Sustainable organic waste treatment in mountainous areas through small biogas plants: Insights from Metsovo, Greece

Conference Paper · June 2017

Nikolas Katsoulakos
National Technical University of Athens

Ilias G. Doulos
National Technical University of Athens

Sustainable organic waste treatment in mountainous areas through small biogas plants: Insights from Metsovo, Greece.

N. M. Katsoulakos[1], I. G. Doulos[2], D.C. Kaliampakos[3]

[1]Metsovion Interdisciplinary Research Center, National Technical University of Athens, Metsovo, Epirus, 44200, Greece
[2]Regulatory Authority for Energy, Athens, Attica, 11854, Greece
[3]School of Mining and Metallurgical Engineering, National Technical University of Athens, Athens, Attica, 15780, Greece

Keywords: biogas unit, organic waste, mountainous areas, social cost - benefit analysis

Presenting author email: katsoulakos@metal.ntua.gr

Abstract

The present study investigates the possibilities of creating a biogas unit in Metsovo, which is a small mountainous town in Greece retaining important activity in the sectors of livestock breeding, cheese and wine production. These activities produce great quantities of residues, which currently are not being treated properly and cause organic pollution. The biogas unit contribute to the treatment of organic residues through anaerobic digestion and, at the same time, will produce heat and electricity. The special characteristic of the unit is that it will not operate with commercial criteria. The energy produced will cover the needs of municipal facilities. Firstly, the biogas potential was estimated, based on primary data, statistical data, as well as laboratory analyses. It is calculated that the organic residues in the area of Metsovo can support the operation of a biogas system producing up to 325 kW of electricity. By taking into account the biogas potential and the energy needs that need to be covered the basic dimensioning of the energy unit is implemented. The necessary electricity capacity of the unit is 180 kW and it is estimated that 270 kW of thermal energy can be recovered. An analysis of the feasibility of the biogas unit was realized, which also included a social cost–benefit analysis. The results of the social cost-benefit analysis are positive and so, it is proved that a small biogas energy unit is a sustainable solution for organic waste treatment in the area of Metsovo.

Keywords

Biogas unit; mountainous areas; social cost-benefit analysis; organic residues; anaerobic digestion; contingent valuation method

1. Introduction

The increasing quantities of waste are one of the most intense problems worldwide. Nevertheless, the conditions, issues and problems of urban and mountainous areas regarding waste management are different. Though the urban areas generate larger amounts of wastes, they have developed adequate facilities taking advantage of the economies of scale, the mild terrain, the current transport infrastructure, etc. On the contrary, many mountainous areas are still in the transition towards better waste management but they currently apply insufficient collection processes and improper waste treatment and/or disposal methods. Steepness, remoteness and vulnerability to natural hazards, makes waste management in mountains more challenging than in lowland areas. Moreover, gravity and river flow can also enlarge the footprint of mountain waste to a thousand kilometers or more downstream. [1]

Under this framework, sustainable waste management should be a priority, in order to avoid the environmental impacts of waste disposal. Current waste management practices are strongly influenced by the ‘waste hierarchy’, which recommends a priority order; from the most preferred option of ‘prevention’ at the top to the least preferred option of ‘disposal’ at the bottom.

In 1975, the European Union’s Waste Framework Directive (1975/442/EEC) introduced for the first time the waste hierarchy concept into European waste management policy. Through this Directive it was emphasized the importance of produced waste minimization as well as the need for enhanced environmental protection. After 15 years, in 1989, the waste hierarchy concept was furthermore formalized into a hierarchy of waste management methods/ options. Finally, in 2008, the European Union introduced through Directive 2008/98/EC a new five-step waste hierarchy to its waste legislation. Article (4) of the Directive 2008/98/EC describes the ‘waste hierarchy’ as comprising of five measures; prevention, preparing for reuse, recycling, other recovery (e.g. energy recovery) and disposal [2]. Relevant guidance documents issued, describes this hierarchy in the form of a reverse triangle (Figure 1).

