Decision support for biogas production from the utilisation of agricultural and livestock wastes

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Abstract: The rapid growth of the global and national agriculture and livestock sector, has led to the development of large quantities of agricultural and animal wastes, resulting in massive problems associated with treatment and disposal into the atmosphere. Biogas installation technology from waste biomass is an effective solution with several significant advantages, providing environmentally sustainable energy while promoting the use of biogas energy and leading to a systematic and integrated treatment of agricultural and livestock wastes, reducing the pollution discharge to the environment by more than 55%. In this work, an analysis of production of biogas through the process of anaerobic digestion is shown, which is commonly used for the processing of agricultural and livestock residues and energy crops for use (energy production and compost). Some critical parameters of this process are summarised, as a tool for comparative evaluation of this route with some other alternatives, which contribute to the decision making in the selection of power systems.

Keywords: biogas; agriculture; livestock; wastes; Greece; energy; renewable energy sources; RES; biomass; anaerobic; digestion.

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1 Introduction

In the past three decades, we have become fully aware of the reduction of fossil fuel supplies and the confirmation from the scientific community of climate change due to greenhouse gas emissions, and in particular from carbon dioxide.

Thus, expanding the usage of renewable energy sources (RES), generating sufficient energy and low energy consumption have become the key goals of achieving sustainable global energy production. Nowadays, the use of RES with assured return values or carbon sharing schemes is supported by many countries in Europe and around the world.

In this research, a specific area is being studied, an area where large quantities of waste biomass from agricultural and animal wastes are being produced, where in other conditions would be left untreated, promoting the pollution of the environment.

With this research, all the potential energy recovery of these wastes are calculated, and comparing with other RES, this technology seems to be the optimal solution with triple benefit:

a protecting the environment

b producing electric and thermal energy for this area

c contributing to achieving the national RES targets of Greece.

In the beginning of the present work, the penetration of RES in Greece will be presented as the country's obligations at European level. Then an area in Greece that has very large amounts of waste biomass will be selected. The energy potential of waste biomass will be calculated in this Regional Unit of Greece and the energy generated by the technology of anaerobic digestion will be calculated. Then, following assumptions that will be made and any restrictions imposed by national and European law, the optimal location for this unit will be selected. The environmental impact of this facility as well as a brief comparative analysis of biogas production by the method of anaerobic digestion will be summarised in the form of tables using scientific literature to finalise the selection of the method. The advantages of the anaerobic digestion method in the specific area over other energy sources will also be mentioned.

2 RES production in Greece

The Greek power sector still relies heavily on fossil fuels, the majority of which are imported. Approximately 54% of its energy needs are met by petroleum products, compared to an EU level average of 33.4%. In addition to being used in the transport sector, these petroleum products are often converted into energy in significant quantities.

The non-connected Greek islands in particular get their electricity primarily from expensive and inefficient diesel power stations.

Nearly 61% of Greece's primary energy needs are met through imports with the remaining 39% are covered by domestic energy sources, mostly lignite 77% and RES 22% (Greece Energy Situation, 2018).

The EU criteria laid down in Directive 2009/28/EC (EEL 140/2009) (promoting renewable energy use and amending and subsequently repealing Directives 2001/77/EC and 2003/30/EC) provide that the contribution of RES to total final energy consumption for Greece by the end of 2020 must be 18% (European Council Directive 2009/28/EC; Ministry of Development of Greece).

As provided from L.3851/2010, the national RES goals are set as follows:

a contribution of the RES produced energy to the total final gross energy consumption in 2020: 20%

b contribution of RES's electrical energy to total electrical consumption: at least 40%

c contribution of the energy generated by RES for the heating and cooling energy consumption: at least 20%

d contribution of electrical energy generated by RES to total consumption of electrical energy for transportation: at least 10%.

Table 1 RES electricity installed capacity per technology (September 2017)

Technology	*Electricity installed capacity in September 2017(MW)*	*NREAP target/2017(MW)*	*NREAP target/2020 (MW)*
Wind plants	2,451.00	5,430.00	7,500.00
Solar PVm	2,604.00	1,456.00	2,200.00
Small hydroplants	231	233	350
Large hydroplants	3,173.00	3,396.00	4,300.00
Biomass-biofuels	*61*	*160*	*350*
CSP	0	140	250
Geothermal plants	0	20	120
Total	8,520.00	10,835.00	15,070.00

Only few biomass energy projects have been developed in Greece, mainly for municipal solid waste utilisation. The installed biomass power capacity of a total of 12 individual projects currently stands at 58 MW (Greece Energy Situation, 2018).

3 Management of agricultural-livestock waste in Greece

In Greece, the management of agricultural-livestock waste is a major problem that needs to be solved, due to the high potential but also its spatial dispersion throughout the country. There is a lack of knowledge on the potential of wastes but also on the alternative of exploitation. The environmental burden from livestock is mainly located on the burden of water recipients with high organic loads and to the atmosphere, with release of odours and methane.

