Energy generation potential in Greece from agricultural residues and livestock manure

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Abstract

Greece is an agricultural country producing a significant amount of crop residues as well as livestock manure. The use of agricultural waste as a major component of renewable energy is suitable for improving energy security and decreasing environmental disruption caused by carbon emissions. Thus, studying the energy generation potential of these wastes is important. The theoretical annual potential of agro-industrial residues (such as wheat products, industrial plants, potatoes, vegetables, olives, fruits, nuts, dairy products etc.) was estimated equal to 30.819.639 tn/y, taking into consideration their annual production and their respective residue production in Greece. Accordingly, the theoretical annual potential of livestock manure, including the residues from animal husbandry in Greece (cattle, chicken, goats, pigs, sheep etc.) was estimated equal to 27.164.112 tn/y. In this study, the possibility of energy production through anaerobic digestion was investigated. Taking into account the biodegradability of the residues, it was estimated that the total 57.983.751 tn/y residues may produce 760.642 tn/y fertilizer and $1,35*10^{10}$ m^3/y biogas. Taking advantage of the energy content of biogas by co-generation of energy and heat, 21,9 TWh/y of electrical energy and 27,0TWh/y of thermal energy could be produced. Given the annual electrical energy consumption in Greece, about 39% of this energy need could be replaced by electrical energy produced from agricultural residues and livestock manure. Conclusively, crop residues and livestock manure may stand as an energy source with significant contribution to the Greek energy balance.

Keywords: anaerobic digestion, biogas, crop residues, electricity, energy, livestock manure

1. Introduction

Greece is located in the east side of Mediterranean Sea, covers an area of 131,940m^2, with a population of around 10.6 million people and is enjoying a moderate growth through the last decades [1-2]. Social, economic and industrial development results in a continuously raising energy-consumption demand. The Greek energy sector is still largely dependent on fossil fuels, most of which are imported. Domestic energy sources include lignite which accounts for around 50% of electricity generation as well as renewable energy sources (RES) such as hydro-power, wind, solar energy and biomass. RES currently account for 13.8 % of gross final energy consumption and a national target of a 20% share by 2020 has been set. Around 61% of Greece's energy needs are covered through imports with the remaining 39% being covered through national energy sources, mainly lignite (77%) and RES (22%). Imported energy sources are mainly petroleum products that account for 44% of total energy consumption and natural gas with a share of around 13%. Gross national electricity consumption in 2012 was 55 TWh, including transmission and distribution losses of 2.9% [3].

Today the Greek energy market is undergoing fundamental reforms. New advanced energy technologies and perpetual environmental issues, requirements arising from European and international cooperation as well as various intergovernmental Agreements are factors shaping and harmonizing the institutional and legislative framework of the Greek

energy market with current tendencies and perceptions. At the centre of this process lies: the liberalization of the electricity and natural gas markets, increased competitiveness, the extension and enhancement of the domestic and cross-border electricity, natural gas and oil networks, the further separation of production and supply from transmission networks, consumer choice, increased share of energy from Renewable Energy Sources, reduced share of fossil-fuel generated electricity, improved energy efficiency, energy saving and the protection of the environment [4]. It is well established that an effective measure to change the national energy map is the substitution of imported energy sources by national resources.

Agro-industrial residues are the most abundant and renewable resources on earth. Accumulation of this biomass in large quantities every year results not only in the deterioration of the environment, but also in the loss of potentially valuable material which can be processed to yield a number of valuable added products, such as food, fuel, feed and a variety of chemicals. The agro-industrial residues have alternative uses or markets. As a common practice, agro-industrial residues including crop residues, forest litter, grass and animal garbage are directly burnt as fuel in developing world. Crop residues are more widely burnt than animal waste and forest litter [5].

Greece is an agricultural country producing a significant amount of crop residues as well as livestock manure [6]. The use of agricultural waste as a major component of renewable energy is suitable for improving energy security and decreasing environmental disruption caused by carbon emissions. Thus, studying the energy generation potential of these wastes is important.

Anaerobic digestion is a biological process that produces biogas from biodegradable wastes by bacteria under no oxygen conditions. In the past two decades, anaerobic digestion has been applied as an effective technology for solving the energy shortage and environmental pollution problems of industries [7]. In general, anaerobic digestion may meet two principal goals: the production of energy from biomass and the stabilization of organic waste, giving two final products biogas (energy fuel) and stabilized sludge – fertilizer respectively.