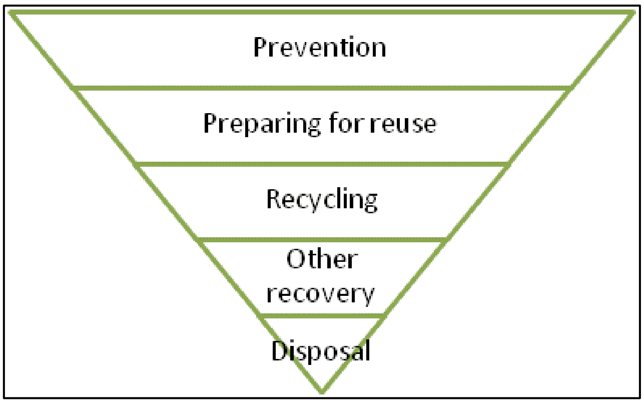

Figure 1. Waste hierarchy as in the Directive 2008/98/EC

Taking into consideration the aforementioned as well as the fact that in mountainous areas the main economic activity, excluding tourism, is agriculture and livestock farming; it is obvious that the waste produced have a high proportion of organic residues. Due to the fact that recovery (including energy recovery) is considered to be a proper method of waste management (Fig. 1); the utilization of high organic load residues for the production of electricity and thermal energy through biogas plants is the most modern technological application that combines the rational management of waste with the production of clean energy.

Agriculture and livestock farming organic residues can be used to meet energy needs (heating, cooling, electricity generation, etc.) either by direct burning or by conversion to gaseous, liquid and/ or solid fuels. Depending on the available biomass source, the corresponding process for optimal energy utilization is selected. The existing biomass energy utilization methods are divided into three categories: thermochemical (combustion, gasification and pyrolysis), chemical (transesterification) and biochemical (alcoholic fermentation and anaerobic digestion) [3].

The combustion of solid biomass as well as the combustion of biogas fuel, which is produced either from the anaerobic digestion method or from the gasification method, are the most common processes for power generation. Biogas can be used as fuel for internal combustion engines, gas burners or gas turbines in order electricity and heat to be produced. It can also be used after a purification process (removal of particles, H_2S, NH_3, H_2O) and its upgrading (CO_2 removal and propane addition) as transport fuel [4]. The produced biogas, after the purification and upgrading process, is called biomethane and is distinguished in L-grade (89% CH_4) and H-grade (96% CH_4) bio-methane. Bio-methane can also be diverted into the natural gas network. The use of bio-methane as a transport fuel is found in Sweden, Switzerland, France and Germany, while in Sweden and Germany it is also fed into the gas grid [5]. Biogas is produced in proper sealed tanks (digesters) from the anaerobic digestion of livestock waste (farms manure), agro-industrial waste (pruning, food waste), waste water as well as the decomposition of the organic fraction of waste. Biogas consists of 55% to 70% methane (CH_4) and 30% to 45% of carbon dioxide (CO_2), it also contains low concentrations of nitrogen, hydrogen, ammonia and hydrogen sulphide, as shown in Table 1.

Table 1. Typical composition of biogas [6]

Component	Chemical Type	Content (% volume)
Methane	CH_4	55-70
Carbon dioxide	CO_2	30-45
Nitrogen	N_2	0-5
Oxygen	O_2	<1
Hydrogen Sulfide	H_2S	0-0.5
Ammonia	NH_3	0-0.05
Vapor Water	H_2O	1-5

Biogas can also be produced by gasification technology, i.e. the thermal decomposition of organic fuel consisting of ligno-cellulosic raw materials in a proper gasifier. Gas synthesis (Syngas) is produced by the previous process. Syngas consists mainly of hydrogen (H_2 - 22%), carbon monoxide (CO - 44.4%) and carbon dioxide (CO_2 - 12.2%). The produced synthesis gas is cooled, purified and converted to biogas with the addition of hydrogen (H_2) and water (H_2O) [7].

