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Potential Production of Biogas from Prinkly Pear (Opuntia ficus-indica L.) in Sicilian Uncultivated Areas

Antonio Comparetti[a], Pierluigi Febo[a], Carlo Greco[a], Michele Massimo Mammano[b], Santo Orlando[a]

a Università degli Studi di Palermo, Dipartimento Scienze Agrarie e Forestali, Viale delle Scienze, Building 4, 90128, Palermo, Italy
b Consiglio per la Ricerca in Agricoltura e l'Analisi dell'Economia Agraria (CREA) - Unità di Ricerca per il recupero e la valorizzazione delle Specie Floricole Mediterranee, S.S. 113 - km 245.500, 90011 Bagheria (Palermo), Italy
massimo.mammano@crea.gov.it

The aim of this work is to evaluate the potential production of biogas and, indirectly, biomethane or electric and thermal energy, from prinkly pear (Opuntia ficus-indica L.), to be grown in a part of Sicilian uncultivated areas and co-digested together with the available livestock manure and slurry.
In order to increase the Renewable Energy Sources (RES) and reduce the dependency from fossil ones, the conversion of biomass into biogas through Anaerobic Digestion (AD) process is paramount for producing biomethane, to be used as fuel for means of transport and agricultural machines or heating, or electric and thermal energy through Combined Heat and Power (CHP) plants. Moreover, the digestate produced through AD process can be applied to soils as organic fertiliser in the place of chemical ones.
Prinkly pear was supposed to be grown, by mechanising the harvest of cladods (modified stems), in a part of the Sicilian Used Agricultural Area that is currently uncultivated (totally 600,000 ha ca.), identified by means of a GIS software. Thus it was possible to compute the potential production of biogas and, indirectly, biomethane or electric and thermal energy.
The results show that the Sicilian potential production of biogas is 612,115 10^3 m^3, from which 342,784 10^3 m^3 of biomethane could be extracted or 67,038 MWh of electric energy and 70,390 MWh MWh of thermal energy could be generated. Moreover the obtained digestate would be used as biofertiliser, within both conventional and organic farming.
This work demonstrates that the production of RES, such as biogas from prinkly pear, represents a very profitable way of using the uncultivated areas: the income of the farmer would include not only that deriving from the sale of biomethane or electric and thermal energy but also the saving for replacing chemical fertilisers with digestate and the subsidy for producing biomethane as fuel for means of transport or electric and thermal energy from biogas.

1. Introduction

Global climate change, driven by greenhouse gas (GHG) emissions, has resulted in a 0.7-1°C increase of mean temperatures over the last 50 years and has already altered precipitation patterns. Furthermore, heating of land areas will result in increased soil drying, because of increased surface evaporation and evapotranspiration from plants.
Several target species have been identified for fighting against desertification, including Opuntia spp. These species can be also used as reserve in arid and semi-arid lands and seasonal or year-round fodders, as well as they can improve soil properties, prevent soil erosion and rehabilitate degraded dryland regions. Given this potential utility in the reclamation of dryland regions, the above species have also attracted attention as raw materials for bioenergy production, because of their high Water Use Efficiency (WUE) and drought tolerance. With the gradual depletion of fossil fuels, the demand for renewable biomass-based substrates as sources of biofuels is expected to increase in the future. This increased demand might be met through the cultivation of high WUE plants, having the capacity for high biomass production, such as Opuntia spp.

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Even if Opuntia spp. (Cactaceae) originated in America and have the diversity centre in Mexico, various species have been introduced worldwide and a major production is obtained in the Mediterranean basin, i.e. in Algeria, Italy (Sicily), and other Northern Africa nations, as well as in Argentina, Bolivia, Brazil, Chile, Israel, Mexico, South Africa and US. Opuntia spp. have historically been cultivated primarily as fodders in semi-arid regions. However, the tender and young cladodes (modified stems called nopalitos) and fruits (tunas) are also consumed by humans, primarily in Mexico, South America, South-Western US and throughout the Mediterranean basin. Opuntia fruits are used as food in both the Mediterranean basin and America, as well as fodders worldwide (Cushman et al., 2015).

