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Cactus Pear (*Opuntia Ficus Indica* spp) in Italy: Economic and energetic evaluation

Carmelo Danzì

Advisor:
Prof. Giorgio Testa
Prof. Vera Teresa Foti

Coordinator:
Cherubino Leonardi

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Abstract

From ancient times the prickly pear represented a crop used for the delimitation of borders within the small plots that characterize the Sicilian territory. As early as the 1990s this crop took on a commercial value within the Sicilian fruit and vegetable basket. In fact, the main competitors in the sector operating in south-west Etna and in the central-eastern area of Sicily so called Calatino,already specialized in the marketing of citrus fruits, decided to include the prickly pear in their own commercial offer to be submitted to the GDO.

The present study deals with the multi-functionality of the prickly pear plant and the possible uses of the fruit, cladode and related extracts. Firstly it analysed the diffusion and expansion of the cultivation of prickly pear in different territorial contexts. This analysis highlights a stabilization of the surfaces with an increase in specialized cultivation and consequently in production. Subsequently the multiple uses of prickly pear are analysed with particular attention to the energy valorisation of pruning residues. It also examined the Italian agro-energy situation.

Finally, the methanigeno potential of the residual biomass produced on the Etna territory is evaluated and is hypothesized, through an economic validation, the possibility of realizing an anaerobic digestion plant to be placed in the Etna area

Sommario

Sin dall'antichità il ficodindia rappresentava una coltura utilizzata per la delimitazione dei confini all'interno dei piccoli appezzamenti che caratterizzano il territorio siciliano.
Già a partire dagli anni '90 questa coltura ha assunto una valenza commerciale all'interno del paniere ortofrutticolo siciliano. Difatti i principali competitors del settore operanti nel sud-ovest etneo e nell'area del calatino, già specializzati nella commercializzazione di agrumi, hanno ritenuto di inserire il ficodindia all'interno della propria offerta commerciale da sottoporre alla GDO.
Il presente lavoro affronta la multifunzionalità della pianta di ficodindia ed i possibili utilizzi del frutto, del cladodo e dei relativi estratti.
All'interno del lavoro viene prima analizzata la diffusione ed espansione della coltivazione del ficodindia in diversi contesti territoriali. Tale analisi mette in evidenza una stabilizzazione delle superfici con un incremento della coltura specializzata e conseguentemente della produzione
Successivamente vengono analizzati i molteplici usi del ficodindia con particolare attenzione alla valorizzazione energetica dei residui di potatura. Viene, inoltre, analizzato il contesto agroenergetico italiano.
Infine viene valutato il potenziale metanigeno della biomassa residuale prodotta sul territorio etneo e viene ipotizzata, attraverso una validazione economica, la possibilità di realizzare un impianto di digestione anaerobica da collocare nell'areale etneo.

Key words
Prickly pear; multipurpose crops; energetic valorization; crop residues; circular economy; social network analysis;

Diffusion and expansion of the prickly pear cultivation on several territorial contexts

1.1 Introduction

The prickly pear is member of the *Cactaceae* family, subfamily *Opuntioideae* and genus *Opuntia*; the cultivated species is the Opuntia Ficus-Indica. This name seems to be ascribed to the belief, not supported by evidence, that its origins were Asian, although it is widespread in all the tropical and sub-tropical countries of the planet. The place of origin seems to be South America at the level of the tropics (the so-called Western Indies according to C. Colombo), a provenance, however, from some representations of the *cactacea* on banners found in places where in the past Aztec civilizations lived and prospered. In the world this species performs different functions and is responsible for the sustainability of many productive and economic-social systems.
Its importance is evinced by the interest shown by FAO especially for dry areas, in which prickly pear can contribute to food security for people and livestock, it can also be an important resource in the context of climate change and the increasing risks of drought. In this context FAO has also created a "cactusnet", a network of professionals in the research world, of innovation in the enterprise for the promotion of prickly pear cultivation in sustainable agricultural and zootechnical systems.

1.2 The worldwide industry of prickly pear

If compared with other fruit crops, on a world scale, with a production of about 400 thousand tons and just over 100,000 hectares of specialized area, the numbers of the prickly pear area seem to be a niche culture until a decade ago, in the last years the numbers have become more important and this sector has grown increasingly important in the markets and in particular in the European ones.

The global offer of this fruit is concentrated in a few countries; Mexico with a specialized area of approximately 60,000 hectares (Table 1) and with a production, including nopalitos ie the "pale" blades used at the end of human consumption, amounting to 250,000 tons, is the world's largest producer of fruit for fresh consumption (Basile,1995). In other countries of South America, such as Chile, Peru, Argentina and Colombia, production in the uncultivated state, along with other cacti, amount to several million hectares. However, in these same countries, specialized plants do not exceed a few thousand hectares, and the small productions are partly destined for domestic consumption, both for food use and for industrial use, while the rest is exported to North-American countries and to Europe, where the demand from Arabic and Italian immigrants is particularly active. Also in South America, a particular importance is assumed by Brazil, which conquers the primacy in terms of the prickly pear surface present species in promiscuous form and as a plant that has colonized entire areas of the country, we speak of over 500,000 hectares (FAO, 2017). Also in South America, a particular importance is assumed by Brazil, which conquers the primacy in terms of the prickly pear surface present

species in promiscuous form and as a plant that has colonized entire areas of the country, we speak of over 500,000 hectares (FAO, 2017).
In this brief overview of the world's major prickly pear producers, the countries of the Mediterranean basin could not be missing, such as Israel, Turkey, Tunisia, Jordan, Greece and Spain, could not be missing. The latter, in both quantitative and qualitative terms, with a specialized area of 6,000 hectares and an estimated production of about 20,000 tons, assumes a dominant role among the Mediterranean countries. A certain interest arouses productions from South Africa, that together with those countries of South America, have the peculiarity of entering to the European Union market during the period between December and April, just when the demand suffers from a Mediterranean product offer, suffers or is almost not existent (Crescimanno, 2001).

Table 1. Worldwide evolution of prickly pear crop, based on data published by the FAO, 2017.

Country		(hectares)		*Country*		(hectares)
Argentine		1.650		Tunisia		600.000
Brazil		500.000		Jordan		300
Chile		935		Syria		100
Peru		10.000		Israel		350
Mexico		53.876		Australia		200
USA		120		Italy		15.000
Algeria		30.000		Portugal		500

In Europe, the plant was introduced by the Spaniards in the mid-sixteenth century, where it spread as mixed and / or specialized crop. The introduction in Sicily dates back to 1827 with the Saracens disembarkation in Mazara, according to other sources instead the *cactacea* was imported around 1830-1840, also because it was considered a plant that did not need any cultivation or other diligence. This means that this crop has the ability to adapt to the climate of Sicily, its drought and / or impervious soils also spreading between the fissures of the lava soil.
It is precisely these characteristics that allowed the prickly pear to assume, over time, a good social, religious and economic value thus entering into the life of Sicilians, to the point of allowing them to define it as "providence of Sicily" (Cucuzza, 1992)

1.3 The prickly pear industry in Italy

Italy, with its current 8,401 hectares of invested area and a production average of the last four years (2013-16) of 114,826 tons, according to the Central Statistical Institute (ISTAT) holds a slice of world market, destined to human consumption as a fresh fruit, equal to 12%.
Only since the first half of the seventies of the past century STAT included the item "other fresh fruit" (08.10) the prickly pear production in the tariff nomenclature, thus making possible an analysis of the size and dynamics of the sector.
The ISTAT data reported in Table 2 make it possible to grasp the changes which took place in the last decade in relation to the areas and in the last two four years in relation to the

production of prickly pears in Sicily and in Italy.
The equivalent area invested in Italy rose from 7,932 hectares in 2006 to 8,401 hectares in 2016, with a relative increase of around 6%. This figure, strengthened by the increase in the yields of the last four years, justifies the particularly incisive evolution in national production which, from 87,895 tonnes (average for the four-year period 2009-12) to 114,826 tonnes (average for the four-year period 2013-16), So much for the evolution of the equivalent area as for that of the total production, Sicily concurs with the national increase, though in a less significant in relation to the equivalent area; in fact,

Table 2 - Evolution of the prickly pear cultivation in Sicily and Italy. Data from "Servizio Statistiche Agricole della Direzione Centrale Statistiche Economiche - ISTAT"

DATA	Italy	Sicily	% Sicily respect Italy
surface"corresponding"			
2006	7,932	7,923	99.9
	100	*100*	*100*
2011	8,666	8,305	95.8
	109	*104*	*96*
2016	8,401	8,025	95.5
	106	*101*	*96*
Total production			
2009-2012	87,895	84,667	96.3
	100	*100*	*100*
2013-2016	114,826	111,569	97.2
	131	*131*	*101*

the surface goes from 7,923 hectares in 2006 to 8,025 hectares in 2016, with an increase of 1% (5 percentage points less than the national figure).
Significant changes can be found even in the analysis of evolution of the island's production, going from 84 667 tonnes (average of four 2009-12) at 111 569 tonnes (average of four years 2013-16), an increase of about 31%, making the leap ' incidence of Sicilian production on the national one from 96.3% of the first reference period, to 97.2% of the second four-year period with an increase of almost 1%.
The incidence of the area affected by prickly pear cactus in Sicily on the national one goes from 99.9% in 2006 to 95.5% in 2016, marking the further national strengthening of *cactacea* investments.
The remaining 3.5% of the area destined for this cultivation in Italy is subdivided between Calabria and Puglia, and to a lesser extent between Lazio e Campania; in particular, the first two regions, in recent years, are gradually increasing their presence on the national market.
Given the delays with which the official statistics follow the evolutionary phenomena occurring in the agricultural sector, it was considered necessary, for a better consideration of the effective expansion of the sector, to proceed to a direct comparison of the data, through surveys carried out by the Sicilian region with the analysis swoot of 2012 and AGEA data for 2015, to highlight any discrepancies between official data published by ISTAT and those acquired through the Regional Institution and the paying agency.
It appears evident in this case that the ISTAT data, with regard to the surfaces, are overrated results. In this regard,

two tables (Tables 3 and 4), of analysis and comparison, were developed between the three sources of detection.

Table 3 - Comparison between the "fichidindicoli" investments in Sicily according to the Istat data and those of investigations of the Sicilian Region and Agea. Data from Sicily Region arise from the 2012 swoot analysis and those of Agea were directly provided by the institution.

Years	ISTAT ha	Sicily region ha	Agea ha
2012	7.471	7.087	/
	100	*95*	
2015	7.990	/	2.405
	100		*30*

In connection with the surfaces, as clearly shown in the tab. 3, during the agricultural years examined, official data shows an overvaluation, in the ISTAT-Sicilian Region comparison, equal to 5% in 2012 and the most evident 70% discrepancy for the 2015 agricultural year, if we refer to the comparison given ISTAT-Agea. This means that if the first comparison there is no doubt that the official data will be specifically considered for the year, made comparable with those actually observed by ISTAT. In the second case it is confirmed that the surfaces in Sicily for the given Agea are strongly influenced by the fact that the data supplied by the paying body is limited and detect areas declared by the agricultural entrepreneurs during the establishment of the company file.

This operation is carried out by those farmers who, in order to receive the contributions foreseen by the CAP, must submit to the census, or again for all those wishing to participate in a call for proposals from the RDP Sicily. Regarding the verification on the productions, this has shown by the data shown in the tab. 4, an overestimation of ISTAT data than 3% swoot analysis of the Region, specifically for agrarian country in 2012, a figure in line with what was observed in tab. 3 in relation to the surfaces.

Table 4 - Comparisons between the Sicilian prickly pear production (Tons) obtained by Istat data and those survey conducted by the Sicilian region. Data of Sicilian Region resulted by the analysis swoot made in 2012.

Data	2012
ISTAT	**76.172** ***100***
Sicilian Region	**73.999** ***97***

In conclusion we can state that, whenever it is necessary studies, for the exact determination of the sector and the identification of a development model for the same, the use of reliable data would be essential, given the approximation that characterizes the official source. These deficiencies appear to be attributed, in the past, the fact that the ISTAT did not provide a specific commodity item to the prickly pears, placing it in the "Other fresh fruits", with all the approximations that this could result in a discrepancy widens moving from a regional analysis to a provincial type.

1.4 Structure of the prickly pear offer in Sicilian provinces

In recent years, the *cactacea* in Sicily, while remaining a niche sector, has assumed a certain interest, in relation to the positive evolution that has characterized the incomes achieved by the operators. Moreover, on the island, the adaptive capacity that the crop has shown to have, in relation to the specific pedo-climatic and orographic conditions, has made it possible to spread throughout the provinces. In the past, the main functions that the field of prickly pear carried out, partly by tradition but also as useful for the protection of the territory, were those of windbreaks, delimitation of funds, feeding animals, in particular pigs, as well as maintaining simply a landscape and ornamental function. This strong character of promiscuity that characterized the plantations already in the fifties, from the official sources, it did not allow to define the exact extension of the cultivated areas. From some sources we have been able to ascertain, in particular, two historical information; the first concerns a survey carried out by the Catasto Agrario in 1929, according to which the "repeated" area in the Indian fig tree was 68,823 hectares, the other refers to a survey of 1853 which ascertained 8,822 hectares (Timpanaro, 1989). As a result for a few decades the ISTAT lost interest in culture, considering it, perhaps, with no statistical significance, with the result of the total lack of data relating to surfaces and productions, until the early seventies. Only starting from 1975 ISTAT will resume the surveys on the sector, with the appearance of the first specialized plants.

From the tab. 5 we can follow the evolution of the areas invested in prickly pear fields in the main Sicilian provinces, during the period between 2006 and 2016.

Table 5 - Evolution of surfaces (hectares) invested in prickly pear fields in the principal Sicilian provinces. Data published by Agricultural Statistics Service of the ISTAT Central Statistics Department.

Provinces	2006	2011	2016
Catania corresponding surface	3430	3440	3800
	100	100	111
Agrigento corresponding surface	813	968	1050
	100	119	129
Caltanissetta corresponding surface	1550	1400	750
	100	90	48
Palermo corresponding surface	589	540	560
	100	91	95
Enna corresponding surface	780	750	750
	100	96	96
Other provinces corresponding Surface	764	1207	1115
	100	158	146
Sicily as a whole corresponding surface	7923	8305	8025
	100	105	101

From the data we can see an evident expansion of the prickly pear in some of the provinces examined, while in others the reality assumes a diversified relative importance.
In 2016 the provinces in which the surfaces had the greatest increase, compared to 2006, are Agrigento (129%), Catania (111%) and all those that fall under the denomination "Others" (146%).

On the other hand, the provinces of Caltanissetta, Palermo and Enna suffer a downsizing of investments. In fact, during this decade analyzed, we have been able to witness, for most of the provinces of the island, a growing interest in the crop that provides a viable opportunity to achieve income, in areas that would hardly allow the plant to other crops (also with reference to water availability and pedo-climatic conditions). Obviously, by themselves, the surface increases do not express any information on which provinces hold the greatest weight within the sector. It is therefore necessary to analyze the evolution of the island's prickly pear crops within a broader framework, including in addition to the areas invested in the individual provinces also their productions. In the decade that preceded 1990, despite the equivalent area recorded increases in all the provinces, most of these showed contractions between 14% and 45% of the productions collected; what is said is useful to clarify that at the time among the operators of the sector, in the face of a growing spread of the crop, there was still no commercial agreement that could allow them to take advantage of a real opportunity to achieve satisfactory income.
Later, as shown by the data on the tab. 6, which shows the evolution of prickly pear production in Sicily, for the main provinces, will follow a completely different trend. If on the one hand it is true that in Sicily there are four productive zones (Figure 1), two of which are part of the western pole of S. Margherita Belice and Roccapalumba, and the other two to the eastern one which includes the Hills of S. Cono and Southwest Etneo, it is equally true to consider, according to the most recent data, that 82% of the total production is concentrated in the eastern pole of the island.

KEY

South-West Etneo
C Hills of San Cono
Po Area of Roccapalumba
Po Area of S. M di Belice

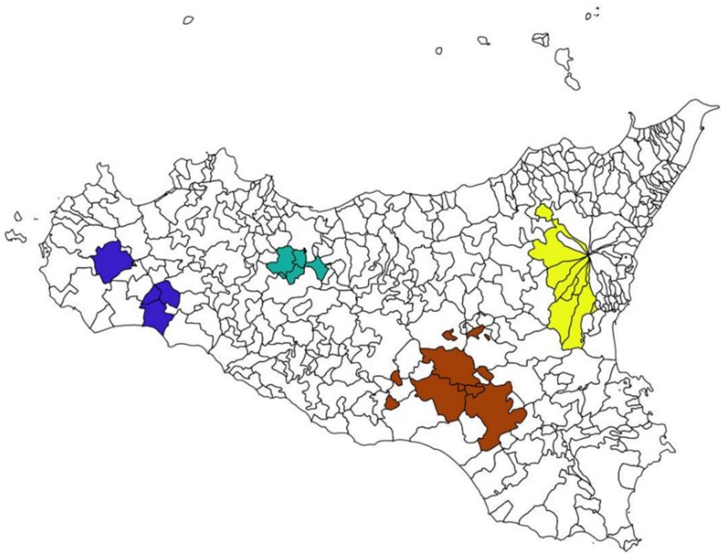

Figure 1 - Location of the main production centers specialized in Sicily

Table 6 – Development of the prickly pear production (tons) in the main province of Sicily. Data published by Agricultural Statistics Service of the ISTAT Central Statistics Department.

Provinces	2006-09	2013-16
Catania Total Production	151.390	269.400
	100	178
Harvested production	149.500	269.000
	100	180
% Harvested production of total	98,7	99,8
	100	101
Agrigento Total Production	46.342	76.447
	100	165
Harvested production	45.033	70.477
	100	156
% Harvested production of total	97,2	92,2
	100	95
Caltanissetta Total Production	42.392	33.600
	100	79
Harvested production	35.936	32.800
	100	91
% Harvested production of total	84,8	97,6
	100	115
Palermo Total Production	16.186	20.100
	100	124
Harvested production	16.112	19.700
	100	122
% Harvested production of total	99,5	98,00
	100	98
Enna Total Production	33.330	33.000
	100	99
Harvested production	30.354	31.348
	100	103
% Harvested production of total	91,1	94,9
	100	104
Other provinces Total Production	21.512	13.730
	100	64
Harvested production	19.967	12.300
	100	62
% Harvested production of total	92,8	89,6
	100	96
Sicily as a whole Total Production	309.067	446.277
	100	144
Harvested production	295.003	435.625
	100	148
% Harvested production of total	95,4	97,6
	100	102

Within the latter, the province of Catania is the leader, holding 49% of regional production, but its relative importance does not end with this figure; in fact, if the surface in recent years has increased by just 370 hectares, while the productions only in the last decade, have recorded increases of 78% denoting a marked increase in unit yields. In order of importance it follows the province of Agrigento (tab. 6); this province goes from a total production of 46,342 tons of the 2006-09 four-year period to 76,447 tons in the 2013-2016 four-year period, reporting an increase of almost double the production, in perfect agreement with that achieved for the area in the same province, between 2006 and 2016, although it appears unclear the percentage by which the harvested production would affect the total. In fact it turns out that 92% of the total product is collected within this province.
It is precisely on these data that some perplexities emerge on the degree of reliability of official statistics; the latter reveal levels of unit yields that can not be compared with the presence of specialized plants, managed according to modern cultivation techniques that provide for irrigation and fertilization as systematic and / or relief interventions, therefore, it is necessary the need to investigate directly on procedures of the real dimensions
If we exclude the particularities of the case just treated together with that of the Province of Palermo, all other provinces feature of increasing percentages of collection on that total production from passing to the next four years 2006-09 203-16, on average of the order of 4%, in relation to the improvement of cultivation techniques and the increasing specialization of manpower.

In the province of Palermo, compared to a decrease, between 2006 and 2016, of 5% of the area planted with prickly pear fields, there is a 24% increase in production, which demonstrates the capacity of certain areas of the province, especially the one of Roccapalumba, to maintain an increasing trend in yields during the period considered.,
Regarding Agrigento, which has seen in the past with its main pole hinterland of S. Margherita Belice, acquire an important role at the regional level, the increase of the area involved, during the period considered, it is a result of 29%, a value that it has more than doubled in terms of increased production, due to new cultivation techniques and greater availability of water resources. In recent years, with the exception of the province of Caltanissetta and those referred as "others", the specialization of the plants has increasingly interested the main production poles, so much that for Sicily in general there is, from 2006 to 2016, a an increase in the surface area of just 1%, which is offset by an increase in production of 44% with a significant 2% increase in the percentage of production collected.
In the rest of the region, those indicated as "other" provinces (Messina, Trapani, Ragusa and Siracusa), almost halves the productions in the face of an increase of 46% of the surfaces; analysing the reality of Messina and Trapani, where the prickly pear field undertakes an ornamental and / or environmental value in the prevention of hydro-geological instability, the data could be surprising but in reality it is about plants on rough terrain, (not very productive and / or associated);while the same can not be stated for Syracuse where the interest that certain territories (in particular Lentini,

Carlentini and Francofonte) prove to have for the cactacea seems to be established.

1.5 Final Considerations

The prickly pear crop in Sicily found the conditions of ideal diffusion, even if not negligible, it results in its role in other contexts of the south of Italy. Its main destination is the production of fruit for fresh consumption, while the uses for the feeding of livestock and / or other uses are still negligible. The innovation thrusts and the progressive affirmation of the principles of the circular economy are progressively transforming the sector, making strengthening more and more necessary: on one hand, aspects such as marketing, processing and exporting fresh fruit and, on the other hand, the enhancement of everything related to prickly pear, beyond the fruit.
In this scenario there are various initiatives aimed at creating supply chain and aggregating various production poles, in the awareness that product and territory can be used to create added value in a strategic key for the local economy.

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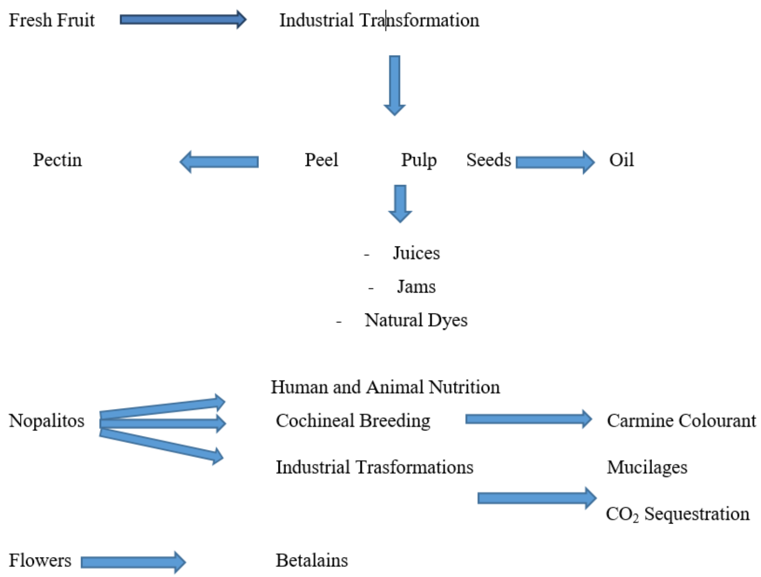
2. Uses, functions and possible enhancements of prickly pear

2.1 Introduction

In recent decades, in particular referring to the recent five-years, the prickly pear sector has undergone a metamorphosis, assuming an increasingly strategic role not only in the agro-food sector but also in the agro-industry arriving to achieve interest in the agro-energy sector. In fact, nowadays the alternative use of prickly pear varies from fresh and processed products, to cosmetics, nutraceuticals, pharmacology, the furniture and leather industry and even that of jewelery, in short, a world in constant evolution that of alternative uses of prickly pear and its derivatives. A recent survey by FAO (2017) in collaboration with ICARA (International Centre for Research in Dry Areas), has highlighted the multiplicity of uses and transformations which can be exploited in different territorial contexts. So it emerges that in addition to the general use of fresh fruits for human nutrition (today also in the ready-to-eat format to solve the problems of peeling), in some countries of the planet, young cladodes (nopaltos) are also consumed for use human and animal food, as well as a multitude of products derived from fruit and nopal (Figure 1). The cactus is characterized by many health and nutritional aspects of particular impact on human health and a multitude of positive externalities on agricultural ecosystems. In conclusion, a holistic view of the species reveals the complexity of goods and services offered in soil erosion control, in the mitigation of climate change through carbon sequestration, in the conservation of biodiversity and of habitat for wildlife, in pharmaceuticals and industrial reliefs, and in addition to the traditional uses known (fresh fruit and transformed) it increases its ecological and social value. (FAO, 2017. Crop ecology, cultivation and uses of cactus pear, Rome.).

Figure 1 – Possible enhancement of prickly pear in the world.



2.2 The consumption of fresh fruit and its relative enhancement

In relation to the fresh fruit market in Sicily and Italy, economic surveys conducted in the recent past, aimed to understand the peculiarities of the prickly pears market, highlighted, on the one hand, the weaknesses of the branch, linked to traditional structural shortcomings (in particular, the concentration of supply), the limited ability to enter to business market, the lack of relevant marketing tools and product enhancement policies of strategic importance in the current phase of the system development. And on the other hand, a particular vitality of the same section (with an increase on the relative demand and on the development of innovations mainly linked to the prickles removal process and packaging of fresh fruit, as well as the research and application of alternative uses such as foodstuffs (jams, juices,...), cosmetic, pharmaceutical and animal husbandry. These processes are largely linked to private initiatives, by commercial companies that see in the prickly pears further possibilities to earn income.

Prickly pear market analyses usually focus on two segments of the distribution chain, such as production and wholesale.

Four production poles have now been accredited to production in Sicily, and those are: Etna South-West, Valle di S. Cono Hills, Roccapalumba and Valle del Belice.

The main features of the production market in these areas can be summarized as follow:

In recent years there has been an expansion of the marketing calendar alongside "*bastardoni*", fruits of early flowering that take advantage of modern cultivation techniques (irrigation, fertilization, thinning of the fruits, etc.), until it assumed characteristics valued by consumers.

The relative importance of the producers is still limited, on this market, in which, alongside some recently established cooperatives, the marketing companies (wholesalers) prevail. There remain numerous intermediary figures (brokers, purchasing officers, binders, etc.) with the existence of long and / or semi-long circuit, in the areas of which in recent years it has also included the GDO increasing the rate of out of the market; Among the commercial enterprises, the joint-stock companies prevail, certifying the interest of private individuals in investing financial resources on the prickly pears crop; In addition to the commercial activities, these companies are engaged also activity in the agricultural phase of own prickly pear cultivation and/or acquired with a "*Strasatto*" method, indicating the need for a vertical integration aimed at the improvement of quality product; Among the commercial activities, those relating to the selection, prickles removal process, calibration and packaging of the fruit have become widespread, thereby increasing the service component, as requested by the modern consumer.

A certain variability is present in the purchase prices of the merchandise and sales of prickly pears (ex-stock of departure), respectively in relation to the way of acquisition of the product, the business choices related to the organization of the commercial activity and the quality of the prickly pears, to the time of placing on the market, the entity of the services connected with the processing in the warehouse, etc.

The companies allocate on average 60% of processed prickly pears on the domestic market, while 35% is directed to European markets (France, Switzerland, Germany and East European) and a small percentage of 5% to those outside Europe (Canada, North America and Oceania).

If we consider the main Italian wholesale markets, the characteristics of the prickly pear market can be summarized

as follows: In addition to Sicilian productions, these markets are also sent to those from other national and / or foreign regions (Mediterranean and South America), especially during the year when Sicilian products are not available; Prickly pears arrive on these markets mainly through refrigerated and rubberized vehicles, with the exception of productions of foreign origin, in the context of "mixed" loads with other types of seasonal fruit and vegetables; By virtue of the mixed transport, the prickly pears transited on these markets escape the statistical surveys, which report lower volumes of prickly pears compared to the quantities actually introduced;
From the markets considered it is noted that prickly pears are mainly destined for Northern Italy, in those cities where there is a substantial presence of southern migrants (Turin and Milan), or re-launched to foreign markets such as France, Switzerland, Germany, Eastern Europe, etc .
Wholesale prices also show a fluctuating trend in recent years, even if, in absolute terms, downsized compared to the past, due to the expansion of the offer. However, the highest prices are reached near the winter months and for the category of fruit of particular quality.
Despite the evolutions some problems still remain: In terms of marketing, the creation of associative organizations that fulfil the dual role of concentrating supply and raise the level of technology in the packaging of the product, in order to improve the presentation of the fruit to the consumer (remove the spines should be further encouraged, reducing the seeds, improve the quality of the product), also through the help of genetic improvement work.

The domestic and foreign demand is active and is able to absorb additional quantities of this fruit.
In particular, on the international front, the seasonal nature of the Italian offer, different from that of other producing countries, allows the Italian product to establish itself on the international markets for most of the year; as regards the tail productions (those obtained between November and December) should be urged to lengthen the marketing calendar of the Italian product.
Further efforts should be made to improve the quality of prickly pears, perhaps solving the long-standing issue of commercial categories that are not sufficiently standardized, also because the modern consumer appreciates the "super-extra" and "extra" categories –
Financial enhancement has recently found a financial support through modern rural development measures co-funded by the European Union, which encouraged both the establishment of new plants and the creation of structures for the prickly pears process.
Finally, other initiatives are determinable by the support of environmentally friendly productions and on the recognition of the Protected designation of origin (PDO) of the "*Prickly Pear of Etna*" and that of "*San Cono*" (Danzì C., 2003, economic analysis on the market of prickly pears in Italy, Catania).
In recent years, the Sicilian prickly pear production district has been set up, which gathers operators not only from the agri-food chain but also from the agro-industrial sector, currently being examined by the regional authorities to obtain the recognition required by law

2.3 The process of transformation of the fruit

As regards the expansion and interest taken by prickly pear in other areas such as nutraceuticals, cosmetics and pharmacology, during the Ph.D. period, other research work was carried out on the properties and uses of the extracts from the seeds, peel and fruit pulp. In particular, these works have been characterized by an intense collaboration between the doctoral student Di3A of Catania and the CNR of Palermo, listed below in order:

Essential Oil	The composition of fatty acids of the seed oil of the yellow fruit of Opuntia ficus-indica widely grown in Sicily shows different distinctive characteristics. The oil obtained in Sicily includes significant amounts of vaccinal acid along with many other unsaturated fatty acids that show numerous health benefits, including linolenic acid, trans-13-octadecenoic, gondo, 7Z, 10Z-octadecadienoic and gadoleic acid. The economic analysis shows the significant advantage to carry out the extraction from fruits considered unfit for consumption.
Dyes	The integral extraction by water diffusion assisted by microwave and hydrodistillation of water-soluble bioproducts contained in the peel of the white and red Opuntia ficus-indica

	varieties harvested in Sicily, offers red and stable aqueous extracts contain mainly betaine, pectin and evaluated biophenols. Potentially useful as nutraceutical products, these aqueous extracts are a source of valuable ingredients that are in high demand for a range of important food, cosmetic, beverage and nutraceutical uses.
Betanin	Betanin is a natural red-violet dye increasingly used by food, beverage and nutraceutical industries. We provide an updated bioeconomic perspective in an estimated betacianin, whose supply and applications, we argue in this study, will expand rapidly.

2.4. Alternative uses for bioenergy production

Since ancient times the prickly pear plant in Sicily was used for the demarcation of borders within the small plots of land that characterize the island territory. Only in the last thirty years, the plant acquired an economic dimension until it became crop to current income, so much to steer some producers to the eradication of other crops, especially in south-western Etna, to supplant them with that one of prickly pear.

