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Assessment of the potential energy supply and biomethane from the anaerobic digestion of agro-food feedstocks in Sicily

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ABSTRACT

This article examines the potential of biogas and second-generation biomethane (BM) obtainable from Mediterranean feedstock through a process of anaerobic digestion (AD), within the territorial context of Sicily. An estimation of the amount of biomass that is suitable for AD produced in Sicily has been calculated using a methodology that has already been employed for other territorial contexts, and which takes into account the loss of biomass during harvesting and of that used for livestock feed. Therefore, the estimate was made for the net availability of biomass after losses and alternative uses, in order to avoid conflicts between food and feed. The assessment of the biogas potential has enabled the examination of Sicily's potential in the field of bioenergetics that, today, is little exploited. In fact, Sicily is lagging behind compared to the rest of Italy, both in terms of the number of biogas plants and electrical installed capacity. The study has allowed us to estimate a figure of slightly more than 3.9 million tons per year of feedstock (from whey, pomace, stalks and dregs, olive residue, slaughter waste, pulp, cattle slurry, pig slurry, straw from cereal crops, fruit and vegetable scraps, crops in rotation, crops in the spring-summer cycle, long-term weed crops/shrub biomass) that is capable of producing 255 million Nm^3 of biogas a year that, net of losses and self-consumption, is enough to produce 408072.1 MWh_{el}/year of electrical energy and 305672.0 MWh_{ter}/year of thermal energy. Another alternative could be that of the production of 145 million Nm^3 of second-generation BM to be used, according to recent Italian legislation, for the transport sector or for feeding into the national methane grid.

1. Introduction

The search for alternative sources to fossil fuels represents an undisputed priority on an international scale. This theme contributes in an increasingly binding way to the agenda of policy choices, from the Kyoto Protocol of 1997 to the "climate package" launched by the European Union in 2009 [1–3], until the text adopted at the Climate Change Conference in Paris, COP21, which starts from a fundamental premise: "climate change represents an urgent and potentially irreversible threat for the human society and for the planet". It requires, therefore, "…the maximum cooperation of all countries" with the objective of "accelerating the reduction of greenhouse gas emissions". There are, therefore, environmental, social, and economic motives that are pushing towards the necessity of combining the reductions of greenhouse gas emissions with the need to achieve a future energy independence [4–6].

The advances in the field of research and the remarkable development of sources of renewable energy during the late twentieth century and the beginning of this century have notably transformed the global lifestyle. Energy assumes a strategic role in the achievement of economic and social development, and access to energy sources and independence on the international scene assume a fundamental role in industrial processes [7–9].

There is a direct relationship between the sources of energy and industrial development. Fossil fuels such as oil, natural gas, and coal represent the main sources of energy for the planet, with 32.6%, 23.7%, and 30%, respectively, of global consumption [10].

The wide use of fossil fuels, which are non-renewable, will lead, in the not particularly far-off future, to a sharp downsizing of activity: in fact, oil, natural gas and coal will be exhausted within 45, 60, and 120 years respectively [11], according to recent studies.

For the countries that are energy-hungry and heavily dependent on fossil fuels, this scenario represents a serious political and economic threat that has led these states to make substantial investments and efforts to tap other sources of energy, following the oil crisis of 1970 [12,13].

The international attention over sources of renewable energy has generated an increase in their global consumption which grew by about

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19% in 2012. It is estimated, moreover, that the contribution of renewable energy is expected to further increase to 55–75% of gross final energy consumption in 2050 [14].

Biomass constitutes the principal source of renewable energy worldwide, representing 59.2% of the total "renewables" in the EU in 2015. On a global level, it held fourth place in energy sources after oil, coal, and natural gas [14,15].

Annually, the energy stored in the biomass produced globally, amounts to nearly 8 times the global energy needs, and it is estimated that, practically, it can provide about 10–20% of the energy demand by 2050 [15,16]. Bearing this in mind that, there are strategies worldwide for promoting the production of sustainable bioenergy from agricultural and agro-industrial biomass residues to generate biogas (electricity, heat, and biomethane (BM)) from anaerobic digestion (AD) [17,18].

Great attention has been dedicated to the production of second-generation biofuels, which compared to first-generation ones produced from edible raw materials such as corn and soya whose production competes with human food supply, at least 70% of these are obtained from waste, crop residues and industrial by-products, or from crops in rotation, which therefore do not compete with food. The annual production of agricultural biomass worldwide is about 11 billion tons, and the plant residues and waste of corn, barley, oats, rice, wheat, sorghum, and sugarcane are potentially able to produce 491 billion litres of biofuels per year [17,19].

The countries of North America, led by the US, are the main producers of biofuels, with a 44.1% share of total production in 2014; the Renewable Fuel Standard (RFS) program envisages that about 44.5% of the 36 billion gallons of renewable fuel will be made with cellulosic biofuels, of which approximately 56.9% will come from agricultural residues by 2022. The remaining market share belongs to South and Central America, including Brazil (28.7%), Europe and Eurasia, including the Netherlands (16.5%), and the Asia Pacific, including China (10.6%) [10,20].