Among Opuntia spp., the most famous is prinkly pear (Opuntia ficus-indica L.). The 100% of Italian production of this specialised crop and more than the 90% of European one are obtained in Sicily, where it is cultivated in 4000 ha ca. for producing 70,000 t ca. per year of fruits (Basile and Foti, 1997).

The Sicilian territory of San Cono (Catania) has the maximum area (60%) cultivated with this specialised crop, followed by that of “DOP Ficodindia dell’Etna”, including several municipalities slope Etna volcano, as well as that of Santa Margherita Belice (Agrigento) and a small but highly increasing area in the territory of Roccapalumba (Palermo).

The crop for fruit production generates high amounts of residues, i.e. premature fruits and exceeding cladods, that are removed for increasing the plant vigour.

Yet, in spite of its potential, the only Anaerobic Digestion (AD) plants currently using prinkly pear are in Chile and the building of others is under evaluation in the dry areas of Brazil and Texas (US).

The decomposition of the cladods is enough fast: the 90% of BMP (Biochemical Methane Potential) was developed in only 12 days during laboratory tests. Therefore, the AD plants designed for transforming residues of prinkly pear could have about half a volume rather than others using conventional biomasses that can be decomposed in 20-30 days. The high water content (90-92%) and the easy mashing of the cladods allow to obtain something like a smoothie, that can be pumped without adding water, as conversely it must be done for silage and similar biomasses. The measured BMP is equivalent to that of other plant biomasses: 350 Nml g^{-1} ca. of Volatile Solids (ml of methane at 0ºC and 101 kPa g^{-1} of Volatile Solids) (Rosato, 2014).

Biogas experiments on prinkly pear in Chile demonstrated that, when the cladods are subjected to AD by themselves, they are not a good methanogenic material (Uribe et al., 1992; Varnero et al., 1992; Varnero and López, 1996; Varnero and García de Cortázar, 1998). Mixing the above raw material with animal manure in the AD plant improved methanogenic fermentation but only when the pH of the mixture is kept neutral or slightly acidic (Uribe et al., 1992; Varnero et al., 1992). In fact, the energy and carbon included in the cladodes favour the development of acidogenic bacteria, that generate the substrate required by methanobacteria. Therefore, the methanogenic process is accelerated and the Hydraulic Retention Time (HRT) is reduced. The fermentation efficiency of manure/prinkly pear mixtures with different proportions of these two raw materials showed that it is crucial to maintain a pH 6 or higher, in order to obtain biogas having a methane content higher than 60%. The composition of biogas produced by fermentation is closely related to the pH of the raw materials. At pH levels lower than 5.5, biogas is predominantly constituted by CO_2, reducing combustibility and energy content. Conversely, with a neutral or basic pH, biogas is rich in methane. It is easier to obtain such a pH value by increasing the proportion of manure in the mixture and using cladodes older than one year (Varnero and López, 1996; Varnero and García de Cortázar, 1998).

As the Sicilian Used Agricultural Area that is currently uncultivated is 600.000 ha ca. (ISTAT, 2011), a part of this area could be cultivated with agro-energy crops.

Among the above crops, prinkly pear is a plant able to produce biomass amounts equivalent to sugar cane by using paltry resource amounts: 200 Mg ha^{-1} by using 150 mm of rain water per year (Rosato, 2014). Moreover, it is a perennial plant that increases the soil organic matter and nutrients, without any anti-parasite treatment, and can be also cultivated in marginal soils. Therefore, this species could contribute to the sustainable development of Sicily and generally of the Mediterranean basin, because it produces an ideal substrate for AD plants.

In the above perspective the aim of this work is to evaluate the potential production of biogas and, indirectly, RES (biomethane or electric and thermal energy), from prinkly pear, to be grown in a part of the Sicilian uncultivated areas and co-digested together with the available livestock manure and slurry (Comparetti et al., 2012, 2013b).

2. Materials and methods

Prinkly pear was supposed to be grown, by mechanising the harvest of cladods, in a part of the Sicilian Used Agricultural Area that is currently uncultivated (totally 600,000 ha ca.).

By means of a GIS software (QGIS) it was possible to use the map of land use of Sicilian Region (2012), the Digital Electronic Model (DEM) of the Sicilian territory and the map of the Sites of Community Importance (SCI) and Special Protection Areas (SPA).