Today, the recent scientific discoveries have guided the prickly pear enterprise to look beyond the commercialization of the fruit, going to the borders of cosmetics, nutraceuticals, pharmacology, furniture industry and derivatives, in short, a company no only oriented to the fresh but also to the multiple uses of the fruit and the plant. Scientific investigations have confirmed that cactus fruits and cladodes can be used effectively as a source of nutrients and phytochemicals (eg sugars, mucilages, fibers, vitamins and pigments) of nutritional and functional importance. Cactus products have promising functional characteristics thanks to their beneficial properties for health. Since ancient times, cactus plants have been used to treat diseases and treat wounds. Cacti are traditionally used as natural medicines in several countries for the treatment of many diseases. In addition, cladodes and cactus pear fruits are still used today in folk medicine as therapeutic agents. In recent decades, considerable progress has been made in characterizing plant constituents and explaining the role of natural molecules in relation to disease prevention. In this context, there are strong recommendations to incorporate fruits and vegetables in the diet. Several manufactured products are currently available on the global market that take advantage of the medicinal properties of cactus plants; there is a growing interest in the industrial use of cactus products as nutraceuticals. Cactus plants are multifunctional crops: they not only provide food and feed, but also contain bioactive phytochemicals. Fruit and cladodes already provide energy and nutrients for both humans and livestock. However, cactus plants are also a rich source of substances that promote human health and are used as natural medicines to prevent and treat serious diseases. These beneficial properties of the cactus, already known to ancient civilizations, are now generating interest among the scientific community. The scientific literature concerning the medicinal properties of the cactus is constantly expanding, with new findings reported on the plant constituents responsible for these activities. Still in the context of the alternative uses of prickly pears, during my three-year research activity, I had the opportunity to collaborate with both UNIPA and the CNR of Palermo, developing extraction techniques and enhancing the by-products obtained from the process of conditioning of prickly pear, these are all those fruits unsuitable for marketing and therefore destined for animal feeding. So, with the research developed by a group of scholars it was discovered that both from the pulp and from the prickly pear peel it is possible to extract substances such as betanins, essential oil, pectins and mucilage. A very precious oil was extracted from the fruit seeds in the field of cosmetics and pharmacology.

Briefly below are the abstracts of the four papers relevant to the topic that have been studied, especially in the part relevant to the economic validation of both the extraction process and the one concerning the placement of the extracts.

It should be noted that every right for the following is for publishers of scientific journals, although we will limit ourselves to mention only the part relating to the summary, excluding tables and related figures, we invite the interested reader to recover the full content of the papers from the official web site of the journals.

- *Betanin: A Bioeconomy Insight into a Valued Betacyanin.* Ciriminna R., Fidalgo A., Danzì C., Timpanaro G., Ilharco L.M., Pagliaro M.

Abstract

Sourced so far mostly from beet root juice, betanin is a red-violet natural colorant increasingly used by the food, beverage and nutraceutical industries. The production and purification methods, emerging sources, extraction

technologies and applications are reviewed. Moreover, we provide an updated bioeconomy perspective into this valued betacyanin whose supply and applications, we argue in this study, will rapidly expand.

- *Opuntia ficus-indica seed oil: biorefinery and bioeconomy aspects.* Ciriminna R., Delisi R., Albanese L., Meneguzzo F., Pagliaro M.

Abstract
In this study we offer a perspective written from a biorefinery viewpoint aimed at expanding the cactus peer seed oil market and utilizations. Besides antioxidant and skin and hair hydrating action which make it suitable as a valued cosmetic ingredient, the oil contained in the seeds of *Opuntia ficus-indica* and *Opuntia dillenii* rich in unsaturated fatty acids also shows significant anti-inflammatory properties which offer significant potential as functional ingredient of nutraceutical and food supplement products.

- *Integral extraction of Opuntia ficus-indica peel bioproducts via microwave-assisted hydrodiffusion and hydrodistillation.* Ciriminna R., Fidalgo A., Avellone G., Danzì C., Timpanaro G., Locatelli M., Carnaroglio D., Meneguzzo F., Ilharco L.M., Pagliaro M.

Abstract: The microwave-assisted extraction hydrodiffusion process of the peel from red and green *Opuntia ficus-indica* fruits affords under mild conditions high quality pectin and betanin of endless stability, thanks to the high amounts of antioxidant polyphenols, saving on water to directly obtain an

aqueous mixture of valued bioproducts in the fruit peel cell water itself. The valued integral extract can be used as such to formulate nutraceutical beverages and products or, upon straightforward separation, to isolate pectin and betanin devoid of chemical contaminants suitable as ingredients for products ranging from food and beverage to cosmetic and pharmaceutical sectors. Here, we describe the simple extraction process and spectroscopic characterization of the extracts from red and green *Opuntia ficus-indica* peel.

➢ *Economic and technical feasibility of betanin and pectin extraction from Opuntia ficus-indica peel via microwave-assisted hydrodiffusion*

Ciriminna R., Fidalgo A., Avellone G., Carnaroglio D., Danzì C., Timpanaro G., Meneguzzo F., Ilharco L.M., Pagliaro M.

Abstract: Investigating the feasibility of betanin and pectin extraction from *Opuntia ficus-indica* peel via microwave-assisted hydrodiffusion and gravity, this study identifies selected important economic and technical aspects associated to this innovative production route starting from prickly pear fruit discards. Which benefits would derive from this process? Would production be limited to *Opuntia*-growing countries or, likewise to what happens with dried lemon peel exported from Argentina, would production take place also abroad? Can distributed manufacturing based on clean extraction technology compete with centralized production using conventional chemical processes?

2.5. Conclusions

It is clear that in Sicily the prickly pear sector, after having been characterized in the last twenty years by an entrepreneurial vision about the valorisation of the fresh product, today the same sector looks at the product in an agro-industrial key. This new approach, also stimulated by recent scientific research, pushes more and more entrepreneurs to look also in the direction of the exploitation of waste, the isolated products have shown a remarkable appreciation by sectors such as pharmacology, cosmetics and nutraceuticals. In fact, the cacti and in particular the fruit, can be considered an important source of bioactive substances that are candidates for nutraceutical preparation and functional improvement of food. The scientific data reveal a high content of some chemical components in fruit, cladodes, seeds and flowers, which can add value to cactus by-products. Furthermore, some components show promising features as health promoting substances. The extracts from both the cladode and the fruit have shown curative effects on the gastrodigerent apparatus, on the circulatory and reproductive ones, limiting the onset of diseases thanks to the high antioxidant power that characterizes this fruit. Several isolated products are currently available in the nutraceutical market benefiting from the medicinal properties of cactus plants.

In the agri-food industry, fruits are now processed to prepare confectionery, syrups, creams, jams and jellies. Fruit juice can be used to cure hangovers. The natural cactus pear juice is promoted as a healthy thirst quencher rich in vitamin C, flavonoids and antioxidants and as an anti-aging and anti-inflammatory agent. It is also believed to promote and promote optimal cellular functioning and detoxify the body. The experience gained in south-west Etna by some entrepreneurs has shown that there is the possibility of further exploiting the functional properties of cactus products in the food, cosmetic and pharmaceutical industries, but in these fields more scientific research is needed, in fact, even today these productive nuclei are limited to isolating the active principles and their actual final enhancement is still distant. Although since now the progress made is significant, it much remains to be explored in the field of the use of active ingredients and the benefit they can have on humans and on the many diseases that afflict them. In the entrepreneurial experiences already present in the island territory, it has been shown that cladodes have health properties and are dehydrated or powdered to prepare pills and nopal capsules. The seed oil, on the other hand, is used in cosmetics. The growing global demand for nutraceuticals and healthy products is accompanied by the development of natural products for the treatment and prevention of human diseases. Further studies on cactus species have to be found for active compounds and their pharmaceutical and industrial applications. In addition, antioxidant formulations must be tested in the search for possible synergistic effects between the components. Market demand should be launched by advertising these cactus properties. Although the beneficial properties of the cactus were known since ancient times, they have only recently been scientifically proven.

For the future it is therefore desirable a greater synergy between researchers from different fields, in order to make available different competences to make the results of scientific horizons still little known to most people If this collaboration can continue, surely the sector will be able to double its turnover and therefore reach a real induced one with the creation of new specialized jobs in a sector in which Sicily will have the primacy in Europe and in the Mediterranean.

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3. Agro-energies in the current energy context

3.1 Energy from renewable sources

The sources of energy that derive almost all from the radiant energy of the sun and can regenerate, at least during the time of human activities, those are defined as renewable and therefore inexhaustible, unlike those fossils that are considered exhaustible. For some sources of renewable energy, however, the inexhaustibility is conditioned to a rate of use that is at least equal or lower than that one of production (for example the forests). Renewable resources generate thermal, chemical, mechanical, electrical energy.
During the second half of the last century the interest in renewable energy sources grew and it was due to oil crises (1973, 1979, 2003), the increase in oil prices and the environmental consequences associated with its exploitation. The sources of renewable energy received a strong impulse after the signing of the "Kyoto Protocol", the international agreement promoted by the UN and signed on December 7, 1997 by over 160 countries participating in the third session of the Conference of the Parties of the Convention on Climate Change United Nations Framework Convention on Climate Change - UNFCCC). The main object of the protocol was to reduce worldwide greenhouse gas emissions, which are considered most responsible for the warming of the atmosphere.
The signatory countries engaged themselves to reduce climate-changing gas emissions [carbon dioxide (CO2), methane (CH4), nitrogen oxide (N2O), sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs), perfluorocarbons

(PFCs)] of 5.2% compared to 1990 levels, through measures designed to improve energy efficiency, correct market imperfections through tax incentives and subsidies, promote sustainable agriculture, reducing emissions in the transport sector. The Treaty entered into force in 2005, but the objectives set, in some important cases have not been respected, so in 2012, during the climate talks held in Doha (Qatar), the agreement was extended until 2020, with a new goal: reduce emissions by 20% compared to 1990 levels. However, over 80% of participating countries (including Canada, Russia, China, Brazil, India) refused to sign binding agreements, while the European Union has signed them.
Italian legislation (Legislative Decree 28/2011, article 2) identifies as energy from renewable sources «wind energy, solar, geothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, the residual gases from purification processes and biogas». Biomass is meant as the «biodegradable fraction of products, waste and residues of biological origin from agriculture (including plant and animal substances), forestry and related industries, including fishing and aquaculture, mowing and pruning from public and private green, as well as the biodegradable part of industrial and urban waste»
Among the sources of renewable energy, biomass derived from energy crops, the agricultural and agro-industrial wastes are one of the most interesting solutions in the short and medium term for several reasons:
- the ability to produce energy short range and with relatively modest investments;
- to present an alternative to traditional crops which can not withstand the competition of a now globalized market;

- to store significant amounts of carbon in the soil;
- possibility of recovery of marginal and abandoned lands by offering new market opportunities to the agricultural world without entering into conflict with food production.

Therefore, agriculture could play an important role both as a supplier of energy and environmental protection. The production and distribution of energy from agricultural, agro-industrial and forest biomass, however presents a complexity far greater than other sources of renewable energy since its availability is discontinuous and dispersed in the territory.

3. 2 Energy needs - the contribution of renewable sources in the world, in Europe, in Italy

It is estimated that worldwide energy needs will grow about 35% in 2035 compared to current needs (Popp et al., 2014). In 2008, renewable sources represent 13% of the energy consumed, which for the most part (10 points, equal to 77%) was made by woody biomass (Figure 1). Currently, according to the International Energy Agency, the contribution of renewables to global needs is around 19% (IEA, 2013) (Figure 2).

Renewable energy is, therefore, still a marginal resource, but it significantly develops. The challenge is above all to find alternative solutions to liquid fossil fuels for the transport sector. The energy needs of the European Union in 2011 amounted to 1698 Mtoe (millions of tons of oil equivalent) (www.Enea.it). To fulfil this demand the EU is forced to import annually more than 50% energy consumed; its dependence on liquid fuels is then much higher, equal to 80%

(Cosentino et al., 2014). The 2012 EUROSTAT report points out that, compared to the total energy consumed, the share of renewables has increased significantly compared to 2008, reaching 14.1%, on average in the countries of Europe of 27. The goal towards which all efforts are converging is that of 2020. By that date, the 27 EU countries will have reached the 20% target of energy from renewable sources.

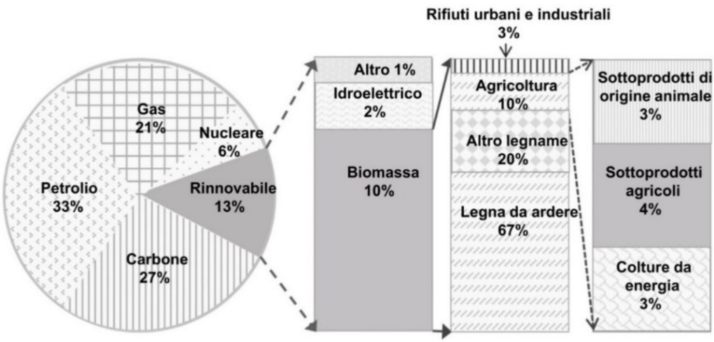


Figure. 1 - Global demand of primary energy by fuels in 2008 (Adapted from Cosentino et al., 2014; Popp et al., 2014)

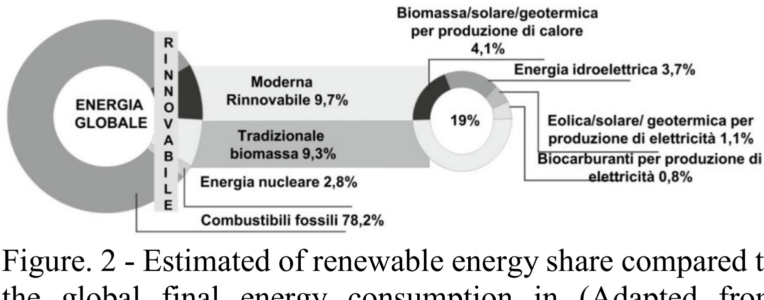
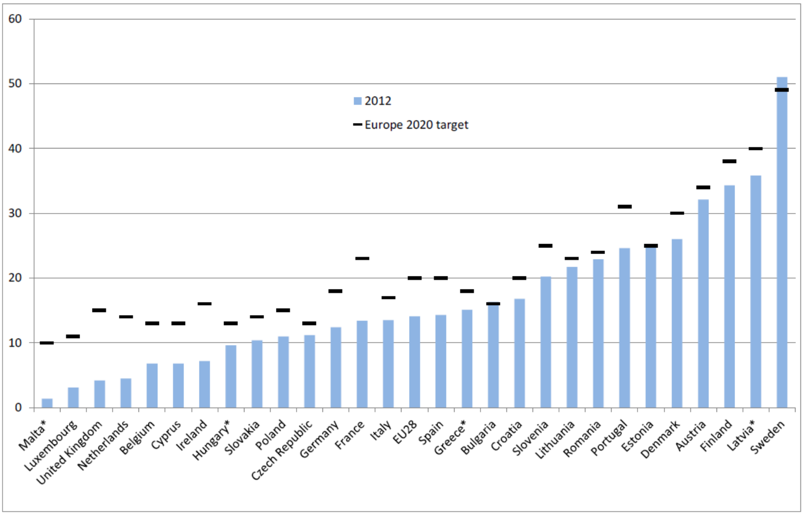


Figure. 2 - Estimated of renewable energy share compared to the global final energy consumption in (Adapted from Cosentino et al., 2014; Popp et al., 2014)

Italy depends on energy imports for over 80% of its needs (www.enea.it). The dependence of our country on oil is one of the highest in the world, however, the use of renewable sources increased sharply in recent years, rising from 5.7% in 2004 to 13.5 in 2012, which it puts us at about half of the European ranking (Figure. 3). The further effort will be to bring this share to 17% by 2020.



* estimated

Figure 3 - Share of energy from renewable sources for Member States (in% of gross final energy consumption) (Eurostat, 2014).

The EU as a whole is the main geographic and political area that has developed energy policies aimed at increasing renewables (Popp et al., 2014). The Directive 2009/28 / EC of the European Parliament and of the Council of 23 April 2009 fixed for each Member State the share of energy from renewable sources in gross final consumption of energy by 2020,which in turn is consistent with the overall objective «20-20-20 » that the Community has given in 2008 (COM / 2008/772). In connection with the transport sector, the share of energy from renewable sources must be at least 10% of final energy consumption. On 3 March 2011 with the legislative decree n. 28 "Implementation of Directive 2009/28 / EC on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77 / EC and 2003/30 / EC" Italy implemented the EC directive n. 28/2009. The mentioned decree defines the instruments, mechanisms, incentives and institutional, financial and legal framework necessary to achieve the objectives by 2020. The Ministry of Economic Development in 2010 launched the National Action Plan for renewable energy in Italy (NAP, 2010) fixing in 23 Mtoe the share of renewable energy, 17% of our energy consumption to 2020: (Table 1).

On July 6, 2012 the Minister for Economic Development, in agreement with the Minister of the Environment and Protection of the Territory and the Sea, promulgated the decree of «Implementation of the art. 24 of Legislative Decree 3 March 2011, n. 28, establishing incentives for the production of electricity from plants at different renewable sources by photovoltaic» which defines the new system of incentives for the production of energy from non-photovoltaic electric renewable sources (hydroelectric, geothermal, wind, biomass, biogas). Legislative Decree 5

December 2013 provided a specific incentive plan for the production of biomethane from cogeneration plants and for the introduction into the natural gas network.

Table. 1 – Brief outline of Italy's obligations in the field of renewable energy share of total energy consumed in 2020 on the basis of EC Directive 28/2009 (National Action Plan for Renewable Energies Italy - PAN, June 30, 2010)

Definition	Acronym	PAN Objective (National Action Plan)
Total expected energy consumption, adjusted to 2020 (Ktep)	GFE (Gross final energy consumption)	133,04 Mtep
Expected quantity of energy from renewable sources to the 2020 target (Ktep)	RES (Renewable Sources of Energy)	22,62 Mtep
Target of RES energy compared to gross final energy consumption in 2020 (%)	RES/GFE	17%

http://www.ebbeu.org/legis/ActionPlanDirective2009_28/national_renewable_energy_action_plan_italy_it.pdf

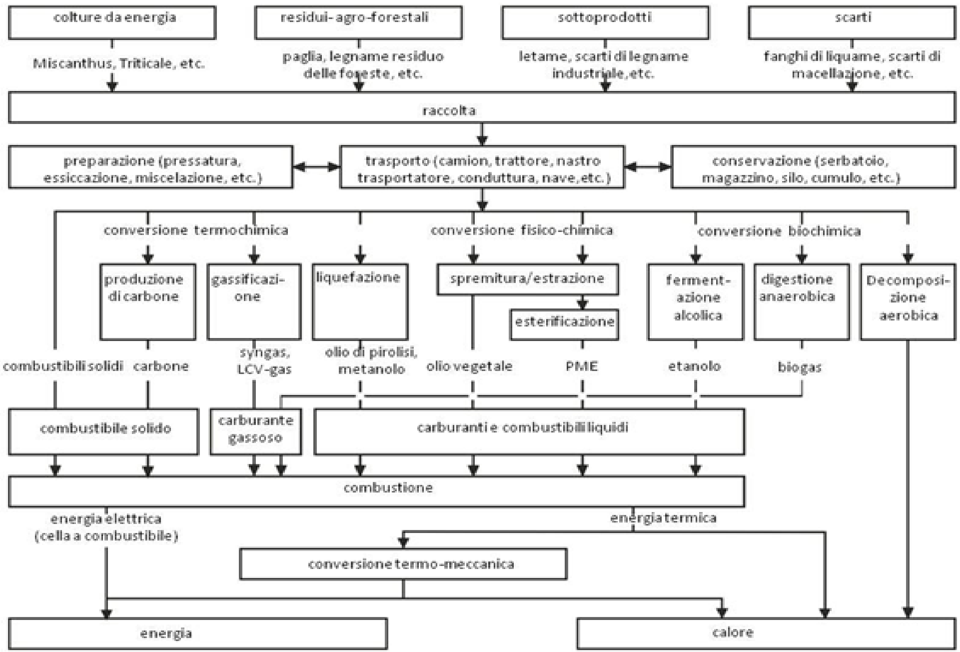
3.3 The agro-energy chains

The energy contained in the biomass derives from the photosynthetic process that transforms water and CO_2 into organic molecules. Biomass is energy stored under the form of cellulose, hemicellulose, lignin, sugary reserve substances, starch, oil, protein, fats, etc …

To obtain an efficient biomass energy production system, it is necessary to optimize the various factors and organize them in a coherent way in the various stages of the supply chain, from biomass production to final energy transformation (Castelli, 2011). The combinations between types of biomass used, technology, energy vector (biomass transformed into fuel) are summarized in Figure 4. Depending on the biomass and energy vector obtained we can be defined chains:

- Solid fuels supply chain;
- biofuels supply chain;
- biogas supply chain.

Figure. 4 - Production of heat, energy and fuel from biomass (Adapted by Cosentino et al 2014).



Based on the distance between the place of production of the biomass and that of utilization, the supply chains are divided into: short (for company level or groups of companies within a maximum biomass supply radius of 70 km), or long (with supply also abroad).
A new approach in the development of energy supply chains is the biorefinery, which integrates more production processes linked to biomass. According to the concept of biorefineries, biomass is first and foremost a source of chemical products with high added value: biomaterials, products intended for human consumption, animal, etc., and only the final residues are used for the production of energy.

3.4 Biomasses

Biomass refers to "the biodegradable part of residual products coming from agriculture (including animal and vegetable substances), from forestry and related industries, as well as the biodegradable part of industrial and urban waste" (Legislative Decree no. 387/2003 article 2, paragraph 1, letter a).
The biomass can be divided into:

- residual, ie originating from agricultural processes, industrial and civil processing and food utilization and of the organic substance in general (livestock wastes, wastes of food industry, by-products of wood processing, FORSU, vegetable scraps various by pruning and maintenance of the public green, etc.);
- dedicated, ie produced as an alternative to food products for energy purposes.

With the term biomass we mean, in a more general sense, all the substances of biological origin in a non-fossil form that can be used for energy purposes and, therefore, in addition to the biomasses of forest origin and the residues of wood processing, are included in this category produced the so-called "energy crops" (plant species that are expressly cultivated to be used for energy and / or fuel production),), agricultural residues, processing waste and effluents from the agri-food industries, animal dejections, the organic fraction of municipal solid waste (MSW), domestic waste in separate waste collection, and civil waste.
Biomass can be considered renewable resources and therefore inexhaustible over time, provided they are used at a pace not exceeding the capacity for biological renewal. In reality, therefore, the biomasses are not quantitatively unlimited, but for each plant species used, the availability finds a roof in the area destined for it, as well as in climatic and environmental constraints that tend to limit in each region the species that can properly and economically grow. The use of biomass for energy purposes can be advantageous when they are concentrated in space and available with sufficient continuity throughout the year, while excessive dispersion in the territory and a too concentrated seasonal nature of the crops make the collection more difficult and onerous. transport and storage.
From a technological and industrial point of view, the alternatives for the energy exploitation of biomasses already subject to industrial realizations and with final products available on the market are basically three:
➢ direct combustion, with the consequent production of heat to be used for domestic, civil and industrial heating or

for the generation of steam (motive power or production of electricity);

- ➢ the transformation into liquid fuels of particular categories of biomass cultivated like oilseed species (production of biodiesel, through the extraction of oils and subsequent chemical conversion of the same in mixtures of methyl and / or ethyl esters) and sugary species (ethanol production by alcoholic fermentation). Such fuels can be used, pure or mixed with gas oil or petrol, as motor fuels (biofuels) or, in the case of vegetable oils, directly in endothermic engines combined with a generator for the production of electricity;
- ➢ the production of biogas by anaerobic fermentation of zoo-technical wastewater, civil or agro-industrial waste and / or biomass of various kinds with high moisture content, and the subsequent use of the biogas produced for the generation of heat and / or electricity.

The biogas can be produced in plants which are specifically manufactured at agro-zootecnical establishments or agro-industrial companies (distilleries etc,) or recovered from landfill of municipal solid waste by means of suitable collection devices. In this last case, the energetic aspect plays a complementary role compared to the more environmentally proper one, as it avoids the dispersion into the atmosphere of methane, considered one of the main gases responsible for the "greenhouse effect" (a single methane molecule has an effect 21 times higher than that of a CO2 molecule).

3.5 The biomass conversion processes

If the biomass contains a lot of carbon (C), little nitrogen (N) and little water (H_2O), it is suitable for combustion for the production of heat or electricity (thermochemical conversion). If, on the other hand, it contains a lot of nitrogen (N) and is very humid (> 30%), it can be subjected to processes that transform organic molecules into methane or ethanol and carbon dioxide (biochemical conversion). Finally, liquid fuels suitable for use in petrol or diesel engines can be obtained by fermentation of the sugary / starch components (microbiological conversion) or by squeezing and transesterification of seed oil (physical-chemical conversion).

The thermochemical conversion processes are based on the action of heat that allows the chemical reactions necessary to transform matter into energy and can be used, as mentioned, for products and lignocellulosic and woody residues in which the C/N ratio has higher values at 30 and the moisture content does not exceed 30%. The conversion of biomass into heat occurs when a fuel (the biomass) and a comburent (oxygen) come into contact with a primer (heat source) which generates an oxidation-reduction reaction. The most suitable biomasses to undergo thermochemical conversion processes are wood and all its derivatives (sawdust, shavings, etc.), the most common lignocellulosic type agricultural waste (cereal straw, vine and fruit pruning residues, etc.) and processing waste (husk, chaff, shells, stones, etc.). From the combustion of biomass, it is possible to generate both electric and thermal energy (separate production); in the most advanced solutions, a single production unit generates a combined production of electrical and thermal energy (cogeneration); the latter

entered into a network, it can be distributed to end users (district heating). The advantage of the cogeneration system is to significantly increase the efficiency of the combustion process (up to 80%).
Trigeneration is a particular form of cogeneration that makes it possible to produce electricity and recover thermal energy to produce chilled water. Trigeneration is a particular form of cogeneration that makes it possible to produce electricity and recover thermal energy to produce chilled water.
Depending on the amount of air used to support the energy transformation, there are different types of process (Fiala and Bacenetti, 2011): exothermic, such as combustion (with the addition of air in excess of the stoichiometric value of complete oxidation), endothermals such as gasification (with a lack of air supply compared to the stoichiometric value of complete oxidation) and pyrolysis (in the absence of air).
Biochemical conversion processes allow energy to be obtained thanks to the contribution of enzymes, fungi and microorganisms that proliferate at the expense of biomass under particular conditions. They are used for biomasses where the C / N ratio is less than 30 and humidity at harvest is higher than 30%. The products of the biochemical conversion are biofuels: biogas, biodiesel and bioethanol.

3.6 The biofuels

Legislative Decree 28/2011 (Article 2, letter i), defines biofuels for all liquid or gaseous transportation fuels, derived from biomass, differentiating them from bioliquids (Art. 2, letter h) which are instead of liquid fuels for energy purposes

other than for transport, including electricity, heating and cooling.
On the basis of the biomass source and the conversion process biofuels are divided into:
- first-generation biofuels;
- second-generation biofuels;
- third-generation biofuels

3.6.1 The first-generation biofuels

First-generation biofuels are bioethanol and biodiesel, often deriving from food biomass. The main conversion processes of biomass for the production of first generation biofuels are shown in Figure 5.

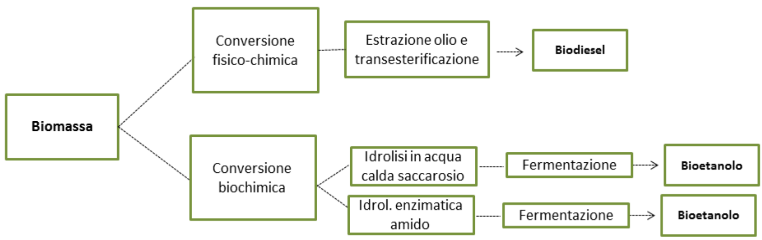


Figure 5 – Main conversion biomass processes for first generation biofuel production.

The bioethanol is a short chain alcohol (CH_3CH_2OH); it is generally produced by the fermentation of C6 sugars (mainly glucose) using classic yeast strains such as *Saccharomyces cerevisiae*. The plant species widely used for this purpose are the sugar cane, which uses the sucrose contained in the culm (Brazilian model) and the corn for the starch contained in the caryopsis, after transformation into glucose by means of enzymes known as "α -amilasi "(American model). Other raw materials used but to a much lesser extent are barley, wheat, potato, sugar beet, sugar sorghum.In the energy field, bioethanol can be used as such as a component of gasolines in variable percentages (E10, E15, E85) or for the preparation of ETBE (Ethyl TerButyl Ether), a high-octane derivative, alternative to MTBE (Methyl TerButil Ether), which added to gasoline increases its anti-knocking power (replacing the tetraethyl lead whose use has been banned in EU countries since 2000).

The biodiesel is a natural product used as a fuel for automobiles and as a fuel for heating, it must present the characteristics indicated respectively in the UNI 10946 and UNI 10947 standards. The biodiesel production process is based on the extraction of oils from oleaginous species (oil palm, rapeseed, soybean, Jatropha, etc.) and conversion of these into biodiesel by breaking the bonds linking the long chain fatty acids to the glycerol and substitution of the latter with methanol; this process is called "transesterification". Biodiesel is considered an excellent substitute for diesel fuel. In addition to vegetable oils can be used raw materials such as waste oils and animal fats whose recovery was governed by Legislative Decree February 5, 1997, No. 22.

The biogas is produced by fermentation (absence of oxygen), by bacteria, of complex organic substances (containing lipids, protides, carbohydrates), derived from the livestock sector (especially waste water) to which substances of vegetable origin are added, such as agricultural and food industry waste, but also energy crops such as corn, sorghum, lucerne, etc .. The biogas is constituted for approximately 50 ÷ 70% of methane and for the remaining part by CO_2 and other components. Thanks to the incentive policies, the agricultural producers, have converted the biogas into electricity that has been sold to the network. The by-products of the biochemical process are excellent soil improvers and fertilizers, because they are rich in undecomposed organic matter (lignin) and mineral elements (micro and macroelements).

3.6.1.1 The biogas

The global demand for Italian hydrocarbons is 1,800 TWh, of which 700-800 TWh are covered by the consumption of natural gas (www.consorziobiogas.it). The development of Biomethane: a sustainable choice for the economy and the environment). Energy from renewable sources would seem to be the ideal solution for the replacement of fossil hydrocarbons, as both are programmable energy sources (in the context of the production of electricity and, with reference to current legislation, renewable sources are classified as "programmable sources" and "non-programmable sources", depending on the availability of the power source of the production unit.
The first group includes hydroelectric production units in tanks and basins, solid urban waste, biomass, similar production units using fossil fuels, process fuels or residues, while in the second group (not programmable) there are the hydroelectric production units fluent, wind, geothermal, photovoltaic - GSE definition energy services manager) and carbon based. But unlike hydrocarbons, bioenergy is characterized by being a dispersed and dense energy source.

Among the various bioenergy biogas production is a technology that can offer long-term positive returns in terms of decarbonisation of the energy and agriculture sectors. Furthermore, it can promote economic development because it acts on the reduction of emissions in the energy system, on carbon storage through the creation of negative carbon systems from CO_2 capture through photosynthesis, giving agriculture a central role as an engine for the bioeconomy.
Among the different bioenergy systems, the chain of biogas is the one that is more integrated with farms because:

• it is achievable in an efficient manner at any production scale, even of a few hundred kWe;
• it is a flexible technology because the anaerobic digester is suitable for different diets, not requiring the creation of monocultures but enhancing the biomasses present in different agricultural contexts;
• it can help to reduce the production costs of farms to eliminate those for chemical fertilizers and fossil fuels, while reducing the cost of management / use of livestock manure and by-products (eg. Citrus pulp).

Unlike the wind and solar source, the energy from anaerobic digestion is programmable and potentially activates 365 days a year, independently of climatic factors (solar radiation, presence of clouds, rainy days, etc.). It makes possible to benefit from incentives related to the production of electricity accompanied by those due to the possibility of creating a district heating network. Biogas represents for the operators of the agricultural sector a second and new source of livelihood that fits perfectly with their normal activity. In fact they are very successful, the anaerobic digestion plants as they allow the exploitation of agricultural waste, waste from the milk supply chain (eg whey) and animal dejections, as the zoo-technical waste that can be disposed by valorising them inside a fermenter through a process of co-digestion, and which should otherwise be disposed of at the expense of the zoo-technical farm. Not surprisingly, this type of management of the plant has spread much faster than that fed exclusively by dedicated crops that must be purchased, not without problems of availability due to the variation of the seasons or market prices. This is compounded by the problem related to competition between the use of agricultural land to energy and food purposes. The anaerobic digestion plants in which biogas is produced represent a well-established and rather widespread technology both in Italy and in Europe in general, but which it still has a lot of potential for development, especially in southern Italy where this technology has yet to be widespread. According to Eursostat, the European Union produced 15.6 Mtoe of biogas energy in 2015, or 630 kouses more than in 2014, and almost 77% of European production is concentrated in the hands of three countries - Germany (7.9 Mtoe), the United Kingdom (2.3 Mtoe) and Italy (1.9 Mtoe) (The State of Renewable Energies in Europe, EurObserv'ER Report 2016). According to the OECD (The Organization for Economic Co-operation and Development), electricity produced from biogas has grown from 3.7 TWh in 1990 to 81.3 TWh in 2016. With an average annual growth rate of 12.7% since 1990, biogas is the third fastest-growing source of renewable electricity in the OECD, with Europe that represented 79.5% of OECD production in 2016. In Germany, production has grown by 20.9% annually since 1990, becoming the largest producer in the OECD (42.0%). The third and fourth largest producers in the OECD were also European. Italy produced 9.0 TWh, or 11.0% of OECD production, and the United Kingdom produced 7.4

TWh (9.2%). The second largest producer in the OECD in 2016 is the United States which produced 13.3 TWh, or 16.3% of biogas electricity in the OECD. However, despite its large share in the production of the OECD, the US growth rate (6.6% per year since 1990) was lower than many European Union countries that use biogas, for example. 38.2% in Italy and 20.9% in Germany. We can state, however, that the interest has considerably increased over the last ten years, during which there was a rapid increase in the number of medium-small size plants, and the corresponding installed power. More recently, however, the attractiveness of the upgrading of anaerobic digestion plants aimed at the production of biomethane has emerged. This step forward brings with it many advantages that add up to those already possessed by technology bound to biogas.