The Process of Anaerobic Digestion in a typical biogas power plant

By anaerobic digestion is meant the biochemical process in which organic carbon through sequential oxidations and reductions is converted to carbon dioxide (CO_2) and methane (CH_4) under the catalytic action of a wide range of microorganisms, in the absence of oxygen. The process of anaerobic digestion is divided into three separate stages: hydrolysis (long-chain organic compounds- proteins, carbohydrates, fats - are broken down into compounds of a lower molecular chain), the oxygenesis (the organic compounds are broken down by the action of acidic and acidogenic bacteria into acetic acid, CH_3COOH, carbon dioxide, hydrogen and low molecular chain fatty acids) and methanogenesis (methane generation due to the degradation of acetic acid and the reaction of carbon dioxide with hydrogen) [8].

According to [9], a typical biogas power plant is divided into the following eight key segments (Figure 2):

1. **Collection and storage facilities**: Storage of the raw material is necessary on the one hand to address seasonal variations and on the other hand to better mix the substrates to be digested. The type of storage facilities varies depending on the type of feedstock. In the case of solid raw materials, silo-type warehouses are used, while in the case of liquid raw materials sealed, watertight and reinforced concrete tanks are used.
2. **Feed systems**: The raw materials, after being stored, are fed to the digester. Centrifugal or displacement pumps are used in case of liquid raw materials as well as if flow from storage tanks to the digester by gravity is not possible.
3. **Digestion tank**: The digester is the “heart” of a biogas plant. This is where microbial activity occurs and organic matter is converted into biogas. The digester unit consists of one or more digesters, and also includes the mixing system and the heating system. A pre-digestion unit and a post-digestion unit can complement the unit. Reactors - digestors may be either dry or liquid digestion, continuous or discontinuous feeding, one step or multistage and one phase or multiple phases. The digesters can operate either in the mesophilic or thermophilic region.
4. **Biogas Upgrading Facilities**: When biogas comes out of the digester, it is vapor-saturated and contains, in addition to methane (CH_4), carbon dioxide (CO_2) and amounts of hydrogen sulphide (H_2S). Due to the corrosive properties of the hydrogen sulfide compounds it is necessary to desulphurize and dry the biogas, which is carried out in a special tower-column located outside the digester.

5. **Biogas storage facilities**: Biogas storage facilities must be air-tight and resistant to pressure, UV radiation, temperature fluctuations and extreme weather conditions. In addition, the storage system should be equipped with a sensor for detecting pressure variations (overpressure and vacuum) and relevant safety valves. Explosion protection must also be guaranteed and an emergency torch is required.
6. **CHP plant**: After the cleaning and dehumidification process, the biogas produced is led to an internal combustion engine (ICE). ICE uses biogas as a fuel and generates electricity and heat.
7. **Digestate Reservoir**: The digestate is pumped out of the digester and piped to a storage reservoir where it is temporarily stored (a few days). The digestion of the digestate can be done in concrete or artificial ponds which are covered by natural or artificial floating layers or membranes.
8. **Control unit**: Appropriate technology is used to monitor and manage the processes of a biogas plant Most of the units use a Programmable Logic Controller (PLC) to control the functions. This includes a central processing unit (CPU) and various individual parts, which can be selected according to the unit's needs.