3.1 Study area

The prefecture of Serres is one of the 13 Prefectures of the area of Greek Macedonia. It occupies its eastern part and stretches from the Gulf of Strymon, located on its southern side to the Greek-Bulgarian border in the north. It borders on the east with the prefectures of Drama and Kavala and on the west with the prefectures of Thessaloniki and Kilkis. It belongs to the lowest plains of the country, as 48% of its total area is characterised as lowland-semi-mountainous, and is enclosed by the Kerkini-Vertiskou-Kerdylia mountain ranges, in the west and Orvilou-Menikiou-Paggaiou, in the East. The prefecture is crossed by the river Strymonas, which originates from Bulgaria and empties into the Strymonikos gulf (Orfanou). Its main tributary is the Aggitis, in the eastern part of the Prefecture (https://en.wikipedia.org/wiki/Serres).

As evidenced by the large number of applications deposited over the last two years (Operator of Electricity Market, Greece, 2018), Central, Western and Eastern Macedonia, due to the excessive availability of various types of biomass (agricultural and forest biomass, livestock waste, etc.) has received considerable investment interest.

In the area of private investment, investment in the biomass sector has slowed in recent years.

At the regional unit of Serres, the current situation in the management of agricultural and livestock waste is alarming, and specifically:

- Farmers use extensively chemical fertilisers, resulting in continued soil, surface water and groundwater pressure in the region. Nutrient accumulation can directly impact the surface and groundwater and is likely to contribute to a characteristic nitrate phenomenon.
- Large quantities are released of methane, ammonia, nitrogen oxides, hydrogen sulphide, and volatile compounds, which are the most significant greenhouse gases that cause climate change.

3.2 Estimating wastes and energy content

The following crop residues were selected as agricultural materials:

- wheat soft
- durum wheat
- barley
- corn
- cotton
- long grain rice
- medium grain rice.

This was sought because there is extensive cultivation of these materials in the Regional Unit of Serres as well as a great possibility of collecting the remains. There is already an established market for their use as a vegetable market and as a bedding in livestock facilities. The calculation of the residues was based on the average acreage yields sought through the Agriculture Directorates of the Prefecture of the Region.

Also, the Regional Unit of Serres, has extensive tree production and for this reason emphasis was given to the calculation of the quantities of pruning by tree planting. The residues studied are:

- pear
- apple
- apricots

- peach
- cherry
- olive
- vines.

The selection of these residues was made based on their increased production in the Regional Unit of Serres, the existence of data on pruning production and their time distribution.

Table 2 Available potential biomass in Regional Unity of Serres from Agricultural production activities

Agricultural production	*Crop area [1,000 m^2]*	*Available biomass utilisation rate an (%) (Balachtsis and Charalambous, 1995)*	*Available biomass potential [kg/y] (Skoulou and Zabaniotou, 2007)*
Wheat soft	15,714.00	15	801,414.00
Durum wheat	533,754.00	15	23,818,772.00
Barley	14,849.00	15	939,050.00
Corn	209,437.00	30	55,291,368.00
Cotton	367,047.00	15	18,168,826.00
Long grain rice	70.00	25	4,746.00
Medium grain rice	33,457.00	25	2,268,384.00
Pear	659.00	90	1,003,525.00
Apple	745.00	90	319,828.00
Apricots	39.00	90	21,867.00
Peach	644.00	90	325,155.00
Cherry	2,339.00	90	1,075,706.00
Olive	1,783.00	90	452,525.00
Vines	6,646.00	90	2,972,755.00
Total agricultural production			*107,463,921.00*

In Table 3, the aggregate inventory of the livestock sector for the Regional Unity of Serres (number of animals, number and capacity of breeding units) has been presented. The livestock activity of cows includes both dairy cows and cattle for meat production. The largest livestock activity in the cow sector is presented in the Municipality of Heraklion (5,571.00 cows in 274 farms). Regarding the livestock activity of the hens, the systematic poultry farming is included and specifically units (meat production and spawning) with a capacity of more than 1,000.00 birds. The most intense poultry activity is presented in the Municipality of Tragilos where 165,300 hens are raised. The Municipality of Kerkini with 910 pig farms and 9 farms is the Municipality with the largest pig farming activity. In the sheep and goat sector, the composition of livestock is distributed as follows: 56% sheep and 44% goats. 44.5% of all units are sheep forms, 28.5% are goat forms and 27% are farms that include both species. The Municipality of Serres displays the largest number of sheep and goats (26,240.00), which are distributed on 128 farms.