3.6.1.2 The anaerobic digestion

Anaerobic digestion is a biological process by which, in the absence of oxygen, the organic substance contained in materials of plant and animal origin is ruined.
Anaerobic digestion (DA) from organic material is generally divided into: hydrolysis, acidogenesis, acetogenesis and methanogenesis (Figure 6) (Demirel and Scherer, 2008). The different phases can coexist in the same environment or be divided into separate environments or reactors.
During hydrolysis, complex organic compounds such as carbohydrates, proteins and lipids are hydrolyzed into monomers such as sugars, amino acids and fatty acids through extracellular enzymes produced by hydrolytic bacteria (Parawira et al., 2005). The monomers obtained from

the hydrolysis are degraded by fermentative bacteria during the acidogenic passage in short-chain organic acids (for example butyric acid, propionic acid, acetic acid), alcohols, hydrogen and carbon dioxide (Chandra et al., 2012). The intermediate compounds formed during acidogenesis are converted into acetate by acetogenic bacteria. The acetate serves as a substrate for the species of Archaea methanigene that convert it into methane (CH_4) and carbon dioxide (CO_2) during methanogenesis, the last phase of anaerobic digestion l. In this phase, the acetate, hydrogen and carbon dioxide are converted into methane and carbon dioxide. In general, 70% of the total methane derives from the conversion of acetate (acetoclastic methanogenesis), while the remaining 30% comes from hydrogen and carbon dioxide, produced during the first fermentation stage (hydrogenotrophic metanogenesis) (Rosato M., 2015).

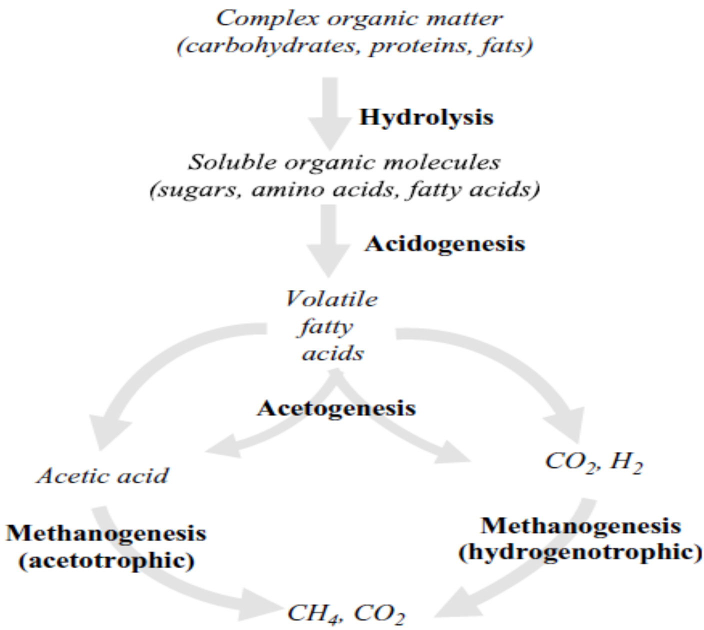


Figure 6 - The steps involved in anaerobic digestion (adopted from Rapport et al. 2008)

Metanigenic bacteria belong to the Archaea domain, a group of organisms with characteristics that diversify them from bacteria, such as the composition of intercellular lipids, the fact of not having peptidoglycan polymers in the cell walls but also by a phenotypic point of view (Moss et al., 2000; Krause et al., 2014). The Archaea kingdom is divided into two sub-branches: the Crenarchaeota and the Euryarchaeota. The first are organisms called extremophiles because they live in environments with extreme values of temperature, pH, pressure or salinity. The Euryarchaeota include all the known Archaea metanigen species.

Anaerobic digesters can work in mesophile, thermophilous or psycho-phylous conditions. Mesophilic digestion takes place in the range 20-45 °C, with optimal digestion between 30 °C and 38 °C. The thermophilic digestion occurs up to 70 °C, with optimal digestion between 47 °C and 57 °C. Psychophilic digestion occurs at low temperatures (<20 °C), with optimal temperatures between 15 °C and 20 °C. The reactor stability is inversely proportional to the digestion temperature, with low temperatures that provide maximum stability. Therefore, mesophilic digestion is considered more stable and more tolerant to changes than thermophilic digestion, but requires longer residence times, and therefore larger digesters. Thermophilic digestion requires an input of energy superior to mesophilic digestion; however, more energy is obtained from biomass, with faster reaction speed and greater sterilization of the digested product (OECD, 2010). Psychrophilous digestion gives global methane yields comparable to mesophilic digestion; however, production rates are so low that the digester's dimensions are generally too large to be cheap (Safley e Westerman, 1990). Mesophilic digesters are most common for the reasons mentioned above, but also because the mesophilic bacteria are most important and most commonly found bacteria in nature, in most of the raw materials. On the contrary, thermophilic and psychrophile bacteria are quite rare, and generally must be seeded in the digester (Schanbacher, 2009). The anaerobic digestion process is sensitive to the type of substrates and their composition; In general, the physico-chemical characteristics of the lignocellulosic biomass can influence the yield in methane. During the DA of the lignocellulosic biomass, the hydrolysis is the phase limited by several factors: cellulose crystallinity, degree of polymerization, surface for the enzymatic attack and, in particular, lignin content (Chang and Holtzapple, 2000). The structure of lignocellulosic materials is mainly composed of cellulose, hemicellulose and lignin, strongly linked to one another through hydrogen bonds and van der Waals forces. The complex structure of the lignocellulosic biomass does not allow an easy degradation of the cellulosic and hemicellulosic contents that are shielded by the lignin that reduces the surface available for enzymatic attacks and hinders the degradation of the structural carbohydrates.

The pretreatment

Pretreatment is an essential requirement to achieve greater energy efficiency. The purpose of the pretreatment is to break the impermeable layer of lignin and resistant, so that the cellulose and hemicellulose present in the biomass to be hydrolyzed by microorganisms and converted into simple sugars.

Therefore, in order to improve the production of methane from lignocellulosic substrates, pretreatment is often necessary (Taherzadeh and Karimi, 2008).

Pre-treatments can be grouped into:

- Physical pretreatment which aims to reduce the solid particles forming the biomass into pieces and thus increase the contact surface with the enzymes during hydrolysis by decreasing the degree of polymerization of the cellulose (extrusion, fine grinding or grinding, disintegration with ultrasound);
- Thermo-mechanical pretreatment, an example is steam-explosion, based on the use of saturated steam, which is interesting for relatively low energy consumption;

- Chemical pretreatment which is carried out with dilute solutions of sulfuric acid, soda, or solvents able to partially remove the lignin. These processes are characterized by a high environmental impact.
- Biological pretreatment that uses the use of microorganisms that break up the cell wall degrading the lignin and inducing an increase in porosity. The most promising microorganisms for biological pretreatment are fungi like those of white rot that belong to the class of the Basidiomycetes. Although they are very effective, these methods are impractical because they require long residence times of biomass in special bioreactors.

Each pretreatment has a specific effect on the cellulose-hemicellulose-lignin system, therefore single pre-treatments can also be combined to improve their overall effect on biodegradability (Hendriks e Zeeman, 2009). The most important factors to consider when choosing a biomass feed for the anaerobic digestion process are the total solids content, the percentage of volatile solids, the carbon-nitrogen (C/N) ratio and the biodegradability of raw materials. The yield is also a function of hydraulic retention times, solids, pH, fermentation temperature, load rate, inhibitory effects of compounds (eg ammonia, VFAS, hydrogen sulfide), degree of mixing / stirring and the presence of any agents pathogens (Abbasi et al., 2012). The management of the reactor parameters define the exercise in terms of residence times of the mass fed into the reactor, concentration of microorganisms, the yields of biogas production in relation to the volume of the reactor and the characteristics of the treated substrate. In these parameters the term substrate may be, from time to time, replaced by a measure of the quantity of biodegradable compounds present in the sample. The substrate is generally defined, in terms of digestion processes, in terms of total solids (TS), of volatile total solids (TVS), of chemical oxygen demand (COD), or of biological demand of oxygen at 5 days (BOD5). The following points show the essential elements of definition of these quantities:

- TS: total solids or dry matter, ie the dry substance content of a sample, determined by drying in an oven at 105 ° C for 24 hours. These represent, in a first approximation, the sum of the organic fraction and inert that of the substrate;
- TVS: total volatile solids or organic substance, ie the fraction of dry substance which is volatized by combustion at 550 ° C up to constant weight.
- These represent, in a first approximation the organic fraction of the dry matter, calculated as the difference of the TS values and TFS (fixed total solids) which represent the inert fraction, consisting mostly from inorganic compounds, as measured by weighing after treatment at 550;
- COD: chemical oxygen demand. Amount of oxygen consumed by the oxidation of the organic substance, determined through the use of a strong oxidizing chemical agent (K2Cr2O7) in an acidic environment;
- BOD5: amount of oxygen consumed in 5 days, under controlled conditions, for the biological oxidation of the organic substance present in the sample;
- BODL: (B0) 20 days biological oxygen demand;
- solids content: the solids must be diluted to form a suitable mixture that can be mixed and allow the gas to flow upwards. Each value is specific to the type of reactor, but generally ranges from 10% to 25% solids;
- C / N: a carbon-nitrogen ratio of 20/30 is typically optimal. If the ratio is too high, the nitrogen is rapidly

consumed by the methanigens for the formation of proteins and the insufficient nitrogen remains to react with residual material. If the ratio is too low, nitrogen is released and accumulates as ammonia, which increases the pH and exerts a toxic effect on methanogenic bacteria;

- pH: the optimal pH input value is between 6 and 7. Initially, during digestion, the pH decreases and then increases as the reaction proceeds, due to the production of ammonia. When methane production becomes stable, the pH is typically 7.2-8.2. Methangenic bacteria prefers a slightly alkaline environment, and can not survive at a pH below 6 (Ostrem et al., 2004);
- temperature: on a large scale the anaerobic digestion is generally operated by mesophilic bacteria, less by thermophilic bacteria and much less psychophilous. Thermophilic digestion is generally more efficient than mesophilic digestion, with a faster digestion rate, but is more difficult to control, bacteria are rarer and therefore typically have to be sown in the reactor, investment costs are higher and require. Anaerobic digestion by psychophilic bacteria is very rare due to the extremely slow digestion rate at such low temperatures;
- loading rate: the organic loading rate is a measure of the biological conversion of the system capacity. So, the amount of volatile solids that a system can tolerate is determined. An overload quickly leads to system errors due to inadequate mixing, increased VFA content and decreased pH;
- retention time: the duration of the contact between the organic material in the digester (substrate) and microorganisms (solids) necessary to achieve the desired degradation;

- hydraulic residence time (HRT): the time when the biomass remains in the digester: HRT [days] = V reactor [m3] / daily biomass input [m3 / day];
- solids residence time (SRT or ST): the time when the active microorganisms remain in the digester: SRT [days] = V reactor [m3] * conc.SV [Kg / m3] / volatile solids effluent [Kg / day];
- the relationship between HRT and SRT, which determines the ratio between the amount of substrate and the amount of bacteria available to consume that substrate; this is the controlling factor in all biological treatments;
- toxicity: mineral ions, in particular of heavy metals and detergents, inhibit normal bacterial growth. Small amounts of minerals such as sodium, potassium, calcium, magnesium, ammonium and sulphur can stimulate bacterial growth, but higher concentrations are toxic. Heavy metals such as copper, nickel, cobalt, chromium, zinc and lead are essential for bacterial growth in very small quantities, but, in larger quantities, they are toxic and prevent the use of digestate as a fertilizer. Detergents (soap), antibiotics and organic solvents can inhibit bacteria;
- mixing / stirring: mixing or stirring is necessary to maintain the homogeneity of the fluid, thus producing the stability of the process. The goal of mixing is to combine the input material with bacteria, stop foaming and avoid marked temperature gradients inside the digester.

Anaerobic digestion techniques can be divided into two main groups:

- wet digestion, when the substrate in digestion has a dry substance content of less than 10%; this is the most widespread technique, in particular with zootechnical sewage;

- dry digestion, when the substrate in digestion has a dry substance content of more than 20%. Processes with intermediate values of dry substance are less common and are generally defined as semi-dry.

The anaerobic digestion process is also divided into:

- single-stage process; when the phases of hydrolysis, acid fermentation and methanogenesis occur simultaneously in a single reactor;
- two-stage process; when there is a first stage during which the organic substrate is hydrolyzed and at the same time the acid phase takes place, while the methanogenic phase takes place at a later time.

An additional subdivision of the anaerobic digestion processes can be made according to the type of reactor feed, which can be continuous or discontinuous (C.R.P.A. Energia dal biogas, 2008).

3.6.1.3. The Biogas legislation

Among the European Directives and Regulations of interest, acknowledged in various capacities by the national legislation, we report:

• Directive 2009/28 / EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources establishes a common framework for the production and promotion of energy from renewable sources. For each Member State, a target will establishes for the share of energy from renewable sources on gross final energy consumption by 2020. Member States should adopt a national action plans, which set the share of energy from renewable sources consumed in transport, electricity and heating by 2020.

- The EC Regulation n. 1774/2002 of the European Parliament and of the Council, dated 3/10/2002, on "Health regulations concerning animal by-products not intended for human consumption" establishes rules concerning the health of humans and animals in terms of collection, transport, storage, handling, processing and use or disposal of animal by-products.
- The EC Regulation n. 208/2006 of the commission of 7/2/2006 modifies annexes VI and VIII of the EC regulation n. 1774/2002 of the European Parliament and of the Council with regard to the processing standards for biogas and composting plants and the requirements applicable to manure.

The main national legislative documents that regulate the production and use of biogas are:

- The Legislative Decree of 29 December 2003, n. 387 "Implementation of Directive 2001/77 on the promotion of electricity produced from renewable energy sources in the internal electricity market".
- Ministerial Decree of 7 April 2006 "Regional regulation of the agronomic use of livestock effluents, referred to in Article 38 of Legislative Decree 11 May 1999, No. 152" introduces a series of very precise provisions concerning the final phase of the production chain of biogas, the result of the implementation of the European legislation on the management of zoo-technical wastewater (Nitrates Directive).

- Legislative Decree 3 April 2006, n. 152 "Environmental Regulations" better known as the Single Environmental Text which represents the fundamental text for environmental legislation in our country and, therefore, also for the environmental effects connected to the construction of new energy plants.
- The legislative decree March 3, 2011, n. 28 (Implementation of Directive 2009/28 / EC on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77 / EC and 2003/30 / EC), also called the Renewable Decree, which introduced measures to simplify and rationalize the administrative procedures for the construction of renewable energy plants, both for the production of electricity and for the production of thermal energy.

As specified by the art. 1 on the purposes, the legislative decree 3 March 2011, n. 28, implementing Directive 2009/28 / EC and in compliance with the criteria established by law n. 96/10 (Community law 2009); it defines the instruments, mechanisms, incentives and institutional, financial and legal framework necessary to achieve the objectives up to 2020 on the overall share of energy from renewable sources on gross final consumption energy and share of energy from renewable sources in transport. As for Italy, this share amounts to 17%. As part of this objective, as established by the European Union, the share of energy from renewable sources in all forms of transport must be at least 10% in 2020 of final energy consumption in the transport sector in the same year. In addition, the decree, which entered into force on 29 March 2011, sets out rules on transfers between Member States of renewable energy shares, on common projects between Member States and with third countries, on guarantees of origin, on procedures administration, on information and training, on access to the electricity grid, on sustainability for biofuels and bioliquids.

3.6.1.4. Incentives

The Decree of 6 July 2012 represents the implementation of Article 24 of Legislative Decree 28/2011. The decree, in accordance with Directive 2009/28 / EC, introduces a new incentive system for plants that produce electricity using renewable sources other than solar photovoltaic (hydroelectric, geothermal, wind, biomass, biogas). The previous tax benefit system based on the Green Certificates and the All-Inclusive Tariff is profoundly modified. The current decree provides an incentive differentiated base rate for the installed power for class and type of power source adopted, with the addition of any bonuses. The remodulation of incentives and access procedures involves the plants in operation after December 31, 2012, for the three-year period 2013-2015 with annual decreasing tariffs to align Italy with the other European countries. The system favours small-scale plants (power not less than 1 kW) thanks to direct access to the incentive tariff. Those with more power, however, must register in appropriate national registers to obtain the facilities, or if they exceed 5 MW participate in auctions on the decline. The duration of the incentives has been extended from 15 to 20 years.
One of the main innovations introduced by the Decree, for biomass and biogas plants, consists precisely in the differentiation of incentives according to the type of food chosen.
In Article 8 the usable substrates are divided into 4 categories:

a) products of biological origin (agricultural products destined or destined for human consumption, products deriving from forest management and forestry, not classified as waste or by-products and not included in Table 1-A of Annex 1 of the Decree);
b) by-products of biological origin coming from: agricultural activity, breeding, management of the green, forestry activity, alimentary and agro-industrial activities, waste of animal origin not destined to human consumption (reported in table 1-A of the decree);
c) wastes for which the biodegradable fraction is determined according to the methods set out in the Decree of the Decree;
d) waste not coming from separate collection different from the letter c).

The Ministerial Decree of 23 June 2016 encourages the production of electricity from renewable energy plants, other than photovoltaics. The incentives may be required both for new plants, either completely reconstructed, reactivated, the object of potentiation or refurbishing.

The ministerial decree of 6 July 2012 continues to apply to plants registered in a useful position in the rankings formed as a result of the auction and register procedures carried out pursuant to the same decree and to plants directly accessing the incentive mechanisms, which entered service in

thirty days before the date of entry into force of this decree, on condition who submit an application for access to incentives under the terms of art. 21 of the ministerial decree 6 July 2012.

The Ministry of the Environment with the Decree of 14 April 2017 regulates the conditions for access to the increase in incentives provided for by the Decree of 6 July 2012 for the

production of electricity from plants fueled by biomass and biogas. The decree establishes the procedures for verifying and communicating compliance with the conditions for access to the tariff reward envisaged by art. 8, paragraph 7 of the Ministerial Decree of 6 July 2012, including the costs of related activities. It also establishes the minimum characteristics and performance of the emissions analysis system (SAE system), which can be used for access to the reward as an alternative to the continuous monitoring system (SME system).
The reward is paid to facilities identified by art. 8, paragraph 4, letters a) and b) of the Ministerial Decree of 6 July 2012.
The Art. 2 points out documents that the plant manager must send to the Regional or Provincial Agency for the protection of the Ministerial Decree of 14 April 2017 for the purposes of the initial verification of the suitability of the SME system or the SAE system.
Moreover, the manager must periodically send to the Agency, for the purpose of obtaining the reward, the monitoring data relating to the monthly average values of the parameters of the table in annex 5 of the ministerial decree 6 July 2012, detected and processed in compliance with the requirements.
After the reception of the information described above, the agencies will evaluate, the purposes of the initial verification of the suitability of the SME system or the SAE system:
- the ability of the system to measure substances in emissions, in any operating condition of the plant, in relation to the characteristics of the substances themselves and the values to be respected, verifying in particular the suitability of the system with respect to the characteristics and relevant technical standards and requirements of the art. 9.

- The correctness of the procedures referred to in art. 2, paragraph 1, letter b) of the Ministerial Decree 14 April 2017. This proof is carried out and based on the documentation sent by the plant operator and based on any activities in the field. According to the provisions of Article 4, the agencies carry out checks at the plants ensuring, for each plant, at least one inspection every two calendar years during which the plant is in operation for one or more months.

The article. 5 provides for the possibility that the initial verification of eligibility (Article 3 paragraph 1 and 3) may be, entirely or partially, delegated by the agencies, through special agreements, to public or private laboratories or other entities having specific expertise in the matter and regulates this possibility by indicating specific tasks to the delegates.

As for the tariff reward (article 6 of the Ministerial Decree of 14 April 2017), the period of access to the same effect from the first calendar month following the date on which the operator uses an EMS system or SAE subject to positive initial verification eligibility and applies the procedures pursuant to art. 2, paragraph 1, letter b), subject to positive initial verification of suitability.

The periods in which the system operated before being subjected to a positive initial assessment of suitability can not be considered for the purposes of the reward.

The article. 7 establishes that the agencies communicate to the Energy Services Manager, using the index of Annex I to the Ministerial Decree 14 April 2017, the results of the verification required by art. 3, paragraph 1, and periodically, the calendar months in which the limit values referred to art. 3, paragraph 3, were respected, for the purposes of payment of the adjustment reward, pursuant to art. 8, paragraph 11, of the ministerial decree July 6, 2012, to be paid in relation to this number of monthly payments.

The communication must be made within 90 days from the reception of the verification object data.

The article. 9, finally, recalls that the costs of verification, checks and communications are charged to the plant operator on the basis of the tariffs set out in Annex II. In case of non-payment or incomplete payment of the amounts due, the agencies can establish to do not proceed to further verification and communication activities referred to this article in relation to the operator concerned.

The Ministerial Decree of 6 July 2012 defines four different methods of access to incentive mechanisms, depending on the power and the category of intervention (Article 4):

- direct access, in the case of new plants, fully reconstructed, reactivated, subject to reconstruction or upgrading with power not exceeding a certain limit (for upgrades, the increase in power must not exceed this limit);
- registration in Registers, in such a position as to fall within the contingent of incentivable power, in the case of new plants, fully rebuilt, reactivated or upgraded, if the relative power (for upgrades the increase in power) is higher than that maximum permitted for direct access, but not exceeding the threshold value;
- participation in competitive procedures of downward auctions, in the case of new plants, fully rebuilt, reactivated or upgraded if the relative power (for upgrades the increase in power) is higher than the threshold value;

registration to Registers for reconstruction operations, in a position to be included within the contingent of incentivable power, in the case of rebuilding of systems whose power is higher than the maximum allowed for direct access.

3.6.2 The second-generation of biofuels

Second generation biofuels are produced from a wide range of raw materials, in particular, but not exclusively, from lignocellulosic biomass. The cost of this biomass is significantly lower than that of vegetable oil, corn starch or sugar cane sucrose.
The conversion process for the production of second generation biofuels can mainly follow two different approaches: the thermal and the biological one. A simplified scheme for the production of bioethanol and by-products is shown in Figure 7.

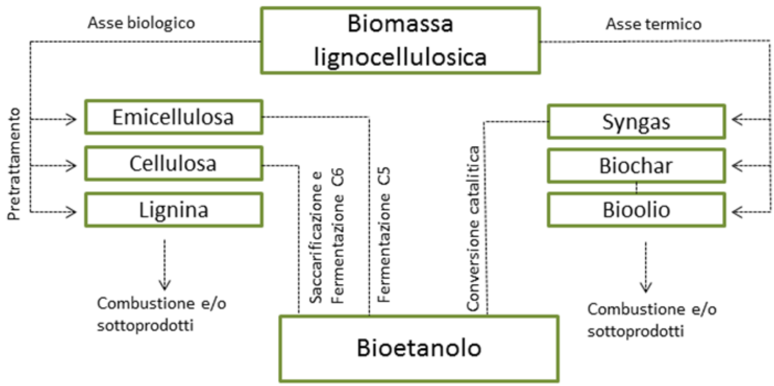


Figure 7 - Simplified flow chart for second generation bioethanol and by-products through thermic or biologic process.

The "thermal" approach includes specific treatments in which the biomass is heated with a minimal amount of oxidizing agent, if present. This process thermally converts the biomass into three fractions: a solid known as biochar, a liquid commonly called pyrolytic oil or bio oil, and a gas known as syngas. In the case of processing at low temperatures (250-350 ° C), in the absence of oxygen, the biomass undergoes a roasting and the main conversion product process is biochar. At higher temperatures (550-750 ° C), even in the absence of oxygen, the process is known as pyrolysis and the main product is the bio-oil. At higher temperatures (from 750 to 1200 ° C) and with limited oxygen inputs, gasification occurs which mainly produces syngas with biochar and bio oil as by-products.

The "biological" approach is the most studied process in the world, leading to the production of second-generation bioethanol. This process includes mainly three phases: a pre-treatment, a subsequent enzymatic hydrolysis followed in turn by an alcoholic fermentation. Enzymatic hydrolysis and alcoholic fermentation can be combined to give rise to simultaneous saccharification and fermentation.

With diluted pretreatment the hemicellulose is collected in a liquid fraction containing sugars with 5 and 6 carbon atoms (xylose, arabinose, glucose, galactose, mannose), which can be directly fermented by yeasts that metabolize some of these carbonaceous compounds, such as Pichia stipitis (Jeffries et al., 2007; Jeffries, 2008).

The fermentation of hemicellulosic sugars to ethanol has been extensively studied by Scordia et al. (2010; 2011; 2012; 2013a; 2013b) that used lignocellulosic biomass of Saccharum spontaneum, Arundo donax and Miscanthus x giganteus. In many cases, a chemical, physical or biological detoxification phase, to reduce the concentrations of inhibitory compounds, is of primary importance for the success of the fermentation phase of the hemicellulosic hydrolyzate (Palmqvist and Hahn-Hägerdal, 2000a; 2000b). The remaining fraction, represented by a solid compound, contains cellulose and lignin. Lignin acts as a barrier to the enzymatic attacks of cellulose and therefore its separation or deconstruction is also an essential prerogative of a good pre-treatment. Cellulose, composed exclusively of glucose polymers can be hydrolyzed in an acidic environment, or more effectively, through enzymatic hydrolysis (Scordia et al., 2010; 2011; 2013a; 2013b).

Many microorganisms have cellulosolytic activity, but nevertheless, only the *Trichoderma* and *Aspergillus* strains have been extensively studied for such purposes (Saha, 2004).

The glucose obtained from the cellulose hydrolysis is fermented to ethanol by yeasts or bacteria. Simultaneous saccharification of cellulose into glucose and fermentation of glucose into ethanol (SSF) improves the kinetics and economics of biomass conversion (Philippidis et al., 1993).

Lignin, the second most abundant natural polymer (after cellulose) makes up 25-35% (dry weight) lignocellulosic biomass (Lavoie et al., 2011). The macromolecule that remains after cellulose hydrolysis or after SSF is biologically difficult to degrade, but is highly energetic and has been used for cogeneration (Dickinson et al., 1998) or combustion (Dayton and Frederick, 1996) from part of the pulp and paper industry.

Although it can be used as fuel or as a hydrogen source in a biorefinery process, the aromatic lignin monomers could also be a very abundant source of high added value chemical compounds, which could be used in the plastics or adhesives industry.

Consequently, the use of lignocellulosic biomass to produce such compounds would lead to a new market, that of bioadhesives and second-generation bioplastics. Recently it has been reported that 10-20% of lignin can be converted into compounds with high added value, such as guaiacol, pyrocatechin and phenol (Beauchet et al., 2012).

3.6.3 Third generation biofuels

Third-generation biofuels can be produced by microalgae. The algae are among the oldest living forms on earth, their simple structure is ordered, in autotrophic forms, the absorption of CO_2 and mineral salts that are converted into sugars, proteins and lipids, potential fuels, but also into food and co-products (pharmaceutical and nutraceutical products, animal feed additives, bioplastics, etc.) (Brennan e Owende, 2010). The quantities and production rates of these compounds are high and make these processes efficient. Microalgae, in fact, if placed in optimal conditions can double their biomass in 24 hours (Brennan and Owende, 2010). Algae are autotrophic organisms, they can live in fresh or salt water, but also on potentially polluting substrates such as sewage (Chisti, 2007). There are more than 2100 genera of microalgae (Wu et al., 2007) and 27,000 species of algae that inhabit the most diverse environments in the world (Ozkurt, 2009). Algae do not compete for the use of soil with food crops nor with those dedicated to energy.
The species on which the research is directed are above all those that accumulate high amounts of lipids: Chlamydomonas reinhardtii, Dunaliella salina, various species of Chlorella including Botryococcus braunii. The

greater efficiency would be determined by the high rate of biomass growth that can contain lipids up to 80% of its dry weight. However, many problems remain unresolved (selection of efficient strains, harvesting systems, breeding substrates). Figure 8 shows the thermochemical and biochemical conversion processes of microalgae biomass.

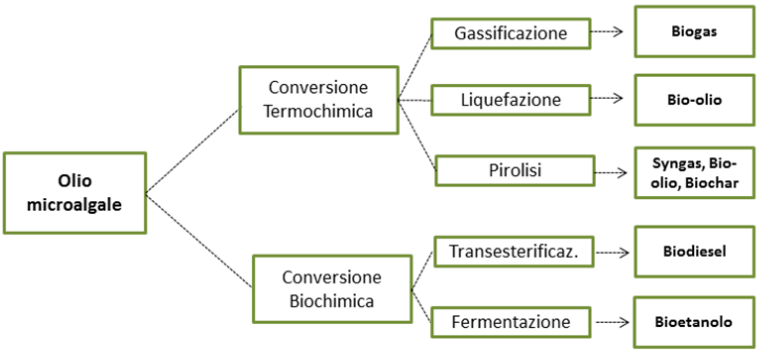


Figure 8 – Main thermochemical and biochemical conversion processes from microalgae biomass.

3.7 Biomass crops for energy in the world and in Italy

3.7.1 The 'first generation' species

In theory, any plant can be used as an energy crop. In a first phase the research turned to food crops, the best known from an agronomic point of view (the cultivation technique does not differ from that used for conventional use) and already improved genetically. The first crops used were sugar for the production of bioethanol: sugar cane in tropical climate countries (Brazil), sugar beet in countries with a temperate climate. For the production of biodiesel, the oil palm was used [Elaeis guineensis Jacq. and Elaeis oleifera (Kunth) Cortès] in tropical countries, rapeseed (Brassica napus L. var. oleifera D.C.) and sunflower (Helianthus annuus L.) in countries with a temperate climate. Later, especially in the United States, the focus was on the use of starch contained in corn grains (Zea mais L.) for the production of bioethanol and soybean oil for biodiesel production. In 2012, the world production of bioethanol was 85 billion liters. The major producer countries were the United States with 51 billion liters (from corn) and Brazil with 21 billion litres (from sugar cane). Europe contributed with a much smaller share, 4.3 billion litres, obtained by the starch of the grains of the winter cereals (Popp et al., 2014). The world production of biodiesel, again in 2012, amounted to 18 million tons, 44% (7.9 million tonnes) was obtained in Europe from rapeseed (Popp et al., 2014) (Figure 9). Also in Europe, significant contributions came from biogas (from livestock waste and various plant material) (Don et al., 2011). The major producer countries were Germany and France (Figure 10).