The vector map of land use of Sicilian Region 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.

The raster DEM of the Sicilian territory was obtained from the regional technical map having a scale 1:10,000 and has a spatial resolution of 100 x 100 m, so that any pixel represents an area of 1 ha. Elevation and slope maps were derived from this DEM.

The vector map of SCI and SPA, produced by the Territory and Environment Department of Sicilian Region, has a nominal scale 1:10,000 and represents the boundary of these protected areas of Natura 2000 network.

Through the intersecting and sampling tools of QGIS software, a new point layer was obtained for collecting the attribute data of land use, elevation and slope, as well as SCI and SPA, for any area of 1 ha.

Thus, the area potentially cultivated with prinkly pear for producing RES was identified by selecting some clusters meeting the following criteria (Figure 1):

- non-irrigated arable land, prinkly pear, pastures, sparsely vegetated areas and erosion scars, according to CLC classification (artificial surfaces, forest and semi-natural areas except pastures, wetlands, water bodies, permanent crops except prinkly pear, greenhouses and cultivations under plastic, as well as arable land irrigated, were excluded, because these areas can be used for other purposes);
- elevation < 700 m (because in these areas the temperature rarely lowers until 0°C, that is the minimum temperature for prinkly pear);
- slope ≥ 5 and ≤ 35% (the flat areas were excluded, because they are used for other purposes, as well as the areas having a slope higher than 35%, where the mechanisation is very difficult);
- SCI and SPA are missing.

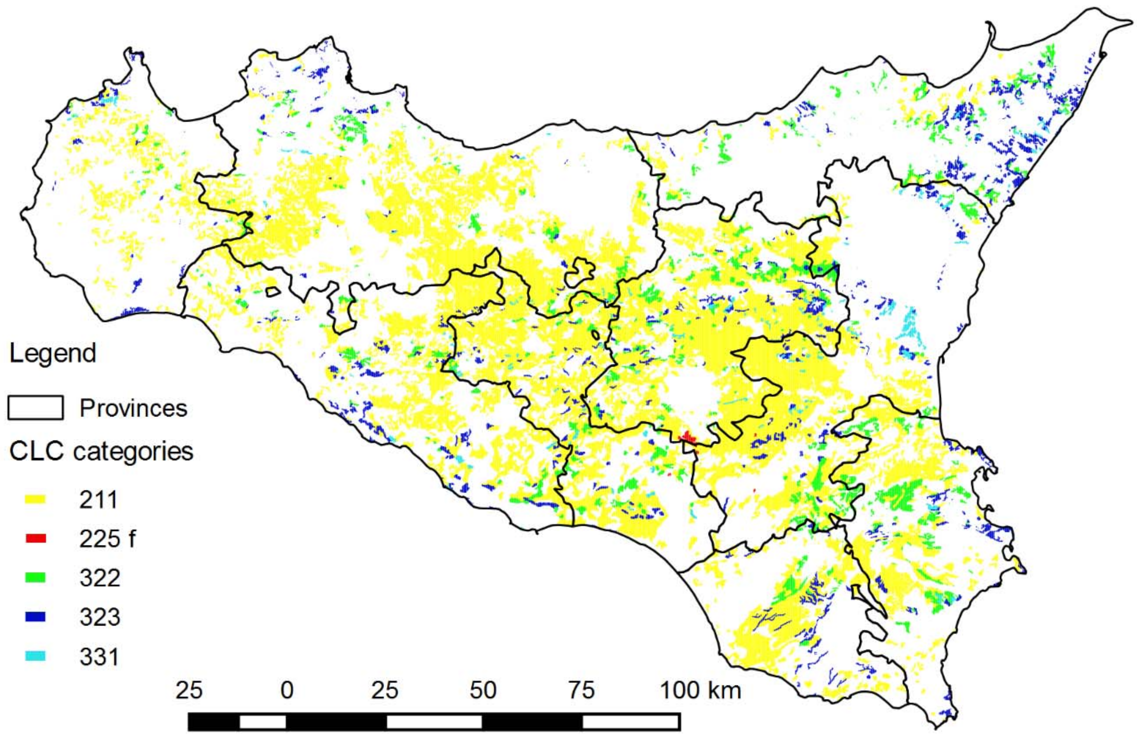

Figure 1: Sicilian area potentially cultivated with prinkly pear for producing RES, distinguished in the following CLC categories: non-irrigated arable land (211); prinkly pear (225 f); pastures (322): sparsely vegetated areas (323); erosion scars (331).

