Challenges and opportunities of anaerobic digestion of agricultural residues and livestock manure in the regional unit of Florina, Greece

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Abstract

Agricultural residues and manure, left behind from crop harvest and livestock production, could be used to create low-carbon fuel and electricity. These biomass resources, if managed properly, can address the many challenges posed by the use of fossil fuels without competing with food supplies. Macro-assessment at a regional scale, Florina region, was evaluated in order to reveal the potential and feasibility of a green perspective for a green energy strategy for Greece. The assessment was based on 11-years period data. Florina is a regional unit of West Macedonia, Greece. It is the most dedicated in agro-industrial activities regional unit of all West Macedonia. Wheat is the principal cultivation species but there are also abundant fruit trees. As far as stock-breeding is concerned, goats, sheep and cattle are the predominant species. Studying the energy generation potential of these wastes is important, since the use of agricultural waste as a major component of renewable energy is suitable for improving energy security. Livestock manure and crop residue can be processed in an environmentally acceptable way through anaerobic digestion to generate biogas, also, under an integrated production scheme, providing fertiliser and heat as by-products. In this paper, the potential of agricultural waste of Florina was estimated equal to 35-67GWh/y of electricity and 83-125GWh/y of thermal energy while that of biomethane was calculated to be approximately $18,5*10^6 m^3/y$. Furthermore, about 2500 tn/y±23% of soil conditioner were estimated that could be produced. Conclusively, crop residues and livestock manure may stand as an energy source with significant contribution to the Florina's energy balance.

Keywords: agricultural residues; anaerobic digestion; energy balance; Florina; livestock manure.

Introduction

Renewable energy sources include wind power, solar power (thermal, photovoltaic and concentrated), hydroelectric power, tidal power, geothermal energy, biofuels and the renewable part of waste. The use of renewable energy has many potential benefits, including a reduction in greenhouse gas emissions, the diversification of energy supplies and a reduced dependency on fossil fuel markets (in particular, oil and gas). The growth of renewable energy sources may also have the potential to stimulate employment in the EU, through the creation of jobs in new 'green' technologies. The European Commission has set out several energy strategies for a more secure, sustainable and low-carbon economy. The 2020 climate and energy package adopted in December 2008 provided a further stimulus for increasing the use of renewable energy sources to 20 % of total energy consumption by 2020, while calling for energy consumption and greenhouse gas emissions to both be cut by 20 %. In January 2014, the European Commission put forward a set of energy and climate goals for 2030 with the aim of encouraging private investment in infrastructure and low-carbon technologies. One of the key targets proposed is for the share of renewable energy to reach at least 27 % by 2030. Furthermore, one of the 10 priorities of the European Commission put forward in 2014 is an energy union. It is intended that a European energy union will ensure secure, sustainable, competitive and affordable energy [1].

The primary production of renewable energy within the EU-28 in 2014 was 196 million tonnes of oil equivalent (toe) — a 25.4 % share of total primary energy production from all sources. The quantity of renewable energy produced within the EU-28 increased overall by 73.1 % between 2004 and 2014, equivalent to an average increase of 5.6 % per year. Among renewable energies, the most important source in the EU-28 was solid biofuels and renewable waste, accounting for just under two thirds (63.1 %) of primary renewables production in 2014. The output of renewable energy in Greece was 10% of gross inland energy consumption. Biomass and renewable waste was the most important contributor to the renewable energy mix (50 % of the total), followed by solar (21%), hydropower (16%) and wind energy (13 %). It is clear that if Greece is to align with the EC Directive 2001/77/EC and reach a 20% contribution of renewable fuels to electricity production, a large amount of energy must be supplied by exploitation of non-conventional energy sources [1].

Therefore, there is renewed interest in the production and use of fuels originated from plants or organic wastes for sustainable development of economy and society in an eco-friendly manner [2]. Bioenergy, especially biogas produced through the anaerobic digestion (AD) of renewable feedstocks, is considered to be one of the highly promising alternatives to fossil-derived energy due to several inherent and significant merits [3]. Anaerobic digestion is the biological process that produces biogas from biodegradable wastes by bacteria under no oxygen conditions [4]. The consortium of microbes works synergistically to deconstruct recalcitrant biomass structures into their respective fundamental components [3]. 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 [4]. Because of its advantages over conventional fossil-derived resources, AD has been adopted and integrated into society over the last century, with thousands of full-scale plants currently in operation worldwide. AD is suitable for converting non-sterile, diverse, complex feedstocks into energy-rich biogas [3].