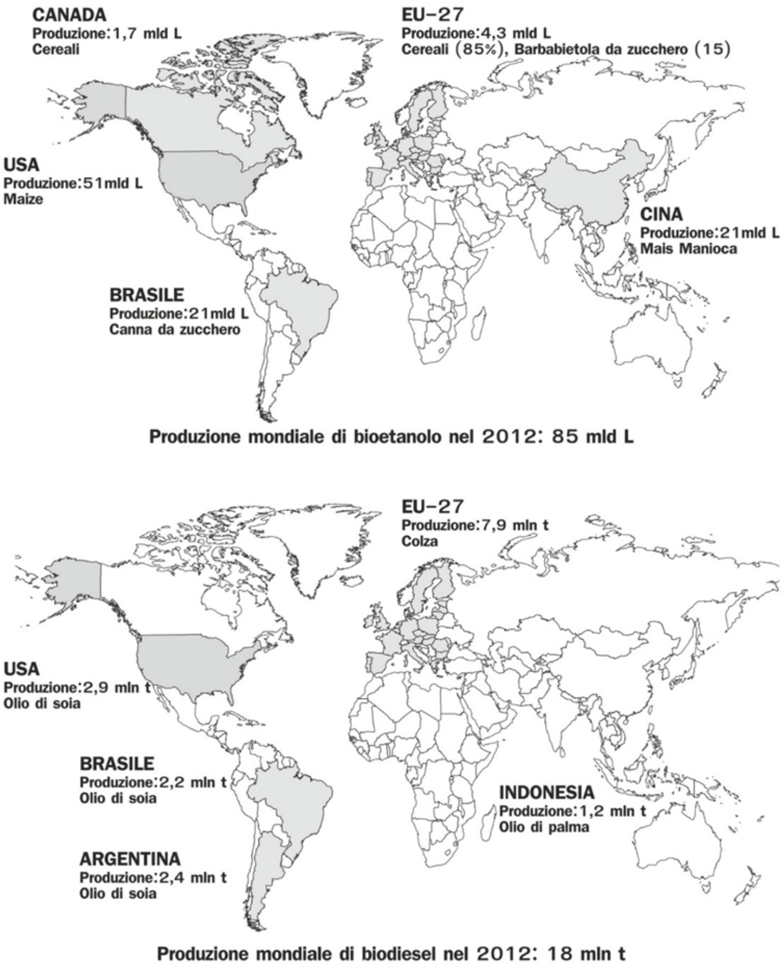


Figure 9 – World production of bioethanol (upper) and biodiesel (down) in 2012 (Adapted from Popp et al., 2014).

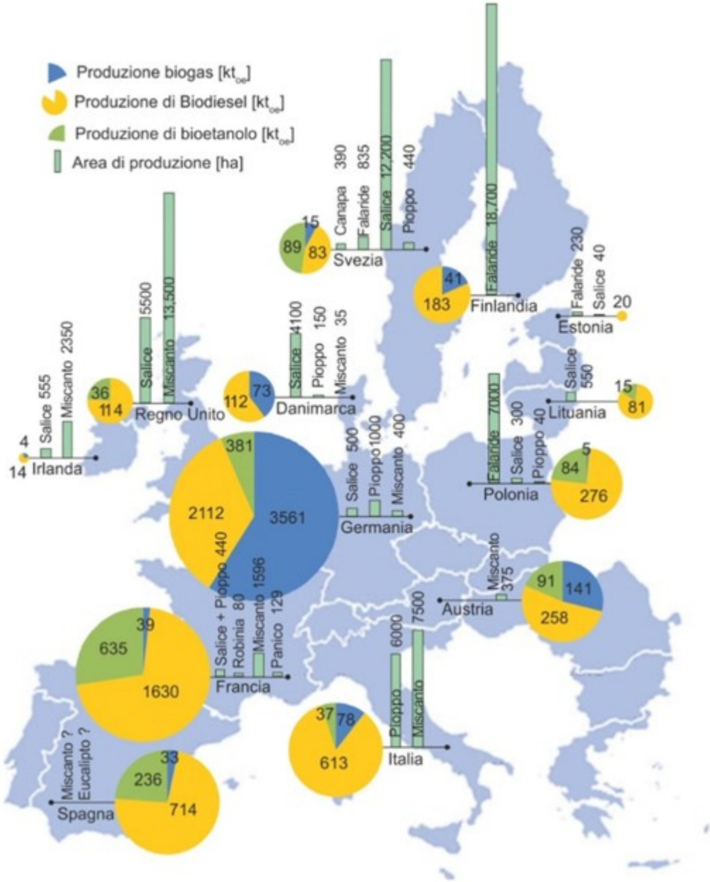


Figure 10 - Energy crops in Europe in 2011: production area (ha) of dedicated energy crops and energy production (ktoe) of conventional energy crops (Adapted from Don et al., 2011).

3.7.2 The doubts about efficiency

Apart from the case of ethanol produced from sugar cane, many exceptions have been raised about the actual possibility of using these crops for energy production due to:

- high production costs and low energy yield, which forced the States to intervene with direct and indirect aid systems so that the costs of biofuels could compete with those of fossil fuels;

- competition with the food destination, which has brought ethical questions to the attention of the public (McMichael, 2010; Mol, 2010; Ribeiro, 2013). The debate is on between 2007 and 2008 because of sudden increases of wheat and corn prices. Although the causes of the augmentation in prices of the aforementioned commodities were not actually due to the conversion into biofuels (Sims et al., 2010), serious doubts were expressed about the opportunity and 'morality' of such a strategy;

- diffusion of these cultures especially in the developing countries, where the increase in population pushes towards a greater demand for food crops.

3.7.3 The risks for the environment

The spread of crops for energy purposes, especially in developing countries, imposed further reflections related to the possible direct and indirect use of natural soil that contains high amounts of carbon in the form of organic matter. The cultivation of these soils would result in the

degradation of organic matter and the release of new carbon dioxide (Nuffield Councilon Bioethics, 2011; Gamborg et al., 2012).
The cultivation of a natural soil (e. Never cultivated) of energy crops, provide a direct change of land use. Cultivation on agricultural land, previously used for food crops, of energy crops, may involve the need to re-place the food crop elsewhere, causing an indirect effect of land use change.
This phenomenon, referred to as 'indirect change in the intended use of the soil' (Indirect Land Use Change - iLUC) has been shown in an interesting work of Searchinger et al. (2008) which highlighted the negative effects of iLUC following the production of biofuels. Based on this, the European Commission mandated by the Council and the European Parliament to present a legislative proposal to consider the impact of iLUC on biofuel emissions of greenhouse gases (European Commission, 2012a; 2012b; 2012c).
The question, however, remains very controversial and did not find yet its final legislative expression to the European Parliament.
The amount of land required to produce biofuels has raised doubts about the fact that this policy would have a great impact on the agricultural sector in the face of a small impact on the energy sector (FAO, 2008). Pearce (2006) states that to achieve the goal of covering 10% of the energy needs of the EU transport sector with biofuels should be allocated to energy crops about 70% of agricultural land.
These data produced strong perplexities in the European Union due to the impact that such strategies would have in developing countries, where there is a real risk that natural land will be put into cultivation.

3.7.4 Cultivation in 'marginal lands'

The resulting proposal was that energy crops can and should be more properly cultivated on marginal areas in order to ensure that land use is sustainable (Reijnders, 2009; International Energy Agency , 2010).

In 2009 the British Government established in the Renewable Energy Strategy that «The use of marginal lands will reduce the risk of competition with existing food production and will contribute to ensuring that any change in land use associated with it does not have a significant impact on the conservation of greenhouse gases or does not entail any other significantly dangerous environmental impact » (HM Government, 2009). The idea to locate the "marginal land" in areas where cultivation is currently unprofitable to bring it to a productive use of energy is very attractive. The energy could be produced locally, with little input, do not compete with food production and it could give farmers an additional gain (Schubert et al., 2008). However, the question remains as to what we intent with the marginal areas (The Gaia Foundation et al., 2008). The concept of marginal area, in fact, it is defined both agronomic (pH, salt content, absence of water, the presence of skeleton, gradient, etc.), with economic meanings of different types depending on the point of view, (remoteness from markets, lack of demand, cost of inputs, cost of labour, such as subsidies to those who cultivate on marginal soil is put into practice, etc.), social (absence of human settlements, unacceptable production of biomass, etc.).

3.7.5 A new ideotype

At the same time the debate was opened on what characteristics a crop should be destined for energy production and to adapt to marginal lands.
Cosentino et al. (2007a) believe that such an ideotype should possess the following characteristics:

- high yields close to those potential for each region;
- high efficiency of use of solar radiation in relation to the environment (temperature, photoperiod, water availability);
- with specific characteristics in relation to the cultivation environment;
  resistant to biotic stress;
- resistant to abiotic stress (water, from high to low temperatures, saline);
- able to effectively use the available natural resources;
- with specific qualitative characteristics suitable for its application (biogas, biodiesel, first-generation ethanol, ethanol from cellulose II generation, from biomass to liquid (BTL), biohydrogen);
- energy and environment budgets favorable.

The definition of the ideotype should correspond to the development of a detailed archive of information able to support decisions and choices (Cosentino et al, 2007a):

- agro-ecological characterization of the areas to be allocated to energy crops;

- identification and characterization of species of potential interest (newly introduced species, local species, species resistant to biotic and abiotic stresses);
- genetic improvement programs and selection of traditional crops for the new use (reduction of the content of N, P, S and microelements (ashes);
- development of an appropriate agronomic technique for sustainable production ("low input" cultivation);
- logistics: collection, pre-processing in relation to the type of product, storage of biomass in relation to moisture content, etc.;
- development of "biorefineries" (Biorefinery);
- environmental and social impact assessment;
- development of simulation models and decision models.

3.8 Regulatory framework and incentives to support agro-energy plants and the design of biogas plants

Among the European Directives and Regulations of interest, acknowledged in various capacities by the national legislation, we note:

- The Directive 2009/28 / EC of the European Parliament and of the Council of 23 April 2009 on the promotion of the use of energy from renewable sources establishes a common framework for the production and promotion of energy from renewable sources. A target is established for each Member State for the share of energy from renewable sources on gross final energy consumption by 2020. Member States must adopt a national action plan setting the share of energy from renewable sources consumed in the transport sector, electricity and heating for 2020.

- The EC Regulation n. 1774/2002 of the European Parliament and of the Council, dated 3/10/2002, on "Health regulations concerning animal by-products not intended for human consumption" establishes rules concerning the health of humans and animals in terms of collection, transport, storage, handling, processing and use or disposal of animal by-products.
- The EC Regulation n. 208/2006 of the commission of 7/2/2006 modifies annexes VI and VIII of the EC regulation n. 1774/2002 of the European Parliament and of the Council with regard to the processing standards for biogas and composting plants and the requirements applicable to fertilize.

The main national legislative documents regulating the production and use of biogas are:

- The Legislative Decree of 29 December 2003, n. 387 "Implementation of Directive 2001/77 on the promotion of electricity produced from renewable energy sources in the internal electricity market".
- The Ministerial Decree of 7 April 2006 "Regional regulation of the agronomic use of livestock effluents, referred to Article 38 of Legislative Decree 11 May 1999, No. 152" introduces a series of very precise provisions concerning the final phase of the production chain of biogas, result of the transposition of the European legislation on the management of zootechnical wastewater (Nitrates Directive) .Legislative Decree 3 April 2006, n. 152 "Environmental regulations" better known as the Single Environmental Text which represents the fundamental text for environmental

legislation in our country and, therefore, also for the environmental effects connected to the construction of new energy plants.

- Legislative Decree 3 March 2011, n. 28 (Implementation of Directive 2009/28 / EC on the promotion of the use of energy from renewable sources, amending and subsequently repealing Directives 2001/77 / EC and 2003/30 / EC), also called the Renewable Decree, which introduced measures to simplify and rationalize the administrative procedures for the construction of renewable energy plants, both for the production of electricity and for the production of thermal energy.

As specified by art. 1 on the purposes, the legislative decree 3 March 2011, n. 28, implementing Directive 2009/28 / EC and in compliance with the criteria established by law n. 96/10 (Community law 2009). So, it defines the instruments, mechanisms, incentives and institutional, financial and legal framework necessary to achieve the objectives up to 2020 on the overall share of energy from renewable sources on gross final consumption of energy and it share of energy from renewable sources in transport. For Italy, this share amounts to 17%; as part of this objective, as established by the European Union, the share of energy from renewable sources in all forms of transport must be at least 10% in 2020 of final energy consumption in the transport sector in the same year. Moreover, the decree, which entered into force on 29 March 2011, sets out rules on transfers between Member States of renewable energy shares, on common projects between Member States and with third countries, on guarantees of origin, on procedures administration, on information and training, on access to the electricity grid and on sustainability for biofuels and bioliquids.

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4. Potential and location of an anaerobic digestion plant of prickly pear biomass in an area with significant diffusion of the cactacea

4.1 Abstract

The paper aims to outline the potential of methanogenic transformation of prickly pear and to detect a biogas transformation plant, within an area with a high production vocation. For these purposes, surveys were carried out with the GIS system, which allowed us to identify an area of particular election within the Southwest of Etna area, as well as a laboratory analysis for the assessment of the methanogenic potential and of the biomethane yield. Finally, an analysis of the relationships among stakeholders active in the territory was performed to test the availability of the biogas plant. The survey confirms the interest shown in the cactacea by public and private subjects on agro-energy.

Key words territorial biomass; agro-energy; methanogenic potential; GIS localization; social network analysis (SNA); technical-economic validation.

4.2 Introduction

The interest in agro-energy has grown over time, under the pressure of a favourable political climate, more generally, due to the achievement of objectives of the millennium sustainability (derived from the pillars of the 1997 Kyoto protocol); and of a consequent interest in the world of production, attentive to the incentives promoted, to the

solution of internal energy problems, to the posed challenges by the circular economy and to the possibility of obtaining income from waste. instead of being only waste, the ability to preserve the fertility of the soil by returning a portion of organic fraction subtracted from cultivation.
This generalized interest was supported by the research community engaged in the testing of technical and technological solutions suitable to achieve these goals. From a first model mass energy production technology, today we have moved to a model of energy production from short chain, to enhance locally produced biomass. For these reasons the production of studies and research has increased the production of studies and research and aimed to estimate biomass from pruning and debris of cultivation in order to make the correct schedules at regional level, with the aim of establishing the potential and the extent to which these may affect the energy balance of the same territory in a way economical sustainable and renewable over time.
In this turmoil prickly pear has not subtracted the prickly pear, multifunctional, traditionally in international species adapted to different uses, including energy. All this happens because prickly pear the *ficodindia* has a great capacity to produce biomass, in contexts arid and/or semi-arid, that which can be energetically enhanced.
International trials demonstrated the adaptability of this species to anaerobic transformation, not always as unique and for this condition it became an emergent biomass in the panorama. In Italy this culture is mainly localized in Sicily (97 %) but almost exclusive use in this area is based on the production of fresh fruit.
The interest towards energy diversification would allow to the Italian prickly pear industries to achieve targeted

economies (recovery of part of the production costs for expenditures of pruning and soil cultivation), an to increase of fertility of land (through the use of digestate), to contribute to the energy balance (by entering into the electricity net electricity or producing biomethane), to reorganize the production unit (with portions of the surface corporate destined to dedicated crops biomass, to balance the income sources of the same factory between primary and secondary production (energy). according to a schedule suited to the capacity of absorption of the fruit market). Such usage can also help to produce a transformation within this production system that can be transformed by introducing dedicated crops and/or by exploiting the large surfaces made by of secondary cultivation secondary currently available.
In this context this work intends try to find an answer to the following questions:

- estimate the current biomass from non-dedicated culture and potential dedicated culture;
- potential energy can be obtained from cactus biomass;
- logistic validation of a sustainable short supply chain plant;
- a sharing project idea with participatory methods, preparatory to a final design.

4.3 Literature on the uses of prickly pear for bioenergy production

The prickly pear – through the different varieties and clones – constitutes a multifunctional species with high adaptability to different uses and cultivation environments even extreme (FAO, 1995; Gallegos Vazquez et al, 2006). In particular, it is observed with interest its adaptability to arid ecosystems with limited water resources, where it can perform a function of contrast to the depletion of vegetation, loss of organic matter and the gradual contraction of natural fertility of the soil up to land degradation (Sánchez and Pérez, 1991). Among the market uses it is certainly necessary to include the destination "food" (Timpanaro et al, 2015a; 2015b) of the first and second flowering fruits ("scotched"), of young cladodes ("nopalitos", in the culinary tradition of some territorial contexts) and related food products (alcoholic beverages, jams, juices, etc.) and the "non-food", which extends the potential uses of biomass (cladodes, fruits of scrap or no commercial value, etc.); for livestock feed (fodder), for the production of bio-energy and, finally, other byproducts (seeds, skins, etc.) used for the extraction of compounds such as pectin, essential oil and dyes, etc., destined to their aimed at the food industry, nutraceutical, chemical, pharmaceutical, cosmetic, etc. (Ciriminna et al, 2017; Ciriminna et al, 2018).

In recent year, biomass, for its potential, started to be used as a substrate in anaerobic digestion (Calabro et al, 2018), although industrial application with these goals goes back to many years ago, as shown by experiments conducted in territorial areas territorial the which the use of the Cactus was traditionally extended from the fruit to cladodes for food or feeding (García de Cortázar and Varnero, 1995). This potential is strongly encouraged in some environments, often dry, to promote corporate energy supply by means of self-handling and, at the same time, the fertility of the soil that can be enriched with the digestate downstream product by these processes (FAO – ICARDA, 2017).

In literature, studies have concentrated both on the evaluation of biomass and on possible energy uses, both on the possibility to of use of biomass first as forage for animal feed and then from energy point of view, enhancing the manure product subsequently quantifying the energy obtainable biomass in regard to variety, at the time of mowing, with at climatic conditions and environmental, etc., from scraps of cactus only or in combination with other types of array is finally on other bio-energetic uses. This variety of topics exposed can be traced back to the functions associated with the prickly pear in the world and the evolution of in its uses.
With regard to biomass and the possibility to modify its composition (especially wet fraction and solid fraction, especially) through appropriate cultural practices, a first experiment was performed in Chile (García de Cortázar and Nobel, 1992). The evidence has shown proved that different planting density (between 0.25 plants/m2 and 24 plants/m2) affects the production capacity of fruits and the relative importance of dry weight of cladodo , tending to increase with the surface itself of the same (stem area varies from 4 to 6, on both sides of the cladodes).
Some studies showed that 1 has 5 years of Opuntia can produce up to 100 tons of fresh cladodes r at the during one year in areas with little few rains (≤ 300 mm) (García de Cortázar and Nobel, 1992). Not only that, but a regular pruning increases the yield and improves the quality of the fruit, of the cladodes/nopalitos that are must be allocated for the production of biogas, manure or animal feed (García de Cortázar and Varnero, 1995). The biomass should be however used quickly, in order to reduce the biodegradation and to improve the efficiency of biogas and biofertilizer; in fact, some evidence has shown that the cladodes are not

immediately used immediately and it should be stored in cool and dry shady, cool and dry for several days (Varnero and García de Cortázar, 2013). The age of the plantation affects the development of biomass; in fact, while the plantation matures, the growth of cladodes slows down, since the rate of net photosynthesis decreases due to the shadowing effect of the upper cladodes (Acevedo and Doussoulin, 1984).

Other experiments involved the vegetative-productive response of most cultivars, some specialized in the production of fruits and other in that of forage (Fouche and Coetzer 2015). Thus the conditioning that derives from the seasonal trend and the balance established between cladodes and fruit production has been demonstrated, through the manipulation of plants through cultivation practices such as pruning, shredding and fruit thinning, defined on the basis of guidelines of the South African Cactus Pear Growers. Moreover it was highlighted that there is a seasonal oscillation in the production of biomass from cladodes between maximum t/ha minimum 24.67 44.57 t/ha, alternating with spikes or contractions in fruit production (17.79 t/ha on average).

Another estimate of biomass availability was achieved in Sicily, a region characterized by Mediterranean cultures such as the cactus, to be exploited in anaerobic fermentation processes to produce thermal electricity or bio-methane (Lynn et al, 2015). For this purpose, several categories were distinguished several categories (a) waste and by-products of processing; animal slurry, b) c) agricultural residues, d) commercial, processing residues and dedicated bioenergy crops)) and estimated the potential regional preparatory studies for the determination of energy obtainable and feasibility assessment technical and economic. The value of young cladodes which forage and the ability to select clones with the highest nutritional benefits (Opuntia ficus-indica, o. rastrera and o. dillenii) is clearly demonstrated in the literature, especially in contexts with issues of global warming and desertification (Mulas et al, 2015). In particular, the young cladodes collected at the end of the growth in the last ten days of August were found to vary between minima of 75.8 g (for o. dillenii) and a maximum of 600 g (for O. ficus-indica) of fresh weight, with a dry matter content of between 6.1% and 10%and an ash content of dry biomass between 17.2% and 24.6%. Palatability of biomass as animal nutrition has then suggested the opportunity to evaluate biogas production from manure, with experiments conducted on material taken from pig farms for fattening, with animals fed to 0, 5, 10 or 15% Opuntia Robusta (Treviño-Amador et al, 2013). In this case, the sun-dried manure stored for 45 days was placed in digesters and a daily evaluation of the production of flammable gas, the flame time and the combustion temperature was performed. It has been so demonstrated a reduction in the production of biogas (from 567 ml per day to 170 ml per day), a flame time between 19 and 4 seconds to working with temperature of 660° C, but also a lower environmental impact compared to the controlled diet manure to a faster rate of degradation during the drying period. Similar experimentation affected herds dairy cattle fed with mixtures containing 0, 20, 40, 60, 80 or 100% cladodes of Opuntia ficus-indica (Treviño-Amador et al, 2013b), proving that biogas production improves to the point that this variety can also be used as a single material for its ability in biogas production (the mixture at 0% doesn't produce inflammable gas; the 20% of the blend produces biogas during every day of 970 ml per day; the 40% of

treatment produced large amounts of gas during 1-4 days, with 2525 ml per day, then a reduction in 5-11 gg with 380 ml per day and no production inperiod 11-14 gg; the 60% of the mix produced gas on 1-4 gg of 2400 ml day and no production on 5-14 gg; 80% of the gas produced about 1-3 gg with 1068 ml day and no one in the rest of the time 4-14 gg; 100% gg no gas produced about 1-3 gg, but product on the rest of the time 4-14 gg 906 ml/day).
In other territorial contexts, it has been realized an additional evaluation of the cumulative production of biogas from co-digestion of cattle manure and scraps of prickly pear, demonstrating the validity to in producing biogas substrate created with a mixing ratio composed by 75% and 25% of cow manure prickly pear Peel (Gebrekidan et al, 2014).
The literature on methanogenic potential of the prickly pear and on the potential of biogas production directly from biomass (cladodes and fruits) shows the slow statement of using Cactus for energy (Hilbert, 2009; FAO, 2011). In particular, the first experiments have shown that some cladodes, Opuntia baby kept in closed containers at atmospheric pressure, spontaneously emit a gas that for 17% consists of hydrogen; the gas production is improved (≈ 500 ml/g dry weight) with the addition of biomass digested until it reaches its maximum at pH 6 and 35-40 °C, with a 60% methane and hydrogen content (Contreras and Toha, 1984). Baeza (1995) indicates that the calorific value of biogas from cactus is 7058 kcal/m3 (6 interval800-7200 kcal/m3) and the potential of biogas Opuntia is equivalent to 0.360 m3/kg DM. The production of 30 tons in a the year is equivalent to 82.2 kg day, which can be used as raw material for biogas production with potential 29 m3/day (82.2 × 0360 = 29 m3 biogas day), or 10885 m3 ha/year biogas comparable to 6.4

tons of oil (Varnero, 1991). In addition, Tohá (1999) indicates that 3 kg of dried cladodes can produce 1 m3 of biogas, which is equivalent to a power of 10 kWh.

In arid and semi-arid developing countries characterized by drought conditions, irregular rains and poor soil subject to erosion, it became important the biomass of Opuntia ficus indica, as a renewable energy source for the Economic and social development (Obach and Lemus, 2006). In this case the anaerobic process conducted under controlled temperature (30°- 40° C) and pH (7.5-8.5) and after 83 days of semi-continuous operation, produced biogas generation rates of 0.861 m3/kg of volatile solids (VS), with a 58.2% methane (CH_4) and 40.0% carbon dioxide (CO_2).

Subsequently it was highlighted the importance of the quality of the material used at the beginning for the limited validity of the prickly pear biomass used exclusively in the digesters (Uribe et al., 1992; Varnero et al., 1992; Varnero and López, 1996; Varnero and García de Cortázar, 1998). Not only that, but using cladodes older than 1 year with higher carbon content, the development of acidogenic bacteria was favoured, accelerating the methanogenic process (Varnero and Garcìa de Cortàzar, 2013).

The prickly pear and other biomasses are considered as possible renewable energy sources useful to satisfy the European Union's obligations in terms of reduction of release of carbon dioxide, demonstrating that by selecting appropriate liquefaction conditions these organic wastes can be used to produce efficiently biogas after conversion into water-soluble substances (Pehlivan and Taner, 2009).). More recent experiments on the potential use of biomass of prickly pear for biogas production has allowed to characterize the chemical composition of more varieties of Opuntia in Brazil

(Mags do Nascimento et al 2016), in order to respond to the current increase in demand for renewable energy and the future prospect of limited water resources. This study demonstrated the presence of significant amounts of uronic acid (10.7%) and oxalic acid (10.3%) in the cladodes, as a natural consequence of a high amount of pectin and calcium oxalate, but even a low potential for ethanol production (1490-1875 L/ha/yr) compared to traditional sources of biomass (e.g. sugar cane and sugar beet) and also high rates of methane production potential (3717 m3/ha/anno), comparable to the conventional energy crops. Also from other recent evaluation of potential biogas was determined in Sicily from Opuntia ficus indica, to grow in uncultivated areas (about 600,000 hectares) co-digested with manure and slurry (Comparetti et al, 2017). In this case, in order to optimize the plant and its location, it has been used the GIS (Geographic Information System) tool or territorial information system for geo-referencing of uncultivated areas. In this way it was possible to calculate the potential production of biogas and, indirectly, biomethane or electric and thermal energy equal respectively to 612.115 103 m3 of biogas, from which 342,784 103 m3 of biomethane could be extracted or 67,038 MWh of electric energy and 70,390 MWh of thermal energy could be generated. The work encompasses reflections on the integration of income for farmer who thus obtains not only the sale of biomethane or electricity and heat, but also the economies generated by the replacement of chemical fertilizers with digestate (biofertilizer which can be used so much in organic farming). as in the conventional one) and the subsidy for the production of biomethane as fuel for means of transport or electrical and thermal energy from biogas.

Finally, three techniques of pre-treatment were considered (thermal, alkaline, acid) on the chemical composition and yield of methane prickly pear biomass, noting productions ranging from 289 to 604 NmL/gVS, with higher values in the presence of an acid pre-treatment (HCI) (Calabro et al, 2018). The cladodes of cactus bioenergy may be intended for other uses such as the production of biodiesel or ethanol.
With an annual production of 40 tons ha of biomass in dedicated crops for energy use or 10 tons has in pruning residues from plantations dedicated to fruit production, it is possible to obtain energy for direct combustion. Some evidence shows that the cladodes collected, sun-dried and crushed, can be used in direct combustion or in a mixture of coal cogeneration, with a calorific value of 3,850-4,200 kcal / kg. Instead, ethanol production technology is more complex and suitable for a larger scale, since it requires higher investments. However, during fermentation specific yeasts are required to maximize alcohol production (García de Cortázar and Varnero, 1995). Some research indicates that it is possible to use cactus mucilage (about 20 ml / kg) to produce small amounts of ethanol, although it was not particularly competitive (8.6 liters of 100 kg ethanol dried cladodes, compared to an average of 24.7 liters obtainable from 100 kg of dried fruit) (Retamal et al., 1987). The biotechnological production of ethanol from different raw materials containing sucrose, starchy materials and lignocellulosic biomass has been analyzed and reported in comparative indices that highlight the value of the cactacea (Sánchez and Cardona, 2008). A subsequent experiment was devoted to the study of the relationship between microbiological yeasts (in particular Kluyveromyces

marxianus and Saccharomyces cerevisiae) and production of ethanol from cladodes of Opuntia (Kuloyo et al, 2014).
The existence of a technical constraint in the commercial exploitation of this process was thus highlighted, due to the relatively low concentration of fermentable sugars.

4.4 Materials and methods

4.4.1 Estimation of biomass

The estimate of the prickly pear biomass that could be used for energy transformation was carried out following an integrated approach. In fact, the main methods used to evaluate the agro-energetic potential adopted in the various censuses produced in Italy were found in the literature. Among the different methodologies it was considered useful to use the following (Di Blasi et al, 1997; Motola et al, 2009; den Boer et al, 2014):

$$B = S*R*I*(1-D)*(1-U)$$

Where
S = corresponds to the surface in production (ha);
R = represents productivity (t ha-1);
I = pruning / main product ratio;
D = common destination of the residual (%);
U = residual humidity (%).
For purposes of determining the individual variables, reference was therefore made to data and information provided by the ISTAT, by the AGEA, appropriately supplemented by information collected through a direct

survey and a face-to-face method. The ISTAT data were used on the surface and production of "fruit wood crops" (2016) and of the General Agricultural Censuses (2010). The AGEA which, as is known, is the national agency for disbursements in agriculture has provided data on the specialized cultivation of prickly pear by anonymous extraction of the information contained in the individual company files in Sicily. This information obtained on a municipal basis has been aggregated on a provincial basis.Since prickly pear crop in Italy is - at the moment - exclusively oriented to the production of fruit (“agostano”, “primofiore” and “scozzolato”), according to a commercial calendar that extends from the end of July to January, it was necessary to directly detect the data on the quantity of potential biomass as there were no specific assessments. For this purpose, during the period between October and March, when is usually the task of pruning, has been highlighted by direct survey, using a specially prepared questionnaire, a sample of prickly pear farms with plants in specialized plots and in a station of productive maturity (from 8-10 years onwards). In these, pruning was collected in several territorial contexts in Sicily. The quantity of waste collected cladodes were weighed and compared to n. plants/HA depending on the sixth and irrigation schemes/dry. They were detected about 25 kg/plant fresh pruning residues, multiplied by approximately 400 plants/ha, usually found in specialized installations for the production of prickly pears. These weighted average values were the object of comparison for two consecutive years (2016 and 2017) and constitute an assessment of the biomass obtainable in a prickly pear plant primarily destined for fruit production. Therefore the biomass values do not compromise the physiological balance of

vegetative plant production and its vegetative-productive capacity on more years. The situation of pesticides in secondary cultivation appears to be different, since these are plants that are often not used for commercial purposes.
The parameters destination (D) and humidity (U) are the result, in the first case, an estimate as a function of the real possibilities of use for the production of renewable energy and, in the second case, laboratory measurement.

4.4.2 Estimation of energy potential

The BMP (Biochemical Methane Potential) test was used to estimate the methanigen potential of prickly pear biomass (cladodes of different years).The BMP test of an organic matrix in a given time, corresponds to the net quantity of biogas and / or methane produced by the anaerobic fermentation of a unit of mas in a given time. The laboratory experimentation lasted 30 days for each matrix used. The tested matrices were taken during two agricultural years (2016 and 2017). The experimentation was conducted using an automatic methane oxygen detection system (AMPTS, Automatic Methane Potential Test System) of the different organic matrices. This volumetric type measuring instrument (μ-Flow® meter) is based on the principle of displacement of a fluid by a gas, according to which the volume of the displaced liquid (at constant temperature and pressure) corresponds to the volume of the biogas that transits inside the meter. The advantage of the instrumentation used is given by the total self-sufficiency of the detection system, which is equipped with a real-time volume normalization system (including also pressure and temperature sensors and a

normalization algorithm that also takes into account humidity) relative to gas).
The µ-Flow® meter used guarantees a high displacement volume (guarantee of a long-lasting test with no risk of data loss) and a constant pressure (guaranteed by the pressure-controlled water column). The meter is equipped with an electronic card that allows constant monitoring of the gas flows generated by the anaerobic digestion plant. The minimum quantity of gas measured by the instrument is 5 ml. The analog outputs of the meters are connected to a data logger system that allows the continuous monitoring of biogas production data, with readings even at 5 minute intervals and the direct acquisition of data in numeric format. The Biogas Endeavor (Bioprocess Control) used in the test has 6 channels that measure the gas flow coming from as many 2 liter batch reactors. For the purpose of quantification of the produced biomethane, a CO2 filtering system has been adopted by passing the biogas through a sodium hydroxide solution (6N) which allows its removal.
For the quantification of the biomass to be included within each single batch, the dry substance and volatile solids were determined both in the organic matrices and in the digestive solution (inoculum). The dry substance was determined by placing the organic matrix in an oven at 105 ° C for a constant weight. The volatile solids were instead obtained as the difference between the weight of the dry biomass and the ashes. For the quantification of the ashes the sample previously placed in an oven at 105 ° C was placed in a muffle stabilized at 550 ° C which corresponds to the self-ignition temperature of the organic matter. The same procedure was carried out on the inoculum which must be as homogeneous

as possible and it is for this reason that it was previously roughly filtered in order to remove the inert particles.
For the test was established a relationship equal 3 between volatile solids of the inoculum and the organic matrix. A far higher ratio would lead to a decrease of biogas production caused by a nutrient deficiency in the system, contrariwise, lower ratio values could lead to a total system congestion caused by the turbocharger of the same, then to a collapse of the process.
Once established the ratio and mixed inoculum and organic matrix these were placed inside glass containers of 2 liter capacity and hermetically sealed. Each batch container had inside a mechanical agitator kept active for the entire duration of the test in order to avoid the formation of lumps and guarantee a correct and constant mixing of the entire mass.