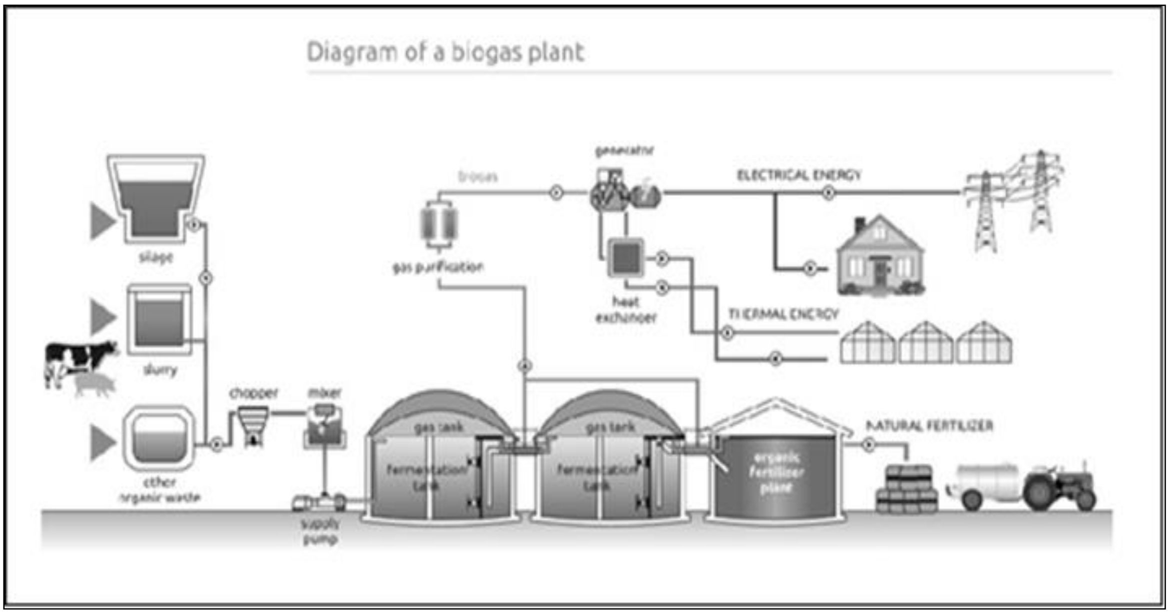

Figure 2: Flowchart of biogas plant

Biogas utilization benefits

The production and utilization of biogas for electricity and / or heat generation provides a number of environmental and socio-economic advantages over fossil fuels, particularly in remote areas such as mountainous regions. Firstly, the use of biogas contributes to reducing dependence on imported fossil fuels, resulting in the improvement of the country's energy balance; enhancing the security of national energy suppliy and reducing greenhouse gas emissions. Moreover, the digested residue is rich in nitrogen, phosphorus, potassium and trace elements and can be applied as soil improvers. In relation to raw animal solid manure, it has improved lubricity due to homogeneity and higher availability of nutrients. In particular, remote farming and farming areas can have a significant benefit from biogas plants, as their development contributes to the creation of new peripheral enterprises, some of which with significant economic potential. Finally, biogas production is an excellent way of complying with increasingly restrictive national and European regulations in the field of waste treatment; in particular in the field of recovery. Table 2 presents units operating in Greece by the end of 2015, according to the Ministry of Environment and Energy.

Table 2: Company Name, Region and Power of operating biogas power stations

Company Name	**Region**	**Electrical Power (MWel)**
Biogas Ano-Liosia	Attica	13,6
EYDAP	Attica	11,4
HLEKTOR	Central Macedonia	5,0
EYATH	Central Macedonia	2,5
Biogas Ano-Liosia	Attica	9,5
BIOENERGEIA SA	Thessaly	1,3
DEYAL	Thessaly	0,6
Gasnakis A SA	Central Macedonia	0,3
Mitrogianni SA	Epirus	0,2
CHITAS FARMS SA	Epirus	1,0
Karanikas SA	Central Makedonia	0,3
BIOAERIO SA	Thessaly	0,5
Gardano Enterprises	Western Greece	0,5
BIOAERIO KOMOTINIS SA	Eastern Macedonia &Thrace	0,3
MATIZION	Western Macedonia	0,1
MANTMOYAZEL SA.	Western Macedonia	0,3
TOTAL		**47,2**

The present study investigates from an economic as well as a technical perspective the possibility of constructing a biogas unit in Metsovo, which is a small mountainous town in the Region of Epirus, Greece. Under the operation of this biogas plant, the local community aims to treat appropriately the organic waste and, at the same time, to produce heat and electricity. Since in Greece the technology of biogas, as seen in Table 3, is not particularly widespread, the Region of Epirus had been planning to finance a pilot biogas unit, with non-commercial operational criteria. The unit was aimed to provide energy to facilities owned by the Municipality, in which it would be installed. In 2014, the Laboratory of Mining and Environmental Technology (LMET) of the National Technical University of Athens (NTUA) conducted a research project, funded by the Municipality of Metsovo, in order to assess the feasibility of building such an energy unit in Metsovo. The unit, studied in the research project, utilizes organic waste and produces electricity for covering the need of the wastewater treatment unit, as well as heat for covering the needs of Metsovo Primary School. The main results of this research effort are presented in this paper.

