0	240.0	50.0
Maximum (t)	28,500.0	16,200.0	60.0	60,000.0	36,000.0	60.0	43,500.0	26,100.0	60.0
Mean (t)	14,002.3	7,913.8	57.5	14,449.6	8,423.9	57.5	14,226.0	8,168.9	57.5
SD (*)	11,867.9	6,779.3	-	22,827.6	13,752.6	-	16,106.7	9,631.3	-

Source: Data collected through direct survey.
(*) Standard deviation

The elaborations carried out for the six citrus processing industries located in the province of Catania, showed that the average amount of processed citrus fruits, during the two investigated harvests (2012/2013 and 2013/2014), equals to 14,226 t, with a variation of about 43,100 t, since it ranges between 400 t and 43,500 t. The table also shows that, during the second campaign (2013/2014), the processed citrus fruits reached a maximum value of 60,000 t, which was about 50% more than the value related to the previous campaign. However, in the campaign 2013/2014 the average amount of processed citrus fruits increased only by about 3% due to the different production of citrus processing industries. The amount of citrus pulp produced by the citrus processing industries is a direct consequence of the amount of processed citrus fruits and the production process for juice extraction adopted by each company. In fact, the obtained citrus pulp varied between a maximum value of 26,100 t and a minimum of 240 t, with an average value of about 8,168 t. The computed SD confirms the citrus processing industry variability. Based on the data obtained from the survey, the indicator $Cp_{av\%}$ was computed for the province of Catania (Table 2); its average value, which equalled 57.5 %, was considered for the elaborations reported in the following of the text.
Figure 4, which was obtained on the basis of equation 3, shows the relevance of citrus pulp potential production in several areas of the municipalities belonging to the Catania Plan district. In detail, the area with the highest citrus pulp production is contained in 6 municipalities of the province of Catania.
By applying equation 4, the total amount of citrus pulp available in the province of Catania theoretically corresponded to about 9.7 million Nm^3 biogas, and 70% of this potentially available biogas (about 7.0 million Nm^3) is located in Catania Plan district. Therefore, the citrus pulp derived from the citrus processing industry

constitutes a promising biomass resource for this area because of its potential utilisation for energy purposes and its could contribute to reduce national dependence on imported fossil fuels (Ghimire et al., 2015; Fountoulakis et al., 2008; Cherubini, 2010).

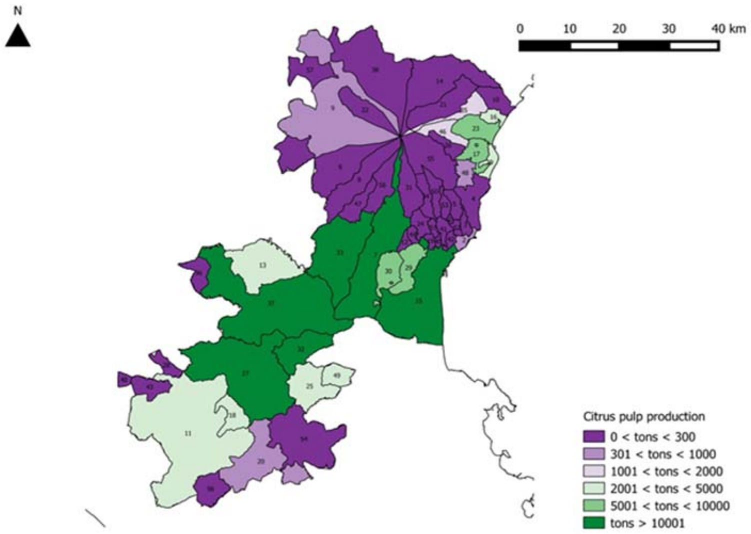

Figure 4: Territorial distribution of citrus pulp indicator $Cp_{\_i}$.

The amount of potentially available biogas computed for the whole province of Catania resulted about 30% more than that obtained by Valenti et al. (2016) for the same province. There are two main reasons for this result. The first explanation regards the higher value of $Cp_{av\%}$, which in this study was obtained by surveying all the citrus processing industries of the study area, compared to that of the previous study carried out at regional level (Valenti et al., 2016), which was derived from a sample of the industries. A second explanation refers to the time interval of the agricultural production data (cultivated surfaces and amount of citrus fruits produced) that was considered in the GIS model. The database considered in this study (ISTAT, 2013) includes data collected in 2010, whereas the database utilised in the previous study (Valenti et al., 2016) contains data relative to the time interval 2011-2014 when a reduction of about 10% was encountered for citrus producing areas (S_{citrus_i}). Therefore, since the value of S_{citrus_i} was utilised in this study to compute the amount of citrus fruits produced in the municipalities of the study area, it affected the amount of potentially available biogas.

4. Conclusions

In this study, a GIS-based method to estimate the availability of biomasses, which was previously defined and tested on citrus cultivation at the regional level, was applied to calculate the potential availability of citrus pulp in the province of Catania. To this aim, citrus producing areas and citrus production as well as the average percentage of citrus pulp production and its availability were computed for each municipality.
The data collection, which was also carried out by specific surveys, and the related elaborations made it possible to reach the objectives of this study since they were suitable for computing and mapping the citrus producing areas and one of their by-products, the citrus pulp, in the whole study area.
The spatial analysis of data allowed for mapping the distribution of the citrus processing industries in the territory, which is not uniform, and the area with the highest citrus pulp production, which is contained in the Catania Plan district. Furthermore, the computation of the potentially available biogas for the study area confirmed that the citrus pulp produced in the area by the local industries constitutes a promising biomass resource suitable for being utilised for energy purposes.
The obtained results lays the basis for a future study aimed at finding a more sustainable and detailed localisation for new biogas-biomethane plants. Therefore, the valorisation of the energy potential of citrus pulp and other biomasses such as by-products would also produce a more sustainable process, due to the fact that re-use of by-products could contribute to solve the problems related to their disposal and reduce national dependence on imported fossil fuels.

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