In this paper, the energy generation potential in Greece through anaerobic digestion from agricultural residues and livestock manure is estimated, taking into consideration the Greek statistical data and literature records concerning production to residues ratios and balances' principles in anaerobic digestion.

2. Agro-industrial residues

The main production in agricultural wastes in Greece comes from agricultural and farming activities in the fields. Agricultural production, cultivated areas and residues that characterize Greek agriculture activity, are shown in the table below (Table 1), in an annual base, along with the indices used to estimate the residues. The agricultural production and cultivated areas depicted in Table 1 are in accordance with the latest data of the National Statistical Service (2006). Two kinds of indices were used: an areal residue yield (kg/1000 m^2) and a residue to product ratio. In general, most of the studied crops perform high yielding potential under Greek climatic conditions. However, differences in yield and therefore in residues have been observed so far depending on the crop species, the climate and the cultural practices [8]. Thus, an effort was performed in order to use literature data that had derived from either Greek or Mediterrannean countries.

Table 1. Basic agricultural wastes in Greece in annual basis

Cultivation species	**Production (tn)**	**Residues (tn)**	**Type of residue**	**Cultivated area** (*10^6 m^2)	**Index**		**Reference**
					Residue yield (kg/1000 m^2)	**Residue/product**	
Wheat for crop	**4.607.562**	**4.634.076**					
Soft and semi-soft wheat	432.824	504.900	Straw, husk, bran	1.700	297		[9]
Hard wheat	1.217.878	1.601.196	Straw, husk, bran	5.678	282		[9]
Barley	281.759	253.976	Straw, bran	1.198	212		[9]
Oat	84.855	135.768	Straw, bran			1,6	[8]
Rye	35.616	110.410	Straw, bran			3,1	[8]
Maize	2.369.387	1.712.913	Cobs, stover	2.389	717		[9]
Rice	185.243	314.913	Straw, husk			1,7	[10]
Industrial plants	**1.935.257**	**2.411.462**					
Tobacco	30.783	30.783	Stems			1,0	[8]
Cotton	1.052.518	2.210.288	Stalk, lint, hull			2,1	[11]
Sugarbeet	851.956	170.391	Leaves, bagasse, collar			1,6	[12]
Potatoes	**929.690**	**371.876**	Stems and leaves			0,4	[8]
Vegetables	**2.008.096**	**803.238**	Stems, foliage			0,4	[12]

			and leaves				
Tomatoes	1.460.642						
Eggplants	69.480						
Okra	13.525						
Red onions	166.809						
Cabbage and cauliflower	254.019						
Leek	43.621						
Viticulture products	221.781	627.711	Sarments	1.263	497		[9]
Must	379.010						
Table grapes	168.666						
Corinthian raisin	32.289						
Sultanas raisin	20.826						
Citrus fruits	**981.695**	**1.963.390**	Pruning			2	[12]
Oranges	778.074	1.556.148					
Lemons	91.905	183.810					
Tangerines	111.716	223.432					
Fruits	**1.260.974**	**5.945.856**	Pruning, peels, seed	10.112	588		[9]
Apples	260.081						
Pears	75.249						
Peaches	783.693						

Apricots	79.188						
Cherries	62.763						
Nuts	**68.245**	**129.666**	Pruning, shell, stalk, leaves				
Almonds	46.130	87.647				1,9	[8]
Walnuts	22.115	42.019				1,9	[8]
Olives	**2.444.226**	**6.354.988**	Pruning, olive stone			2,6	[8]
Edible	281.917						
Oil producing	2.162.309						
Cheese	193.547	7.577.376					[13]

Thus, from all the data presented above it was estimated that the total agro-industrial residues amount up to 30.819.639 tn/y. Their classification is presented more colourfully in Figure 1.