2. Methodology

In order to evaluate the techno-economic feasibility of the proposed biogas unit in Metsovo, the methodological steps described below were followed. Firstly, the theoretical biogas production potential was estimated. In order to gain a clear and accurate view, an extensive study in the area was realised, in order to collect both primary and statistical data. Moreover, laboratory analyses of manure and organic waste from cheese production units (whey) samples were conducted, aiming at the determination of crucial parameters (pH, tCOD, TS, VS) so as the economically and technically feasible potential of biogas to be estimated. After the experimental analysis the produced biogas per tonne of waste, under the procedure of anaerobic digestion was calculated. Furthermore, the basic dimensioning of the biogas unit was realized. Finally, a thorough socioeconomic analysis was conducted in order to check if such an integrated solution for treating waste and producing energy is viable for the case of Metsovo. The socio-economic analysis aims at correcting the economic magnitudes of private analysis, according to the externalities of the project (positive and negative), i.e. costs and benefits not valued by the conventional mechanism and market prices. This approach evaluates the contribution of the investment plan to the economic prosperity of a region or the whole country. Therefore, the evaluation is carried out for the whole society and not just for the private investor. It is noted that the work presented in this paper included a primary survey, under the Contingent Valuation Method (CVM), in order to express in monetary terms the environmental benefits of treating the organic waste in the town of Metsovo. In Figure 3, a schematic overview of the methodology followed is presented.

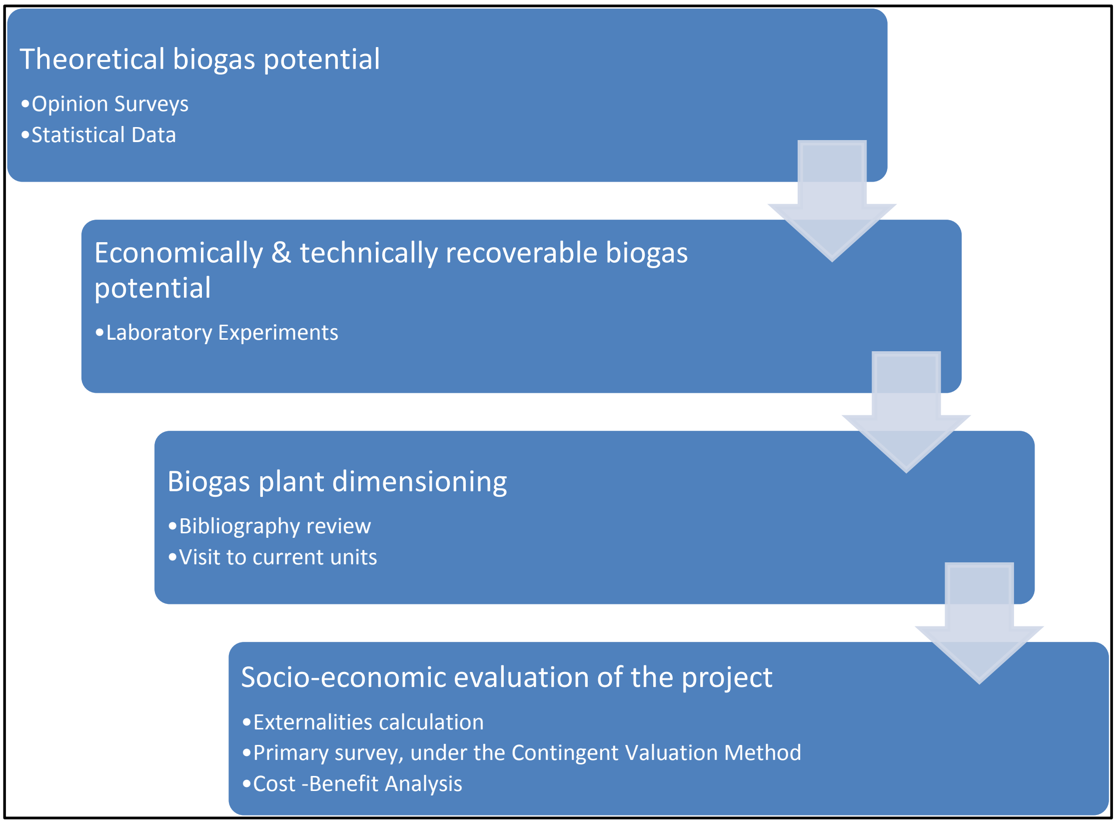

Figure 3. Overview of the methodology followed

3. Results and Discussion

In this Section the main results related to the biogas potential in the area of Metsovo, as well as the technoeconomic characteristics of the biogas utilization unit are presented.