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 the 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. According to [4], 39 % of the annual electrical energy consumption in Greece could be replaced by electrical energy produced from agricultural residues and livestock manure. Thus, studying the energy generation potential of these wastes is important.

This line of research was followed for Florina regional unit. Florina is one of the regional units of Greece. It is part of the region of West Macedonia. The regional unit Florina is subdivided into 3 municipalities: Amyntaio, Florina and Prespes. According to the 2011 census, the population of Florina regional unit was 51.414 people. Florina is the most dedicated in agro-industrial activities regional unit of all West Macedonia. More than 50% of its gross agricultural revenue comes from the production of forage plants for animal feed. Wheat is the principal cultivation species while the cultivation of beans near Lake Prespa, recognized as a Protected Designation of Origin (PDO) product, exhibits great interest. In Florina, there are also abundant fruit trees such as apple, pear, peach, almond and cherry trees. Furthermore, there is intense activity on viticulture in Amyntaio. As far as stock-breeding is concerned, the livestock in Florina includes almost every farmed animal, with goats, sheep and cattle being the predominant species. Apart from the data mentioned above, Florina is one of the Greek regional units set at high priority in the development strategy of Greece.

Keeping aforesaid statements into the considerations, this paper aimed to present one-sight comprehensive information on production and potential of major agricultural residues and livestock manure for methane generation via anaerobic digestion route of energy conversion process in Florina regional unit. Informative details on the annual production of agricultural crop wastes biomass, fundamental requirements for methane generation, properties of biomass and methane generation potential have been presented [2].

The present research seeks to assess the potential of biogas production based on the utilisation of manure and crop residues. The assessment was based on 11-years period data.

Methodology

Residues estimation

With the term “agricultural residues” hereon, a wide variety of biomass types is included, which can be divided into three main classes:

- Primary agricultural residues, like straw of wheat, barley, oat, corn, rice etc. that remain after harvesting in the fields.

- Secondary agricultural residues, like bagasse, rice husks, sunflower husks, nut shells, coffee and cocoa bean shells, kidney bean shells and similar biomass, arise after processing of the primary crops.
- Manure like pig, cattle and chicken manure.

By-products from further processing of agricultural products like molasses, vinasse, etc. are not included. They are regarded as residues from the food industry.

Secondary residues are generally easier to collect since they are released at a central processing facility, while primary residues have to be collected from the fields. Manure is organic matter used as organic fertilizer in agriculture. Animal manure can be available as a liquid (farm slurry) or in a more solid form.

Existing biomass resource assessments use a broad variety of approaches, methodologies, assumptions and datasets that lead to different estimates of future biomass potentials. Biomass Energy Europe (BEE) project [7] aiming at improving the accuracy and comparability of future biomass resource assessments for energy by reducing heterogeneity of terms and definitions, increasing harmonisation of data and calculations and exchanging knowledge on methods and approaches proposed methodologies to assess biomass resources, which are adopted in this study.

The theoretical potential is the overall maximum amount of terrestrial biomass which can be considered theoretically available for bioenergy production within fundamental bio-physical limits. The theoretical potential is usually expressed in joule primary energy, i.e. the energy contained in the raw, unprocessed biomass. Primary energy is converted into secondary energy, such as electricity and liquid and gaseous fuels. In the case of biomass from crops, the theoretical potential represents the maximum productivity under theoretically optimal management taking into account limitations that result from soil, temperature, solar radiation and rainfall. In the case of residues and waste, the theoretical potentials equal the total amount that is produced.

Regarding primary agricultural residues (PAR), the most important type of agricultural biomass available for bioenergy is straw. It is left after the harvesting of mainly cereals and other annual lignocellulosic crops. The parameters that affect the straw potential are the area of land covered by these crops and the amount of straw produced per decare or tonne of crop. Competitive uses reduce the straw potential for bioenergy like the use for litter and animal feeding. Other types of residues that should be included in the category of primary residues are the products of cultivation process (e.g. fruit trees prunings). The potential of primary residues could be reduced in case environmental and sustainability issues would be taken into account, like the remaining of residues on the agricultural terrain for recycling of nutrients.