Within the above area, the 20% of CLC non-irrigated arable land, pastures, sparsely vegetated areas and erosion scars were selected, because in the rest of these areas the existing land use must be kept.

Thus, based on a prinkly pear biomass production of 8.5 t ha^{-1} of dry matter per year and a downbeat BMP of 300 Nm^3 t^{-1} of dry matter (Rosato, 2014), it was possible to compute the potential production of biogas and, indirectly, biomethane or electric and thermal energy.

3. Results and discussion

By using the above procedure it was possible to identify 798 10^3 ha from 4439 10^3 ha, distinguished in the following CLC categories: arable land (3987 10^3 ha), prinkly pear (1.6 10^3 ha), pastures (252 10^3 ha), sparsely vegetated areas (119 10^3 ha) and erosion scars (79.7 10^3 ha). Within the above area, that potentially cultivated with prinkly pear for producing RES resulted 159 10^3 ha (Figure 2).
The results show that the Sicilian potential production of biogas is 612,115 10^3 m^3, from which 342,784 10^3 m^3 of biomethane could be extracted or 67,038 MWh of electric energy and 70,390 MWh of thermal energy could be generated (Table 1).

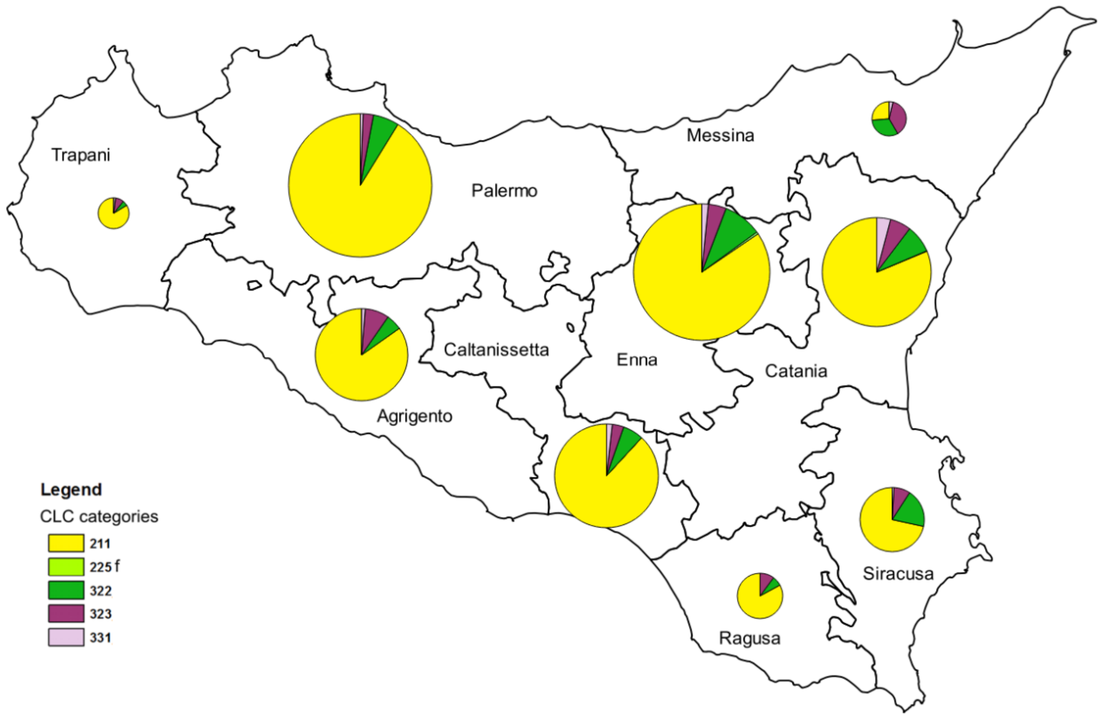

Figure 2: Area potentially cultivated with prinkly pear for producing Renewable Energy Sources (RES) in the nine provinces of Sicily.