3.1 Biogas potential in the Municipality of Metsovo

The organic residues in the area of Metsovo are produced, mainly, by: (a) agricultural activities, (b) livestock activities and (c) cheese and wine production. It was chosen not to include in the estimation of the organic residues potential the sludge from the wastewater treatment unit of the town of Metsovo.

Agricultural residues

According to the statistical data kept by the Municipality of Metsovo regarding agricultural holdings in the area, the dry weight of agricultural residues in the area are about 1,740 tn/ year. The vast majority of these residues, about 1,700 tn, come from fodder plants, like clover and rye and this is the kind of agricultural residues taken into account for calculating the potential biogas production. Table 3, contains the biogas potential of agricultural residues in the area of Metsovo.

Table 3. Potential biogas production from agricultural residues in the area of Metsovo [10]

Quantity (tn/year)	**Availability (%)**	**Dry content (%)**	**VS content (% dry content)**	**Biogas production (m^3/kg VS)**	**Total biogas production (m^3/ year)**
1,700	50	80	55	0.15-0.35	56,000 – 130,700

Livestock and dairy residues

The area of Metsovo has a long tradition in livestock farming. Nowadays, the most important category of livestock activities is the operation of poultry farms. In Table 4, the number of animals in the livestock holdings is presented, as well as their residues. The data of Table 4, have been gathered mainly by surveys in the area.

Table 4. Number of animals and quantities of organic residues in the Municipality of Metsovo

Animal species	**Number**	**Total residues per day (tn)**	**Total residues per year (tn)**
Sheep and Goats	1,535	4.91	1,792
Poultry	1,256,550	63.33	15,832
Cattle (for milk production)	140	7.7	2,812
Cattle (for meat production)	964	20.35	3,663
Pigs	9,850	4.88	20,640
TOTAL	-	101.17	44,739

The whey produced as a residue from the main dairy unit in Metsovo, which belongs to the Tositsa's Foundation amount about 1,750 tn/ year.

Since the livestock (and dairy) residues are the most important factor for producing biogas in the case under study, apart from estimations based on the relevant literature, samples of manure were taken from livestock units in Metsovo and were analyzed in the Laboratory of Organic Chemistry of the National Technical University of Athens. A small anaerobic digester with a capacity of 80 lit was used for implementing the experimental analysis. The mix analyzed in the Laboratory had the following percentile composition:

- Cattle (for meat production) manure: 3.93%
- Poultry manure: 34.71%
- Sheep and Goats manure: 6.17%
- Cattle (milk production) manure: 8.03%
- Pig manure: 45.25%
- Whey: 1.91%

In Table 5, the results of the characteristics of the residues mix is presented. The parameters measured in the laboratory were humidity, total solid content (TS), volatile solid content (VS), pH and total COD.

Table 5. Characteristics of the residues mix components, according to the laboratory analyses

Component	**Humidity (%)**	**TS (g/g mix)**	**VS (g/ g mix)**	**pH**	**tCOD (g/ gTS)**
Cattle (for meat production) manure	74.74	0.2526	0.1998	8.47 (20.5o C)	0.748
Poultry manure	61.94	0.3806	0.337	7.45 (20.1o C)	0.697
Sheep and goats manure	74.15	0.2585	0.2281	7.44 (20.5o C)	0.834
Cattle (for milk production) manure	87.8	0.122	0.097	8.68 (20.5o C)	1.18
Pig manure	86.30	0.137	0.0875	7.3 (16.7o C)	1.02
Whey	93.02	0.0698	0.05	6.03 (16o C)	2.185

The total COD of the mix was 0.19 g tCOD/ g mix. After the procedure of the anaerobic digestion, the average reduction in the total COD content was calculated to be over 78%.