The theoretical potential of annual crop residues, like cereals, is estimated on the basis of cultivated area, and agricultural production in tonnes per decare, for each specific crop and average residue to product ratios (RtP) [7].

$$THP\_RAP = \Sigma (CA_i * AP_i * RtP_i * Av_i) \quad \text{(Eq. 1)}$$

where:
THP_RAP= primary agricultural residues (e.g. straw, stalks), in tonnes
CA_i = cultivated area of i crop, in decares (da)
AP_i = agricultural production of i crop, in tonnes per decare (t/da)
RtR_i = residue to product ratio of i crop
Av_i = availability of residues for i crop according to current harvesting system

The estimation for fruit tree prunings is based on an average of prunings per tree for specific cultivations [7].

$$THP\_RAP_{pr} = \Sigma [Production(tn) * RtPr_i * Av_i] \quad \text{(Eq. 2)}$$

where:
THP_RAPpr= primary agricultural residues (prunings), in tonnes
RtP_i = residue to product ratio of i crop
Av_i = availability of residues for i crop according to current harvesting system

The method estimating the theoretical manure potential is based on the factor “heads of livestock of animals and poultry”. By multiplying the amount of heads with the ratio “manure per head” for specific type of livestock, the total amount of manure that is produced, which equals the theoretical potential, may be estimated. The above mentioned method is simple and is represented by the following equations [7]:

$$THP\_Manure = \Sigma (NHeads_i * MpH_i) \qquad \text{(Eq. 3)}$$

where:

THP_Manure = theoretical potential of manure (tn/year)

$NHeads_i$ = the number of heads for the i type of livestock

MpH_i = amount of manure for the i type of livestock, in tonnes per head = type of livestock, i.e. cattle, pig, poultry etc.

Results

Agro-industrial residues

From all the cultivated species that characterize Florina's agriculture activity, the species that had either high production or high residue yield were chosen to be studied. These are the following: wheat, barley, maize, rye, oat, lentils, beans, chickpeas, potatoes, tobacco and sugarbeet. As far as trees are concerned, the following were selected: pear, apple, apricot, peach, cherry and almond trees.

The agricultural production, cultivated areas and residues are shown in the table below (Table 1), in an annual base for 2015, along with the indices used to estimate the residues according to equation 1. Differences in yield and therefore in residues have been observed depending on the crop species, the climate and the cultural practices [8,19]. The agricultural production and cultivated areas depicted in Table 1 are in accordance with the latest data of the regional state of Florina since the latest data of the National Statistical Service refer to 2012. In general, most of the studied crops perform high yielding potential under Greek climatic conditions. In reality, the indices mentioned above obviously fluctuate since they are influenced in each case by several parameters such as climate conditions, cultivation practices and crop management. In Table 1, the range of the indices from the literature and their mean values that were considered are presented.

From Table 1, it is obvious that regarding annual crops, the predominant species in terms of percentage of the total cultivated area are rye (26%), wheat (20%), maize and barley (10%). Nevertheless, in terms of produced product, maize with a percentage of 44% takes the lead, and rye and barley are following with percentages of 15% and 14% respectively. As far as the residue production is concerned, the cultivation of maize yields the highest amount of residues (68% of the total quantity produced), while the cultivation of rye and barley play a secondary role with respective percentages of 52% and 19%.

Besides the agricultural wastes that were mentioned above, in the primary agricultural residues the tree prunings are also included. In Table 2, the agricultural production, the cultivated areas and the residues that characterize the cultivated trees in the region of Florina, in an annual basis for 2015, as well as the indices that were used to estimate the residues are presented. Thus, from all the data presented above it was estimated that the total pirmary agro-industrial residues amount up to 82.813 tn/y.

Animal wastes in Florina, Greece

In Florina, animals produce a substantial amount of wastes, as animal breeding activity is highly developed. The livestock system constitutes of sheep, goats, cows and calves and swine breeding. Sheep and goats breeding represent the highest percentage of livestock industry, amounted for over 90% of the total animals in the year 2015 (National Statistical Service) [8]. All these animals produce a substantial amount of wastes. The number of animals that were breaded in Florina in year 2015 is depicted in Table 3 according to the latest data of the competent Regional Directorate (2015). After a rough estimation, it is underlined that due to intensive animal farming, 110.764 tn, 1.330 tn and 113.569 tn of cattle, pig and sheep and goat manures respectively are produced annually, resulting in that way to an annual load of 225.663 tn of animal manure stock. Those animal wastes spreading in Florina's rural areas come mainly from medium and large-scale animal farms and are placed all over the regional unit. Nevertheless, the fact that there are, traditionally, many small-scale animal farms in the rural areas must not be ignored [19]. The average volume of feces and urine largely differ from one type of animal to another and mainly depend on their age and lifeweight [20-21]. However in order to assist in the planning, design and operation of manure collection, storage, pre-treatment and utilization systems for livestock enterprises mean values have been developed by various researchers [20]. In this analysis, the coefficients presented in Table 3 were adopted. The values represent fresh feces and urine. As was the case for agricultural residues, these coefficients are mean values.