Table 3 Available biomass potential from livestock activities

Livestock production	*Number of animals*	*Medium animal weight (MAW) – (kg AW/animal) (Georgakaki et al., 1986)*	*Daily waste production per kg AW(*) (kg/kgAW/d)*	*Special production (kg/animal per year)*	*Annual livestock production waste (tn/year)*	*Availability [%]* (Prefecture of Thessaloniki, 1999)*	*Available biomass potential (tn/year)*
Sows	5,364.00	1,900.00	0.058	40,223.00	215,756.00	50	107,878.00
Poultry	481,600.00	3.00	0.0246	26.9	12,955.00	50	6,478.00
Cows	8,039.00	500.00	0.084	12,955.00	123,238.00	50	61,619.00
Sheep and goats	222,690.00	40.00	0.04	580.00	129,160.00	10	12,916.00
Total					*481,109.00*		*188,891.00*

Note: (*) AW = Animal weight

Table 4 Total produced biogas from agricultural production wastes

	Available quantity of fresh raw material (kg/year)	*Total solids% (Balachtsis and Charalambous, 1995)*	*Total solids (TS) – (tn / year*	*Volatile solids % of dry matter (Balachtsis and Charalambous, 1995)*	*Volatile solids (kg)*	*Biogas production m^3*kg-1VS (Karaj et al., 2010)*	*Produced quantity of biogas (m^3/y)*
Agricultural production	107,463,921.00	~37.3449	~40,132,300.00	80	32,105,840.00	0.6	*19,263,504.00*

Table 5 Total produced biogas from livestock wastes

Livestock production	*Available quantity of fresh raw material (kg/year)*	*Total solids (TS) – (%)*	*Total solids (TS) – (tn/year)*	*Volatile solids (VS) (%TS)*	*Volatile solids (VS) (tn/y)*	*Φbg (m^3/kg)*	*Produced quantity of biogas (m^3/y)*
Sows	107,878.00	7	7,551.46	80	6,041.00	0.35	2,114,350.00
Poultry	6,478.00	25	1,619.5	80	1,269.00	0.29	368,010.00
Cows	61,619.00	10	6,161.9	80	4,930.00	0.2	986,000.00
Sheep and goats	12,916.00	23	2,970.68	80	2,377.00	0.02	47,540.00
Total	*188,891.00*		*18,303.54*				*3,515,900.00*

In order to calculate the biogas production, we must calculate the quantity of volatile solids. So, through the calculation of volatile solids, we can estimate the biogas production.

3.2.1 Total production of agricultural and livestock wastes and energy content

Table 6 shows the total production of agricultural and livestock wastes in Serres and the energy content that can be produced from these wastes.

Table 6 Available biomass potential from livestock activities

Production in Serres	*Total incoming quantity available (tn/y)*	*Total incoming feedstock-volatile solids (tn VS/y)*	*Biogas production (m^3/y) (Karaj et al., 2010)*	*Energy content (MJ/Nm3)*
Total agricultural production	107,464.00	32,105.840	19,263,504.00	404,533,584.00
Livestock production	188,891.00	14,643.00	3,515,900.00	73,833,900.00
Total	*296,355.00*	*46,748.84*	*22,779,404.00*	*478,367,484.00*

From Table 6, we have a daily enter of *~811.00 tn/day* feedstock, which corresponds to *62,409.00 m^3/day* produced biogas.

The technology that will be used for the recovery of biogas is the combined heat and power (CHP). A CHP plant using internal combustion engine (ICE) has efficiency up to 90% and produces an average of 35% of electricity and 65% heat (Walla and Schneeberger, 2008).

- *Thermal energy:* Considering that the thermal energy generated by the biogas is in the order of 6.8 kWh per m^3 of biogas, the thermal energy generated is estimated at:

$$Eth = 6.8\ kWh/m^3 \times 62,409.00\ m^3/day = 424,381.00\ kWh/day\ of\ thermal\ energy \quad (1)$$

- *Electricity:* The performance of an ICE ranges from 36 % to 39 %. Considering *n* = 37.4 % (Metcalf & Eddy, 1991) and as a CHP plant operates 90 % of the time on an annual basis, the electricity produced will be:

$$Eel = Eth \times \eta \times 0.9 \times 365\ kWhel / year \quad (2)$$

Table 7 Installed capacity (KW) / efficiency

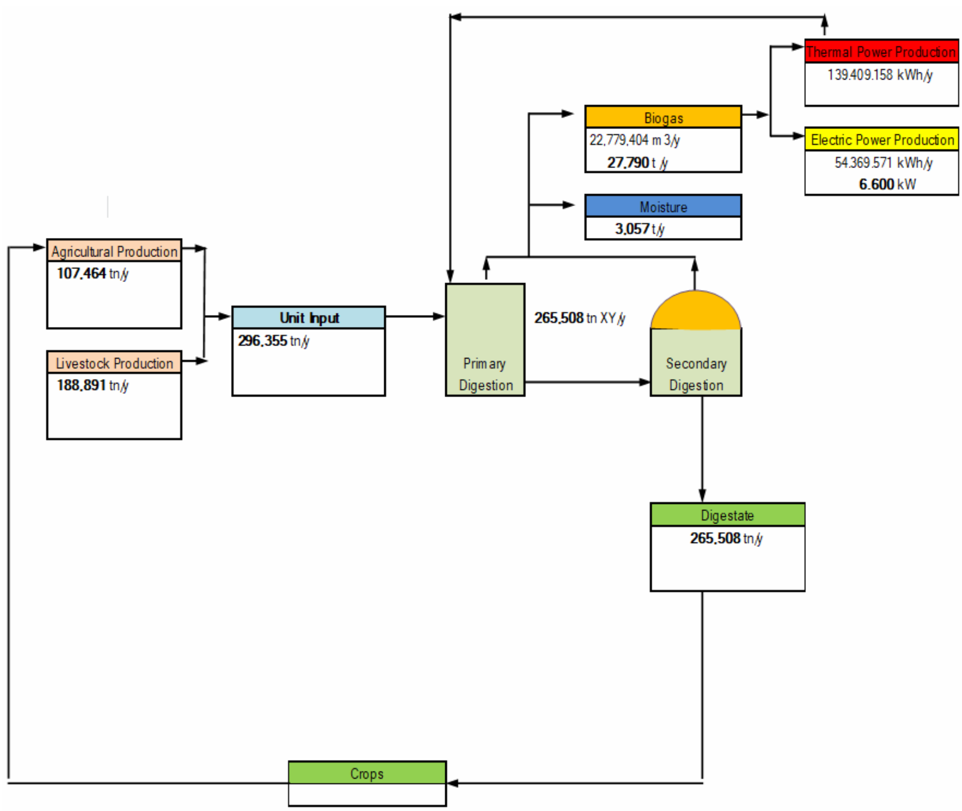
Efficiency (η)	*Electric power/year (kwh)*	*Installed capacity (KW) ~ (328.5 days) of operation*
Min = 0,36	50,187,297.6	6,365.71
Nom= 0.374	*52,139,025.28*	*6,613.27*
Max= 0,39	54,369,571.82	6,896.19

Installed power capacity of 6.6 MW, would be a good approach for the biogas plant.

3.2.2 *Flowchart process of central combined biogas production from waste biomass*

The flowchart (Figure 1) summarises the various steps that take place in the biogas plant. Initially, in the (unit input), the collection and storage of raw materials for anaerobic fermentation is the first stage. This is followed by the improvement of the substrate, which consists of the stages of cutting, sorting, depending on the quality and origin, mixing, pasteurisation, etc. preparation for the following anaerobic digestion process. In the anaerobic digestion stage, the already prepared substrate is led to the primary (primary digestion) and then to the secondary digesters (secondary digestion) to carry out and complete the anaerobic digestion process. From the process of anaerobic digestion, biogas is produced, which is subject to a series of treatments (desulphurisation, drying, etc.) in order to become suitable for use. Finally, the refined biogas is burned in an ICE unit for the production of electrical and thermal energy. The residue of the anaerobic digestion process (digestate) is stored and then available as liquid fertiliser for the fields (agriculture production).

Figure 1 Process flowchart of central combined biogas production from waste biomass (see online version for colours)

