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Sicilian potential biogas production from Citrus industry by-product

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Summary
In Europe, Italy is the second nation after Spain in Citrus production and 49% ca. of national fruit production is located in Sicily. The by-product obtained from the industrial processing of Citrus fruits into juice and essential oils is called "pastazzo" or Citrus Waste (CW). This study is aimed at evaluating the Sicilian potential biogas and energy production from the above "pastazzo" and verifying the possibility of using this by-product for Anaerobic Digestion (AD) process within 30 km from processing plants.
The areas cultivated with Citrus species in Sicily and their distribution in the various municipal districts were mapped and analysed by means of QGIS software, together with the main Citrus processing plants and the three existing AD plants. The statistical data about the amounts of the by-product of Citrus processing industry were evaluated, in order to compute the Sicilian potential biogas and energy production.
In Sicily it is possible to obtain, through the use of "pastazzo", a yearly production of 12,916,800 m^3 ca. of biogas, equal to 24,250,930 kWh of electric energy and 25,463,477 kWh of thermal energy or 6,200,064 m^3 of biomethane. This high potential biogas and energy production is not be currently used in a sustainable way from the energetic and economic points of view, because the existing AD plants are farer than 30 km from Citrus processing plants.
The CW produced in Sicily could be used inside a bio-reactor, together with other raw materials (e.g. pomace and wastewater from olive oil mills, cereal straw, poultry manure and Italian sainfoin or *Hedysarum coronarium*), for AD process.

1. Introduction

The increase in agricultural investments, driven by the growing demand for biofuels, can stimulate the development of a sustainable agriculture through the cultivation of dual purpose crops, integrating food and energy production (FAO, 2013). Moreover, the increasing needs to protect the environment require a correct management of wastes, including the by-product deriving from Citrus industry. In Europe, Italy is the second nation after Spain in Citrus production, with 2,924,531 tons produced per year and 49% ca. of national fruit production is located in Sicily, i.e. 1,418,567 t (of which 40% ca. are processed), mainly orange, followed by lemon, mandarin and clementine, above all in the provinces of Syracuse and Catania (ISTAT, 2015). Yet, the Citrus fruits produced in the provinces of Agrigento, Trapani and Caltanissetta are marketed as fresh ones.
The industrial processing of Citrus fruits produces juice (35-45%), essential oils (0.2-0.5%) and a by-product called "pastazzo" or Citrus Waste (CW) (55-65%), that is composed of peels, squeezed pulp residues, seeds and residual fruits (Interlandi, 2013). It is essentially composed of carbohydrates, acids (mainly citric and malic ones), lipids, mineral elements (mainly nitrogen, calcium and potassium), volatile components (e.g. alcohols, aldehydes, ketones, esters and hydrocarbons), flavonoids, essential oils (d-limonene, 95%), enzymes, pigments and vitamins. This very acid by-product, having a pH ranging from 3.5 to 5.8 (Valenti et al., 2016), is mainly used, both in Italy (especially Sicily) and in other countries, as food for livestock, but recently also in Anaerobic Digestion (AD) process for producing biogas and digestate. Biogas can be used for extracting biomethane, a fuel that can power surface transportation and agricultural machines, or Combined Heat and Power (CHP) plants for co-generating electric and thermal

energy (Comparetti et al. 2014, 2015). Moreover, the digestate, if treated and transformed into a dry form (e.g. pellets), can be used as organic fertiliser.
This study is aimed at evaluating the Sicilian potential biogas and energy production from the above "pastazzo" and verifying the possibility of using this by-product for AD process within 30 km from processing plants.