The main technologies used to convert the energy stored in biomass are based on biochemical and thermochemical processes. In biochemical conversion (for example, fermentation and AD), enzymes and microorganisms are used to convert lignocellulosic materials in a specific biofuel, while during thermochemical conversion (for example, pyrolysis and gasification), long chain biopolymers of biomass are heated in the absence of oxygen to produce a mixture of short chain hydrocarbons, gaseous products such as hydrogen and methane, as well as solids [21,22].

In this context, among the various available sources of energy, it is considered indispensable to explore the theme of renewables from agricultural sources, from the perspective of the generation of energy for distribution as a tool to activate local development that primarily involves agricultural enterprises. There is a clear awareness that the primary role of agriculture is the production of goods destined directly or indirectly for human consumption, a task that is intended to reaffirm, enhance, and promote. Due to this awareness and attention it is believed that there are opportunities in the production of energy generated by matrices and agricultural products and that it would be wrong to underestimate them, because, if properly directed, they can create opportunities for development and for supporting the income of the enterprises themselves. It has been showed by several studies that, in addition to dedicated cultivation, there are interesting opportunities in the energy market for the by-products and residues of agricultural crops, animal rearing, forestry, and agro-industry [7].

The production of energy through the use of specialised agro-energy crops may represent an ideal strategy for agricultural enterprises to escape from the crisis of the market that periodically affect the agricultural sector. Entrepreneurs can now aspire to new models of production, by including energy crops into cropping systems in rotations and in second harvests, in order to achieve better economic results for the business [23]. Furthermore, the indirect role that these productions may have on environmental components is important (containing emissions, strengthening of natural safeguards to protect the soil, defence against hydro-geological instability, etc.) [24,25].

The methodology used for assessing the potential of the agricultural sector, in energy terms, is without doubt innovative for its content and has examined, firstly, the evaluation of the biomass available in the territory, and secondly, the possibility of introducing crops dedicated to energy purposes on areas of marginal land in the region, for the construction of three possible energy supply chains (the solid biofuel chain, the biogas chain and the advanced bio-fuel one) always in a framework of environmental sustainability and of safeguarding the landscape [7,26,27].

Biogas is produced by AD coming from a range of feedstocks, particularly agricultural residues (e.g. manure and crop residues), energy crops, agro-chains and organic waste [18]. Anaerobic digestion takes place in four stages of reaction: firstly hydrolysis of the substrates; secondly acidogenesis or fermentation with the formation of volatile fatty acids, ketones and alcohols; when acetogenesis starts acetic acid, formic acid, carbon dioxine and molecular hydrogen are formed from the fatty acids; lastly there is methanogenisis when the formation of methane is observed, starting from acetic acid or through the reduction of carbon dioxide using hydrogen as a co-substrate. The types of processes and systems of AD can take place according to two different techniques: a single-stage process with a single reactor or a two-stage process when two separate reactors are present. In the first process the hydrolysis and acidification take place, while in the second one there is acetogenesis with methanogenesis. Furthermore, depending on the feeding of the reactor the following distinction is made: continuous or discontinuous. In Sicily as far as the type of plant is concerned, the most common solution for this type of biomasses is the up-flow digester, completely mixed with a variable number of digesters and post-digesters [2].

Currently, most attention is being given to BM obtained from suitably treated biogas through several processes of upgrading, such as the use of polyetheretherketone (PEEK) membrane that obtains BM usable directly in the secondary grid injection which has a pressure lower than 10 bar. Its properties are similar to those of natural gas and, therefore, it is suitable to be used as a fuel for vehicles, or to be distributed in the urban gas networks [18]. The upgrading of biogas to BM is environmentally sustainable, in terms of GHG emissions and the reduction of NOx and particulate matter (PM) local emissions, compared to what happens in the simultaneous production of electrical energy and thermal [28].

The annual quantity of agricultural biomass and the potential of bioenergy production has been addressed in the literature in different territorial contexts, such as that of the municipality of General Pueyrredón Partido in Argentina [29], in Shanghai and in China itself [30,31], in Europe (including Ukraine) [32], in EU27 [33], the Lawra-Nandom district in Ghana [34], in Nigeria [35], Zimbabwe [36], in Canada [37], in Malaysia [38], in Mexico [39], China [40], in India [41], in Albania [42], in Romania [43], in Egypt [44], in Iran [22], in the Czech Republic [45] and in Italy [27,46–51] analysed according to the different types of biomass such as agricultural residues from agriculture harvesting or processing; industrial waste and co-products, from manufacturing and industrial processes, etc.

According to the latest Agriculture census of 2010 in the Italian agricultural system, Sicily is characterised by the presence of about 220000 agricultural holdings, 14% of the national total, affecting a total land area of over 1.5 million hectares (9% of the national total) and a Utilised Agricultural Area (UAA) of less than 1.4 million hectares (11% of the national total) [52].

The Utilised Agricultural Area in Sicily in 2010 (a total of 1.4 million hectares) was constituted by 49% arable land, 23% permanent grassland and meadows with the remaining 28% by permanent crops and kitchen gardens. The productive allocation of land in Sicily is characterised by the presence of cereals and permanent crops while citrus fruit, olives and vines that distinguish the Sicilian agri-food offer