Table 1: Potential production of prinkly pear biomass (cladods) and Renewable Energy Sources (RES) per year in the nine provinces of Sicily.

Provinces	Area (ha)	Biomass production (10^3 t)	Biogas production (10^3 m^3)	Biomethane production (10^3 m^3)	Electric energy production (MWh)	Thermal energy production (MWh)
Agrigento	97,247	2139	74,865	41,924	8199	8609
Caltanissetta	108,726	2392	83,720	46,883	9169	9627
Catania	113,645	2500	87,500	49,000	9583	10,062
Enna	142,287	3130	109,550	61,348	11,998	12,598
Messina	36,121	795	27,825	15,582	3047	3199
Palermo	149,412	3287	115,045	64,425	12,600	13,230
Ragusa	47,607	1047	36,645	20,521	4013	4214
Siracusa	67,675	1489	52,115	29,184	5708	5993
Trapani	32,239	709	24,815	13,896	2718	2854
Total	794,959	17,489	612,115	342,784	67,038	70,390

The largest potential area and, therefore, the highest potential production of biomass and biogas and, then, RES (biomethane, electric and thermal energy) are in the provinces of Palermo and Enna, due to the largest non-irrigated arable land. Moreover, in these two provinces there is a high presence of arable land (544,604 and 506,943 ha, respectively), situated in areas having a slope ranging from 5 and 35% and an elevation lower than 700 m. In fact, even if there is a high presence of arable land in the provinces of Catania (595,275 ha) and Agrigento (557,079 ha), most of this land is flat and, therefore, has a slope lower than 5%. Instead in the province of Messina, though a high presence of arable land (516,274 ha) and pastures (67,668 ha), the slope higher than 35%, the elevation higher than 700 m and the protected areas of Natura 2000 network limit the area potentially cultivated with prinkly pear.
Moreover, the obtained digestate, sometimes after being transformed into pellets, would be used as biofertiliser, within both conventional and organic farming.

4. Conclusions

According to the statistical surveys of the Ministry of Economic Development, in Sicily the consumption of natural gas for industry purposes resulted 1026 million of m^3 ca., that for producing thermal and electric energy was 2486 million of m^3 ca. and that for house heating was 723 million of m^3 ca., for a total amount of 4235 million of m^3 (Rosato, 2014).
The results of this work show that the Sicilian potential production of biogas from prinkly pear is 612 million of m^3 ca., that could satisfy the 14% ca. of the above demand for natural gas. From the above volume of biogas 343 million of m^3 ca. of biomethane could be extracted or 67 thousand of MWh ca. of electric energy and 70 thousand of MWh ca. of thermal energy could be generated.
Therefore, in order to increase the production of RES and reduce the dependency from the above fossil energy sources, the conversion of biomass into biogas through AD process is paramount for producing biomethane, to be used as fuel for means of transport and agricultural machines or heating, or electric and thermal energy through Combined Heat and Power (CHP) plants (Comparetti et al., 2015).
Moreover, the digestate produced through AD process can be applied to soils as organic fertiliser in the place of chemical ones (Comparetti et al., 2013a).
In this perspective this work demonstrates that the production of RES such as biogas from the co-digestion of prinkly pear, together with livestock manure and slurry, represents a very profitable way of using the uncultivated areas: the income of the farmer would include not only that deriving from the sale of biomethane or electric and thermal energy but also the saving for replacing chemical fertilisers with digestate and the subsidy for producing biomethane as fuel for means of transport or electric and thermal energy from biogas.
Generally Opuntia spp. have been considered as potential biofuel substrates, because of their historical use in ethanol production. However, the perspective of an increasingly warmer and drier climate have led many researchers to evaluate again the use of these high WUE, heat-resistant and drought-durable CAM (Crassulacean Acid Metabolism) species as bioenergy raw materials in semi-arid and arid lands. Using these species as raw materials would allow food and biofuel production in lands that are not currently cultivated with C_3 and C_4 crops (Garcia De Cortezar and Nobel, 1992).
Among these species, a detailed LCA (Life Cycle Assessment) is needed for O. ficus-indica, in order to obtain a more realistic estimate of biofuel production in terms of life cycle energy and GHG balances, as well as an economic analysis of the profitability of converting its biomass into biofuels. For example, one of the major barriers to the economic viability of these biofuel substrates is the high production cost, such as the high cost of manual labour traditionally performed for this crop. This problem can be partly overcome by the development of specialised and mechanical harvesting, as well as automated biomass-processing equipment for this species (Cushman et al., 2015).
Thus, prinkly pear has a great potential as bioenergy raw material and its relative importance is likely to increase as terrestrial crop production areas become warmer and drier in the future.