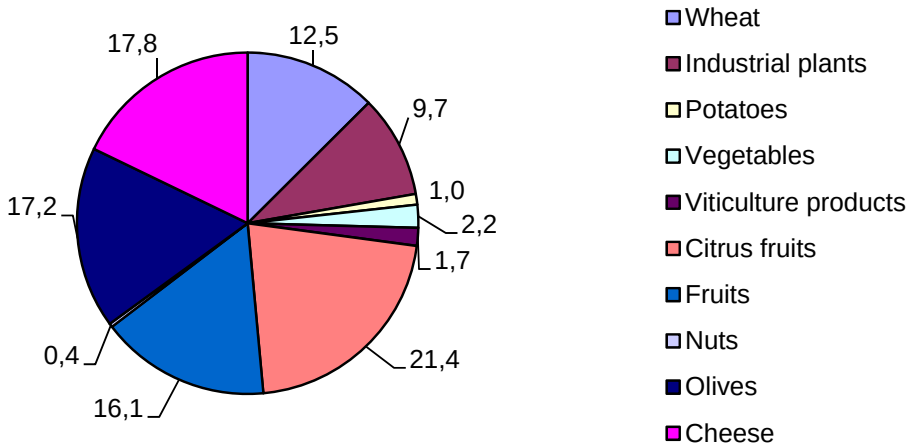

Fig. 1 Basic agricultural wastes in Greece (tn/yr)

3. Animal wastes in Greece

The Greek livestock system constitutes of sheep, goats, cows and calves, swine and pullets breeding. Poultry farming, sheep and goats breeding represent the highest percentage of livestock industry, amounted for over 95% of the total animals in the year 2006 (National Statistical Service) [11]. However, sheep and goats breeding are extensive and thus the produced manure is spread all over the grazing land [14-15]. Intensive livestock consists of cattle, brood sows and poultry farming. All these animals produce a substantial amount of wastes. The number of animals that were breaded in year 2006 is depicted in Table 2 according to the latest data of the National Statistical Service. After a rough estimation, it is underlined that due to intensive animal farming, 28.335 tn of pig, cattle and poultry manures are produced daily, resulting in that way to an annual load of 10.342.633 tn of animal manure stock (Figure 2). Those animal wastes spreading in Greek rural areas come mainly from medium and large-scale animal farms and are placed all over the country. Also, the fact that there are, traditionally, many small-scale animal farms in Greek rural areas must not be ignored [1]. Hence, from the data presented inTable 2 it was estimated that the total livestock manure amounts up to 27.164.112 tn/y.

Table 2. Number of animals and animal waste production in Greek farms in annual basis

Animal species	Number of animals	Residue/animal (tn/head)	Residues (tn)	Reference
Cattle	684.019	11,16	7.633.622	[16]
Pigs	1.055.029	1,34	1.413.739	[16]
Poultry	32.381.802	0,04	1.295.272	[16]
Goats and sheeps	14.017.899	1,2	16.821.479	[16]

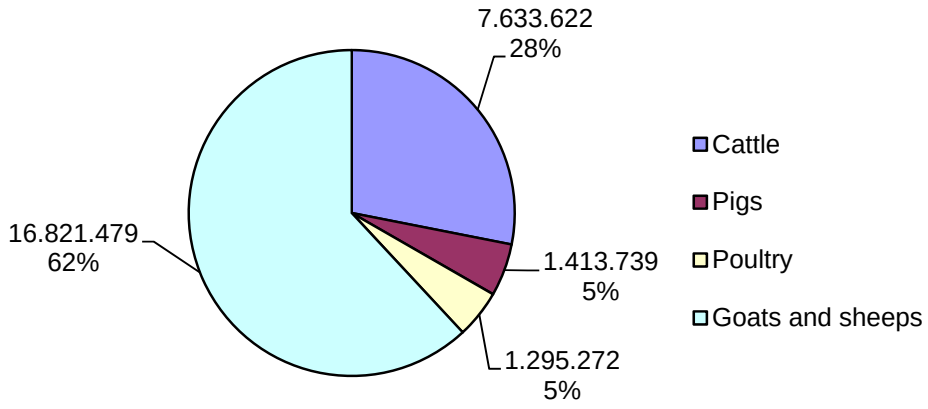

Fig. 2 Animal waste production estimation in Greece (2006)

According to the new EU Regulation (1/5/2003), stricter conditions on safe collection, transport, storage, handling, processing, use and disposal of animal by-products are imposed. It is, additionally, known that animal manure and waste contain large amount of pathogen organisms, and is a source of problems like odour emissions, wastewater pollution and vector attraction. As a result, they should be treated with special care as an obligation against public health protection and general environmental protection [1]. As a result, huge amounts of wastes remain unexploited and their potential for energy production reasons could be, now on, under consideration.