4.4.3 Estimate of the feasibility of a project for a biogas plant

4.4.3.1 Identifying the area in which to locate the investment

This part of the research was mainly conducted using AGEA data and operating with a GIS. The latter, as we know, it is a powerful tool for representing information geo-referenced in the territory, for the management and spatial analysis of land resources and the creation of decision support systems (DSS), already used in energy planning-planning (Voivontas et al., 2001; Noon and Daly, 1996).
For this purpose, we incorporated the information available in the database Corinne into the allocation of road infrastructure and the location of facilities and equipment for the agro-industrial transformation of prickly pears, citrus

fruits, grapes and olives. This information was superimposed on data about farms collected through the General Agricultural Censuses.
The objective of this part of the work was, therefore, to circumscribe possible areas for an economically sustainable harvesting, both in terms of transport both in terms of processing of residues from different matrices. In this way, a limited territorial area emerged, all within the province of Catania and included within the territory delimited by the production regulations for the prickly pear of Etna PDO.
For the delimitation of this area, the following conditions were sought in particular:

• proximity with installations and structures able to offer waste and / or by-products of limited commercial value to be allocated - alternatively - to the energy transformation;
• distance between the biomass production centre and the energy transformation main office, included within a radius of 70 km, which guarantees, according to current literature, the conditions of economic transport;
• connection with a provincial and / or regional road network, to allow an easy flow of biogas installation, in / out means of transport;
• lack of territorial allocation of similar infrastructures.

The study was carried out with ArcGIS 9.3 software.

4.4.3.2 Analysis of the system of preliminary territorial relations to the feasibility of the investment

Once defined the area in which to locate the investment, a sample of stakeholders was surveyed with the aim to evaluate the availability, with a participatory procedure, of the construction of a biogas installation according to a "decentralized production" model (small installation of a few megawatts of power, spread throughout the territory, fed by alternative and renewable sources produced in the territory); favoring in this way policies more aimed at sustainable development and ecological and environmentalist visions. This evaluation starts from the consideration that for this type of investment the successful models are based on self-consumption, and on the creation of real agro-energy supply chains in rural areas with the aim of creating an economic system integrated with the production of clean energy.
The selection of stakeholders was realized through regional survey that saw the involvement of operators in the sectors concerned, public and private bodies (provincial inspectorates of Agriculture; operational sections for technical assistance, producer groups, cooperatives and other producers), whose assistance has proved particularly useful. The main interlocutors were invited to participate in two workshops specifically organized for the presentation of the project idea and for the discussion on the opportunity of its realization. These events took place, in particular, the first in February 2017 and the second in October 2017, at the Department of Agriculture, Food and Environment (Di3A) of the University of Catania. A total of 50 subjects were invited to participate, reduced to 20 in the interval between the first and second event. The residual stakeholders are however

represented by parties belonging to the world of enterprises and institutions active in the area (prickly pear producers and processors; wine cellars and producers; the olive-growing and oil mills manufacturers, breeders, traders, representatives of municipalities, etc.).

During the workshops, a specially prepared questionnaire was distributed. This was divided into 4 sections aimed at acquiring information of a general nature (main and secondary activity), on the activated relations system (on the supply market of production facilities and services and placement of finished products, on the territorial extent of reference; motivations and evaluations), on the availability to energy production through a participatory project proposal (endowment in alternative energies, resources and matrices to be shared, availability to co-finance the initiative, availability to technical support) and, finally, on income and environmental issues (with technical and economic evaluations, such as actions against the exhaustion of organic matter, soil and water pollution, adaptation to climate change, profitability, resilience, bioenergetic valorization of waste). Some variables were collected on a non-metric scale (nominal or ordinal), others on a metric scale using, in particular, a 5-step Likert scale.

For the analysis of direct and indirect relational structures, we used the Social Network Analysis (SNA) which is known to use graph theory to explain the nature and intensity of the relationships A graph is defined as a set of ordered pairs consisting of n vertices (nodes) and arcs (or bridges) that connect them together

$$\mathbf{G = (V,A)}$$

In particular, to explain the level of relevance of the subjects within a given network structure, the so-called "Structure" was taken into consideration. (analysis of the effects that the structure of the social network as a whole has on the ability of individual actors to initiate aggregation processes on the proposed project idea and on their ability to assume prominent positions and prestigious roles within the network); the "centrality" or the relevance of the actor; the "role" within the network. The degree of centrality expresses the number of relationships (or their relative importance, if they are expressed as intensity) that refers to a given node (Freeman, 1977). In particular, for the i-th node, the degree of centrality can be defined as:

$$\boldsymbol{DC_i = \sum_{k=1}^{N} h(n_i, n_k)(N-1)^{-1}}$$

where h assumes a non-zero value if the arc connecting the i-th node with the k-th node is active. This is based on the actor's level of activity in the network, measured by the number of relationships developed, to the degree of popularity among the other actors.

$$AC_i = \frac{1}{\lambda} \sum_{k} a_{k,i} X_k$$

4.5 Results and discussion

4.5.1 Potential biomass

The prickly pear biomass potentially available for energy recovery can be collected at plants in main cultivation and at secondary cultivation crop plants. These systems are prevalently situated in Sicily (95.5%), traditional production region for climatic conditions in this crop.

The cactacea is, in fact, present in all the provinces (table 1) and, in some of them, it reaches conditions of high specialization. The areas of interest are in order of importance the "Hills of San Cono", a territory straddling the provinces of Catania (San Cono and San Michele di Ganzaria), Enna (Piazza Armerina) and Caltanissetta (Mazzarino)); the "Sudovest Etneo", in the province of Catania along the foothills between Misterbianco, S. Maria di Licodia, Biancavilla, Adrano up to Bronte; the "Valle del Belice", in the province of Agrigento (S.Margherita Belice, Menfi and Montevago) and the "Valle del Torto", in the province of Palermo (Roccapalumba) areas defined in previous studies and research (Foti and Timpanaro, 1997; Basile et al, 2002).

In these areas of high specialization in the production of primofiore and scotch fruits (from second flowering), Biomass production potentially takes place during the annual pruning operations in two temporal moments (October and March), during which these interventions are performed to regulate the plant's vegetative-productive activity (figures 1).

Figure 1 - Localization of prickly pear crop specializes in Sicily (AGEA, 2017)

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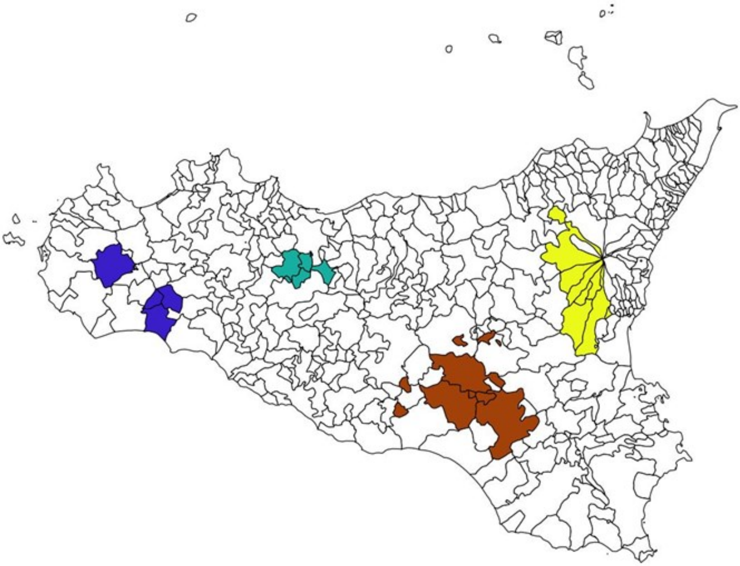


Within these production units, the use of biomass for energy purposes would allow the industrialist to find a solution to the use of pruning waste (considered for the purposes of Legislative Decree No. 22/97 - Ronchi decree – such as residues to be disposed of as waste; if, contrary to this, an energy destination is reserved, as per Legislative Decree No. 152/06 - ex DPCM 8 March 2002 - and DM 6 July 2012, can be considered fuels for all purposes) as an alternative to traditional chopping and planting, to recover part of the production costs, which for pruning operations accounted for 28.7% of unit costs (between 4,500 and 6,000 USD $ / ha),

as shown in recent studies (Timpanaro and Foti , 2014) and to use the "digestate" as a means of fertilizing the soil.
The highly specialized areas amount to over 3 thousand hectares and are capable of producing over 37 thousand tons of pruning biomass (69% of the Italian one). This biomass has increased to almost 71 000 tonnes in the well considers the production from secondary systems (approximately 79% of the total Italian).
This production, in terms of quality and quantity, can alone justify the creation of a multitude of small-sized installations, located throughout the entire territory, according to a decentralized production model that would see the co-presence within the "typical" production unit (on average 5-7 hectares) of a portion of the surface entirely dedicated to this function (introducing varieties suitable for the production of biomass, of recent experimentation and adaptation in Sicily).
This model of productive diversification - widespread in other territorial contexts - can find a possible adaptation in Sicily where distance in kilometers between the various production centers and intrinsic characteristics of the biomass of prickly pear (contained in water), would make its transport economically inconvenient. Not only that, but the latter would lend itself to remaining on the plant to be mowed only in the vicinity of use in the anaerobic digestion process, reducing storage operations and the related costs.

Table 1. Estimation of prickly pear biomass as pruning residue (*)

Territory	ISTAT 2016, ha	AGEA 2017, ha specialized crop	Biomass estimation (t)		
			from specialized crop	from secondary crop	Overall t
Messina	900,00	33,40	935,09	5.615,59	6.550,68
Catania	3.800,00	878,18	24.588,99	18.933,41	43.522,39
Enna	750,00	751,39	21.038,90	6,75	21.045,65
Ragusa	70,00	16,43	460,13	347,11	807,24
Siracusa	95,00	99,87	2.796,45	23,68	2.820,13
Agrigento	1.050,00	161,53	4.522,81	5.757,29	10.280,11
Caltanissetta	750,00	741,24	20.754,64	56,78	20.811,42
Palermo	560,00	208,44	5.836,34	2.278,10	8.114,44
Trapani	50,00	187,19	5.241,39	666,76	5.908,15
Sicily as a whole	8.025,00	3.077,67	86.174,74	33.685,48	119.860,22
Other regions	376,00	1.378,59	38.600,54	2.436,48	41.037,02
Italy	8.401,00	4.456,26	124.775,28	36.121,96	160.897,24

4.5.2 Identification of an area for the location of the bioenergy plant

The cartographic representation with the GIS system allowed to identify a potential target area of the project to create a biogas plant. This is an area entirely located on the South West of Etna, between the town of Paternò (225 m above sea level) and the municipality of Ragalna (830 m above sea level), all in the province of Catania.

In the same area are more than 600 hectares of prickly pear orchard, other productions that can generate biomass to be added to the cactacea during anaerobic digestion. These are olive and citrus groves (table 2) that directly or indirectly through activities related to them, can contribute to the local supply of the structure during the design phase.

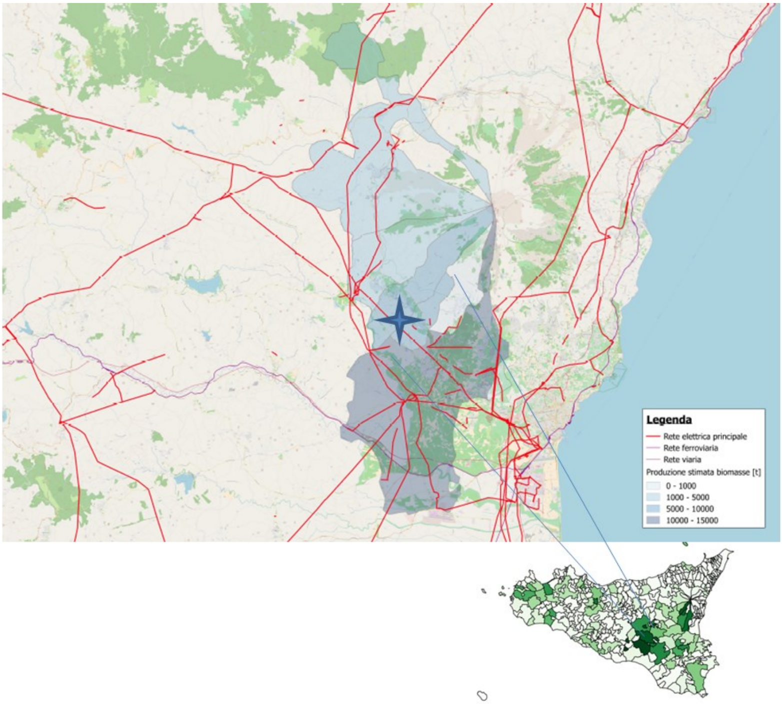


Figure 2. Location of the cactus area where to locate the biogas installation (2017)

Within the same area are produced over 16000 tons of prickly pear biomass (accounting for 23% of that produced by the whole of Sicily), 14600 tonnes of pomace and over 12000 tons of pulp. To accomplish these values, it has undertaken an average yield found in literature and in the case of the pomace of 50% with 2.5 extraction phases (and an average production of 5 t/ha of olives); in the case of the 60% pulp (with an average yield of 20 t/ha of citrus).
Apart from the prickly pear biomass that currently has no commercial value (eg cattle feeding) except for a limited extraction of "mannani" polysaccharides and "Iso-Ramnetina" polyphenols (natural painkillers), substances similar to those in nature are found in Aloe vera (Timpanaro et al, 2015c), the other matrices can have other market destinations, alternative and competitive with respect to bioenergy production. The pomace is subject to high control in application of the Nitrates Directive and as such it is usually directed towards *sansifici* (factories for the treatment of olive pomace), inside which the pitting is carried out and, using solvents, the extraction of "olive oil". The peanut will return to the mill to be used as a matrix for the production of thermal energy which is in turn necessary in the olive processing cycle, with a clear saving in production costs. In recent years, however, the advent of seed oil, which is less expensive than pomace oil and with more advantageous market prices, has produced a reconsideration of this practice, which is now neglected also following the experimentation conducted towards use as biogas production. In fact, some studies show that it is possible to obtain about 70-80 Nm3 of methane from 1 t of pitted pomace to about 26% of dry substance (Valenti et al, 2017). On the other hand, as far as pulp is concerned, this originates as a result of the industrial

transformation of the fruit that cannot be consumed in the fresh state and is commonly directed towards the production of pectins, that is towards the zoo-technical feeding, the extraction of essential oils or the energy transformation. In fact, it is possible to use anaerobic digestion processes to obtain biogas from a citrus fruit pulp (mixture of 50-55% methane and 40-45% carbon dioxide), provided that the essential oils in the substrate do not exceed concentrations of the 0.25% (Lane, 1984), which inhibit the regular growth of bacterial mass. The biogas yield (of the order of 0, 500, 75 m^3 per tonne of dry matter) is also influenced by factors such as the variety of citrus fruit, the availability of nutrients for microorganisms, the concentration of organic substance in the substrate, the temperature and pH (Gunaseelan, 2004; Plöchl and Heiermann, 2006).
Within the area, a greater zoo-technical specialization can be found in Bronte (with UBAs of cattle, sheep and poultry (table 3) spreading as much as 66.6%, 54.7% and 89.3% respectively. In order of importance followed Paternò (14.5% and 22.2% respectively of the UBA for cattle and sheep in total), Belpasso, with specialization in sheep (13%) and pigs (88.4%). Overall, the entire range is able to produce as much as 556 thousand m3 / t p.v./year of sewage and over 992 thousand t / t p.v./years of manure per year.
The plant anaerobic digestion power supply can be guaranteed during the entire year using the different matrices available on the territory in combination with each other or used individually in relation to their possible storage and availability throughout the year (able 4). A part of this is made available only at certain times of the year, in correspondence of the crops (prickly pears in March and October) and / or agro-industrial processing activities (the

pulp from November to April; the pomace from October to December). Other biomasses, especially if connected to livestock farms, are constantly produced and, as such, only partly generate storage problems at the site and / or at the energy transformation facility.

Table 2. Evaluation of the potential biomass in the area of relevance of the biogas plant designed in a participatory mode (*)

Area	Specialised areas (AGEA), ha				Biomass potential, t			
	prickly pear	grapevine	olive	citruses	prickly pear	grapevine waste	olive waste	citrus waste
Adrano	10,0	31,0	637,6	108,5	240,2	92,9	1.594,1	130,2
Belpasso	180,5	43,1	1.604,7	4.452,5	4.993,2	129,4	4.011,7	5.343,0
Biancavilla	226,6	178,6	701,3	317,4	6.022,3	535,9	1.753,2	380,9
Bronte	3,9	101,8	851,9	8,1	106,1	305,3	2.129,7	9,7
Camporotondo Etneo	0,7	0,1	40,8	1,1	19,1	0,3	102,0	1,4
Paternò	71,0	0,1	1.032,7	5.037,6	1.938,7	0,3	2.581,7	6.045,1
Ragalna	0,8	4,3	310,4	2,4	20,9	12,8	775,9	2,9
S.M. di Licodia	107,6	37,9	661,5	409,8	2.847,7	113,8	1.653,7	491,8
Overall	**601,1**	**396,9**	**5.840,8**	**10.337,5**	**16.188,2**	**1.190,7**	**14.602,0**	**12.405,0**

(*) Our processing.

Table 3. Biomass from farms practised in the area identified for the construction of the biogas plant designed with participatory mode (UBA) (*)

Area	cattle n.	buffaloes n.	equines n.	sheep n.	goats n.	pigs n.	poultry n.	bunnies n.
Adrano	426	-	-	825	18	4	220	-
Belpasso	236	-	3	2.581	76	2.526	382	24
Biancavilla	82	-	7	303	20	28	20	-
Bronte	2.843	60	89	10.940	624	162	16.170	-
Camporotondo Etneo	-	-	-	-	-	-	1.200	-
Paternò	618	-	14	4.431	483	46	70	30
Ragalna	-	-	-	290	-	-	-	-
S.M. di Licodia	65	-	10	632	78	92	40	-
Overall	4.270	60	123	20.002	1.299	2.858	18.102	54

Matrix	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year	Livestock slurry, m3/t p.v. /Year
Adrano	12.229,2	-	-	20.130	439	116	3.187	-
Belpasso	6.774,9	-	73	62.976	1.854	73.170	5.534	312
Biancavilla	2.354,0	-	171	7.393	488	811	290	-
Bronte	81.614,4	1.441,8	2.172	266.936	15.226	4.693	234.234	-
Camporotondo Etneo	-	-	-	-	-	-	17.383	-
Paternò	17.741,0	-	342	108.116	11.785	1.332	1.014	390
Ragalna	-	-	-	7.076	-	-	-	-
S.M. di Licodia	1.866,0	-	244	15.421	1.903	2.665	579	-
Overall	**122.579,5**	**1.441,8**	**3.001,2**	**488.048,8**	**31.695,6**	**82.786,7**	**262.220,4**	**702,0**

Matrix	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year	Livestock manure, t/t p.v. / Year
Adrano	12.229	-	-	20.130	439	116	3.187	-
Belpasso	6.775	-	73	62.976	1.854	73.170	5.534	312
Biancavilla	2.354	-	171	7.393	488	811	290	-
Bronte	81.614	1.442	2.172	266.936	15.226	4.693	234.234	-
Camporotondo Etneo	-	-	-	-	-	-	17.383	-
Paternò	17.741	-	342	108.116	11.785	1.332	1.014	390
Ragalna	-	-	-	7.076	-	-	-	-
S.M. di Licodia	1.866	-	244	15.421	1.903	2.665	579	-
Overall	**122.579,5**	**1.441,8**	**3.001,2**	**488.048,8**	**31.695,6**	**82.786,7**	**262.220,4**	**702,0**

(*) The size of the farms by species has been surveyed in the General Census of Agriculture of ISTAT, 2010. The conversion into livestock effluent was made using the Ministerial Decree of 25 February 2016 on "general technical criteria and standards for the regional regulation of the use of livestock waste and digestate", MIPAF, Rome.

Table 4. Availability of fresh biomass in the area identified for the construction of the biogas plant designed in a participatory mode (*)

Matrice	January	February	March	April	May	June	July	August	September	October	November	December
Prickly pear	-	-	4.629,0	-	-	-	-	-	-	5.786,0	5.786,0	-
Grapevine waste	-	-	-	-	-	-	-	-	595,3	595,3	-	-
Olives waste	-	-	-	-	-	-	-	-	-	5.841,0	5.841,0	2.920,0
Citrus waste	3.720,0	2.480,0	1.240,0	1.240,0	-	-	-	-	-	-	1.240,0	2.485,0
Livestock slurry	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6	46.365,6
Livestock manure	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3	82.706,3

(*) Our processing.

4.5.3 Evaluation of metanigeno potential of residual biomass prickly pear pruning

According to the BMP test conducted in the laboratory some differences emerged in the behaviour and in the potential methanes of cladodes of different ages (Table 1). Larger differences were in relation to the percentage of dry biomass and moisture of the fresh biomass. In particular the younger cladodes (1-3 years) showed a water content of 91.9% while the cladodes with a greater age (3-10 years) showed a water content of 88.4% thus showing a higher aptitude for energy conversion by recording a higher percentage of dry biomass and therefore of an organic matrix available for energy conversion.

Table 5 – Dry biomass, water and volatile solids content, methanogenic potentials, dry biomass yield and methane yield (*)

Array	DM (%)	H_2O (%)	VS gDM^{-1}	BMP30 (Nml/gSV)	BMP30 (Nml/g)	BMP30 (Nml/g SS)	DM (t he^{-1})	Yield (Nm^3 ha^{-1})
Cladodes 1-3 years	8.1	91.9	76.1%	219.0	16.3	201.3	0.78	160.5
Cladodes 3-10 years	11.6	88.4	75.5%	284.6	29.2	251.6	2.01	372.4

(*) Our processing.

The quantity of biomethane produced in relation to the volatile solids introduced into the digester gives us the methanigen potential of the matrix introduced into the digester. Observing the data it emerged that the cladodes aged between 3 and 10 years show a higher methanogenic potential due to the different chemical composition of the biomass producing over the 30 days of testing 278.0 Nml of methane per gram of solids volatiles placed in the digester (Figure 1). The younger cladodes instead produced 241.5 Ml of methane per gram of volatile solids.

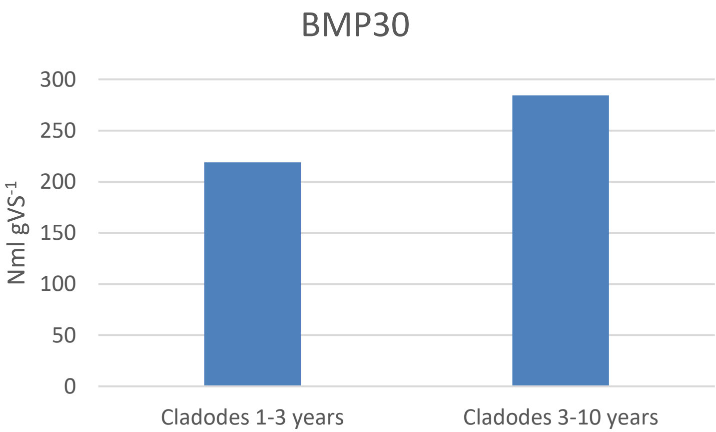


Figure 3 – Methanogenic potential (Nml/g VS) of the cladodes of prickly pear in relation to age.

From the observation of the normalized curve representing the daily flow rate and therefore equivalent to the daily production of methane, it is possible to observe that in the case of cladodes of 3-10 years the digestion and conversion process of the organic matrix takes place more rapidly. In fact the productive peak occurs within the first ten days from the beginning of the process, while in the cladodes of 1-3 years the digestive process shows a slower trend and the maximum production occurs in the first 15 days.

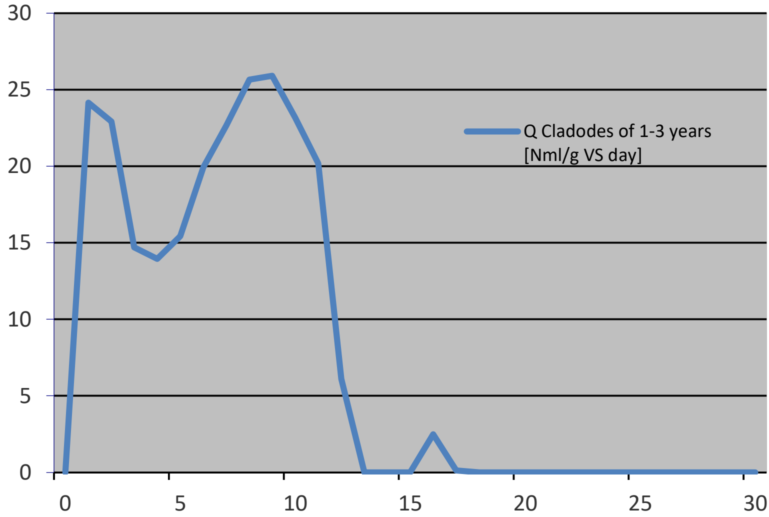


Figure 4 – Daily flow (Nml/g VS) of the cladodes of Cactus trees of 3-10 years over the 30 days test BMP.

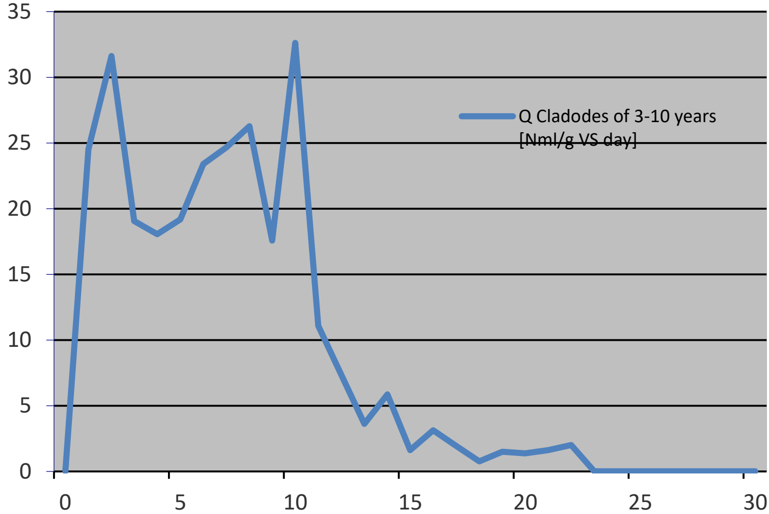


Figure 5 – Daily flow (Nml/g VS) of the cladodes of Cactus trees of 1-3 years over the 30 days test BMP.

The observation of the normalized curve, representing the cumulative production of methane during the 30-day production cycle, shows in the case of cladodes of 3-10 years a first part of intense growth.Then in the second part the rate of digestion and conversion reduce until it reaches a plateau phase which represents the maximum output value amounted to 278 Nml/gVS. In cladodes of 1-3 years, the cumulative production curve shows a lower slope and therefore a lower degradation rate with a maximum production value of 241 Nml / gVS.

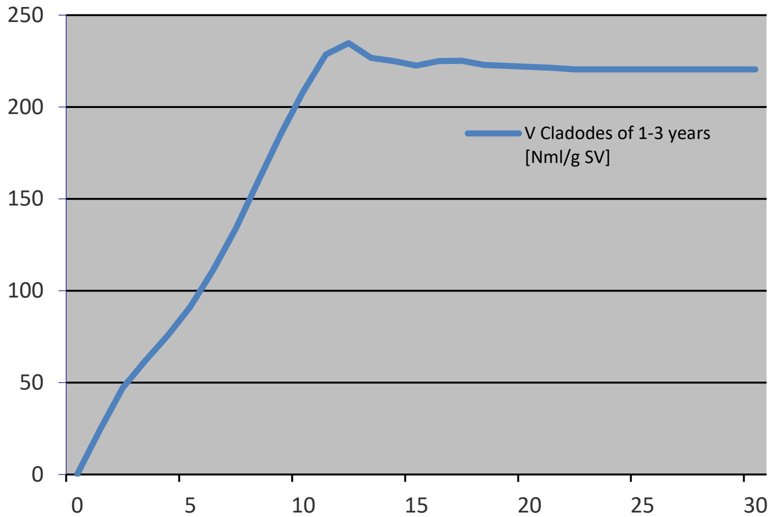


Figure 6 – Accumulated volume of biomethane (Nml/g VS) of the cladodes of Cactus trees of 1-3 years over the 30 days test BMP.

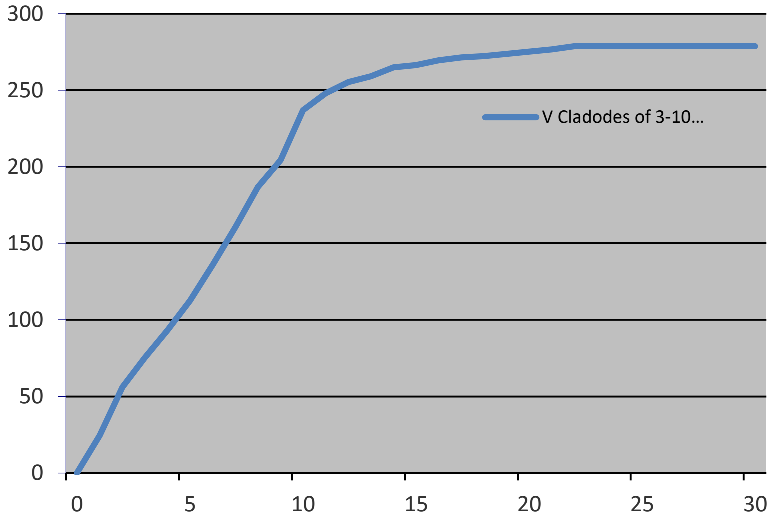


Figure 7 – Accumulated Volume of biomethane (Nml/g VS) of the cladodes of Cactus trees of 3-10 years over the 30 days test BMP.

Reasoning instead in terms of biomethane produced from the pruning residues of each hectare of prickly pear cultivated in the Etna area (Figure 8) it is possible to estimate the potential production of methane from these residues. Methane yields per hectare were obtained by multiplying the real production of methane in relation to the quantity of volatile solids by the yield per hectare expressed in volatile solids (tVS has^{-1}). By cladodes of 1-3 years a yield per hectare of 160.0 Nm^3 was obtained while a significantly higher yield was obtained in cladodes between the ages of 3 and 10 with 469.3 Nm^3 ha^{-1}. The total production of biomethane for every acre of cultivation of prickly pear is equal to 629.3 Nm^3 has^{-1}.

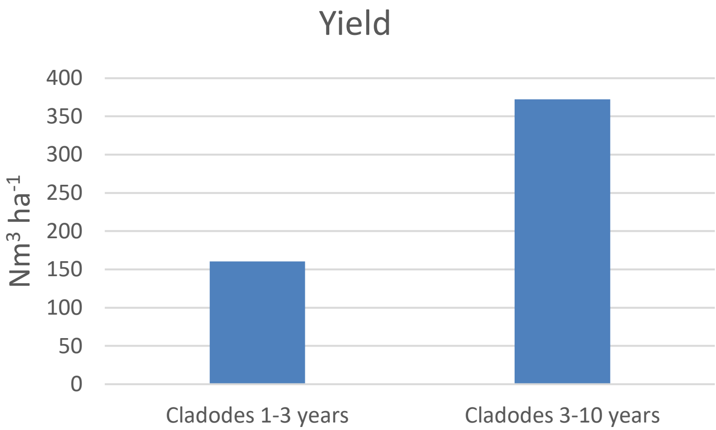


Figure 5 - Biomethane yield ($Nm^3\ ha^{-1}$) of pruning of prickly pear for each hectare of cultivation of the Etna area.

4.5.4 Participatory planning of the installation and formal and / or informal relations

4.5.4.1 Design idea

The project idea proposed during the workshops is related to the construction of an anaerobic digestion plant aimed at producing electricity from renewable sources, through the enhancement of agro-industrial waste produced by short chain, zoo-technical waste and dedicated crops. In the latter case, having defined a power level, in the hypothesis that part of the fig tree is destined to the installation of biomass varieties, in addition to what is collected annually, it has been foreseen the possibility of integrating the treatment with waste such as pomace, whey, fruit and vegetable scraps, lees, pomace, manure and livestock manure.