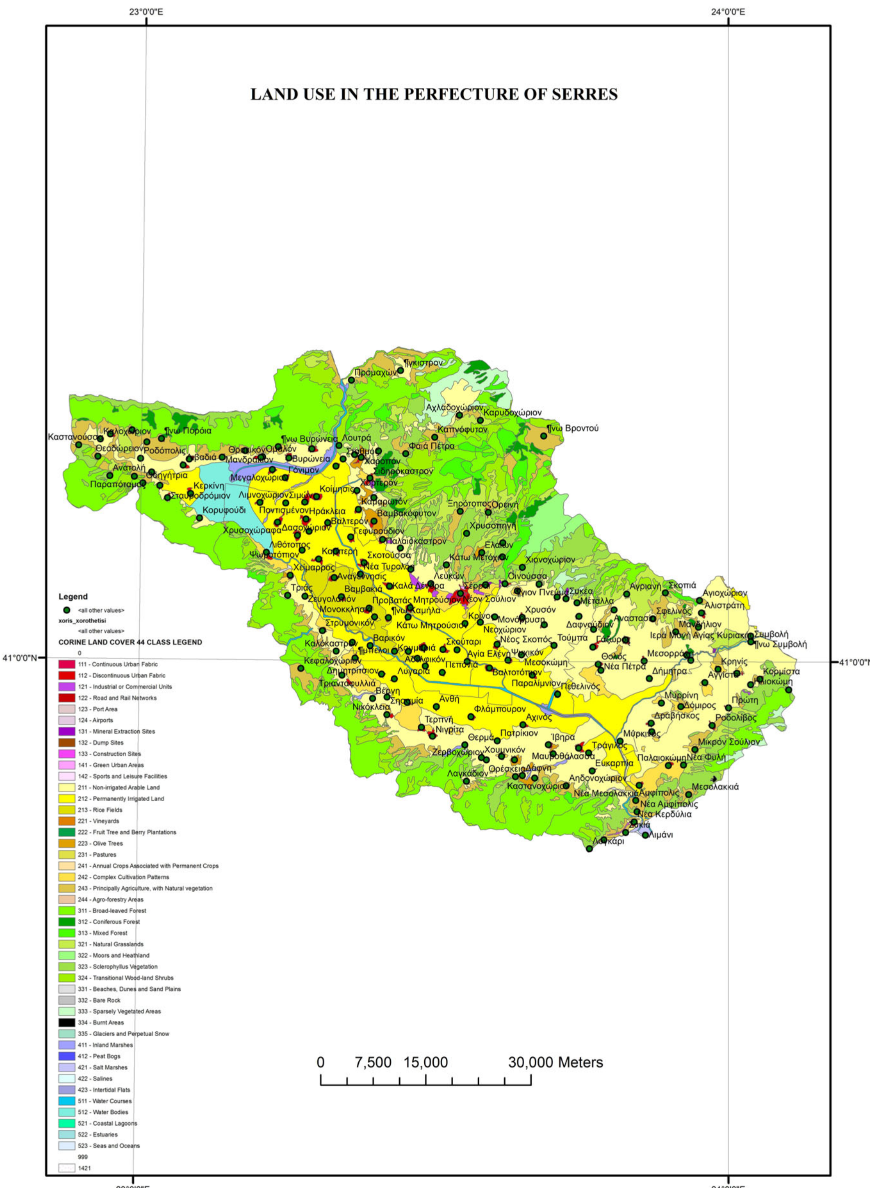


The general layout and methodology of the process for biogas plants is designed for digestion and anaerobic treatment of a total mix of farms and residues such as: cattle manure, pigs (livestock production) and agricultural residues.

3.3 *Location of the biogas plant*

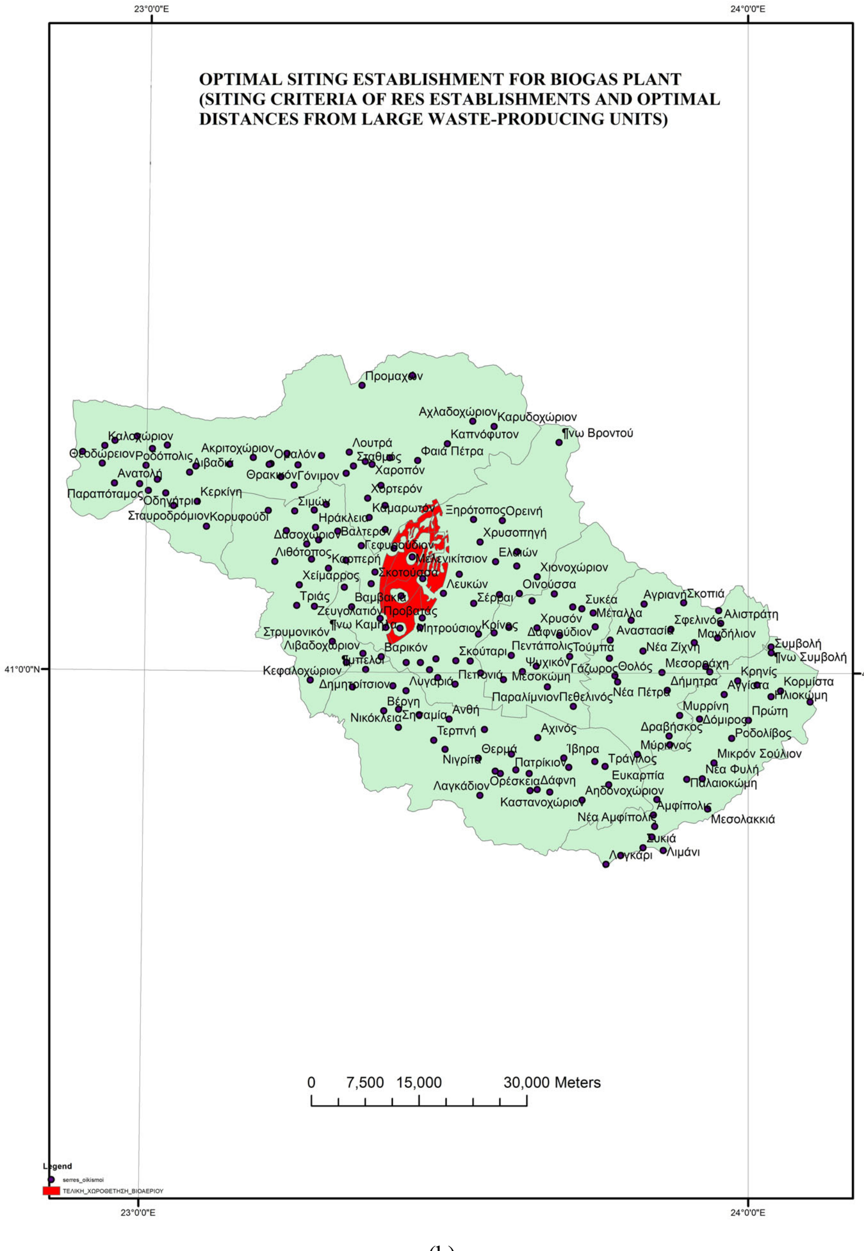
There are distances to be observed for the installation of a biogas plant, according to the Joint Ministerial Decision no. 2464/3-12-2008 "Approval of a special framework for spatial planning and sustainable development for RES".