4. Total energy potential

Biogas production by anaerobic digestion of biomass may help in partially replacing fossil-fuel-derived energy and thereby in reducing environmental impact by providing a clean and diffused fuel from renewable feedstock. In some EU countries, such as Italy, Austria and Germany, substrate supply is often achieved by dedicated energy crops, such as cereals and maize [17 -18]. However, an energy crop requires a high expenditure in terms of arable land, energy (irrigation, machines, transport) and environmental resources (groundwater). Residual biomasses, such as agro-industrial by-products and residues, animal manures and source-separated organic wastes represent the spatially diffused sources of the substrate for its anaerobic biotransformation to biogas. Biogas is rich in methane (CH_4) which can be used in internal combustion engines either, for electricity generation, or burn directly for cooking, and space and water heating [17].

In a typical steady state mass balance for anaerobic digestion, the influent carbon is equal to the sum of output carbon, carbon in biogas and carbon in the biomass produced. In order to estimate the potential of biogas production, the following assumptions were taken into consideration:

- Carbon content in residuals: 25% w.b. [1, 4]
- Anaerobic digestion efficiency: 60% [19]
- Biomass production coefficient Y: 0.05 [19]
- Biogas composition: Methane 60% and Carbon Dioxide 40% [19]
- Biogas behaves as ideal gas [19].

The total annual residues production in Greece amounts to 57.983.751 tn/y taking into consideration the estimations for the annual production of agro-industrial residues and livestock manure. Although exploitation of residues for energy production through anaerobic digestion process would be feasible only in cases of medium-large scale units, for the purpose of this study the number of medium and small scale units was also taken into consideration. Thus, anaerobic digestion of the whole amount of residues could result in the production of $1,35*10^{10}$ m^3/y biogas. Given that:

- the energy content of biogas with 60% methane is 6kWh/m^3 [20],
- the overall efficiency of the co-generation of electrical and thermal energy is 80% [21] and
- the efficiency of thermal energy generation of cogeneration is 65% while that of electricity is 35% [21],

21,9 TWh/y of electricity and 27,0 TWh/y of thermal energy may be produced by the utilization of biogas . Apart from the energy produced, the excess of anaerobic stabilized sludge could be used as a soil conditioner. About 760.642 tn/y of soil conditioner were estimated that could be produced.

Figure 3 graphically illustrates a rough balance of the exploitation of residues through anaerobic digestion and co-generation of energy.

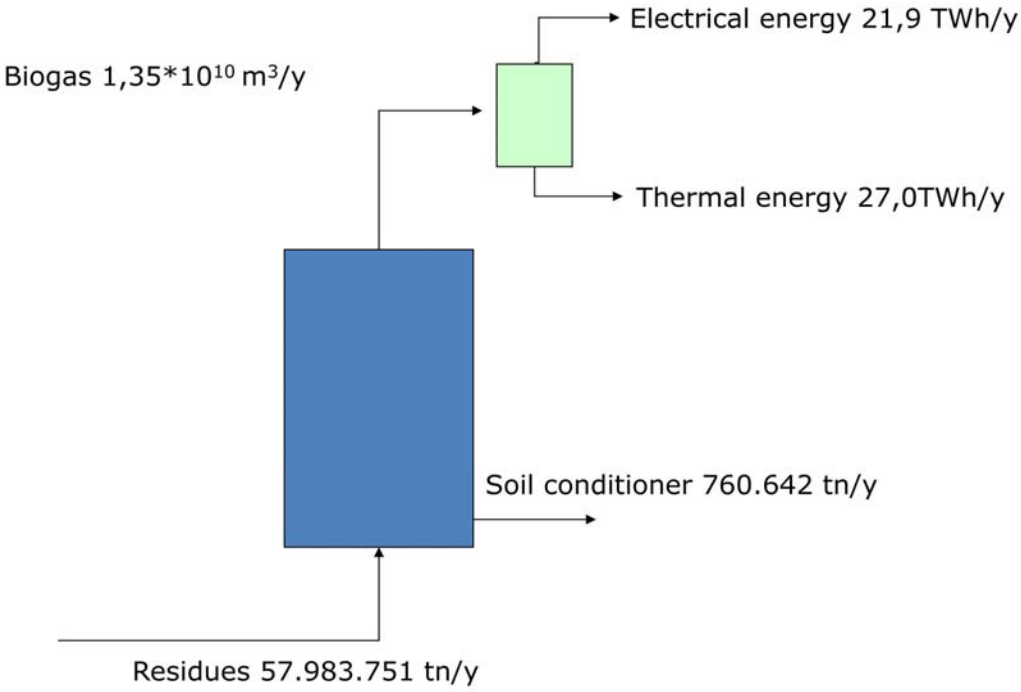

Fig. 3 Graphical representation of the utilization of residues

According to the aforementioned balance, 21.9TWh of electricity could be produced, amount that corresponds to 39% of the gross national electricity consumption in Greece (55 TWh in 2012). The thermal energy on the other hand, could only be used in-situ either for the thermal needs of anaerobic digesters or for neighboring activities.