Table 1. Basic agricultural wastes in Florina, Greece and the corresponding indices in annual basis (2015).

			Index							
Cultivation species (i)	**Production (tn/y)**	**CA_i Cultivated area (da*)**	**AP_i Agricultural production (t/da)**	**RtP_i mean Residue to Product ratio**	**RtP_i Literature range**		**Av_i mean Availability of residues**	**Av_i Literature range**		**Residues (tn/y)**
Cereals										
Wheat	9.819	49.098	0,20	1,28	0,69-2,57	[4,8-16]	0,40	0,22-0,85	[14,18]	5.028
Durum wheat	5.457	28.274	0,19	1,28	0,69-2,57	[4,8-16]	0,40	0,22-0,85	[14,18]	2.794
Barley	17.963	44.908	0,40	1,19	0,6-2,5	[4,8-9,11-12, 14-16]	0,40	0,22-0,85	[14,18]	8.550
Maize	53.889	44.908	1,20	1,17	0,55-4,33	[4,8-10,12-17]	0,55	0,22-0,85	[8,14,18]	34.678
Rye	18.277	65.275	0,28	1,71	0,7-3,10	[4,10-12,14-15,17]	0,40	0,22-0,85	[14,18]	12.501
Oat	373	1.869	0,20	1,36	0,68-2,13	[4,8-17]	0,40	0,22-0,85	[14,18]	203
Leguminous crops										
Lentils	48	407	0,12	1,49	0,8-2,10	[9-11]	0,40	0,22-0,85	[8,14,18]	29
Beans	2.980	9.934	0,30	1,42	0,8-2,10	[9-11]	0,40	0,22-0,85	[8,14,18]	1.693
Chickpeas	65	448	0,15	1,69	0,8-2,27	[9-11]	0,40	0,22-0,85	[8,14,18]	44
Industrial plants										
Tobacco	2	8	0,28	1,23	1,00-2,00	[4,8-9,12,14]	0,73	0,22-0,85	[8,14,18]	2
Sugarbeet	850	2.127	0,40	0,42	0,15-0,79	[8-9,11,14-15]	0,70	0,22-0,85	[8,14,18]	250
Potatoes	11.924	3.408	3,50	0,38	0,2-0,72	[4,9,11,15]	0,40	0,22-0,85	[8,14,18]	1.812
								TOTAL		**67.585**

*1 da=0,1 ha =1000m^2

Table 2. Primary residues from cultivated trees in Florina, Greece in annual basis (2015).

Cultivation species (i)	Total Area (da*)	Production (tn/y)	RtP_i	RtP_i Literature range [4,8-9]	Av_i [8]	Residues (tn/y)
Pears	507	300	0,54	0,38-0,79	0,80	130
Apples	3.568	10.200	0,53	0,32-0,83	0,80	4.325
Apricots	108	15	0,37	0,35-0,41	0,80	4
Peaches	9.405	23.903	0,35	0,3-0,4	0,80	6.693
Cherries	1.257	132	0,89	0,83-1,0	0,80	94
Almonds	1.185	93	2,74	1,9-3,57	0,80	203
Vines	9.375	7.351	0,65	0,5-0,83	0,80	3.822
				TOTAL		**15.271**

*1 da=0,1 ha =1000m^2

Table 3. Number of animals and animal waste production in farms in Florina in an annual basis (2015).

Animal species	$NHeads_i$ Number of animals	THP_Manure Theoretical potential of manure (tn/head)	THP_Manure Literature range (tn/head)	MpH_i Amount of manure (tn/y)	Reference
Cattle	13.834	8,81	4,50-12,78	121.878	[4,22-23]
Pigs	1.200	1,21	0,56-1,90	1.452	[4,22-23]
Goats and sheeps	143.831	0,71	0,17-1,20	102.120	[4,23]
		TOTAL		225.663	

Hence, from the data presented in Tables 1-3 it was estimated that the total agricultural residues amount up to 308.306 tn/y.

It is therefore evident that huge amounts of wastes remain unexploited and their potential for energy production reasons could be, now on, under consideration.

A one-year analysis could give a hint on the perspective of energy potential of agricultural and manure residues. In order to ensure safer results and depict the general trend, a 11-years period database was evaluated. Data were collected following the same design and identical procedures for a period of eleven years, from 2005 to 2015. Figure 1 presents the agricultural residue generation by year, expressed in tonnes per year in the Florina.