Figure 2 Location of the biogas plant in Serres (using software (arcgis v.10.0)), (a) land use in the Regional Unit of Serres (EEA), (2017 – CLC data download) (b) schematic (in red) of the suitable areas for development of biogas plant (see online version for colours)



(a)

Figure 2 Location of the biogas plant in Serres (using software (arcgis v.10.0)), (a) land use in the Regional Unit of Serres (EEA), (2017 – CLC data download) (b) schematic (in red) of the suitable areas for development of biogas plant (continued) (see online version for colours)



(b)

In order to be economically viable, a Central Unit, such as the one under consideration, must be located within a radius of 15 km, from large waste producing units (Al Seadi et al., 2003; Al Seadi and Holm Nielsen, 2004).

Figure 2(a) has been created using the ArcGis V.10.0 software and shows all land uses within the Regional Unit of Serres. Figure 2(b) shows all land uses within the Regional Unit of Serres, in which, according to the current Legislation, the installation and operation of a Central Combined Energy and Heat Generation Unit from Biogas, is optimal and economic viable to be constructed. Thus, all the restrictions imposed on Greek and European legislation are observed, as well as the financial viability of the facility.

3.4 Summary of environmental impact assessment of biogas plant

During the construction and operation of a biogas plant, the wider environment can be affected.

In Table 8, the environmental parameters that are affected from the construction and operation of a biogas plant are presented briefly.

In conclusion, no significant environmental degradation is expected during the construction and the operation of the proposed biogas plant, while environmental benefits are very significant.

4 Decision support tool – producing energy from biogas versus other energy sources

Biogas plants from anaerobic digestion of organic waste from agricultural and animal farms is chosen for the implementation of the proposed RES energy generation project due to substantial advantages over other sources of energy (coal, nuclear, etc.) and other RES (e.g., wind, solar, hydroelectric, etc.).

In Table 9, a comparison is presented between energy source produced by Biomass and other energy sources (including RES).

4.1 Biogas from anaerobic digestion vs. other RES

In fact, unlike other sources, the anaerobic digestion technology does not require special conditions in respect of the installation site. For instance, the cost-effective operation of a wind farm requires high available wind energy, the output of photovoltaic systems depends on the area's sunshine and the availability of water is a required condition for the operation of hydroelectrical plants.

The only necessary requirement for the operation of the biogas plants is the possibility of supplying biogas to the ICEs generated in the installation site during anaerobic digestion of organic wastes.

Electricity generation is possible almost everywhere, without impacting the environment in an esthetic way, although biogas plants can easily be combined with other sources of energy to create hybrid systems.

A significant benefit of biogas plants is that these systems can be easily extended with the installation of modern ICEs and are transported without much difficulty or conversion of the original system.

Table 8 Summary of environmental impacts in matrix form

		Impact assessments	
		Construction period	*Operation period*
Natural environment	Soil	The construction of the proposed biogas plant will affect the terrain and morphology of the soil due to the changes that will be caused and are related to the necessary landscaping work, road construction, excavations for the construction of buildings, as well as the installation of transmission lines and wiring. The specific changes concern small-scale and deep-scale interventions, which in the final analysis do not imply significant effects on the ground.	During the operation phase of the biogas plant, no effect is expected on the soil, geological and tectonic characteristics of the area. An exception is the case of accidental pollution after any oil leakage in the installation, which however is considered a rare phenomenon in similar installations. In any case, the biogas plant must take all necessary protection measures for any such eventuality.
	Air	During the construction phase of the biogas plant, the air quality in the immediate study area may be burdened. These effects are identified in the dust released from construction work on the site and in particular by excavations, vehicle movements and loading and unloading of materials, as well as from the exhaust gases of the vehicles during their movements to and from the installation. More specifically, in addition to emissions of gas and particulate pollutants from vehicle and machinery exhaust fumes, particulate pollution is caused by the handling and disposal of various materials. Especially when the winds are blowing, the materials create dust (dust fall) a short distance from the project. Particles larger than 30 microns settle to the ground a few meters away. The smaller ones are carried away by the wind and transported to significantly longer distances.	Exhaust gases from the combustion of biogas are produced during the operation of the proposed biogas plant. The operation of the biogas plant has indirect positive effects on the atmosphere, due to the replacement of conventional fuels for electricity generation and meeting the growing energy needs of a renewable source. The project contributes to reducing the greenhouse effect and improving the global climate, while reducing the demand and consumption of conventional energy resources.