5. Economic aspect

In order to render the calculations more realistic, the cost factor has to be taken into consideration. Taking into account the residue transportation costs as well as the fixed and operational costs (anaerobic digestion and co-generation), the cost per kWh of electrical energy produced was estimated in relation to the installed power capacity of operating plants necessary to treat the whole amount of residues [22]. The transportation cost was estimated considering the operating anaerobic plants evenly distributed in the greek territory. The period of time required to recoup the investment was assumed 10 years. Figure 4 shows a cost estimation of the electricity produced through anaerobic digestion.

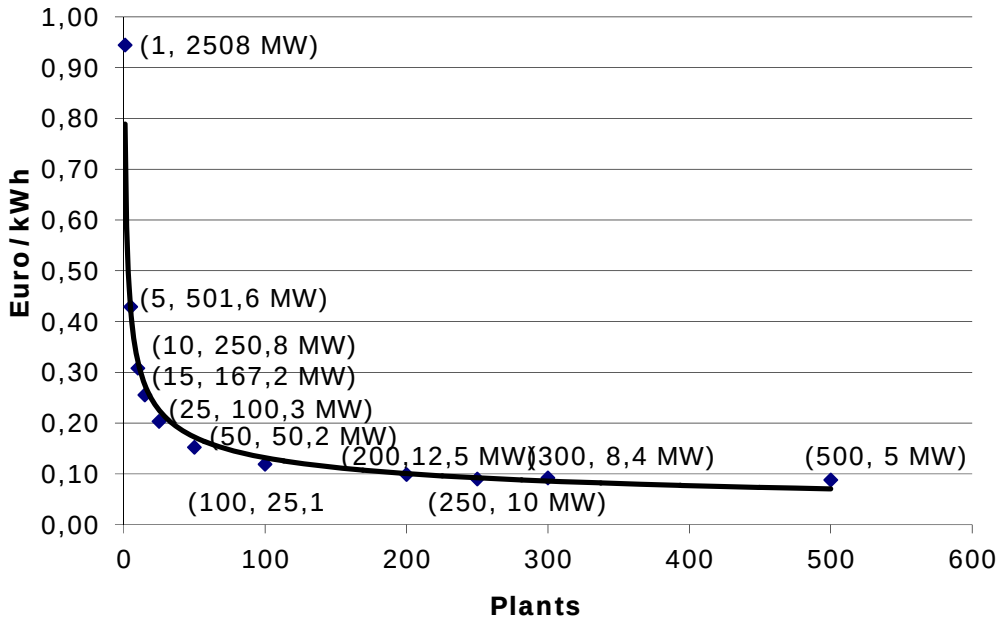

Fig. 4 Cost estimation of the electricity produced through anaerobic digestion in relation to the number of operating plants and their installed power capacity necessary to treat the whole amount of residues

As it can be seen the cost gets lower as the number of plants increases and their installed power capacity decreases. The limiting value of the cost is 0.09€/kWh for 250 operating plants of 10MW capacity. The selling price of electricity to the national energy network according to current Greek legislation is 0.20-0.22€/kWh [23]. Thus, the energy production by anaerobic digestion of residues could be also feasible from an economic point of view.

6. Conclusions

It is clear that Greece has a great opportunity to exploit its huge biomass stock, and specifically agricultural and animal wastes. Diverse topography and climate is a very important factor for country's energy autonomy and is of strategic importance. Under the recently set national commitments on EU legislations over environmental protection, alignment with Kyoto protocol emissions abatement and climate change protection, Greece could viably exploit its renewable energy sources, under an environmental friendly and economic viable way.

In this context, it was estimated that the total annual residues production in Greece amounts to 57.983.751 tn/y taking into consideration the annual production of agro-industrial residues (53%) and livestock manure (47%). Studying the scenario of anaerobic treatment of these residues, it came up that 21.9TWh of electricity could be produced, amount that corresponds to 39% of the gross national electricity consumption in Greece.

To sum up, the need to explore new forms of energy in Greece is an imperative given the increasing energy demand and the need to find alternatives to fossil fuels as the world moves towards green fuels. Crop residues and livestock manure have a potential to contribute significantly to the energy map in Greece.

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