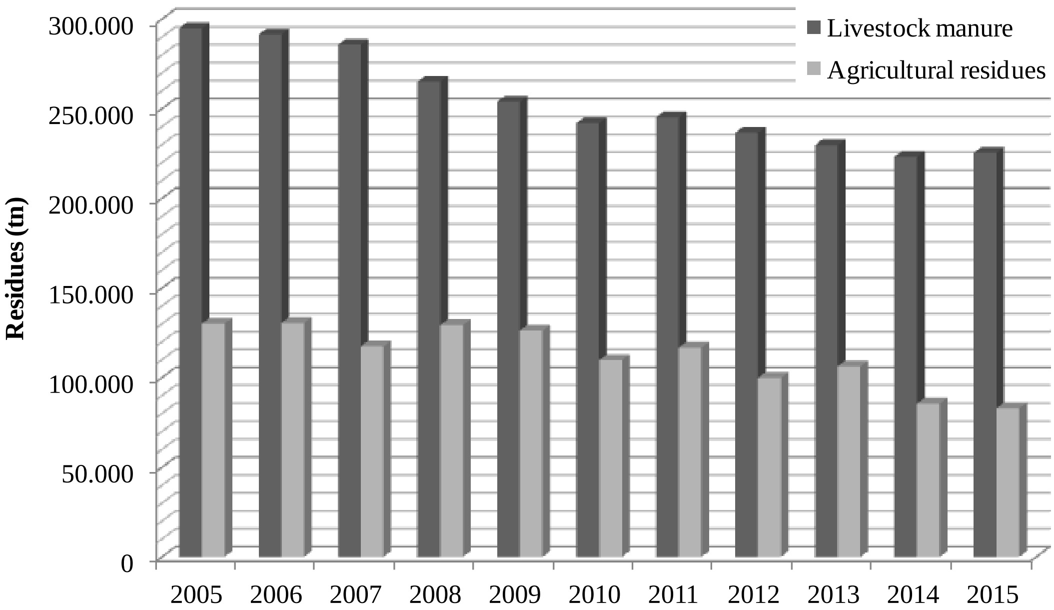

Figure 1. Agricultural residue and livestock manure production by year for the period 2005-2015.

Annual crop plantations have declined during recent decade. For the 2005–2015 period, a decrease of roughly 24% can be observed in the livestock manure and 36% in the agricultural residues. This decrease has not been uniform, with more substantial decreases occurring in wheat, barley and potatoes. This fall has been partly counterbalanced by the cultivation of rye, oats and lentils.

In Figure 2, the participation of each species of residues in the total residue production for the whole period 2005-2015 is presented.

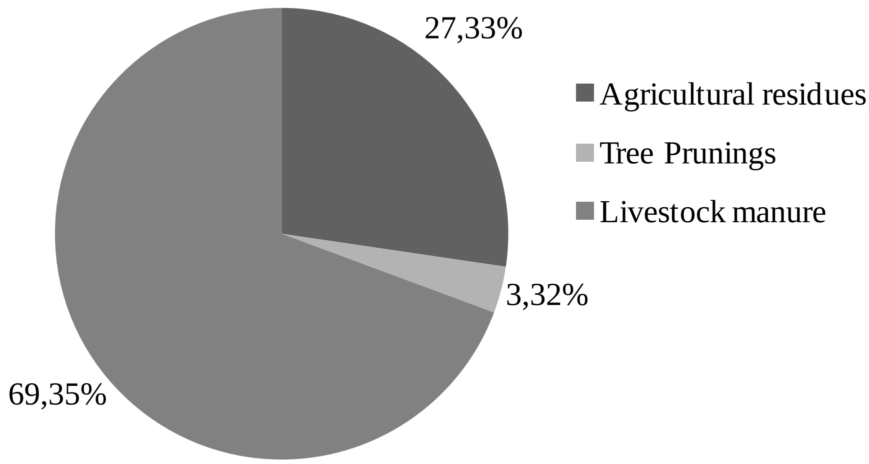

Figure 2. Residues percentage per species for the period 2005-2015.

According to agricultural cultivation practices, the annual harvest timeline of residue production is depicted in the following Gantt chart (Figure 3). From the data collected, it was estimated that livestock manure contributes monthly to the total of agricultural residues from 43 to 100%.

