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Anaerobic co-digestion plants: a case study in the Province of Udine

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Abstract. Sustainable development, limiting the negative impact of human activities on the environment, has become a critical concern for those working in the energy field. In this sense, there is a strong interest in alternative energy sources, in the re-use of waste materials, and in the reduction of greenhouse gas pollutants. The process of anaerobic co-digestion, the anaerobic digestion of two or more types of substrates, is a promising technology in this sector. This study examines a selected district in the Province of Udine, with the aim of establishing two treatment plants in co-digestion for the following types of substrate: sewage sludge and the organic fraction of municipal solid waste.

Key-words. Anaerobic digestion, organic waste, sludge treatment, energy conversion park.

1. Anaerobic digestion. Anaerobic digestion is the biochemical transformation of complex organic substances in an oxygen-free atmosphere. These substances are degraded until they are converted into solid matter and a gas (biogas). Digestion takes place in four successive stages: hydrolysis, in which extracellular reactions catalyze the liquefaction of putrescible materials and hydrolyze simple carbohydrates, proteins and fats; acidogenesis, where the products of the previous step are converted by the action of intracellular enzymes into volatile acids, acetic acid, carbon dioxide and hydrogen; acetogenesis, in which the volatile acids are turned into acetic acid; and finally, methanogenesis, which consists in the reactions leading to the

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formation of biogas (Visamara 1998).

The bacteria that take part in the different phases can be facultative or obliged anaerobes. These microorganisms are able to reduce the organic compounds and can be acidogenic or methanogenic (Visamara 1998). They are linked by a trophic chain in which the resulting products from a degradation stage are the substrate for the next stage (Bonomo 2008).

The main parameters that influence the metabolism of the microorganisms, as well as the digestion process, are temperature, pH, presence of short chain fatty acids, and C:N ratio. The speed of reaction governs the process, so temperature is a very important parameter that must be taken into account. The digestion reactors can operate in psychrophilic (temperature lower than 20 °C), mesophilic (between 20 and 40 °C) and thermophilic conditions (higher than 50 °C) (APAT 2005). Regarding the pH, the optimal pH range for the digestion process is very narrow and corresponds to values between 6.8 and 7.2 (Ward et al. 2008). Each phase is also characterized by a specific optimal pH range, so designers usually prefer to opt for the separation of the process in two stages: the hydrolysis-acidification stage and the acetogenesis-methanogenesis stage. Short chain fatty acids are intermediates of reaction and their production alters the pH in the reactor, negatively affecting the methanogenesis phase. The C:N ratio refers to the content of nitrogen present in the substrate: an excess of nitrogen can have toxic effects while a deficiency indicates a lack of nutrients (Ward et al. 2008).

The substrates sent to the digestion phase are the organic fraction of municipal solid waste, i.e. the immediately degradable fraction of municipal waste consisting of kitchen waste, food waste, grass and garden waste; sludge from wastewater treatment plants (by-products of the physical, chemical and biological processes to which wastewater is subjected in wastewater treatment plants); agricultural waste and organic waste from the food industry (yard trimmings, crop residues, scraps of food production); dedicated energy crops and finally agricultural livestock effluents.

The digestion process can also be distinguished taking into account the solids content (TS, total solids) that characterises the treated substrates. Three types of processes can be identified: the wet process with less than 10-15% TS, the semidry process with around 15-20% TS, and the dry process with a TS between 20 and 50 % (APAT 2005).

2. The research. The study focuses on the concept of Energy Conversion Park (ECP). As defined in a research carried out in Belgium and Denmark, an ECP is a site where the synergistic and multidimensional conversion of the locally available substrates takes place. The ECP is equipped with a set of technologies for the conversion of the substrates into energy. The use of local origin substrates and their conversion into energy or products, which can be used in the same region where the plant is, contributes to lim-

Table1. Required conditions for anaerobic digestion (Dornak 2012).