Table 8 Summary of environmental impacts in matrix form (continued)

		Impact assessments	
		Construction period	*Operation period*
Natural environment	Water	During the construction phase, excavations and other work will be carried out outside the aquifer, and as a result the groundwater will not be affected. There will be no change in the movement of surface water, nor will the current situation change in terms of water absorption rate or soil leaching. No other works are also planned, which could affect the course of flood waters or indirectly pose a risk of human or property exposure to flood damage. During the construction works of the power plant and the restoration works of the area after the end of its construction, liquid waste will be produced by the staff of the construction site, which will include personnel wastewater, washing machine fluids and mineral oils from the maintenance of machinery and vehicles.	During the operation of the biogas plant, no works are foreseen from which liquid waste can come. Similarly, the current state of groundwater movement will not change. To meet the needs of the operation of the power plant in the water, the required quantities will be taken from the water supply network of the area. The loading and unloading areas will be equipped with liquid leakage protection devices, which are emptied, if necessary, and the collected materials are fed to the trench receiver. During the operation of the biogas plant, no liquid waste will be produced from the production process since the used water will be reused. The resulting liquid waste will only concern staff sewage and internal combustion engine oils. In conclusion, during the operation of the biogas plant, the pollution of water resources is avoided but they will be affected due to the extraction of water required for anaerobic digestion, as well as to cover the needs of the unit's staff for hygiene and fire protection reasons.
	Flora	The effects on the flora during the construction phase come from the deforestation of limited and common vegetation, especially during the construction of the foundations. In the areas where the small-scale projects will take place, there will be minimal vegetation loss, while the continuous presence of people and vehicles during the projects is expected to have little negative impact on the existing balance of the ecosystem. The vegetation that will be removed in any case does not rarely affect ecosystems or protected plant species. As mentioned above, the area of operation does not belong to any of the protected areas.	No change is expected in the variety of animal species. Also, as the unit will be fenced the physical presence of animal species will not be allowed within the boundaries of the field.

Table 8 Summary of environmental impacts in matrix form (continued)

		Impact assessments	
		Construction period	*Operation period*
Natural environment	Fauna	The possible harassment of animal species during the construction of the project is not a significant disturbance, due to its small size. The effects on the animal communities of the study area during the construction phase of the plant focus on the direct effects of noise and limited pollution due to pollution and dust from the movement of vehicles and the operation of construction machinery.	During the operation phase, species of fauna that live in the immediate area of the project will not be affected. Since noise will not exceed the limits of the legislation, while emissions from combustion will be within the limits, there will be no significant effects and the movement of the animal population will not be affected.
	Land use	Land uses, during construction will not be affected	Land uses during the operation of the project will not be affected, as the uses of the area are mainly agricultural in nature. It should be noted that the activity is directly related to agricultural production.
	Natural resources	The construction of the proposed biogas plant will affect the natural resources due to the changes that will be caused through road construction, excavations for the construction of buildings. Also, to meet the needs of the operation of the power plant in the water, the required quantities will be taken from the water supply network of the area.	Treatment and planned disposal of digested waste, reduces the negative effects on natural resources in relation to the uncontrolled and unprocessed dispersion-disposal.

Table 8 Summary of environmental impacts in matrix form (continued)

		Impact assessments	
		Construction period	*Operation period*
Social/economic environment	Noise	During the construction of the biogas plant, there is expected to be noise on the construction site due to excavations, construction work, the movement of vehicles and the operation of machinery.	It is noted that the main equipment of the biogas plant does not consist of mobile parts and its operation is completely silent. The internal combustion engine is going to be housed inside a chamber with special protection against noise. The internal combustion engine ventilation systems will be equipped with noise absorption devices. All other noise-generating equipment will be housed inside the facility building.
	Population	The proposed biogas plant does not bring about changes in the human population, therefore no change is expected due to it and the structured environment of the wider area.	It is not expected to be negatively affected. Instead, new jobs will be created, both during the construction and during the operation of the proposed project
	Residence	Demand for housing during construction will increase due to the large supply of labour in the area	Demand for housing during operation will increase due to the large supply of labour in the area
	Transportation-traffic	There will be no significant traffic problems in the road network, because the traffic load will be limited, while the vehicles will not pass through residential areas.	There will be movement of waste vehicles – raw materials that will not cause significant traffic problems on the road network, because traffic will be limited, while vehicles will not pass through residential areas.
	Energy	A small amount of conventional fuels will be used, for excavation machinery etc.	The energy balance will be surplus by 54.369.571 kwh RES quantity of electricity corresponding to the annual output of the Project
	Human Health	The environmental effects are located in the dust released by the movements of vehicles to and from the installation as well as by the emissions of the power plant. The burden of the atmospheric environment on residential areas and ecosystems in the area from dust and exhaust emissions from vehicles will be negligible if the environmental protection measures are followed.	There will be no significant effects from the operation of the activity, as no significant noise, gas pollutants and unpleasant odours are expected, as well as the protection measures that will be taken.
	Cultural heritage	There will be no impacts in cultural heritage from the construction of the biogas plant.	There will be no impacts in cultural heritage from the operation of the biogas plant.