	January	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
Wheat												
Barley												

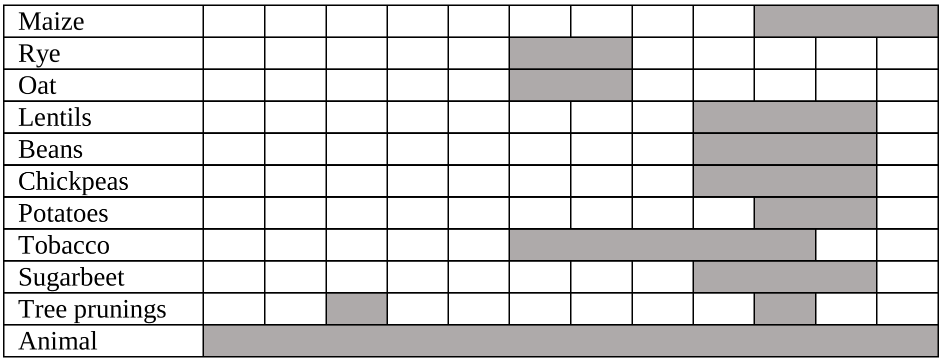

Figure 3. Monthly residue production throughout the year

Total energy potential through anaerobic digestion

During the digestion of biomass, in which bacteria ferment organic matter in an oxygen-free environment, biogas is generated. This gas is constituted mainly of methane (40–70%), carbon dioxide (30–60%) and a complex mixture of trace compounds. The most straightforward way of using biogas is through combustion for electricity generation. Reciprocating engines for electricity are by far the dominant technology for electricity generation. It is a reliable technology and electricity can be generated in varying power profiles (1 kW_e to 6 MW_e) although thermal and electrical efficiency is highly dependent on capacity. The combustion principle can be based either on spark-ignition, with engines that work with the Otto cycle, or through compression ignition, which operates under a diesel-cycle akin to a vehicle engine. Because a mixture of biogas and air cannot fulfil the conditions necessary for ignition when compressed, the spark-ignition engines demand a supplementary fuel such as diesel, biodiesel or vegetable oil. Modern spark-ignition engines typically operate with 10% supplementary ignition fuel. However, consumption in the 3–30% range has also been reported. In contrast to the reciprocating engines, Stirling engines have an operating principle based on the continuous expansion and compression of a confined gas, which allows the pistons to move up and down, generating mechanical energy for subsequent electricity production by a generator. Microturbines can generate electricity and heat in a low range (0,5–200 kW_e) and can be powered by natural gas, propane, hydrogen, diesel as well as biogas. The electrical efficiency of microturbines can reach roughly 30% [24].

Biogas potential is estimated on Biomethane Potential (BMP) assays basis. Due to the fact that the BMP test is not standardized, the extent of degradation reported for different biomass materials is not only the result of their composition but also of the design of the tests used. Several operational conditions influence the outcomes of the described tests including: retention time, pH, temperature, type of hydrolysis biomass, concentration of hydrolyzing biomass i.e. inoculums to substrate ratio, water addition, nutrient addition i.e media. The equipment used and applied laboratory analytical procedures also exert an influence in the outcomes [25].

In this context, an extent literature review was performed and presented in Table 4. Thus, the biogas and methane potential for each cultivated species was estimated taking into consideration the literature data as well as the quantities of residues estimated in Tables 1 and 3.

Table 4. Estimation of biogas and methane potential for all cultivated species examined.

	VS (%)	BMP* (m^3/ kg VS)	CH_4 content (%)	Reference	CH_4 efficiency (m^3/ kg residue)	CH_4 Potential (m^3/y)	Biogas Potential (m^3/y)
Cereals							
Wheat	76,10-85,37	0,15-0,45	51,50	[26-29]	0,24	1.206.625	2.342.961
Durum wheat	76,10-85,37	0,15-0,45	51,50	[26-29]	0,24	670.627	1.302.189
Barley	17,65-43,66	0,35-0,66	62,20	[28]	0,17	1.453.575	2.336.937
Maize	24,42-49,56	0,34-0,54	58,90	[28]	0,15	5.201.669	8.831.356
Rye	23,05-57,95	0,28-0,54	63,80	[28-29]	0,26	3.250.387	5.094.650
Oat	59,60-81-20	0,07-0,32	60,00	[28]	0,10	20.335	33.891
Leguminous crops							
Lentils	13,00	0,29	60,00	[30]	0,04	1.164	1.941
Beans	13,31	0,24-0,35	60,00	[28]	0,04	67.711	112.852
Chickpeas	13,00	0,29	60,00	[30]	0,04	1.758	2.929
Potatoes	6,95-19,80	0,41-0,55	60,00	[26,31]	0,07	126.872	211.453
Industrial plants							
Sugarbeet	6,10-18,72	0,11-0,52	57,89	[26,28-29]	0,03	7.497	12.950
Trees							
Pears	63,88-83,84	0,13	60,00	[32]	0,09	12.299	20.498
Apples	63,88-83,84	0,13	60,00	[32]	0,09	410.424	684.039
Apricots	63,88-83,84	0,13	60,00	[32]	0,10	421	702
Peaches	63,88-83,84	0,13	60,00	[32]	0,10	635.137	1.058.562
Cherries	63,88-84,20	0,13	60,00	[32]	0,10	8.919	14.865
Almonds	63,88-83,84	0,13	60,00	[32]	0,09	19.269	32.115
Vines	91,97	0,134	60,00	[32]	0,12	373.909	623.181
					TOTAL	**1.460.378**	**2.433.963**

*BMP: Biomethane Potential in m^3 CH_4/kg VS.