Parameter	*Hydrolysis/acidification*	*Methane fermentation*
temperature	25-35 °C	mesophilic: 35-40 °C thermophilic: 52-57 °C
pH value	5.2-6.3	6.7-8.2
C:N ratio	10-45	20-30
solid matter content	< 40% dry matter	< 30% dry matter
redux potential	< +400, > -300 mV	< -250 mV
nutrient demand C:N:P:S	500 : 15 : 5 : 3	600 : 15 : 5 : 3
trace elements	no specific requirements	essential: Ni, Co, Mo, Se

it the use of fossil fuels, reducing the emissions of greenhouse gases, the costs of energy production, and those of managing the waste materials. The design of an ECP includes the following steps: localization of the plant, detailed analysis of the region in terms of substrate available from the various sectors, estimation of the local demand of energy, formulation of ideas about the practical realization of the ECP, assessment of technical and economical aspects and business plan (Guisson et al. 2012).

2.1. The co-digestion plant. An anaerobic co-digestion plant can be divided into three sections. The first section includes reception and pre-treatment of the substrates received. The reception phase can be performed using a square exhaust satin or an underground pit. Pre-treatments allow to obtain a matrix suitable for the digestion process.

The second section comprises the substrate preparation steps (homogenization, regulation of humidity and temperature) which allow to obtain a matrix with optimal characteristics. This second section includes also the anaerobic digestion itself. The digestion can be influenced by the reactor configuration and depends on various factors that should be closely monitored to ensure successful operations.

For this reason, an integrated approach needs to be planned: appropriate equipment, staff preparation, specialized technical assistance are required in order to ensure the control and compliance of microbial metabolic and growth factors.

The third section deals with the production, purification and use of biogas (APAT 2005). Biogas is composed of 60% methane while the remaining 40% is constituted of carbon dioxide and other gases (Table 2).

The biogas can be used to produce heat and electricity (even in cogeneration) and biofuels. It can also be used as a fuel or introduced di-

Table 2. Biogas composition (APAT 2005).

Components	*Percentage*
methane ($CH4$)	55-65%
carbon dioxide ($CO2$)	35-45%
hydrogen sulfide ($H2S$)	0,02-0,2%
water vapor	saturation
hydrogen, ammonia	traces
oxygen, nitrogen	traces

rectly into the grid (Figure 1). Before its use, it is refined with desulphurisation and dehumidification.

Finally, the slurry produced can be used in its liquid component and in its solid part, both rich in nutrients and used as fertilizer or culture medium.

3. The case study. The study consists of a survey carried out at local level that includes the estimation of the local flows of substrates, the estimation of the volume of methane that can be produced by co-digestion, the planning of Energy Conversion Parks, the evaluation of the energy produced and finally the estimation of reduction in carbon dioxide emissions.

3.1 The substrates analyzed. The substrates analyzed are the organic fraction of the municipal solid waste (MSW) and the sewage sludge. Regarding the organic fraction of the MSW, the Italian legislation (DPR 915/82, D.lgs. 22/97, D.lgs. 152/06 *Norme in materia ambientale*) requires the re-use of the waste materials generated after primary treatments of cleanup and recycling. The objectives are the reintegration of the materials in the production cycle, the

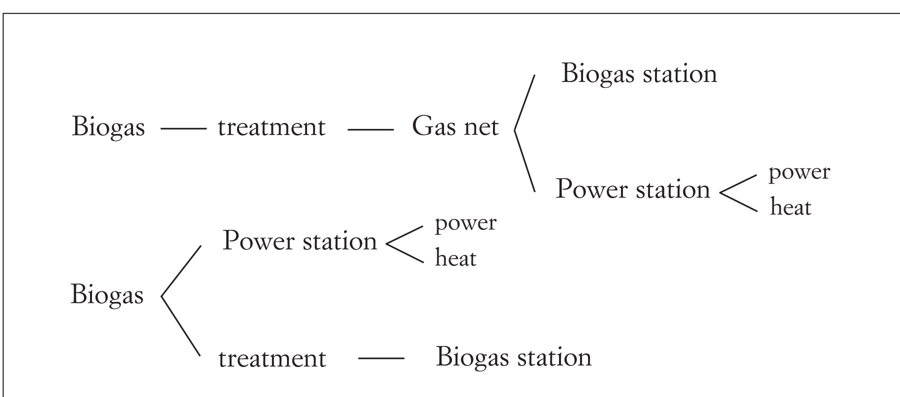

Figure 1. Biogas utilisation options (Dornack 2012).