The first objective of participatory planning was, therefore, to define the salient aspects of a possible willingness to contract out the supply of biomass necessary for feeding the anaerobic digester.
The second objective was to enable a discussion about a possible solution and the possibility to realize the initiative through access to forms of economic incentives laid down by the legislation in force. Thus it was proposed to build an installation with an energy production capacity of 300 KWh electric, destined for steady-state conditions, continuous operation for 24 hours / day and 7 days / week. Through the process of anaerobic digestion of the organic matrices that are degraded and converted into biogas (mainly methane) and, therefore, electrical energy and heat through cogeneration. The design of anaerobic digestion as a whole provides, in addition to the digestive system, the storage area, loading systems, possible biogas purification line, component for combustion and production of electrical energy and digestate treatment (separation solid / liquid, solid digestate drying and relative storage), in line with process schemes and unit operations models currently carried out in similar design activities. The third objective was to present some possible benefits to the subjects involved, such as energy recovery (methane or electricity), the use of a single tariff for electricity produced and fed into the grid and, finally, stabilization of digestate for its internal use to the subjects who have joined the project.

4.5.4.2 General characteristic of the sample

The stakeholders invited to share the project idea are variously engaged in the production sector (47%), transformation (40%) and the tertiary sector (13%), with a high propensity to different forms of income diversification in a multi-functional way (especially agritourism and direct sales on the farm, including company butchery).
Worthy of interest are the physical amplitudes of reference, which in some cases (37.5%) intercept an extension between 50 and 75 hectares. Industrialists have taken action using distinctive brands of quality and origin for the main productions (PDO *Ficodindia dell'Etna*- Etna prickly pear), tools that have made it possible to conquer ever wider markets (in 37% it is international).
A propaedeutic character to the acceptability of the project idea is represented by the attitude to the establishment of relationship systems in the territory (around 86%).The favoured legal forms are, above all, producer organizations (33%) and consortia (42%).The forms of aggregation are considered particularly useful in addressing problems in some stages of the supply chain and, in particular, downstream in the relations between "farmers and first processing" (46%) and, upstream, between "farmers and input suppliers" (27%).Among the widely shared motivations we find the "exchange on technological advancements" (with an average score of 3 out of 5) and on "strategic information" (2.7) and services (1.8), allowing a glimpse of a mentality favourable to project aggregation. These stakeholders show an interest in renewable energies (in 43% they are equipped with a wind or photovoltaic plant) and towards the potential for biogas production. For these purposes, they were asked to

reflect on the quantity and quality of potential biomass to be conveyed to the planned plant. Thus, the availability of pruning waste (31%) and dry (25%) and wet (6%), together with pomace and pomace (about 13%) and others emerged above all.
The interest in the project idea derives from the limited valorization of the waste, often disposed of free of charge (63%) and without any economic advantage for the company, as well as by various other reasons. Stakeholders, in fact, have been highly sensitive to the evaluation of the internal energy consumption (86%) and the opportunities for involvement of other actors in the territory (86%).Prudence was instead manifested towards the potential biogas market (29%), also due to the limited knowledge of aspects linked to practices, public subsidies and incentives (49%), but above all to logistical problems (71%) and relative organizational and management aspects. Other aspects of interest for the realization of the project idea must be traced back to the sensitivity shown towards initiatives and measures of adaptation to climate change, through the inclusion of species with lower water requirements such as, in fact, prickly pear (average 4.3 out of 5 , with variability equal to 0.16), the forms of diversification of rural income (3.9 and 0.26 respectively), the valorization of agricultural residues for the production of bio-based products and bioenergy (3.9; 0.32), the increase in the added value of local products through sustainable development (4.0; 0.19) .

Table 6. Characteristics of stakeholders invited to participatory planning for the establishment of a biogas plant (2017) (*)

Indication	value	Indication	value	Indication	value
Sector, %		Join associations/networks of operators active on the territory?, %		Renewable energy plant equipment, %	
- make	46,7	- yes	85,7	- yes	42,9
- conversion	40,0	- not	14,3	- not	57,1
- business	13,3				
		Contractual nature of relations, %		Type of biomass produced, %	
Production sector, %		- collaborative	8,3	- pruning waste	31,3
- figodindiculus	21,4	- organisation	16,7	- other vegetable biomass	12,5
- olive oil/oil	42,9	- OOPP	33,3	- livestock slurry	6,3
- viticulture/enoic	14,3	- cooperatives	41,7	- livestock manure	6,3
- citrus fruit/suckers	14,3			- wet processing waste	6,3
- livestock	7,1	Critical stages in the supply chain, %		- dry processing waste	25,0
		- Between farmers and input providers	27,3	- grapes waste and olives waste	12,5
Areas concerned, %		- Between farmers and first processing	45,5		
- up to 25 hectares	25,0	- Between first and second transformation	9,1	Current biomass destination, %	
- from 25 to 50 hectares	25,0	- Between the last stage of transformation and wholesalers	9,1	- sold free of charge	62,5
- from 50 to 75 hectares	37,5	- Between wholesalers and retailers	9,1	- alienated for consideration	37,5
- over 75 hectares	12,5				
		Motivations, average score, coefficient of varazione		Main evaluations of the proposed project	
Reference market for production, %		- Exchange of raw materials	1.5 (0.75)	- determination of energy consumption	yes (85.7%)
- place	18,8	- Exchange of semi-finished products	1.5 (0.51)	- biogas sale opportunities	yes (28.6%)
- rest of region	12,5	- Exchange of services	1.8 (0.66)	- information on prices, incentives, agronomic ac	yes (42.9%)
- rest of Italy	31,3	- Exchange of strategic information	2.7 (0.47)	- analysis of logistical problems	yes (71.4%)
- International	37,5	- Exchange on technological advances	3.0 (0.43)	- involvement of other actors in the territory	yes (85.7%)

(*) Our processing.

4.5.4.3 Analysis of relationships and availability for project implementation

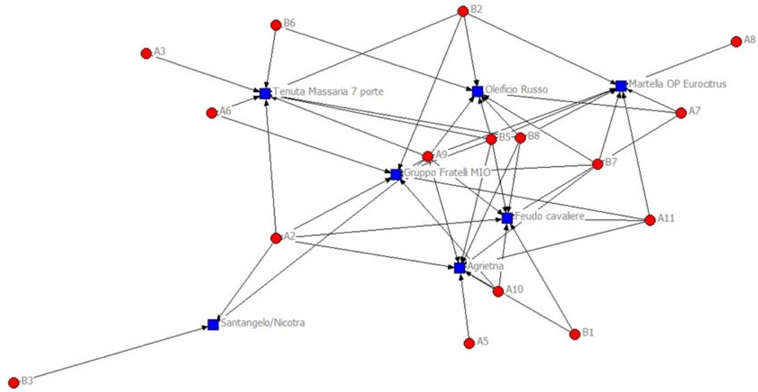
The analysis of the relational system, preparatory to the project implementation, was carried out with reference to two main features related to "attitude to relationships" and "quality of relationships". For both traits were selected a series of indicators and evaluation was carried out the relative coding. To this end, the selected indicators on the attitude to relationships are reported in table 6.

On the basis of the responses collected, a first weighted affiliation matrix was built, where the stakeholders who participated in the workshop and the sub-themes were reported for each row. Each element of the matrix is made up by the value assigned to information given by the companies specifically to a particular sub-topic. Therefore, this matrix has set itself the objective of linking the actor (stakeholders) of the network to an event (quantified information). The graph of the affiliation network thus constructed (figure 3) shows the link between "actors and events", thus representing the sharing of a specific rating judgment related to a subfield dealt with, while the length and thickness are related to the rating value , the first in an inversely proportional measure and, the second, in a directly proportional manner.

Table 7. Variables for the measurement of the "Relationship attitude" in the sample of stakeholders interviewed in the participatory design of a biogas plant or index (*)

Field of investigation	Subfield	Code
Critical/positive aspects found in the reports	Criticality farmers-suppliers	A1
	Criticality farmers-first transformation	A2
	Criticality product - wholesalers	A3
	Criticality wholesalers - retailers	A4
	Unfavourable economic conditions	A5
	Unfavourable delivery/payment times	A6
	Opportunistic behaviour of the counterparty	A7
	Good collaboration with Farms	A8
	Good cooperation with suppliers	A9
	Good cooperation with distributors	A10
	Good cooperation with transformers	A11
Type of relationship	Time transactions same counterparty 3-5 years	B1
	Time transactions same counterparty 5-10 years	B2
	Time transactions same counterparty > 10 years	B3
	Exchange with other subjects over time	B4
	Membership of associations/networks of operators active in the territory	B5
	Joins Producer Associations	B6
	Adheres to OOPP	B7
	Adheres to Consorzio Tutela	B8

Figure 9. The matrix of affiliation for attitude to relationships in the network of stakeholders interested in participative planning of a biogas prickly pear installation (2017)

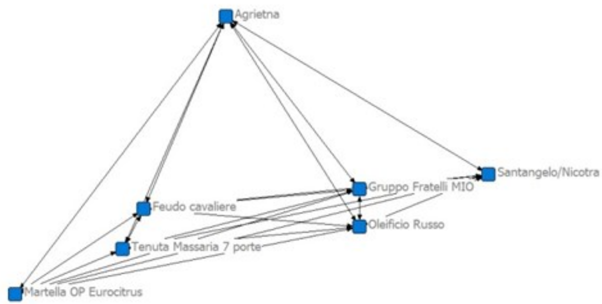


From a general view of the Affiliate Network it is clear how the aspects linked to the relationships between wholesalers (or last transformation) and retailers (traditional retail and supermarket chains or hypermarkets) have lower average rating values than the others, together with the duration of commercial transactions with the same counterparty and the climate of trust with other agricultural companies, showing less share in the network. In particular, it is a question of some components of the corporate capital of companies that are not structured on the territory and that relate to the sphere of intra-sectoral relations within the supply chain and to the trust system often created with other subjects in the chain. In order to identify which stakeholders have a central role in the network, the actors-actors matrices have been built, where each element represents the number of shares that each actor has with others (with intensity measured inversely proportional to its length) and the "event-event" one, where each matrix element is given by the subfield (indicated with its relative ID), while the link is given by the number of shares, in order to identify which are the main sharing elements (figure 10).

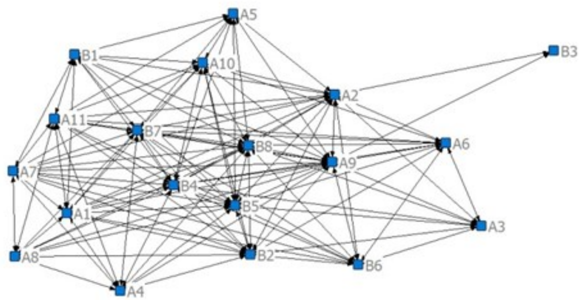
The first figure shows the absence of a central role between companies, but these, as shown in the second figure, have many elements in common to cement their sharing on the biogas installation project. For the latter, a non-secondary role can be played - waiting for the propensity of the stakeholders to adhere to forms of aggregation existing on the territory- from producers' organizations and, above all, from the Consortium for the protection of *Ficodindia dell'Etna* (Etna Prickly pear) PDO potentially interested in the promotion of the main product (fresh fruit) but - in a more holistic sense - to sustainable enhancement (in economic, social, environmental and cultural terms) of the entire fig culture of the Etna area.

The realization of the energy transformation installation of the prickly pear crop residues and of the other wastes produced by the local agri-food system, can represent for the area a driving force of economic and social development, according to the dictates of the modern circular economy, with a specific attention to environmental issues.

Figure 10. "Actors X actors" and "events X events" matrices built on the criticality of the network of stakeholders interested in the participatory planning of a prickly pear biogas installation (2017)



actors X actors



X-events events

The Consortium can for this purpose to promote social interaction and the development of relationships of trust, both in terms of social capital "business," which can allow, even informally (White, 1981), better access to a range of goods services and capital, contacts with partners, suppliers, consultants and public officials useful for business activities, both suggestions regarding new production techniques or organization and management of the company, the recruitment of skilled labor, and the creation and maintenance of stable niches in the market. It refers, as well, to the relational dimension of the life of industrialists and all those connections that can be "bridges" (known in the literature as "social capital bridges") to facilitate the circulation of information and the building of trust between the different socio-economic environments (Timpanaro and Foti, 2016). Not surprisingly, the stakeholders that attract more ties are a wine-producing company (Degree of centrality 0.708) and an OO.PP that revolves around the *fichidindicoltura* (Degree of centrality 0.688), as it resulted from the measurement of the degree of centrality (table 8).
As proof of the findings, the quality of the relationships within the network was also assessed, for which the main indicators were identified (table 9).

Table 8 - Degree of centrality in the matrixes "actors X actors" and "events X events" for attitude to relations in the network of stakeholders interested in the participatory design of a biogas plant with a prevalent prickly pear matrix (*)

Matrix "actor X actor"	Nrm Degree	Matrix "event X event"	Nrm Degree
Feudo cavaliere	0.708	B8	0.500
Martella OP Eurocitrus	0.688	B7	0.481
Agrietna	0.688	A9	0.481
Gruppo Fratelli MIO	0.667	B4	0.407
Oleificio Russo	0.646	B5	0.333
Tenuta Massaria 7 porte	0.604	A2	0.333
Santangelo/Nicotra	0.208	A11	0.324
		B2	0.315
		A1	0.250
		A7	0.250
		A10	0.241
		B1	0.167
		A6	0.148
		B6	0.148
		A4	0.093
		A8	0.093
		A5	0.083
		A3	0.074
		B3	0.019

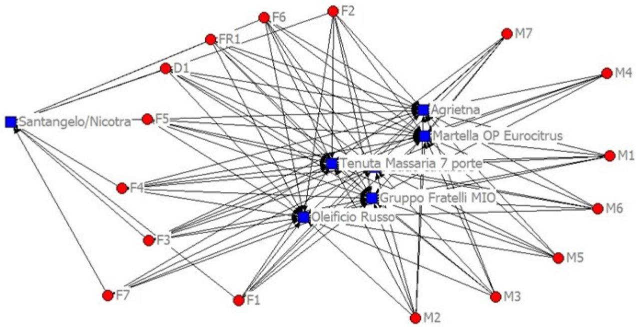
(*) Our processing.

Table 9. Variables to measure "quality of relations" in the sample of stakeholders surveyed in participative planning of a biogas prickly pear installation (2017)

Field of investigation	**Subfield**	**Code**
Motives *(ascribe a value to 1 = none to 5 = highly defined relationships)*	Commodity exchange	M1
	Traditional machining subcontracting	M2
	Exchange of semi-finished products	M3
	Trade in services	M4
	Exchange strategic information	M5
	Exchange on product development	M6
	Exchange on technological advances	M7
Form relationships *(attribute a value from 1 = none to 5 = highly defined relationships)*	Casual relationships with other actors in the supply chain	F1
	Annual formal contracts with other enterprise	F2
	Annual informal (verbal) contracts with other enterprise	F3
	Formal contracts with other enterprise	F4
	Informal (verbal) contracts with other enterprise	F5
	Membership of an association or cooperative	F6
	Other (specify)	F7
Strength of relationships *(attribute a value from 1 = none to 5 = highly defined relationships)*	Strength	FR1
Duration of relationships *(attribute a value from 1 = none to 5 = highly defined relationships)*	Duration	D1

For this set of variables, the considerations previously noted are partly confirmed, with the emergence of a central role by new stakeholders, represented by wine-making and olive-oil companies, as shown by the affiliation matrix (Figure 11).

Figure 11 - Affiliate matrix for quality of relationships in the network of stakeholders interested in the participatory planning of a prickly pear biogas installation (2017).



It is no coincidence, in fact, that the entrepreneurial type of organization is a decisive "character" for the purpose of identifying and assessing the potential offered by the biogas plant construction project. Mission and vision are, in fact, essential preconditions for defining peculiar aspects of strategic and operational business planning, as it happens in structures such as cellars and oil mills traditionally "relational tools", derived from the contractual economy (table 10).

Table 10. Degree of centrality in the matrixes "actors X actors" and "events X events" for quality of relations in the network of stakeholders interested in the participatory design of a biogas plant with a prevalent prickly pear matrix (*)

Matrix "actori X actor"	Nrm Degree	Matrix "event X event"	Nrm Degree
Oleificio Russo	0.500	F6	0.400
Agrietna	0.333	M7	0.233
Tenuta Massaria 7 porte	0.333	F2	0.167
Martella OP Eurocitrus	0.250	F3	0.167
Gruppo Fratelli MIO	0.167	M5	0.167
Feudo cavaliere	0.167	F1	0.167
Santangelo/Nicotra	0.083	F7	0.100
		M1	0.100
		M2	0.100
		M4	0.067
		F4	0.067
		F5	0.067
		M3	0.000
		M6	0.000
		FR1	0.000
		D1	0.000

(*) Our processing.

It is confirmed, as a more shared element, the adhesion to association or cooperative and, among the motivations that push the actors to the relationship, the exchange on technological advances. Furthermore, the most common types of relations are above all the formal and informal (verbal) annual contracts with another company.

4.5.5 Conclusions and research perspectives

In recent years the prickly pear biomass has assumed a growing role in the agro-energy landscape, aimed at the production of biogas and biomethane. All this for its vegetative capacity and for its potential diffusion in arid contexts, with limited water requirements. Although the technical validation of this biomass in various territories do not exist in the literature, there are no similar studies in Sicily, a region that catches more than 90% of cactacea in Italy. The research has shown a greater aptitude for energy conversion in cladodes from 1 to 3 years, due to the higher rate of dry biomass, unlike the greater methanigeno potential in cladodes aged between 3 and 10 years.

The total production of biomethane per hectare of cultivation was 629.3 Nm^3 ha^{-1}.

Technical analysis not only confirmed what the stakeholders hoped for in these investments, but it offered the opportunity to identify new uses alternative to the consumption of fresh fruit, which is mainly carried out in the investigated area, creating value for the territory (including improvement of pruning waste, commercial processing and more). This was delimited with a GIS tool, which allowed the geo-referencing of a portion of south-western Etna, near road and electric networks and epicenter in the municipality of S. Maria di Licodia. Within the area, not only was cladode-based biomass defined, but also other biomasses potentially available in a range of economic transportation convenience for the creation of a balanced diet intended for feeding a biogas installation. Finally, with Social Network Analysis (SNA) the existing relationships were studied, aimed at identifying a convergence on the project idea, highlighting local interest and availability. Looking ahead, we hope to strengthen research for validation of cactus mixes and other biomass and economic validation of the installation, according to hypothetical public incentives and investment of different sizes, in order to support the action of public and private decision-makers. These evaluations will also be used to guide technical assistance programs, operator training and information.

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5. Prickly pear for biogas production: technical-economic validation of a biogas power installation in an area with a high prevalence of cacti in Italy

Abstract

The prickly pear in Italy is mostly used exclusively for human nutrition, although in the world different cultivars of the cactacea are intended for different uses. Today there is a new bio-economy of prickly pear which is linked to the use of cladodes and fruit wastes for energy uses and numerous biotechnological derivatives. The following chapter focuses on the technical and economic validation of a bioenergy production installation, since the scientific literature has shown for years its possible use in diets mixed with other materials. The hypothesis that we argued is the varied reconversion of a portion of the traditional Italian prickly pear company, in biomass cultivars and the construction of a biogas installation of a district type, networking between different subjects of the territory. The results show, considering also the current Italian incentive system, that the ideal power of the installation is 300 Kw and that the prickly pear is a valid matrix in association with citrus fruit and olive pomace mash.

5.1 Introduction

In the last years it was observed a continuous increase in bioenergy and biofuel request. Biogas and biomethane obtained by the conversion of biomass crops and organic residues could contribute to the reduction of the dependency

of fossil fuels. The obtained biomethane could be used as fuels for transport or for the production of electric and thermal energy. Furthermore, the digestate could be applied to soils as organic fertiliser.
Prickly pear presents an high ability to produce biomass in marginal land (eg. low water availability) and in presence of low agronomical input (eg. fertilization). Prickly pear is a plant high resistant to drought thanks to its CAM (Crassulacean Acid Metabolism) photosynthetic mechanism that allow to produce high biomass also in semi-arid environment.
The availability of data regarding the chemical composition and the biomethane potential of prickly pear cladodes are scarce in Mediterranean environment. Also the economic evaluation of the possibility to build a biogas power installation that use prickly pears cladodes are scarce.
In the present work we evaluate the possibility, in terms of biomethane production and economic convenience, of use prickly pear cladodes and a mix of cladodes and others agro-industrial residues in a biogas power installation.

5.2 Analysis of literature

The literature review was carried out with the dual purpose of detecting both the most significant scientific contributions on the use of prickly pear for the production of energy (alone and / or mixed with other matrices) and for the purpose of identifying the instruments more suitable for economic evaluation of the relative investments (Inglese et al, 2017).

Prickly pear and other biomasses have been found as possible renewable energy sources to help meet the European Union's obligations to reduce the release of carbon dioxide, demonstrating that by selecting appropriate liquefaction conditions these organic wastes can be used to produce biogas efficiently after conversion into water-soluble substances (Pehlivan and Taner, 2009). More recent experiments on the potential use of prickly pear biomass for biogas production have allowed us to characterize the chemical composition of several varieties of Opuntia present in Brazil (Taciana do Nascimento et al, 2016), in order to respond to the current increase in renewable energy demand and the future prospect of more limited water resources. This study demonstrated the presence of significant amounts of uronic acids (10.7%) and oxalic acid (10.3%) in cladodes, as a natural consequence of a high quantity of pectin and calcium oxalate, but also a potential of low ethanol production (1490-1875 L / ha / year) compared to traditional biomass sources (for example sugar cane and sugar beet) and also high potential methane production rates (3717 m3 / ha / year), comparable to traditional energy crops. Also from other recent evaluation of biogas potential was determined in Sicily by Opuntia ficus indica, to be cultivated in uncultivated areas (for about 600 thousand hectares) co-digested together with manure and slurry (Comparetti et al, 2017). In this case, in order to optimize the installation and its location, it was used the GIS (Geographic Information System) tool or territorial information system for geo-referencing of uncultivated areas. In this way it was possible to calculate the potential production of biogas and, indirectly, biomethane or electrical and thermal energy equal respectively to 612.115

103 m^3 of biogas, from which 342.784 103 m^3 of biomethane could be extracted or 67.038 MWh of electric energy and 70.390 MWh of thermal energy could be generated. The work reflects in depht on the integration of income for the farmer who thus obtains not only the sale of biomethane or electricity and heat but also the economies generated by the replacement of chemical fertilizers with digestate (biofertilizer which can be used so much in organic farming). as in the conventional one) and the subsidy for the production of biomethane as a fuel for means of transport or electrical and thermal energy from biogas. Moreover, three pretreatment techniques (thermal, alkaline, acid) were evaluated on the chemical composition and methane yield of the prickly pear biomass, detecting variable productions from 289 to 604 NmL/gVS, with higher values in the presence of a pre- acid treatment (HCI) (Calabro et al, 2018).
Cladodes of cactus can be used for other bioenergetic uses such as the production of biodiesel or ethanol. With an annual production of 40 tons ha of biomass in dedicated crops for energy use or 10 tons has in pruning residues from plantations dedicated to fruit production, it is possible to obtain energy for direct combustion. Some evidences show that the cladodes collected, sun-dried and crushed, can be used in direct combustion or in a mixture of coal cogeneration, with a calorific value of 3,850-4,200 kcal/kg. Instead, the technology for the production of ethanol is more complex and adapted to a larger scale, because it implies higher investment.
However, during fermentation specific yeasts are required to maximize alcohol production (García de Cortázar and Varnero, 1995). Some research indicates that it is possible to

use cactus mucilage (about 20 ml/kg) to produce small amounts of ethanol, although it was not particularly competitive (8.6 liters of 100 kg ethanol dried cladodes, compared to an average of 24.7 liters obtainable from 100 kg of dried fruit) (Retamal et al., 1987).

The biotechnological production of ethanol from various raw materials containing sucrose, starch materials and lignocellulosic biomass has been analyzed and reported in comparative indices that highlight the value of the cactacea (Sánchez and Cardona, 2008). A following experiment was devoted to the study of the relationship between microbiological yeasts (in particular Kluyveromyces marxianus and Saccharomyces cerevisiae) and production of ethanol from cladodes of Opuntia (Kuloyo et al, 2014). It was thus shown the existence of a technical constraint in the commercial exploitation of this process, due to the relatively low concentration of fermentable sugars. The production of biogas from the co-digestion of Opuntia ficus-indica skin with cow manure in five mixing ratios was evaluated under mesophilic conditions (38ºC) using a batch digester in Haramaya University's microbiology laboratory, demonstrating its validity of the mixture with 75% of prickly pear and 25% of manure (Gebrekidan, 2014).

The Nopal (*Opuntia ficus-indica* (L.) Mill.) has been evaluated as an alternative for the production of biogas in co-digestion with dairy cow manure, the second source of greenhouse gas emissions in dairy farms. In this case, a life cycle assessment was performed to assess the environmental impact and the energy balance of biogas production, demonstrating that it is possible to achieve cleaner energy production as the global warming potential has a lower value

to that reported for similar raw materials (Ramírez-Arpide et al, 2018).
Another recent experiment carried out on samples of different ages, cut, purified in centrifugation and homogenized and sent to co-digestion at different temperatures (cacti <1 year at 27 ° C and 37 ° C; 1 year cactus at 27 ° C and 37 ° C, 2-year-old cacti at 27 ° C and 37 ° C, 3-year-old cactus at 27 ° C and 37 ° C), showed that the highest biogas production occurred in cladodes of <1 year at 37 ° C (3500 ml of biogas and 49% CH_4) (Belay and Yimam, 2018).
In Mexico it was recently conducted an analysis of biogas from agricultural waste including the cactus pear, in order to identify the current status and opportunities for the coming years. The goal of the Mexican National Energy Strategy (ENS) is to produce about 35% of energy from clean technologies in 2024, implying scientific and technological challenges. The Mexican data indicated for bioenergy production are Production (408.445.05 t), Harvest (102.111.26 t), Post-harvest (32.675.60 t), Available (111.097.05 t), Wastes (111.097.05, t), Biogas (43.327.850.90, m3) and Energy (879,338,734.10, MJ) (Hernandez and Jimenez, 2018). As intead for the economic evaluation of the opportunity to construct installations and equipment for bioenergy production, literature presents contributions aimed - in different territorial contexts - at the determination of optimal investment conditions. Some evaluations concern large-scale installations with econometric methodologies, others instead develop economic-financial micro-economic analyses on small-sized installations aimed at satisfying a business and / or area-based demand.

In the first case, the econometric analysis allow to extend the level of the evaluation to not only economic but also environmental and sociological variables. A good example is offered by China where, through an accounting model based on the life cycle of a domestic biogas system, it resulted a complete analysis (input-output economic evaluation complemented by ecological and social influence evaluations) with a prospect of sustainability (Dai et al, 2015). In the same perspective of integration of economic evaluation with environmental performance, a series of composite indicators have been developed, such as the Renewability Report, the Environmental Loading Report (ELR) and the Composite Sustainability Indicator (CSI), which reflect. Thus it was possible to integrate the existing methods of financial accounting and environmental accounting with the environmental characteristics of a biogas project (Zhang and Chen, 2017). The use of two multi-criteria decision-making techniques (MCDM), such as the AHP determine the importance of the evaluation criteria and VIKOR for the classification of alternatives to energy projects, and allowed the evaluation of several energy projects different for technology, dimensions, costs, environmental aspects, etc. The implementation took place in Turkey, through the use of Group Decision Making (GDM) to aggregate the opinions of experts and a comparison between a thermal energy project and three renewable energy projects (Büyüközkan and Karabulut, 2017).
In the second case, we reported the experience of Nigeria in which they realized both the engineering project both microeconomic evaluations of discounted cash flow for the evaluation of a biogas project in family size of 6.0 m3, with

use of VAN , IRR, B / C and an amortization period of 6.6 years (Adeoti et al, 2000). A similar economic evaluation was conducted in Germany, where two biogas plants were compared for the exploitation of energy crops, together with manure and biological waste, determining annual costs and also considering subsidies for the production of electricity from biogas according to the German law on renewable energy sources of 2012. The study concludes with a hope for the future development of the German biogas sector following the overcoming of various technical, social and political barriers (Balussou et al, 2014). An analysis of agro-energy supply chains, in particular of vegetable oil, was conducted in Italy through the use of a cost-benefit analysis of the economic performance of biogas plants, demonstrating how the policies and prices of raw materials influence the relative supply chains (Finco et al, 2010).

An economic analysis extended to all the elements of evaluation to be considered in the construction of an agro-energy supply chain (finding the matrices, investment, management costs, incentives, digestate management). In Italy we owe to Ragazzoni, who through various contributions presents the economic convenience of a cogeneration plant of agricultural biogas energy, taking into account the annual management and, therefore, by calculating different revenues for each type of entrepreneur, as well as the influence of the new Green Certificates on total profits (Castellini and Ragazzoni, 2008; Ragazzoni and Castellini, 2012; Ragazzoni, 2013; Pirazzoli and Ragazzoni, 2013; Gaviglio et al, 2014).

Finally, an analysis of the district in Italy has been proposed to locate a digester and choose its power and to identify the optimal mixture of the substrate, reducing the complexity of the design and management operations. It has thus been shown that if the planned installation is powered by an overriding substrate of a single company, the most economic power is 300 kW, which size also depends on the Italian system of grants to renewable energy (Zema, 2017).

5.3 Materials and methods

5.3.1. Identification of the area in which to place the investment

The area of the Southwest Etneo represents an ideal territory for the placement of an anaerobic digestion plant of the predominantly prickly pear biomass due to the significant diffusion of this cultivation, together with other possible fractions represented by pulp and pomace coming from the local processing industries (Foti et al, 2018).
In particular, the aforementioned area alone intercepts almost 30% of the Italian prickly pear surfaces and productions, equal to over 2,000 hectares in main and secondary cultivation (Timpanaro and Foti, 2014).
As specified in the previous chapter, there is both a high level of social capital and systems of widespread relations in the territory, capable of supporting the business idea. The prickly pear entrepreneur, now in its second or third generation, has fully acquired the multifunctional dimension of the economy and society, supported by rural development policies, and intends to implement the principles of the circular economy.

5.3.2. Technical analysis

In order to estimate the theoretical Biochemical Methane Potential (BMP), calculated from the BMP of each component of the biomass, an analysis of the chemical composition of the biomasses was carried out using the Van Soest method. The biomasses analysed were prickly pear cladodes, "pastazzo", "sansa", *Arundo donax*, *Saccharum spontaneum*.

The Van Soest method

The qualitative analysis of the biomass was carried out in the laboratory using the Van Soest method which allows to determine the composition of the fibrous fraction of any vegetable matrix.

Determination of Neutral Detergent Fiber (NDF)

The method allows to separate the fibrous constituents of plant cell walls, identified with the NDF (cellulose, hemicellulose, lignin, cutin and mineral constituents), from the soluble cellular content (NDS) represented by sugars, pectins, organic acids, proteins and non-proteins nitrogenous substances, lipids, soluble mineral salts.

Neutral detergent fiber (NDF) is the residue obtained after hydrolytic treatment of the sample with neutral detergent solution.

Reagents used for NDF determination (Neutral-detergent solution):

- Distilled water (1 l)
- Sodium lauryl sulfate (30 g)
- Disodium dihydrogen ethylenediaminetetraacetate dihydrate (EDTA) (18,61 g)
- Sodium borate decahydrate (6,81 g)
- Disodium phosphate anhydrous (4,56 g)
- 2-ethoxyethanol (10 ml)

1 g of dry sample was transferred to the tared glass crucibles fitted on an extraction apparatus (Fibertec Velp Scientifica, model FIWE), and added to 100 ml of neutral detergent solution.

The mixture is boiled for 60 min and then the solubilized is filtered with vacuum; After being rinsed twice with boiling water and twice with acetone, the sample is dried overnight at 105 °C and weighed.

The results are expressed as follow:

$$NDF\ (\%) = [((\text{tare weight} + \text{NDF residue}) - \text{tare weight}) / \text{sample weight}] \times 100$$

Determination of Acid Detergent Fiber (ADF)

The hydrolytic treatment of NDF residue with an acid detergent solution leaves a fibrous residue composed by cellulose, lignin, cutin, tannins, pectins and insoluble mineral substances, identified as acid detergent fiber (ADF).