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Reference

Basile F., Foti V.T., 1997, Economic features of cactus pear production in Italy, Acta Horticulturae, 438,139-150.

Comparetti A., Greco C., Navickas K., Venslauskas K., 2012, Evaluation of potential biogas production in Sicily, Proceedings of the 11th International Scientific Conference "Engineering for Rural Development", Jelgava, Latvia, 24-25 May 2012, 555-559.

Comparetti A., Febo P., Greco C., Orlando S., 2013a, Current state and future of biogas and digestate production, Bulgarian Journal of Agricultural Science, 19 (1), 1-14.

Comparetti A., Febo P., Greco C., Orlando S., Navickas K., Venslauskas K., 2013b, Sicilian potential biogas production, X Convegno Nazionale di Ingegneria Agraria, Viterbo, 8-12 settembre 2013, Journal of Agricultural Engineering, XLIV(s2):e103, 2013, 522-525, DOI: 10.4081/jae.2013.s2.e103

Comparetti A., Febo P., Greco C., Orlando S., 2015, Italian Potential Biogas and Biomethane Production from OFMSW, IV International Conference Ragusa SHWA on "Safety, Health and Welfare in Agriculture, Agro-food and Forestry Systems", Lodi, Italy, 8-11 September 2015, 206-215.

Cushman J.C., Davis S.C., Yang X., Borland A.M., 2015, Development and use of bioenergy feedstocks for semi-arid and arid lands, Journal of Experimental Botany 66 (14), 4177-4193, DOI: 10.1093/jxb/erv087

Garcia De Cortezar V., Nobel P.S., 1992, Biomass and Fruit Production for the Prickly Pear Cactus, Opuntia ficus-indica, Journal of the American Society for the Horticultural Science 117(4): 558-562.

ISTAT - National Institute of Statistics. 2011, 6th General Census of Agriculture, Sicilian Region.

Piga A., 2003, Il Fico d'India, una specie dalle innumerevoli potenzialità, Industrie alimentari, Vol. 42 (425), 585-594. ISSN 0019-901X.

Rosato M.A., 2014, Il fico d'India: una biomassa trascurata. AgroNotizie - Notizie agricoltura - tecnica, economia e innovazione . http://agronotizie.imagelinenetwork.com/bio-energie-rinnovabili/2014/02/13/il-fico-drsquoindia-una-biomassa-trascurata/36494

Uribe J.M., Varnero M.T., Benavides C., 1992, Biomasa de tuna (Opuntia ficus-indica. L. Mill) como acelerador de la digestión anaeróbica de guano de bovino, Simiente 62 (1), 14-18.

Varnero M.T., Uribe J.M., López X., 1992, Factibilidad de una biodigestión anaeróbica con mezclas de guano caprino y cladodios de tuna (Opuntia ficus-indica. L. Mill), Terra Aridae, 11, 166-172.

Varnero M.T., López X., 1996, Efecto del tamaño y edad de cladodios de tuna en la fermentación metanogénica de guano de bovino, Sociedad Chilena de la Ciencia del Suelo, Boletín Nº 11,80-89.

Varnero M.T., García de Cortázar V., 1998, Energy and biofertilizer production: alternative uses for pruning-waste of cactus-pear (Opuntia ficus-indica. L. Mill). In C. Saenz, ed. Proceedings of the International Symposium on Cactus Pear and Nopalitos Processing and Uses. Facultad de Ciencias Agrarias y Forestales, Universidad de Chile, FAO International Technical Cooperation Network on Cactus Pear (FAO-CACTUSNET), Food and Agriculture Organization of the United Nations, Rome, 96-102.