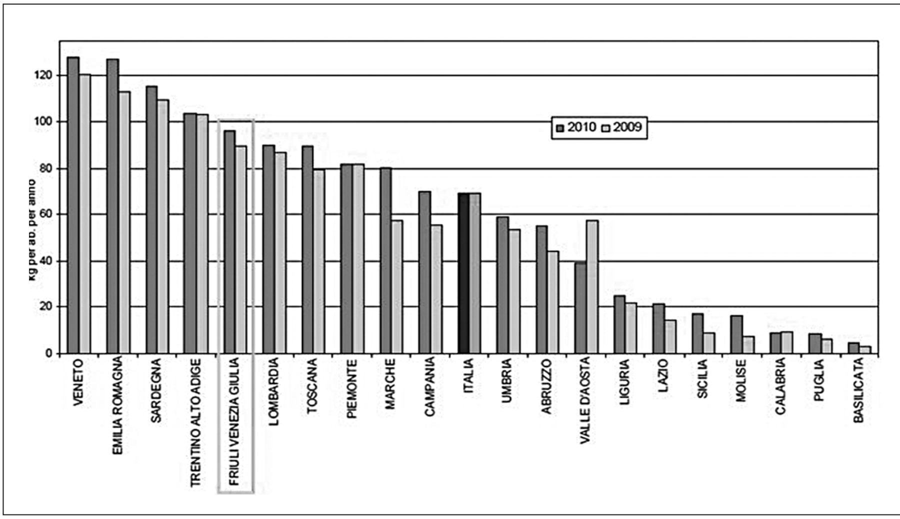

Figure 2. Separate collection of organic waste per capita by region (ISPRA 2012).

separation of hazardous materials and bulky waste and the treatment of fractions of quality. When examining the organic fraction generation rate (nationwide), expressed as kg/(capita year), Friuli Venezia Giulia appears to maintain a production above the national average (Figure 2).

The other substrates of interest are the sewage sludge from plants treating urban wastewater and wastewater from industrial sources. Primary and secondary sludge are treated.

3.2. The territory selected. The areas of Friuli Venezia Giulia considered include Udine and other municipalities in the Province of Udine located to the south of the province itself. The selected area is fairly compact and characterized by a sufficient population density and by the presence of numerous industrial, commercial and agricultural activities. The municipalities selected are (Figure 3) Bagnaria Arsa (8), Basiliano (9), Bertiolo (10), Bicinicco (11), Campoformido (16), Castions di Strada (20), Codroipo (27), Gonars (44), Lestizza (48), Martignacco (57), Mereto di Tomba (58), Mortegliano (62), Palmanova (70), Pasian di Prato (72), Pavia di Udine (74), Porpetto (77), Pozzuolo del Friuli (79), Pradamano (80), Remanzacco (91), San Giorgio di Nogaro (100), Santa Maria la Longa (104), Talmassons (114), Torviscosa (123), Trivignano Udinese (128), Udine (129). The companies in charge of the integrated management service of the waste cycle operating in this area are A&T2000 and Net. The data about sludge from the wastewater treatment plants are from AMGA, CAFC and Acquedotto Poiana.