In a similar way, taking into account the relevant literature, the biogas and methane potential for the livestock manure were estimated. The results are presented in Table 5.

Table 5. Estimation of biogas and methane potential for all animal species examined.

	TS (%)	**VS (% TS)**	**BMP (m^3/ kg VS)**	**CH_4 content (%)**	**Reference**	**CH_4 Potential (m^3/y)**	**Biogas Potential (m^3/y)**
Cattle	10,40	8,17	0,12-0,46	58,79	[4,28-30, 33-37]	1.696.616	2.885.891
Pigs	7,00	5,44	0,25-0,50	66,82	[4, 28,30, 33,35-37]	20.066	30.030
Goats and sheeps	33,65	27,66	0,197-0,201	59,40	[34,36,38]	3.356.116	5.650.027
				TOTAL		**5.072.798**	**8.565.948**

To summarize, in the region of Florina the total biogas potential from agroindustrial residues amounts up to 31.284.022 m^3/y, with 73% coming from primary agricultural residues whereas the rest is due to livestock manure.

In general, biogas is an energy carrier that may be used in several energy applications, such as electricity and heat production, combined heat and power production and transport applications. Biogas may also be used for all application designed for natural gas, subject to some further upgrading. The most suitable system that may be applied after the production of biogas from the anaerobic digestion of agricultural residues is a Combined Heat and Power (CHP) unit that operates with combustion engines/motors. The combined heat and power unit is considered a very efficient system for biogas use and energy production. Prior to the transformation in CHP system, biogas needs to be dried. The system's efficiency depends on the technology used for the production of electrical and thermal energy, the system' s design as well as on the amount of thermal energy that is consumed from the unit itself. Thus, each CHP system may have a different efficiency once installed. Nevertheless, for biogas, the CHP systems usually used render relatively constant efficiencies (75-90%)[33].

Thus, anaerobic digestion of the whole amount of residues could result in the production of $1.9*10^7$ m^3/y methane. Given that:

- the Lower Heating Value (LHV) of methane is 10 kWh/m^3 [39],
- the overall efficiency of the co-generation of electrical and thermal energy is 75-90% [40] and
- the overall electricity efficiency equals to 25-40% [4],

the total amount of electricity and thermal energy produced may be estimated. The total energy content of the biogas produced may be estimated by multiplying the LHV of methane by the total amount of available methane. The latter reflects the total quantity of energy input in the CHP system. Given the overall efficiencies of electricity production and cogeneration of energy, it was estimated that 35-67 GWh/y of electricity and 83-125 GWh/y of thermal energy may be produced by the utilization of biogas.

The generation of renewable energy from anaerobic digestion is well established. However, in order to guarantee the maximum recovery value of organic wastes, the residual product, i.e. biogas residue, should have a meaningful purpose, and optimal benefits derived from its production. The application of residue as a fertilization agent that is recycled back to arable land ensures that crops receive the majority of the essential nutrients required for growth, i.e., soil fertility is conserved, and the soil structure and humus balance is improved, thus promoting closure of the natural nutrient and energy cycles. In contrast, application of inorganic fertilizers to crop fields is supplementary to the nutrient cycle, resulting in the need for increased production of fertilizers requiring significant energy input, along with continued escalation in the amount of residual waste treatment products with no way of benefiting from its nutrient-rich nature. Thus, the use of biogas residue as an alternative should not only close the global nutrient cycle, but also indirectly reduce greenhouse gas emissions to the atmosphere through decreased need for inorganic fertilizers and new landfill sites [41].

The amount of soil conditioner that may be produced by anaerobic digestion of agro-industrial residues results from the excess biological sludge produced during digestion. In a typical mass balance under steady state conditions, the carbon that is inserted in the system is equal to the sum of the carbon that is removed from the system, the carbon in the biogas as well as the carbon of the produced biomass. Thus, assuming an average anaerobic digestion efficiency 55-70% and a biomass production coefficient Y = 0,05 [42], about 2.500 tn/y ± 23% (in terms of VS) of soil conditioner were estimated that could be produced. In the latter estimation, the data of Table 4 regarding VS were taken into account.