Reagents used for ADF determination (Acid detergent solution):

- Distilled water (1 l)
- Cetyl trimethylammonium bromide (20 g)
- Sulfuric acid (H2SO4) (29 ml)

To the crucibles containing the NDF residue are added 100 ml of acid detergent solution in the extraction unit (Fibertec Velp Scientifica, model FIWE). The mixture was boiled for 60 min. The contents were filtered through a Gooch crucible, washed with boiling water, acetone and hexane. The residual acid detergent fiber (ADF) was dried at 105 °C and weighed.

The results are expressed as follow:

$$ADF (\%) = [((\text{tare weight} + \text{ADF residue}) - \text{tare weight}) / \text{sample weight}] \times 100$$

The difference between NDF and ADF is a measure of hemicellulose content.

Acid-detergent lignin

Acid-detergent lignin (ADL) was determined on the residue from the ADF procedure. The crucibles content were treated with sulfuric acid 72% at room-temperature for 4 h and then thoroughly washed with boiling water until free from acid. The sample was dried at 105 °C for 8 h and weighed.

The results are expressed as follow:

$$ADL (\%) = [((\text{tare weight} + \text{ADL residue}) - \text{tare weight}) / \text{sample weight}] \times 100$$

The difference between ADF and ADL is a measure of cellulose content.

To determine the lignin content, the crucibles with ADL residue are ignited in muffle furnace at 550 °C for 3 hours. The difference between ADL and ashes is a measure of lignin content.

BMP test

Biochemical Methane Potential (BMP) tests

The BMP test was used to estimate the methanogenic potential of different vegetable matrices, The BMP test of an organic matrix represents the net quantity of methane produced by the anaerobic fermentation of a mass unit at a certain time.

The BMP was assessed for prickly pear cladodes, “pastazzo”, “sansa”, *Arundo donax*, *Saccharum spontaneum* and several mix of these biomasses in different proportions:

- Mix 1 with 1/3 cladodes, 1/3 “pastazzo” and 1/3 “sansa” as proportion of volatile solids;
- Mix 2 with ¼ cladodes, ¼ “pastazzo”, ¼ “sansa” and ¼ Saccharum as proportion of volatile solids;
- Mix 3 with 3.85% cladodes, 76.1% “sansa” and 20.1% “pastazzo” as proportion of volatile solids.

Mix 3 has been formulated applying the same proportion of the available biomass (on the basis of volatile solids) in the Catania province.

The Biochemical Methane Potential (BMP) lasted 30 days and it was determined in an Automatic Methane Potential Test System (AMPTS).

Before starting the BMP test, the optimal mixture (inoculum and substrate) was prepared, using a 3:1 ratio between volatile solids of respectively inoculum and substrate.

The reactors were loaded with the mixture, closed hermetically and connected to the measuring devices of the produced gas.

Two reactors were loaded with the inoculum previously degassed.

The measuring devices read the gas flow every 5 minutes.

Readings were reported on a spreadsheet previously set.

Data processing

To process the data was created a spreadsheet containing following data: day, daily gas flow of each reactor including blank bottles filled only with inoculum and the averages of all reactors net of value of blank. To calculate net daily methane production of each crop (Nml CH4 day^{-1}) these values will be divided by the weight of sample volatile solids added to each bottle. Finally, yield curves will be created using the graph function of the spreadsheet.

Inoculum health status

Before to start the BMP test, the inoculum health status was evaluated using substrates (starch, oil, vinegar, sucrose, etc.) with known BMP to test each group of microorganisms. The health of amilolytic, cellulosolytic and glycolytic microorganisms was evaluated using substances such as potato starch (source of starch), kitchen sugar (glucose and fructose source) etc. Generally, the BMP of these substances (carbohydrates) ranging between 280 and 410 Nml/gSV. For the evaluation of the activity of lipolytic microorganisms were used different types of lipid substances such as cooking oil. The BMP of these substances ranging between 700 and 1000 Nml/g SV and the rate of degradation of these substances is rather slow, given the complexity of molecular structures.

The evaluation of the proteolytic component of the inoculum was done using protein matrices such as casein-based

substances or fish glue. The theoretical yield of methane of these substances is about 350 Nml/gVS.
The presence of microorganisms, mainly Archaea acetoclastics, responsible for the degradation of organic acids, such as acetic acid, is very important because they intervene in the last passage of anaerobic digestion, leading to methane production.

Dry matter and volatile solids
First of all we carried out the determination of the dry matter and the volatile solids of the organic matrices used to feed the AMPTS, as well as the determination of the content in volatile solids of the digestive solution (by convention these correspond to the dry matter of the latter).
The conversion of dry matter into bio methane depends on the biomass composition in macronutrients, on the lignification level of the fibres and on the ash content.
Tuttavia un'elevata concentrazione di sostanza secca non per forza si traduce in elevate produzioni di metano; questo dipende sostanzialmente dalla composizione in macronutrienti, dal grado di lignificazione della sostanza organica e dal suo contenuto in ceneri.
To determinate the dry weight the samples were dried in a ventilated oven at 105 °C until constant weight. For the estimation of the volatile solids, the dried samples were placed in a muffle furnace at 550 °C for 5 hours. Volatile solids were calculated by difference between dry substance and ashes. During this process, all the compounds containing carbon, hydrogen, oxygen and nitrogen volatize and only ashes remain in the tray. The volatile solids are calculated by subtracting the weight of the ashes from the weight of the dry

matter. The same test was carried out on the inoculum that must be as homogeneous as possible, so it must first be subjected to filtration and stirred.
Generally, the inocula used in anaerobic digestion plants for the biogas production have a quantity of dry substance (therefore of volatile solids by convention) which varies between 2 and 5 %.

The BMP equipment
The test was carried out using an automatic methane detection system of different organic matrices (AMPTS, Automatic Methane Potential Test System, Bioprocess control)
The AMPTS system includes:

- Sample incubation unit
- Batch reactors
- Carbon dioxide absorption unit
- Flow measuring device μ-Flow®
- Data logger

The BMP tests were conducted in 2 l capacity batch digesters loaded with inoculum and samples. The reactors were placed in the incubation unit with a thermoregulated solution at a constant temperature of 37 ± 1°C (the microorganisms involved are mostly mesophiles), avoiding risks of thermal swings and they will be hermetically sealed. The medium will be mixed by a slow bent rotating agitator to prevent lumps formation and to ensure correct and constant mixing of the entire mass.
Each reactor was connected to a carbon dioxide trap bottle filled with a 1 M NaOH to retain acid gas fractions (mainly

CO_2), only allowing CH_4 to pass through to the gas monitoring unit solution.
Without filters with caustic soda the volume of the gas measured corresponds to the gross biogas produced, therefore the sum of the biomethane and CO_2 and by convention is assumed a ratio of 6 to 4 methane / CO_2.
The volume of methane released was measured using a wet gas flow measuring device µ-Flow® connected to a data logger.
Flow measuring device µ-Flow® works according to the principle of liquid displacement. Each µ-Flow® meter is equipped with a pressure and room temperature sensor in order to provide a normalized reading in real time. The analogue outputs of the µ-Flow® meters are connected to the data logger, which allows continuous monitoring of biogas production data, with readings even at 5 minute intervals and the direct obtaining of data in numeric format.

5.3.3. Economic analysis

The economic convenience for the realization of the biogas plant with a predominantly Ficodirary matrix was carried out through the financial and economic analysis, based on the comparison of all the cost items connected to the plant, with the benefits related to the sale of electricity produced.
From a methodological point of view, we considered what it reported in the literature on the cost-benefit analysis (CBA) of private investments (private cost benefit analysis), based on some elements a) the transition from financial to economic analysis; b) classification of benefits and costs; c) the price system; d) discounting; e) profitability indicators (Casoni, Polidori 2002; Castellini, Ragazzoni, 2008; Ragazzoni, 2010; Campbell, Brown, 2003; Finco et al, 2010; Timpanaro et al, 2018). Therefore, the costs, the benefits of the investment and the rate of discounting have been quantified; then synthetic indicators were drawn up and on the basis of this information it was decided on the opportunity of the investment.
The indicators used are:
V.A.N or Net Present Value of the investment, calculated as the difference between the discounted cash flows of the expected benefits and the discounted flows of the costs envisaged during the life of the project. It is useful to measure the discounted net profits that the project is able to provide:

$$VAN = \sum_{i=0}^{n} \left[\frac{B_i - C_i}{(1+r)^n}\right]$$

where Bi and Ci are respectively the benefits and costs deriving from the investment in the period i; n is the investment period expressed in years and the discount rate. If

the NPV assumes a positive value, the project is cheaper than alternative uses of capital; on the contrary, if it is negative, the amount measures the losses to which the investor faces by choosing the project with respect to alternative uses of capital.
T.I.R or Internal Rate of Return represents the rate that makes the transaction fair, or is the rate at which the current value of future revenues is equivalent to the current value of future costs. To assess the profitability of the investment, it is necessary to compare the IRR with alternative investment return rates, of equal duration at the level of risk:

$$\sum_{i=0}^{n} \frac{(B_i - C_i)}{(1+r)^n} = 0$$

R.O.I or Return On Investment is the profitability index of invested capital or return on investment. ROI is one of the most widely used valuation indices in accounting practice by companies. Normally the components, to which the ROI refers, belong to the operational or typical management. In particular, the index is equal to the percentage ratio between operating income or net operating margin (MON) and the capital invested in the company. ROI measures the profitability of the total capital invested in the company, taking into account both the capital carried as a risk and that in the form of borrowed debt:

$$ROI = \frac{MON}{K}$$

Gross Operating Margin (MOL) or EBI-TDA is the profitability indicator that shows the income of a company based only on its characteristic management before interest (financial management), taxes (fiscal management), depreciation of assets and armotisation.

Net Operating Margin (MON) or EBI-T is the operating result, also called operating income, net operating margin (MON) or EBIT (Earning Before Interest and Taxes), is the quantity obtained by deducting depreciation from the gross operating profit.

Return Time (PBT) is the estimate of the number of years necessary to ensure that the net cash flows generated by the investment (ie the difference between annual revenues and costs) cover the amount invested. It is given by the ratio between the investment and the gross operating margin and provides an indication of the soundness of the investment, evaluating in how many years the initial investment falls.

Finally, Net Revenue (RN) is equivalent to the difference between the Net Operating Margin and the interest portion calculated on the initial investment.

It is important to underline that in practice the most commonly applied criteria are NPV, TIR and Return Time (PBT): therefore, they represent the minimum information set through which they verify the suitability test of investment projects.

5.4 Results and discussion

5.4.1. Evaluation of a possible diet

Most of the tested biomasses showed the peak of biomethane production in the first 15 days of experiment. This could be considered as a positive feature of the tested biomasses for an

industrial application in a continuous plant, since the retention time could be reduced while maintaining most of the productive potential (Figure 9).
Among the assessed biomasses, “pastazzo” and prickly pears cladodes of 3-10 years had the highest BMP, with 286.4 and 278.8 Nml gVS^{-1} respectively. These biomasses were followed by Mix 1 and Mix 2 with 255.1 and 252.1 Nml gVS^{-1}. Lower potentials were achieved by Mix 3 with 206.2 Nml gVS^{-1} and prickly pears cladodes of 1-3 years with 220.4 5 Nml gVS^{-1}. The lowest potentials were achieved by “sansa”, *S. spontaneum* and *A. donax*, with 182.3, 148.0 and 135.3 Nml gVS^{-1} respectively (Figure 10, Figure 11).

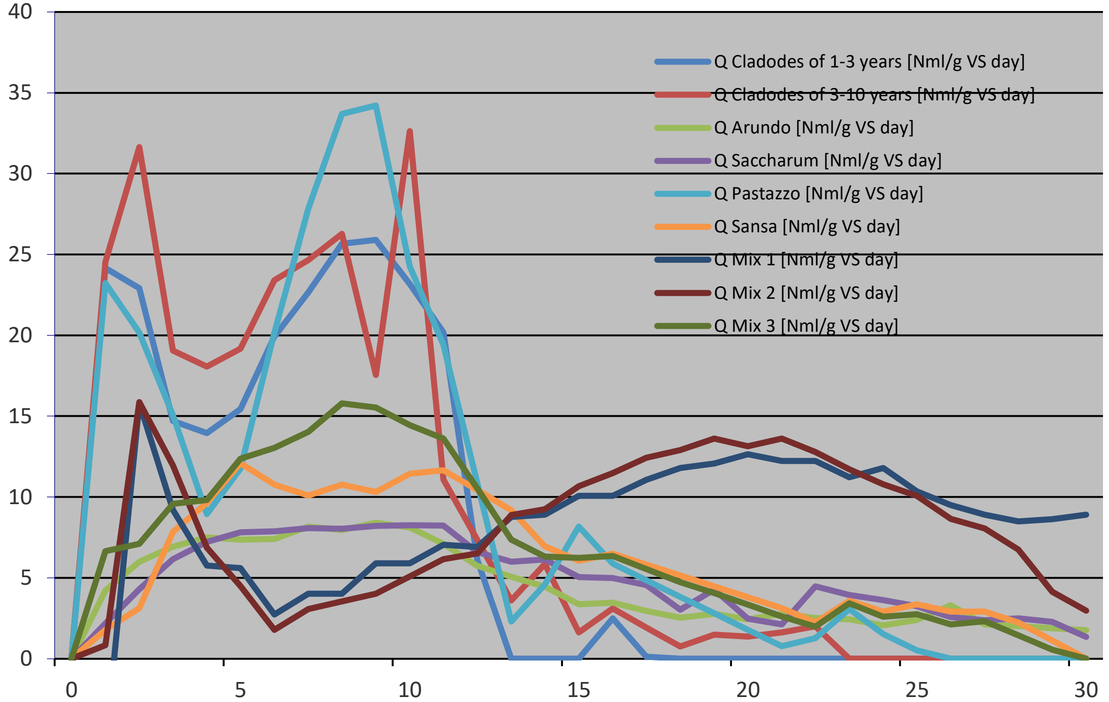


Figure 9 – Daily flow (Nml/g VS) of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses over the 30 days test BMP

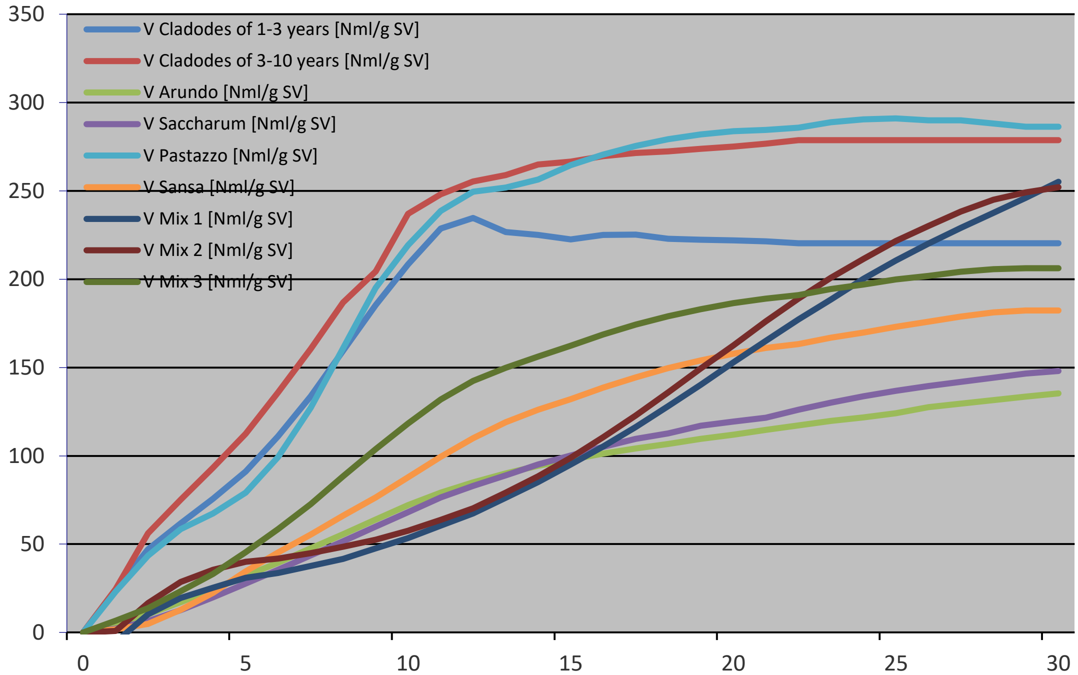


Figure 10 – Accumulated Volume of biomethane (Nml/g VS) of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses over the 30 days test BMP

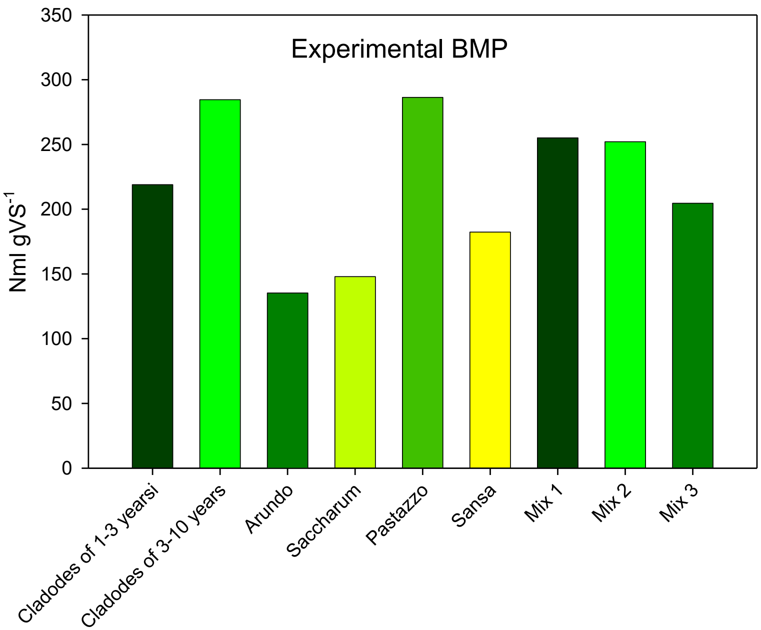


Figure 11 – Experimental Bio Methane Potential (Nml/g SV) of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses over the 30 days test BMP.

The highest theoretical BMPs, calculated from the BMP of each component of the biomass, were achieved by *S. spontaneum*, “pastazzo” and *A. donax*, with 317.2, 308.6 and 305.9 Nml gVS^{-1} respectively. “Sansa” had the lowest theoretical BMP, and therefore Mix 1, Mix2, Mix3, which included “sansa” in the formulation, had lower theoretical BMP than the other biomasses (Figure 12).

This result is ascribable to the higher content in lignin and lower in NDS of “sansa” and thus of the mixes (Figure 13, Figure 14). Lignin envelops the cellulose and hemicellulos fibrils, slowing and reducing the enzymatic digestion carried out by the bacteria of the inoculum.

Cellulose was the principal component that was responsible for BMP in *S. spontaneum*, and *A. donax*, while the soluble components (mainly lipids and non-structural carbohydrates) (Figure 13, Figure 14) were the component mostly responsible for BMP in “pastazzo” and cladodes. Soluble components are readily available for bacterial enzymatic digestion and thus the peak of BMP for those biomasses is reached earlier.

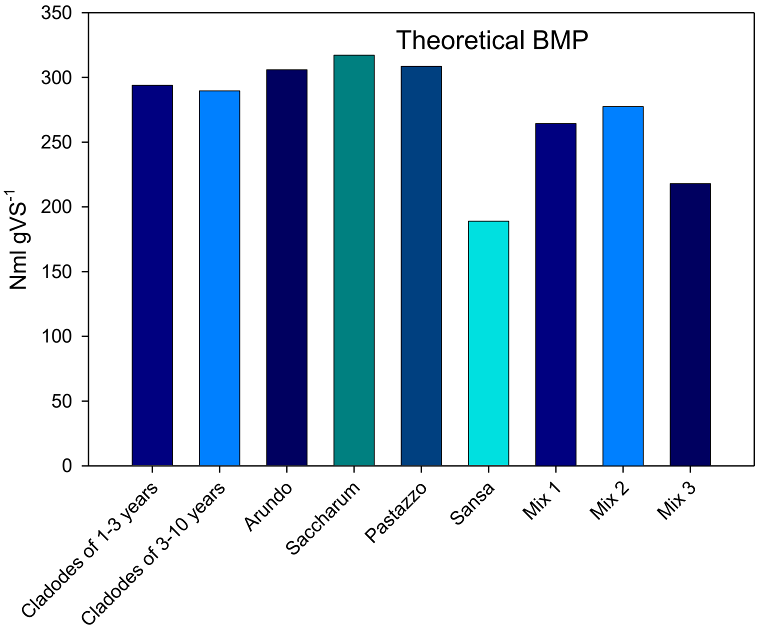


Figure 12 – Theoretical Bio Methane Potential (Nml/g SV) of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses according to the biomass composition.

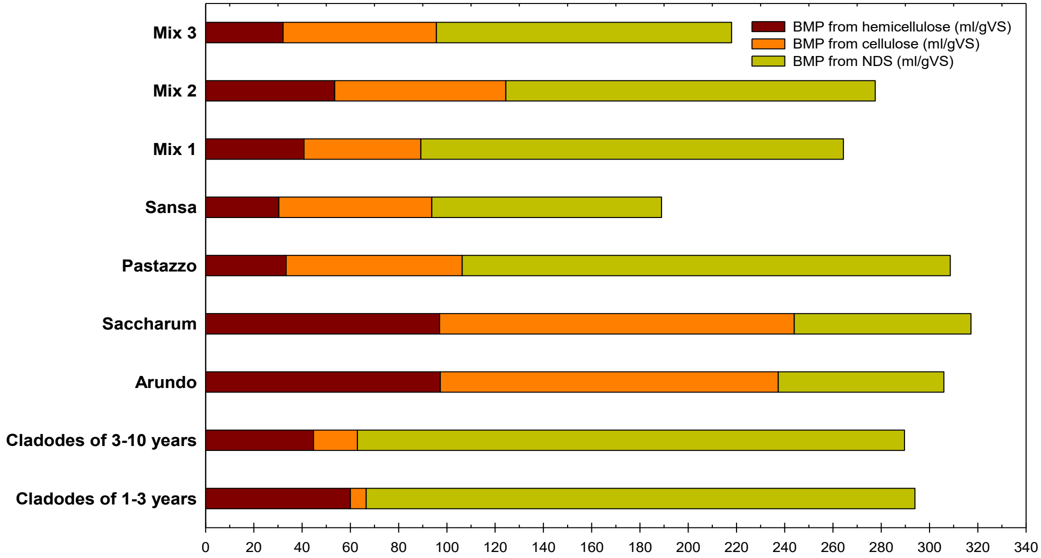


Figure 13 – Theoretical Bio Methane Potential (Nml/g SV) of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses calculated for each biomass constituent.

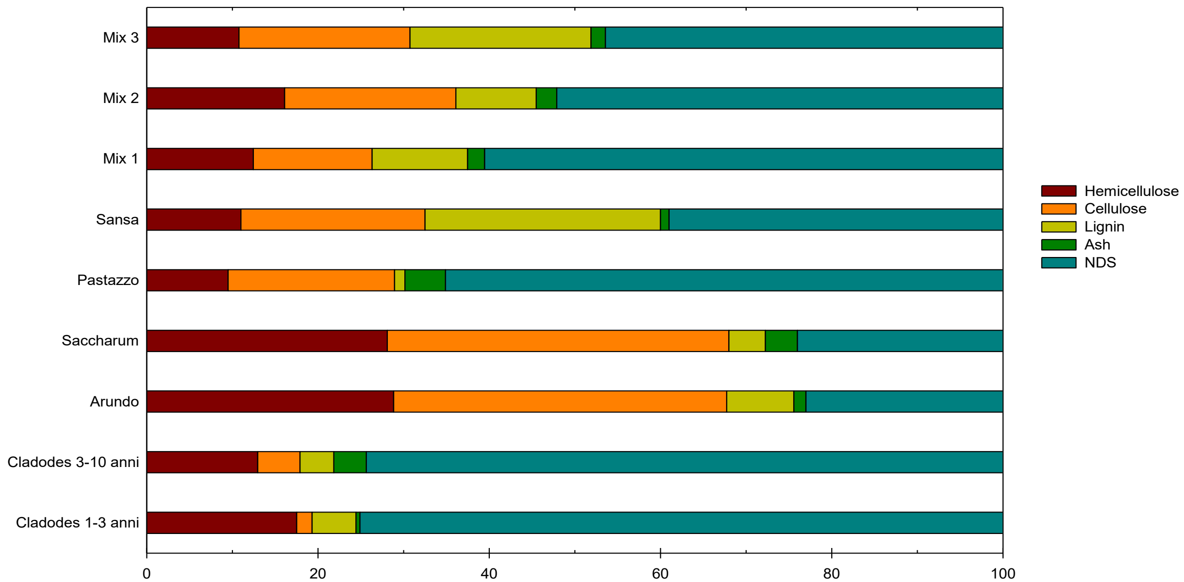


Figure 14 – Components of several biomasses from dedicated crops, agricultural residues and mixtures of these biomasses, measured trough the Van Soest method.

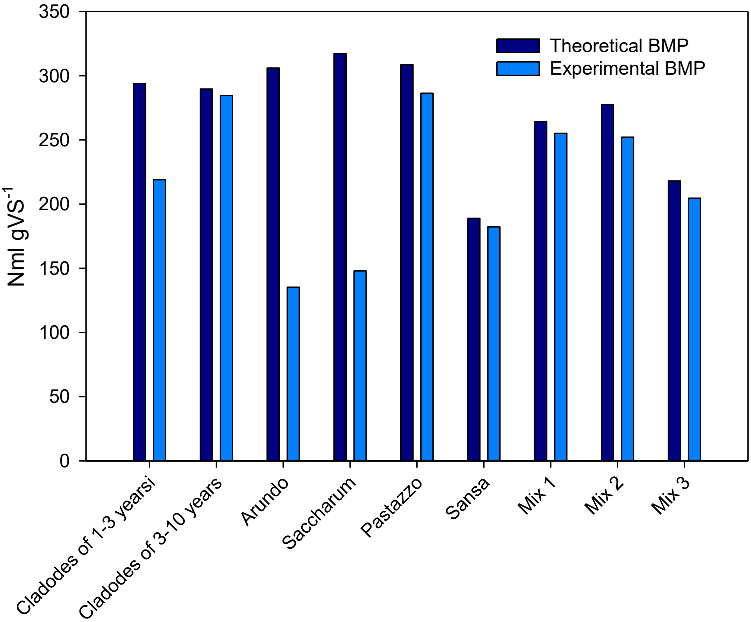


Figure 15 – Comparison of theoretical and experimental Bio Methane Potential (Nml/g SV).

From the comparison of theoretical and experimental BMP is it possible to notice that most of the biomasses have slightly lower experimental BMP. This result confirm that the inoculum is efficient and that the inoculum-substrate ratio is well balanced. Only A. donax, S. spontaneum and cladodes of 1-3 years had much lower experimental BMP than the theoretical and likely they need a longer time to complete the enzymatic digestion.

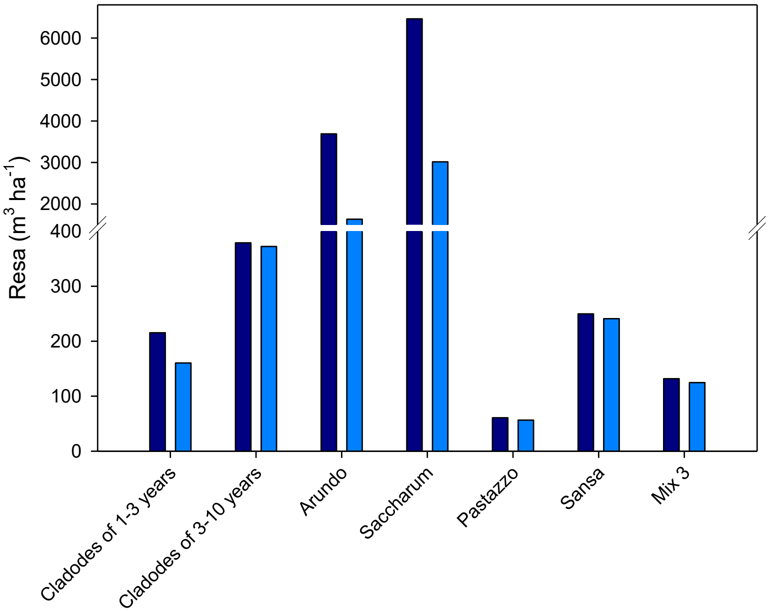


Figure 16 – Comparison of theoretical and experimental Bio Methane yield (m^3 ha^{-1}).

The BMP yield per hectare has been calculated considering the available production of by-products in Catania province in relation to the cultivated surface for biomass. Concerning A. donax and S. spontaneum, the yield achieved in experimental trials in the same environment has been used. These crops could be integrated into the cropping system of the agricultural companies with the aim of assuring a higher consistency of the biodigestor diet.

As expected the highest biomethane yield per hectare were observed in the two lignocellulosic crops due to the high biomass yield per hectare of cultivation (22.6 t ha^{-1} for *S. spontaneum* and 13.4 t ha^{-1} for *A. donax*). *S. spontaneum* gave an experimental methane yield equal to 3015 m^3 ha^{-1} while *A. donax* achieved 1631 m^3 ha^{-1}.

Lower experimental methane yield were obtained in the crops residues. Cladodes with an age ranging from 3 to 10 years gave 372 m^3 ha^{-1} of methane while cladodes of 1-3 years gave 161 m^3 ha^{-1}.

Prickly pear cladodes showed lower methane yield per hectare despite a high BMP potential due to the low dry matter of the biomass, while the yield of total biomass from pruning is relatively high (17.3 t ha^{-1} for cladodes of 3-10 years and 9.6 t $ha^{-1}$for cladodes of 1-3 years).

"Sansa" showed a methane yield per hectare of 241 m^3 ha^{-1}, consequence of a relatively low BMP and biomass yield per hectare (about 2.5 t ha^{-1}) and a high dry matter concentration.

The low methane yield of "pastazzo", 56 m^3 ha^{-1}, is the consequence of the low biomass yield per hectare (about 1.2 t ha^{-1}) and the low dry matter concentration, despite the high BMP.

The methane yield per hectare of Mix 3 obtained from cladodes, "pastazzo" and "sansa" gave a methane yield per hectare of 124 m^3 ha^{-1}, calculated considering a biomass yield of 2.04 t ha^{-1}. The biomass yield results from the weighted average of the biomass yield of the constituent fractions.

The methane yields for Mix 1 and Mix 2 were not calculated because the composition is non representative of the actual availability of the crop residues in the province of Catania, thus it is not possible to define a biomass yield per hectare.

5.4.2. Economic validation of the plant in a case study

5.4.2.1. Supply of the raw material

From the investigations carried out on the territory concerning the retrieval of the matrices to be used for the transformation of biogas, a diversified scenario emerged which changes according to the considered matrix.
In particular, as regards the pulp, for citrus industry this fraction represents a waste deriving from the production cycle with various disposal problems, to the point of constituting a considerable item of the relative production costs, linked to the collection and disposal of the aforesaid by-product by specialized subjects generating a cost for the industry. In recent years, various private agreements have been signed between some citrus fruit processing companies and the managers of anaerobic digestion installations in Sicily and Calabria that use vegetable waste as components of the diet. These agreements provide for the free sale of the pulp differently from the transport charge that remains at the expense of the citrus fruit transformer. For as it concerns the mills, the context changes, since these give the pomace to the oil mills at a price of 3.6 euros / ql, with transport paid for by the mill. In this case, the contribution can relate to the two-phase pomace, the sanseries, in turn, separate the liquid fraction from the solid fraction and then the peanut from the solid component; the latter has a market as it is used to produce thermal energy that averages around 20 euros / ql, while the remaining solid part is sent to a process of treatment with chemical solvents in order to extract the pomace oil. The sale of the pomace from the mills to the biogas installations

can only follow the same economic conditions. However, this purchase cost of pomace from the biomass plant could be cancelled out by the sale of the peanut extracted inside the plant. The presence of peanut rich in lignin reduces the efficiency of bacteria in converting the other components of biomass into biomethane. In fact, there are no concrete experiences of transfers of this biomass for energy purposes, however it was hypothesized a scenario of cladode contribution by the producers, with the administration of a questionnaire.