2. Materials and Methods

By means of QGIS, an open source GIS software, it was possible to use the vector map of land use of Sicilian Region (2012). This map is coded according to the legend Corine Land Cover (CLC) and reclassified from the Corine Biotopes map, selected from EU Corine Biotopes classification manual (EUR 12587/3 EN), where the minimum areas classified are 1 ha. Through the intersecting and sampling tools of QGIS software, a new point layer was obtained for collecting the attribute data of land use, provincial and municipal boundaries, for any area of 1 ha. Thus, the areas cultivated with Citrus species in Sicily and their distribution in the various municipal districts were mapped and analysed, together with the processing plants and the three existing AD plants: Mussomeli (Caltanissetta), Vittoria (Ragusa) and Resuttano (Caltanissetta), having an electric power of 999, 600 and 100 kW, respectively. Moreover, the areas cultivated with Citrus species in the various municipal districts compared with Used Agricultural Area (UAA), according to the 6th General Census of Agriculture, were mapped and analysed (ISTAT, 2012).
CW samples, taken at the processing plant Agrumaria Corleone (Palermo), were subjected to laboratory analysis, in order to determine their main chemical properties.
The statistical data about the amounts of the by-product of Citrus processing industry were evaluated, in order to compute the Sicilian potential biogas and energy production.
The potential biogas production from CW (B_{CW}) was determined according to the following Eq. (2.1):

$$B_{CW} = b_{CW} \cdot m_{CW} \quad (2.1)$$

where: b_{CW} is the specific biogas yield of CW mass unit, $m^3\ t^{-1}$;
m_{CW} is the CW mass, t
The yearly electric energy potential production from CW Ee_{CW} was determined according to the following Eq. (2.2):

$$Ee_{CW} = B_{CW} \cdot ee_B \quad (2.2)$$

where ee_B is the electric value of biogas, depending on the concentration of methane in biogas, kWh m^{-3}
The yearly thermal energy potential production from CW Et_{CW} was determined according to the following Eq. (2.3):

$$Et_{CW} = B_{CW} \cdot et_b \quad (2.3)$$

where et_b is the thermal value of biogas, depending on the concentration of methane in biogas, kWh m^{-3}
The yearly biomethane potential production from CW M_{CW} was determined according to the following Eq. (2.4):

$$M_{CW} = B_{CW} \cdot m_{CW} \quad (2.4)$$

where m_{CW} is the biomethane content inside biogas volume for CW, % (Comparetti et al., 2012, 2013).

3. Results and Discussion

Citrus area, also compared with Used Agricultural Area (UAA), the production of Citrus fruits, processed fruits and CW in Sicily are shown in Table 3.1.

Table 3.1: Citrus area (CA), also compared with Used Agricultural Area (UAA), production of Citrus fruits (CF), processed fruits (CPF) and CW in the nine provinces of Sicily

Provinces	CA (ha)	CA / UAA (%)	CF (t)	CPF (t)	CW (t)
Agrigento	3394	2.24	61,092	-	-
Caltanissetta	214	0.18	3852	-	-
Catania	29,425	17.38	529,650	211,860	127,116
Enna	2981	1.63	53,658	21,463	12,878
Messina	5242	3.23	94,356	37,742	22,645
Palermo	3801	1.43	68,418	27,367	16,420
Ragusa	2518	2.77	45,324	18,130	10,878
Syracuse	21,033	18.92	378,594	151,438	90,863
Trapani	1062	0.77	19,116	-	-
Total	69,670	2.24	1,254,060	468,000	280,800

The areas cultivated with Citrus species in the various municipal districts compared with Used Agricultural Area (%), the processing plants and the three existing AD plants are shown in Figure 3.1.