Table 9 Comparing energy sources in matrix form

Source of energy	*Fossil fuel*	*Alternative*	*Renewable*	*GHG emission levels of electricity generation methods (g CO_2-eq/kWhe)*	*Land use (m^2/MWh)*	*Extra environmental benefits*	*Cost (LCOE)** $/kW-hr*
Biomass	x	✔	✔	650	450 (from crops), 0.1 (from residues)	✔ +Waste treatment, +Economic income for farmers + Limiting odours and pollutants + Improve organic fertiliser quality	$0.092
Coal	✔	x	x	888	0.2	x	$0.13
Hydro*	x	✔	✔	74.9	3.5	x	$0.039
Natural gas	✔	x	x	499	0.1	x	$0.043
Nuclear	x	✔	x	24.2	1.0	x	$0.093
Solar	x	✔	✔	150	8.7	x	$0.038
Wind	x	✔	✔	50	0.7	x	$0.037 $0.106

Notes: *Large hydropower plants can cause significant damage to the ecosystems in which they are constructed, so hydropower is not always classified as renewable.
** Levelised COST OF ENERGY (LCOE)

Source: Amponsah et al. (2014), Our World in Data (2020), Fritsche et al. (2017) and UNEP (2016)

Furthermore, these systems are ideal for central and distributed energy production, as they can make a major contribution to the 'Distributed Power Generation,' which is the latest paradigm for the implementation of modern energy production and transport systems and also for the distribution of electricity (Doukas, 2013; Doukas et al., 2008).

Combined with the high percentage of oil dependency and the avoidance of more environmental emissions, the diversification of energy output provided by ICEs will create conditions for economic growth within a new energy landscape that is currently taking shape in developed countries.

At the same time, anaerobic digestion technology uses the biogas as biofuel, which is generated during the anaerobic digestion of organic wastes, which is an inexhaustible source.

Finally, a significant advantage of this technology is the significant lifespan of a similar investment that can exceed 25 years, with low maintenance and operating costs.

In addition to providing energy from renewable sources, the combined anaerobic digestion of animal manure and other suitable categories of organic waste in central biogas plants has interrelated environmental and agricultural benefits, such as:

a low emissions of greenhouse gases (CO_2, CH_4)

b farmer money-saver

c improved soil fertility

d economic and ecological recycling of waste and wastewater

e reduced discomfort related to odour removal and insects (e.g., bugs, mosquitoes)

f reduction of pathogens in digestate.

The most commercially and technologically ready anaerobic digestion plants are those developed for digestion of animal manure, both on and off the field, as well as for the digestion of specific animal manure and residues from the food industry.

Organic sludge is another raw material of interest in terms of anaerobic digestion and common digestion. Organic sludge digestion is a popular practice in many European Union countries, especially in medium and large facilities operated by the communities and other involved businesses.

5 Conclusions and discussion

In this work, through the analysis of the total production of agricultural and livestock wastes in a regional Unit of Greece as a case study, and the energy content that can be produced from these wastes, it has shown that the installation of biogas technology from waste biomass is the optimal energy source in this area with many important advantages, as it provides eco-friendly energy and, at the same time, the use of biogas energy potential, participates in a comprehensive and integrated waste treatment of agricultural and livestock waste and reduces its polluting load.

Also, this work is an introduction to anaerobic biorefinery as a promising new technology where the anaerobic reactor/digester act as a hub for the conversion of feedstocks into a lot of high-value products and intermediate products.

This design presents a dynamic culture of innovation, where new materials that have significantly higher value or energy content than biogas or the digestate material, can be produced (Al Seadi et al., 2013).

Finally, through comparative analysis and thorough search of international literature, we conclude that this project is an essential and real solution in protecting the natural environment, especially in an area where waste management is problematic, and will also contribute to energy production in the region, through a renewable source.

5.1 Advantages of a central operating unit of biogas of 6,6 MW installed power

The purpose of a central operating unit biomass (livestock waste and organic agricultural residues) would display the following advantages:

- It will contribute to the centralised management of organic waste and the conservation of sensitive ecosystems in the region.
- It will contribute to electricity-Greece's sustainability goals for renewable energy production and climate change mitigation.
- It will enhance the autonomy of the energy network of Greece and contribute to self-sufficiency by imports electricity during peak periods.
- It contributes towards replacing chemical fertilisers with natural – renewable agricultural fertiliser material. The benefits will be very important for both economic and environmental considerations (reduction of the cost of chemical fertilisers, improvement of agricultural soil quality) for Greek farmers and Greek Agricultural production.
- It helps to maintain the cycle of carbon, nitrogen, phosphorus and general nutrient elements in nature.
- It would support job creation

5.2 Without the operation of the central operating unit of biogas of 6.6 MW installed power

- The energy balance will be in deficit by *54.369.571 kwh* RES quantity of electricity corresponding to the annual output of the Project.
- Farmers will use chemical fertilisers which result in ongoing soil, surface water and groundwater burdens in the region. The need for income growth and hence greater production will push farmers to increase chemical fertiliser quantities by polluting more.
- Nutrient accumulation can directly impact the surface and groundwater and is likely to contribute to a characteristic nitrate phenomenon.
- Significant amounts of methane, which is the main greenhouse gas and causes climate change, will continue to be emitted into the atmosphere. The 25,000 tons of cow manure is estimated to release about 5 tons CH_4 in air.
- Large quantities of ammonia, nitrogen oxides, hydrogen sulphide and volatile compounds will continue to be released into the atmosphere.

It is obvious that the above made analysis is capable to provide us with adequate information and data, in order to establish and quantify the suitable criteria for decision making, in the case of evaluating and comparing various alternative plants for power generation.

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