This hypothesis calls into question a cooperative idea of conferring the matrix and at the same time the management of the anaerobic digestion installation. Specifically, it hypothesized that, considering a median agricultural SAU of 6.5 hectares on Etna, about 100 prickly pear operators have a necessary and sufficient business base to guarantee about 13,600 tons / year of biomass (ie, about 650 ha). These operators carry out their activities on a restricted area without interruption between their farms specialized in the cultivation of prickly pears. It is assumed that they are willing, on one hand, to provide free biomass at the anaerobic digestion installation and on the other that they will be allowed to collect a proportional amount of digestate free of charge from the installation, at the plant, in addition to receive dividends of company profits. As concerns the real quantity of liquid and solid digestate which is returned to the user, it must be considered that with respect to what is injected into the digester, in terms of matrix, the volume of the produced biogas multiplied by its density itself.

With this hypothesis, the resulting advantage for the individual operator would be multiple and linked to:

• reduction of the costs of "shredding of pruning residues" and / or of negative externalities generated by the abandonment of residual cladodes on the substrate and / or subsequent burial which generates excessive and harmful ammonia for the plant and which escapes the indications and recommendations of the EU Nitrates Directive which covers a large part of the area under consideration. The problems are partially reduced by the use of the digestate, in fact, the calculation of the nitrogen supply to the substrate is strongly reduced on the basis of what is indicated in Annex IX of the D.I. 5046/2016. Moreover, from this adhesion to the circular economy process, the farmer would have an undoubted advantage in economic terms, considering that he would reduce the cost item related to the purchase of fertilizers, taking into account that the digestate is considered, by the current legislation, such as a fertilizer for all legal purposes (art. 26 of DI no. 5046/2016).

• Obtaining a portion of company profits generated by the recognition of the incentive for the government injection of electricity on the national grid amounted to 246 euro / MW.

In reference to the decree referred to above, pursuant to Art. 1 paragraph 1 the anaerobic digestion of the "residues of the agri-food business" (defined according to the letter "c" paragraph 1 article 3) produces a digestate as per paragraph 1 art. 22, which may have an agronomic use pursuant to articles 5 and 26, to be understood in all respects a fertilizer, a soil conditioner whose contribution in terms of nitrogen is calculated with the criteria described in annex IX. In particular, if a total annual profit of 306,819.89 euros is assumed in the management of the cooperative plant, the per capita quota recognized to a producer that confers the

biomass equal to 136 tons deriving from the pruning of 6.5 ha, is 3.068, 20 euros, or, 2.26 euros/ql of conferred cladodes. To this it must be added the fertilizer equivalent recognized per capita, in particular, will be awarded annually to the individual producer, about 120 tons of liquid digestate and 16 tons of solid digestate, this value is to be considered approximate, given that it must be reduced by the value of biogas produced multiplied by its density (see Annexes to DI 5046/2016 compared to the characteristics of the digestate to object). We must consider that to imagine the digestate an excellent fertilizer, this must satisfy the indications contained in the Law 784/84, moreover, in the case in which the same is intended used in organic farming, it is necessary to comply with the provisions of the regulation EEC 2092 / 91 and the circular of the Ministry of Agricultural Policies of 13 September 1999. However, in both cases the usage limits are 170 kg / ha / year in the vulnerable zones for nitrates and 340 kg / ha / year in the remaining areas.
The importance of digestate as a fertilizer is so overt that in some countries, such as Germany, where the digestate bag was born, designed and implemented by some operators of plants falling in a limited and contiguous area, united in associative form, such scholarship is managed by an organization called Maschinenring.

5.4.2.2. Economic validation of procurement costs for prickly pear cactus biomass by ad hoc construction

To estimate the pruning and the higher costs made by the storage of biomass, a questionnaire was prepared and

administered to ten different active operators operating in the area under study. The operators, in order to respond analytically to the questionnaire, set up a worksite in their company to calculate the higher costs.
From the analysis of the questionnaires, it emerged that as a rule a prickly pear entrepreneur who manages a specialized installation, with an average incidence of 300 plants / ha, for pruning operations bears costs of about 300 euros / ha. The activity is carried out with the help of four workers per day. The amount of biomass pruned daily amounts to 15,000 kg, so it follows that the incidence of pruning costs that the operator regularly incurs every year amounts to 2 euros / ql.
The results of this experience in the field, conducted in a specialized installation, revealed that in the framework of a working day in which two pruning workers were engaged and two additional workers for half a day, whose a worker assigned to support the pruners and to the storage on the field of biomass, another worker assigned to the storage, through the aid of a mechanical means and a means for short-range transport, the quantity of biomass assignable is 7,500 kg / day.
The work experience has shown that these "higher costs" would amount to around 1.0 euro / ql, while in relation to the business profit for the single prickly pear operator participating in the process, this is to be counted for the difference between 2.26 euro / ql of dividends and 1.0 euro / ql of higher costs, that is, 1.26 euro / ql of net profit for the company for an additional service that the multi-purpose prickly pear company participates in it.
This means that the installation management should not assume any economic burden in the raw material

procurement phase, even if in the income statement of the case study, as we shall see, it will still be considered an annual emergency budget for any procurement costs for other raw materials and services digested disposal.

5.4.2.3. Technical features of the installation and its related investments

The cogeneration installation considered, it has a power of 300 kW and produces 2.4 million kWh of electricity per year (tab. A). It is made in association between local producers, through a network contract and, therefore, represents a part of the phases of the supply chain external to the actual energy transformation process. The installation choice with these small power characteristics is dictated by the fact that the government incentive proves to be more advantageous to below this threshold (246 EUR / MW - Electrical Services Manager or GSE for two decades). It is therefore predictable that this represents the type of installation that is most widespread in the region.

Tab. A - Dati tecnici del progetto di impianto di biogas a prevalente matrice ficodindicola (2018) (*)

Dati cogenerazione	valori	unità
Potenza introdotta	780	kW
Potenza elettrica	299	kWe
Potenza termica	342	kWt
Rendimento elettrico	0,383333333	%
Rendimento termico	0,438461538	%
Rendimento globale	0,821794872	%
Giorni lavorativi anno (manutenzione)	335	g
Ore lavorative anno	8040	h
Produzione annua di energia elettrica:	2.403.960,0	kWe/h
Produzione annua di energia termica:	2.653.000,0	kWt/h
Consumo combustibile (Biogas 53% CH4)	140	Nm3/h
Consumo combustibile anno	1.125.600,0	Nm3/anno

(*) Nostre elaborazioni.

The installation is destined to operate for 335 days / year, net of the maintenance period and, therefore, for over 8 thousand hours / year. Examining the technical laboratory analyses, a diet compatible with the availability of vegetable waste and / or residues available in the area has been hypothesized, made up of 85% cladodes of prickly pear, 10% of pulp and the remaining 5 % from oil pomace (tab. B).

The total biomass volumes required for the plant to function thus amount to 13.6 thousand t / year of cladodes, 1.6 thousand t / year of pulp and 0.8 thousand t / y of pomace, while the expected yield in biogas amounts to approximately 140 mc / h of biogas for an equivalent of 7,200 kw / day, this energy is managed in the first phase inside a company booth and then passes into two Enel cabins which are assumed to be placed directly on the electricity grid .

Tab. B - Piano di alimentazioe giornaliero dell'impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

	2	ton/h
TOTALE BIOMASSA	47	ton/g
	16.000	ton/anno
Resa in biogas (53% CH4)	75	Nm3/ton
Produzione combustibile (Biogas 53% CH4)	1.200.000	Nm3/anno
Cladodi e altro fico d'india (85%)	13.600	
Pastazzo (10%)	1.600	ton/anno
Sansa (5%)	800	

(*) Nostre elaborazioni.

During the design stage, the storage phase of the different matrices that make up the diet was the object of particular attention to favour, on one hand, the inclusion in the production system of all the players in the supply chain and, on the other, to contain investments in ad hoc structures.
For these reasons, considering a supply calendar of the raw material, because of seasonal availability it was foreseen that, during the year, the moment of maximum accumulation of the raw material is represented by the month of November, moment in which most of the cladodes deriving from autumn pruning are available, estimated at around 10,000 t / year, to which must be added the quantities of two-phase pomace to be pitted.

Therefore, considering this (10,000 t) the maximum storage limit, the suitable structure - in the design phase - has been provided consisting of an iron roof, with a minimum height of 7 m and a maximum of 9 m, which amounts to a covered area about 1500 square meters (tab. C). The investments are completed with two 200 m3 insulated collection tanks for storing the pulp, as well as various systems and equipment.

Tab. C - Caratteristiche generali e configurazione dell'impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

Investimenti	n.
Silo biomassa (50 mc)	2
Alimentatore biomassa	1
Frammentatore miscelatore	1
Fermentatori: Ø 18 - h 6 m	2
Post-fermentatore: Ø 24 - h 6 m	1
Sala pompe	1
Trattamento biogas	1
Torcia	1
Cabina d'allaccio	1
Cogeneratore 300 kW	1

(*) Nostre elaborazioni.

Analysing in details the process, this starts with a "preload" phase in which the biomass inserted in the containing tank and the one inserted in the mixing tank pass into the "biopalper" which mixes and weighs the biomass as well as eliminating - with membrane aid - the inorganic sulfur

component. Such diet before being inserted in the hot digester (mc. 2,280) passes inside a shredder that homogenizes the biomass. Inside the hot digester the temperature must be kept between 38-40 ° C, in order to ensure that intervenes an intercooler system, fed by the hot water coming from cogenerator.
The cycle inside the hot digester lasts on average about 30-35 days, within this time the bacteria perform their function; the methane collected is deposited in the upper part of the digester while the solid digestate precipitates down, inside, for a correct life of the microbial mass, the pH must be kept on basic values 7.5-8, conditions, of course, are anaerobic, while beneath the digester there are collection tanks that rise to the safety function in the event of leakage of sewage. In the top part of the digester there is a safety valve that has the function of venting if the internal pressure reaches the safety limits.
The liquid and volatile phase produced in the hot digester at the end of the cycle passes to the "cold digester" (300mc.) Inside which the biogas is separated from the liquid digestate, the first, passing through filters that eliminate organic sulfur, this being tolerated by law within 2.5%, while the second is received in two collecting tanks of 1000 mc each, around which containment tanks have been set up for safety purposes.
The liquid digestate is partly used to bring the diet used inside the hot digester to volume, as it should contain a dry substance between 30-35%. The ratio between dry substance and volatile substance is maintained around a value of 3.

From the chemical point of view the biogas produced by this installation of this kind provides approximately the following values:

- 67.3 % methane
- 2,8% H_2S
- 32,48% CO_2
- 0% O_2

It is important to note that the CO_2 that escapes from the process is the same fixed by the plant in nature during the phase of the chlorophyll photosynthesis process.
It is evident that this type of biogas has a purity of 53%, to be able to commercialize the digestion result as biomethane this purity must be around 98%, although we are waiting for the GSE guidelines to be published, this process can be achieved by providing an additional component that carries out the up-grutting process, with an investment of around 150,000 euros.

5.4.2.4. Economic evaluation

The cost structure was subdivided into the items relating to the initial investment (planning, plant cost and cost for ancillary works), which were accompanied by the annual ordinary and extraordinary management costs that were kept constant throughout the period considered, as well as the financial costs.
According to investments (tab. D), over 50% are represented by building works (including the construction of a fermentation reactor), followed by electrical installations

(23%), also necessary for the establishment of an internal cabin for the electrical energy storage, in view of its transfer to cabins of the national electricity manager and to various mechanical installation (20%).
To support the total investment, amounting to 2.45 million euros, an external financing was envisaged with the use of the bank loan at a rate of 5% for a period of 15 years. The period considered takes into account both the useful life of the installation and the duration of access to the GSE incentive rates.

Tab. D - Principali investimenti nell'impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

Indicazioni	Valori Euro	%
Opere edili	1.300.000,0	53,1
Impianti meccanici	500.000,0	20,4
Impianti elettrici	570.000,0	23,3
Altri costi	80.000,0	3,3
In complesso	2.450.000,0	100,0

(*) Nostre elaborazioni.

Regarding the ordinary maintenance costs we refer to the expenses necessary to carry out all installation control and management operations (tab. E) In the case study, a unit maintenance cost of € 0.01 / kWh was used. As for extraordinary maintenance of the installation and the CHP it has been considered a unit cost of 0.006 € / kWh, as well as usually reported in the literature.

The total cost of ownership is thus amount to over 160,000 euros / year; the individual items are affected by this, especially for staff (37%), disposal of liquid digestate (approximately 29%) and ordinary maintenance (19%).

Tab. E - Costi relativi all'impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

Indicazioni	Valori		%
	Euro	%	
Costi di gestione e di esercizio	*160.503,8*		*44,8*
Gestione (personale)	60.000,0	37,4	
Costi eccezionali materia e servizi di trasporto	10.000,0	6,2	
Smaltimento digestato liquido	46.080,0	28,7	
Manutenzione ordinaria	30.000,0	18,7	
Manutenzione straordinaria	14.423,8	9,0	
Incidenza sulla produzione di energia (Euro/kWe/h)	*0,067*		
Costi finanziari	*197.500,0*		*55,2*
Ammortamento (20 anni)	122.500,0	62,0	
Oneri economici e finanziari	70.000,0	35,4	
Altri oneri	5.000,0	2,5	
Incidenza sulla produzione di energia (Euro/kWe/h)	*0,082*		
In complesso	**358.003,8**		**100,0**
Incidenza sulla produzione di energia (Euro/kWe/h)	**0,149**		

(*) Nostre elaborazioni.

From the table it is clear that the costs of supplying the raw material and transporting are irrelevant.
As we stated in the previous pages, the supply of biomass follows the production and transformation cycles that generate them; some components are purchased, for others only the cost of transport is provided and others are free. In

particular, the pomace from two-phase plants is purchased and, if not pitted, it is necessary to provide the pitting device inside the installation where the peanut will be resold for wholesale heating use. To be sure of the costs, we have to consider that the pomace is paid 36 euros / t ex-biomass plant, while around 200 euros / t ex-works are obtained from the peanut, so according to the net costs, the sale of the hazelnut compensates the necessary expense to peg the pomace, the difference between the pomace content is around 10,000 euros.

From this derives a cost for the biomass from which this installation is annually nourished equal to:

• € 0 for cladodes as conferred by the shareholders
• € 0 for the free pulp biomass installation
• 10,000 euros for the free pomace from the biomass installation

The digestate management poses to the factory various problems and consequent related costs, as it is largely demonstrated in the literature, relating to the final transportation of the digestate (becoming an additional expense chapter), to the enhancement of the fertilizing and soil improver power and to the production, through the separation of two distinct phases, of a palatable solid fraction and a clarified liquid.

In the installation there is the presence of 1 fixed and 1 part time work unit, as well as 1 figure in charge of finding the raw material, with a commission fee compared to the results deriving from its function. Maintenance is important because the mechanical components are subjected to continuous stresses. Revenues are given by profits from the sale of electricity and the sale of solid digestate and respectively amount to over 650 thousand euros (tab. F).

Tab. F - Ricavi dalla cessione di energia elettrica da un impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

Indicazioni	Valori Euro	%
Tariffa incentivante, €/MW	*246*	
Produzione annuale, kWe/h	*2.403.960,0*	
Cessione omnicomprensiva elettrica	537.612,9	82,7
Cessione energia termica	54.000,0	8,3
Cessione digestato solido	38.400,0	5,9
Altri ricavi	20.387,0	3,1
In complesso	**650.399,87**	**100,0**

(*) Nostre elaborazioni.

The energy produced is paid by the GSE through the energy account which provides 0.246 euros / kw for a daily total of 1,880.59 euros / day. The digestion results are electricity sold to 0.236 € / kw, the heat for which there is an increase of the incentive for further € 0,010 / kw, the solid and liquid digesto on which the company makes a one-off sanitary controls for traceability for the purpose of entering the agricultural production process as fertilizer. Following the analysis of the

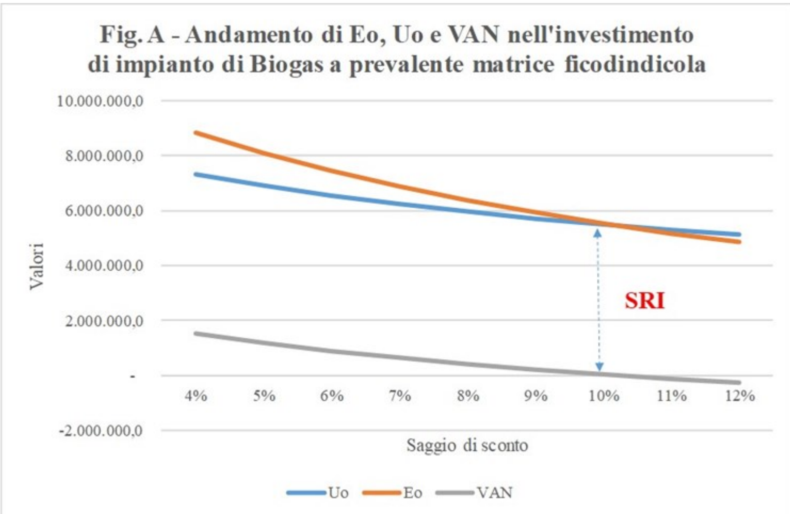
economic criteria, through the study of cash flows it is clear that the NPV depends not only on the benefits and costs but also on the discount rate chosen. The value of the discount rate would indeed indicate the so-called opportunity cost of capital and it represents the costs supported by the contractor to finance the initiative. In this case the rate of opportunity is chosen equal to 3% (rate of return in the medium-term bonds issued by private companies with low-risk).
The project hypothesis is generally economically worthwhile since the NPV value is positive (therefore the project generates value), confirming the feasibility of the installation to its realization The remuneration is, however, determined by the all-inclusive tariff (€ 0.246 / kWh) provided for this type of installation as well as by the availability, for free, of the prickly pear biomass and the limited transport costs, the prerogative of the short chain. (table G).
All these factors set the conditions for the development of the sector at the local level. And this is made possible also because the management of residual pruning biomass does not currently constitute a special "waste" to be disposed of pursuant to current legislation in Italy, because actually it is generally buried after having been shredded. The proposed network contract, on the other hand, aims to reward the availability of biomass by obtaining a counter value represented by the excellent fertilizer / soil improver which is the solid digestate.

Tab. G - Indici economici di valutazione dell'investimento per un impianto di Biogas a prevalente matrice ficodindicola (2018) (*)

Indici	Valori
VAN, Euro	1.844.771,01
Internal Rate of Return, %	10,0
Margine Operativo Lordo, euro	489.896,87
Margine Operativo Netto, euro	197.500,00
Utile/perdita esercizio, euro	292.396,87
Return On Investment (ROI), %	8,1
Return on equity (ROE), %	19,5
Return on sales (ROS), %	30,4
Payback period, anni	6,8

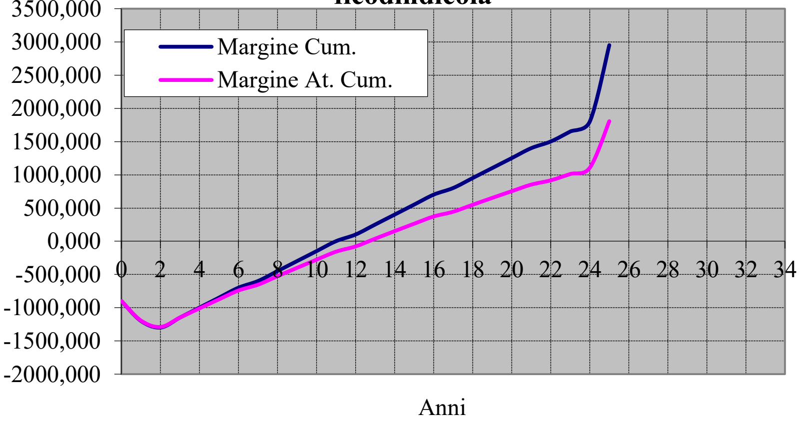
(*) Nostre elaborazioni.

Another index used is the internal rate of return (IRR) represented by the value of the discount rate that cancels the NPV (fig. A). In the case of investments in the agro-energy sector, such as the one examined, it is usually the biomass price fluctuations that expose the entrepreneur to risk. The higher rate of return, lower is the recovery time of the investment. As can see from the tab. G the TIR assumes positive values and it confirms what is shown by the NPV, compared to updated entries and exits. In this case, on the 10% IRR value the liabilities due to the long-term depreciation (20 years), the financial charges connected to the interest on mortgages and the annual margins, derived from the collection / disbursement ratio, have a significant impact.



Another comparison criterion is provided by the calculation of the return time (PBT Pay-Back Time); from fig. B shows that the time required for full recovery of the investment is 6.8 years.

Fig. B - Curva di rientro del capitale investito nel progetto di impianto di Biogas a prevalente matrice ficodindicola



Looking at the economic profitability ratios used in professional practice, it emerges that the return (percentage) of the investment (ROI) amounts to 8.1%, value that must be compared with the average reference values of the same energy sector, as well as the return on net invested capital (ROE) is 19.5%, far above the returns on alternative investments, such as government bonds (BOT, CCT or others). Finally, the project's ability to generate net profits on sales (ROS) is particularly high (over 30%).

5.5 Conclusion

In conclusion, the tests carried out on the digestion of prickly pear that has a high methanogenic value equal to 240 mc / ton, in the overall scenario, assumes an important value from

the point of view of economic validation of the planned installation located in the south-west Etna. This leads to the conclusion that prickly pear cultivation can take this opportunity by focusing on the organization of the energy supply chain, both by developing the short supply chain and therefore a virtuous process in full autonomy, and by signing supply chain agreements with energy entrepreneurs.
For such a project, finding 13.6 thousand tons of prickly pear biomass means creating an energy supply chain to which they give well 500 hectares of fig trees, that is 50 companies considering an average unit width of 10 hectares. At the same time, it is useful to underline that rural development policies can favour corporate investments through measures devoted to the financing of companies, individually or in partnership, for the creation of micro-installations aimed at favouring the diversification of production and the competitiveness of companies.

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ANNEX

SURVEY:

- Survey: bioenergy monitoring - prickly pear farm of the south-west etnea side

- Survey: willingness to set up a district-type biogas production installation and analysis of the reports

BIOENERGY MONITORING - PRICKLY PEAR FARM OF THE SOUTH-WEST ETNEA SIDE

1) Company Name ………
2) Location ....
3) Geographical coordinates of the company
4) Company organization …………
5) Total company surface ……… .Ha
6) Distribution of the surface in relation to the different crops implemented and age differentiated pruning by plant type:

Cultivation/Crop	SAU (ha)	Type plant	Age plant	Sixth plant or number of plants	Pruning period Ordinary	Pruning quantity (tonn/ha)	Pruning period Extraordinary Average	Pruning quantity Average (*) (tonn / ha)

7) Quantity and type of waste from processing into mustard, jam, juice, liqueurs, etc:

Type of scrap	Quantity (tons)	Destination	Value (euro/ton)	Disposal cost

				(Euro / tonne)

8) Cultivation technique adopted (fertilization, irrigation, etc.) irrigation, manure fertilization, pruning

9) Accessibility of the company (road network etc.) accessibility from the municipal road

10) Fruit production breakdown according to the type of plant:

Cutlivation/Crop	SAU (ha)	Type plant	Age Plant	Sixth plant or number of plants	Total Amount (tons) 2016/2017	Quantity pro quota (Kg)2016/2017

11 Breakdown of the pruning costs:

Operazione colturale	SAU (ha)	Type plant	Age Plant	Applications n. hours / ha	Cost Eur / ha	% Impact on total costs (*)

12 Transfer phase to the commercial conditioner chosen by the company:
Commercial Conditioner Name ……………………………

Location ....
Geographical coordinates of the installation ……………………

13 Marketing costs:

Type of scrap	Quantity (tons)	Destination	Value (euro/tons)	Disposal cost (Euro / tonne)	Cost (euro/km)	%Impact on Disposal Cost

Catania ………………..

The Detector
Dr- Carmelo Danzì

Department of Agriculture, Food and Environment (Di3A)
University of Catania

PhD in "Agriculture, Food and Environmental Science"

Survey form of the willingness to set up a district-type BIOGAS production installation and analysis of the reports

1 objective to understand if there is a will of the companies (of prickly pear or not, depending on the ration we are studying) of a territory to join the project
2 objective to understand if there exist between the companies of the territory "formal" or "informal" relationship systems that can be called into question for the realization of the project (even in the absence of an explicit will)

Method Social Network Analysis

1. COMPANY DATA

1.1. General data

- Denomination ____
- Contact person ____
- Extent, ha ____
- Production Field:

□ Prickly Pear □ Zoo-tecnichal ________ □ Olive □ Viticulture
□ Arable □ Oil Mil □ Cheese factory □ Other ___________

1.2. Produced productions

- Main productions and destinations ______________________________________
- Reference market for the main products (percentage):

□ Local, ___% □ Other areas of the region, ___% □ Other Italian regions, ___%
□ Foreigner, ___%

1.3. Secondary activities of diversification of corporate income

□ Agri-food Transformation
• Company agricultural products
• Products from other farms ____

□ Other handicraft productions (indicate) ____
□ Direct sales in the company ____
□ Tourist activities ____
• Tourist hospitality _______________ n. beds _______________
• Agritourism catering _______________ n. covered _______________
• Other forms of hospitality _______________ n. places _______________
• Educational / social farm ____
• Other ____
□ Energy production ____

1.4. Enhancement of the main production

• Is production protected by quality brands? □ Yes □ No
• If yes, indicate the type of brand:
□ EU trade mark □ Collective territorial mark □ Certified organic production □ Certified production process □ Own brand □ Other
• Has the introduction of the quality signal introduced changes to relations with the market? □ Yes □ No
• If yes, which ones (put in order of importance):
□ Changes in contracts (with previous customers)
□ Changes in the composition of the demand (different customers)

□ Increase in demand (increase in the quantities demanded)
□ Increased demand (increase in customers)
□ Expansion of the market area

2. SYSTEM OF ACTIVATED Relationships

• Short description of the supply chain organization in which the company operates
□ Direct channel ______________________________
□ Short channel ______________________________
□ Long channel ______________________________
• Critical stages of the supply chain
□ Between farmers and input providers
□ Between farmers and first processing
□ Between first and second transformation
□ Between last transformation stage and wholesalers
□ Between wholesalers (or last transformation) and retailers (traditional retail and supermarket chains or hypermarkets)

• Geographic location of suppliers (in% on the value of supplies)
□ Local market □ Regional market □ National market □ International market

• How long have you been transacting with the same counterparty?
□ <1 year □ 1-3 years □ 3-5 years □ 5-10 years □> 10 years

• Did you first trade with others? □ Yes □ No
• If yes, why has it changed?
□ Adverse economic conditions
□ Unfavorable delivery / payment times
□ Opportunistic behavior of the counterparty
□ Other

• Do you find a climate of collaboration with other companies, both agricultural and at other stages of the supply chain in the area?

	With agricultural companies	With suppliers	With distributors	With transformers
Yes	□	□	□	□
No	□	□	□	□
Not always	□	□	□	□

Are you part of associations / networks of operators active in the area? □ Yes □ No
If yes, indicate
□ Cooperative □ Producer association □ OOPP □ Protection consortium □ Other association forms of the agri-food supply chains

Reasons (**Assign a value from 1 = none to 5 =highly defined relationships**)
• Exchange of raw materials _______________
• Traditional subcontracting of processing _______________
• Exchange of semi-finished products _______________
• Exchange of services _______________
• Exchange of strategic information _______________
• Exchange on product development _______________
• Exchange on technological advances

Form relationships (assign a value of 1 = none to 5 =highly defined relationships)

• Occasional relationships with other subjects in the supply chain _______________
• Annual formal contracts with another company _______________
• Informal annual (verbal) contracts with another company _______________
• Formal multi-year contracts with another company _______________

• Informal multi-year contracts (verbal) with another company _______________
• Membership in an association or cooperative _______________
• Other (specify) _______________

• Strength of relationships (Assign a value from 1 = none to 5 = highly defined relationships) __

• Duration of relationships (Assign a value from 1 = none to 5 = highly defined relationships) __

3. ENERGY PRODUCTION

3.1. Does the company already have a supply of renewable energy plants (both for sale and for re-use in the company)? □ Yes □ NO

• In case of answer Yes indicate the type of system by type of energy source

□ Wind □ Biomass - including biogas □ Solar □ Other renewable energy sources (specify …………………………)

• How long have you diversified your income sources in terms of energy?

□ <1 year □ 1-3 years □ 3-5 years □ 5-10 years □> 10 years

• The human resources involved in extra-agricultural activities are:

□ Only the tenant and his family members

□ The tenant, his family members and other collaborators

□ Exclusively non-family labour

• Who manages mainly this activity? ________________________________ (eg. The son, the entrepreneur, external labor, etc.).
• The resources used in the activity value (in percentage)
□ Company products ___% □ Products of other companies in the territory ___%
□ Products of other companies in the region ___%   □ Products of other Italian companies ___%
□ Products of foreign companies ___%
• The reference customer for this activity is:
□ Local, ___% □ Other areas of the region, ___% □ Other Italian regions, ___%
□ Foreigner, ___%
• What is the incidence of specific costs related to energy production?

Indicate the% of costs with respect to turnover

3. 2. Willingness to join a project / installation for the production of biogas
□ Yes □ No

• Plant biomass production dedicated and / or finalized to the digestion process
□ Pruning waste _____t □ Channel cleaning _____t □ Street cleaning _____t
□ Grassy patches _____t Mixed _____t

• Biomass of animal origin
□ Dejections of bred animals (cattle, pigs, poultry) _____t □ Livestock waste _____t
□ Other _____t

• Processing waste
□ dry processing residues (hazelnut shells) _____t □ pomace, husk and marc_____t□ wet processing scraps (skins and fruit and vegetable waste) and waste _____t

Production period
□ Spring □ Summer □ Autumn □ Winter

• Duration of production in the season
□ 3 months □ 2 months □ 1 month □ 3 weeks □ 2 weeks □ 1 week

• Total / annual quantity of biomass produced, t ________________________________

• Biomass treatments:
It is available for transport on their own to the composting center? □ Yes □ No
Is it available for the free transfer of biomass? □ Yes □ No
He is available to pay for the transport of biomass to the center
of composting? □ Yes □ No
Are you available for temporary storage at your company?
□ 3 months □ 2 months □ 1 month □ 3 weeks □ 2 weeks □ 1 week
Current utilization of biomass ____

3.3. Feasibility of the biogas installation

• In the neighbourhood, do you know anyone who is interested in providing livestock waste, by-products or residues?

□ Other livestock farms ____

□ Schools or catering companies (food / kitchen waste) ____________________________

□ Agri-food companies (industrial organic waste) ________________________________

□ Other ____

• Evaluation of transport
□ How is the quality of the infrastructure around your company? ________________________
□ Can trucks freely use these roads? ___________________________________
□ How much the logistics will affect (EURO / year) and will be worth it (normally a journey of less than 18 km ensures profitability) ____

• Purpose of the project
□ Have you ever determined the energy consumption of your company / home? ____________
□ Are there biogas sales opportunities nearby? ______________________________
□ Have you ever been informed about prices, incentives, conditions? _____________________
□ Have you ever thought about how to transport energy? ________________________________
□ Have you identified the people who could take part in this project? ________________
□ Have you ever discussed about each other's involvement and responsibility? _____________

4. JUDGMENTS ON BUSINESS, PROFIT AND ENVIRONMENTAL ISSUES

• To what extent do you feel the severity of the following issues (Score 1 = unimportant - 5 = very important)
o Limited profitability due to the reduced average company size _______
o Abandonment of the territory in disadvantaged areas due to difficult living conditions _______
o Exhaustion of soil organic matter and water scarcity _______
o Pollution of soil and water _______
o Reduction of agricultural land use
o Impact of climate change on agricultural systems _______
o Biological and chemical contaminants in agricultural products _______
or Alien plant and animal species _______
o Diversification of rural income _______
o Increasing the added value of local products through the sustainable development of agriculture and food production locally _______
o Identification, protection and enhancement of local biodiversity, of agricultural eco-system services with reduction of land degradation _______
o Enhancement and reuse of agricultural residues for the production of bio-products and bioenergy _______

o Entry of young and experienced farmers into the sector thanks to new income opportunities _______

o Increasing the share and productivity of organic farming and breeding _______

o Adoption of adaptation measures to climate change (for example crops with lower water and fertilizer demand, use of local varieties, medium-long term planning) _______

or other ____