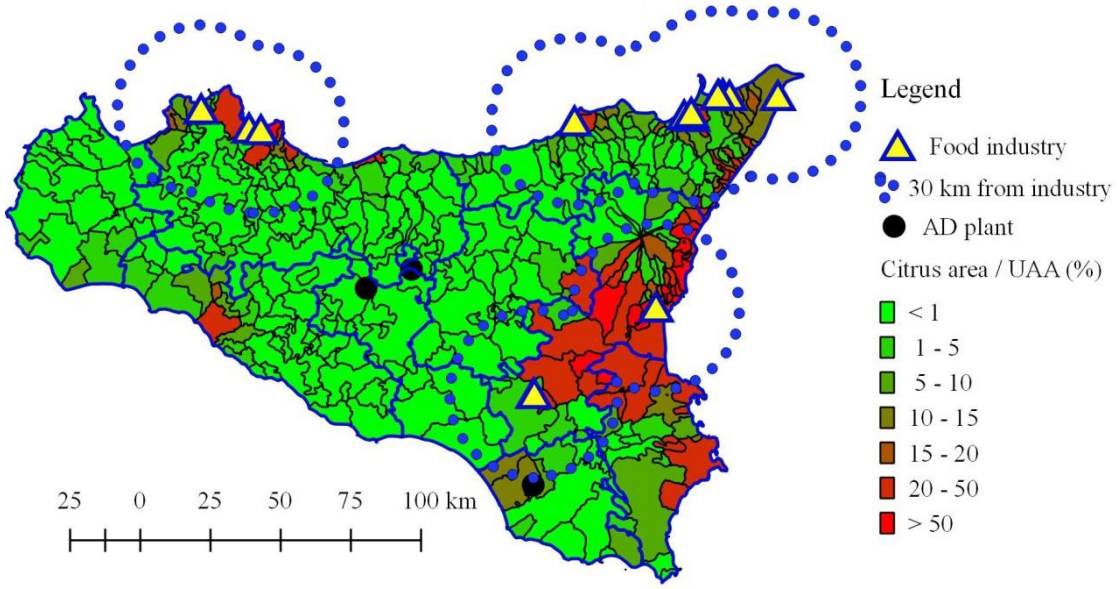

Figure 3.1: Sicily map showing the ratio between the areas cultivated with Citrus species in the various municipal districts and Used Agricultural Area (%), the processing plants and the three existing AD plants.

The results of laboratory analysis of CW samples are: dry matter of 10.26%; ash/dry matter of 4.96%; biogas yield of 45.65 m^3 t^{-1}; biomethane content inside biogas volume of 48%.
By using the above formulas it was foreseen that in Sicily it is possible to obtain, through the use of "pastazzo", a yearly production of 12,916,800 m^3 ca. of biogas, equal to 24,250,930 kWh of electric energy and 25,463,477 kWh of thermal energy or 6,200,064 m^3 of biomethane. This high potential biogas and energy production is not currently used in a sustainable way from the energetic and economic points of view, because the existing AD plants are farer than 30 km from Citrus processing plants.

4. Conclusion

Italian legislation, with the Legislative Decree no. 205/2010, clearly defines when a residue has to be considered waste or by-product (Cerruto et al., 2016). On this basis the Regional Department of Agricultural and Food Resources of Sicilian Region issued the document n° 14843 of 01/03/2012, that defined CW as a by-product rather than a waste and indicated the following uses for it:

- agronomical, as soil organic fertiliser or raw material for compost production;
- energetic, for bioethanol (biofuel) production or as raw material for biogas production;
- human food, for the production of fibres;
- fresh or ensiled or dried feed for livestock (Valenti et al., 2016);
- industrial, for the extraction of pectin (used as jelly in the food industry producing, above all, marmalade and jams).

Yet, the agronomical, human food, livestock feed and industrial uses of CW were not able to consume the high amounts of this by-product produced in Sicily (Interlandi, 2013). Therefore, CW can be considered as a resource rather than a by-product, as it can be used for producing biogas and digestate through AD process. This use contributes to minimise its environmental impact and also allows its energy valorisation. Furthermore, CW is characterised by an optimum attitude to AD process (due to its content of sugars), the above written plentiful availability in Sicily and a low cost of biomass unit (€ 10 t^{-1}) and, therefore, of biogas unit that can be produced from it (€ 0.11 m^{-3}) (Interlandi, 2013). The CW produced in Sicily could be used inside a bio-reactor, together with other raw materials (e.g. pomace and wastewater from olive oil mills, cereal straw, poultry manure and Italian sainfoin or *Hedysarum coronarium*), for AD process.

Yet, the disadvantages of using this by-product for AD process are its seasonal availability (from December to June), the difficult storage (due to its high water content and high fermentation attitude), the rapid acidification, inhibiting the activity of bacteria producing methane, and the presence of D-limonene in the peels and water, both inhibiting the process. Therefore, before AD process, CW must be subjected to a treatment aimed at removing limonene (Interlandi, 2013).

The use of "pastazzo" could be a potential solution to the problem of disposal of organic materials, caused by its high cost (€ 30 t^{-1}) and a significant lack of suitable landfills. Due to these problems some food processing companies illegally disposed the CW (Last Orange operation by police).

Therefore, this work suggests the need for a territorial plan where new AD plants must be located nearer than 30 km to Citrus processing plants, in order to reduce the transportation cost of CW and the environmental impact of its energy valorisation process.

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