Figure 4 presents the evolution of electricity, thermal energy and soil conditioner production throughout the whole period studied (2005-2015).

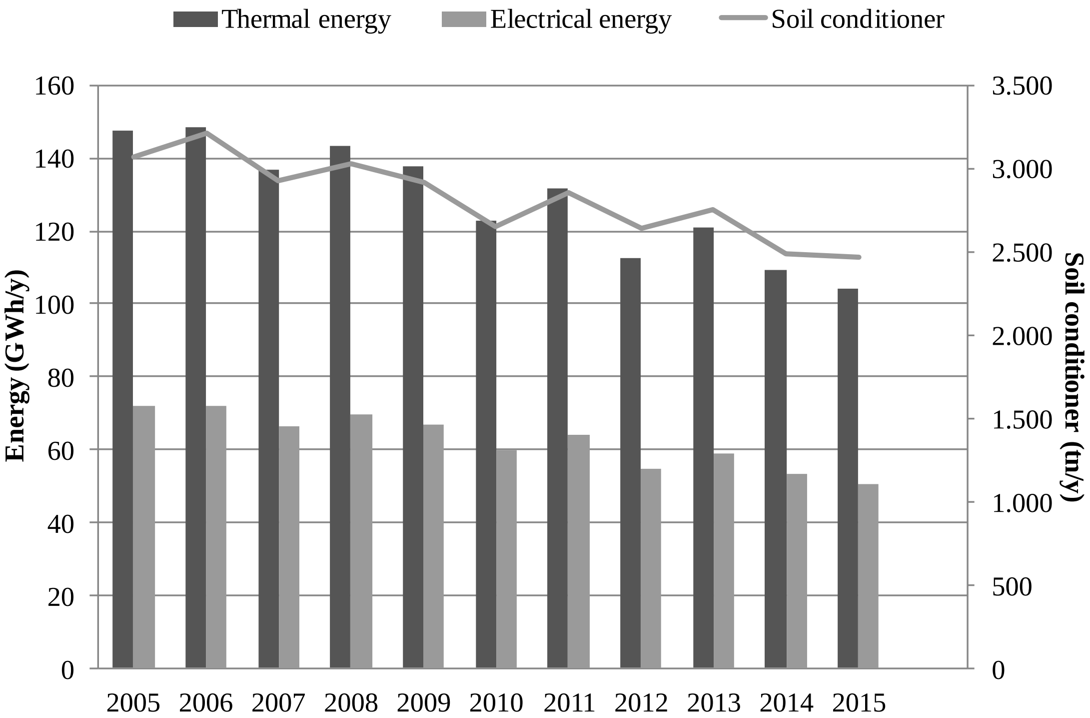

Figure 4. Electricity, thermal energy and soil conditioner production for the period 2005-2015.

The potential of energy production has declined during the last decade as was the case for the residues production. According to the latest statistical data (2012), the total electricity consumption was 181 GWh and the respective consumption for agricultural use was equal to 37,5 GWh in the regional unit of Florina. Thus, electricity produced from agricultural and manure residue could contribute by 20-36% to the total energy needs and turn agricultural activities totally energy independent. Nonetheless, the amount of energy as well as soil conditioner are large and may contribute substantially to the energy balance of Florina.

Conclusions

This paper has discussed the importance and potential application of agricultural crops residues (maize, wheat, rice and sugarbeet etc.), fruit trees prunings and animal manure produced, in order to produce and utilize renewable biogas energy via methane fermentation route. Huge amount of agricultural biomass remains unexploited in field releasing harmful gases. The prime concern of "second generation of biofuel production" is to produce renewable fuels from agricultural wastes biomass in order to meet the goals of sustainable and ecological development of earth planet. Agricultural and animal wastes are able to contribute in a clean and safe renewable energy production and support country's socioeconomic development. Under sustainable conditions of exploitation, biomass could be a very promising alternative to fossil fuels. Under this assumption, it is clear that Florina, Greece which is considered as the most dedicated region in agro-industrial activities in West Macedonia has a great opportunity to exploit its huge biomass stock. In this context, it was estimated that the total annual residues production in Florina amounts to 308.306 tn/y taking into consideration the annual production of agro-industrial residues (27%) and livestock manure (73%). Studying the scenario of anaerobic treatment of these residues, it came up that 35-67 GWh/y of electricity could be produced. Thus, it is evident that Florina could viably exploit its renewable energy sources, under an environmental friendly and economic viable way.

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