3.3. Data processing. Taking into ac-

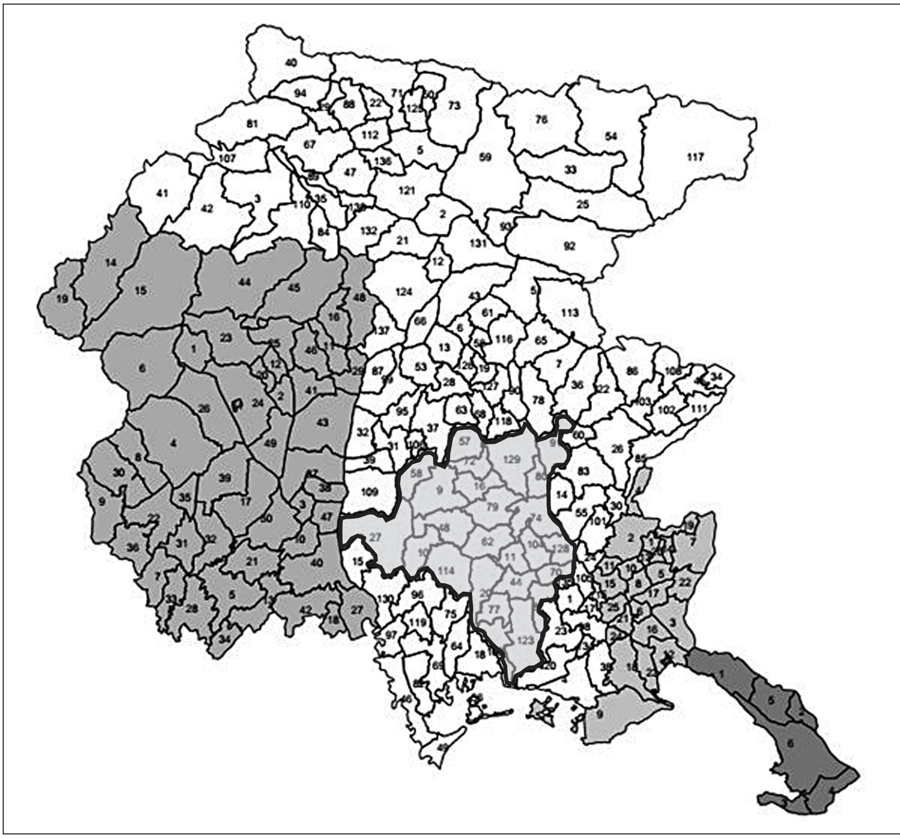

Figure 3. Municipalities selected for the analysis.

count the data on the organic fraction of MSW, two estimations have been made: a theoretical and an experimental estimation. The theoretical estimation refers to the per-capita production on a monthly basis, calculated using data published on ISPRA Waste Report 2012. This production rate amounts to 3.32 kg/(capita month). The practical estimation refers to the municipalities selected and to data supplied by A&T and Net. The latter is greater than the first and equals to almost 5 kg/(capita month). Considering also the sewage sludge, the total substrate locally available amounts to 184558 kg/day, of which 33280 kg of the organic fraction of MSW and 151278 kg of sludge.

3.4. Individuation of possible co-digestion plants. Two possible suitable sites for the treatment of the selected substrates were identified and they correspond to the wastewater treatment plant of Udine and that of San Giorgio di Nogaro. These sites were chosen for the advantages in terms of management that they offer for the post-treatment of the liquid fraction of the digested material. The territory was then divided into two parts corresponding to the areas of Udine and San Giorgio. From data relating to the two areas, the plant located in Udine can potentially treat 168115 kg per day, while the San Giorgio one can treat 16443 kg per day. For each plant the following parameters were analyzed: C:N ratio of the mixture, percentage by volume of organic MSW and sludge in the mixture, TS% (total solids) and VS% (volatile solids) of the mixture. The plant of Udine can receive the waste produced by 186158 inhabitants and the waste flow materials received can be treated using two digestion reactors respectively of 2800 and 952 m^3. The plant of San Giorgio can treat waste from an area of 37188 inhabitants, the flow rate received per day can be digested in a reactor of 383 m^3. The properties of most of the substrates are based on literature values and estimations relating to different types of substrates, including the organic waste fraction and the municipal sewage sludge. For the calculations, it was assumed a methane yield of 300 Nl_{CH4}/kg_{VS} for the organic fraction of MSW and 200 Nl_{CH4}/kg_{VS} for the sludge. The production of methane that was estimated for the two systems is therefore respectively 2834 Nm^3/day in the plant of Udine and 347 Nm^3/day at the plant in San Giorgio. Knowing the methane yields for each plant, it is possible to estimate the energy produced if the biogas is entirely used in cogeneration. From the literature data, it can be assumed that from 1 Nm^3 of methane 2.9 kWh of electricity and 4.9 kWh of heat are obtained. The plant set in Udine can produce 8218 kWh/day of electrical energy and 13885 kWh/day of heat, the San Giorgio one 1007 kWh/day of electrical energy and 1702 kWh/day of heat. The electrical energy obtained from biogas is sufficient to meet the energy demand of 935 families. It should also be noted that the pay-back times for the plants are usually of about 5-6 years.

4. Conclusions. The anaerobic co-digestion of the organic fraction of municipal solid waste and sewage sludge is a process that allows to eliminate and use profitably waste that was previously not exploited. In the selected district, after the evaluation of the available substrates, it was possible to plan two anaerobic co-digestion plants.

The results obtained have shown that it is a satisfactory method for the production of renewable energy and that it also allows the recovery of the digested materials which can be employed in agriculture in accordance with local regulations. It was also possible to estimate the reduction in the emissions of carbon dioxide compared to those of traditional fossil fuels: the reduction amounted to 820 tons per year.

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