The biogas production potential of the residues mix was experimentally determined to be 31 m^3/ tn of mix. This means that the biogas potential from livestock and dairy residues in the area is almost 1.210.000 m^3/ year. This estimation does not differ importantly from estimations based on literature data, such as these found in [3].

Wine production residues

Wine production is an important activity in Metsovo, despite the relatively high altitude. In the study presented, it was chosen to estimate the residues of the most important winery of the area, called "Katogi Averof", which keeps a steady wine production each year. About 300 tn of grapes are processed every year in the winery. The residues of the wine production procedure are about 115 tn/ year. In Table 6, the biogas potential of the wine production residues is presented [11].

Table 6. Wine production residues and potential production

Quantity (tn/year)	Availability (%)	Dry content (%)	VS content (% dry content)	Biogas production (m^3/kg VS)	Total biogas production (m^3/ year)
115	50	60	55	0.9	16,930

Based on the abovementioned data, the total biogas potential in the Municipality of Metsovo amounts between 1,282,930 and 1,357,630 m^3. The thermal content of this biogas quantity, by taking into account that the calorific value of biogas is 6 kWh/m^3, is 7,697,580 - 8,145,780 kWh.

3.2 Description of the biogas energy utilization system

The biogas potential mentioned in Section 3.1, by assuming that the efficiency ratio of converting biogas into electricity is 35%, can support the operation of an electricity generator with a power between 308 and 325 kW. Bearing in mind the pilot-character of the unit and the fact that is designed for supplying with energy the wastewater treatment unit and the primary school, the necessary electrical power is 180 kW. The available energy potential in the area of Metsovo is sufficient for covering this magnitude of electrical power. Moreover, by choosing to install a generator with a capacity about 45% smaller than the biogas potential allows, we ensure the operation of the unit without problems caused by fluctuations in agricultural and livestock activities. In addition, a small unit is a safer choice, under the condition that it has a non-commercial character and it will be the first biomass unit in the area of Metsovo. Considering that the electrical output is 180 kW, a typical cogeneration system can produce about 270 kW of thermal energy by recovering heat from the system.

A summary of the characteristics of the main parts of the proposed system for utilizing biogas in the Municipality of Metsovo is presented below, based on the findings of the research project implemented by NTUA [12].

Storage of residues

Three main storage facilities will be constructed, one for each category of residues entering the digester.

- Manure storage system: The manure storage tank will simultaneously operate as a homogenization tank. About 6 tn of manure will enter the tank daily. The volume of the tank is estimated to be 75 m^3. The manure mix will stay in the tank for up to 10 days. The tank includes a stirring system for the homogenization of the mix.
- Whey storage tank: About 3.25 tn of whey will enter the tank daily. The material should stay about two days in the tank. So, a tank with a volume of 16 m3 will be appropriate for storing whey.
- Agricultural residues/ wine production residues storage tank: This kind of residues will be transferred to a special bunker silo. Since the production of agricultural residues is characterized by seasonal differentiations, the bunker silo will have high storage capacity, estimated to be about 2,000 m3. This tank will be constructed by prefabricated reinforced concrete parts. Inside the bunker silo a special device for cutting the pieces of the residues will be located.

Digester

The anaerobic digester is, somehow, the “heart” of the system, since inside it the main chemical procedure needed for biogas production takes place. It is planned to have a continuous feed digester, in which 10 tn of residues will enter, coming from the storage tanks, at a daily basis. The residues will enter the digester under pressure below the level of the fluid inside it. The duration of the digestion will last about 50 days. The necessary volume of the digester is estimated to be 625 m^3. It will have a cylindrical shape. A special membrane will cover the space over the level of the fluid inside the digester, in order to ensure the air-tightness of the system. A special heating system in the wall of the digester will keep the temperature inside the device at steady levels (between 24 and 45^o C). A stirring system will operate in the digester for the homogenization of the mix.

Biogas upgrade and storage

The biogas that goes out from the digester is “rich” in vapor water and contains, apart from methane, carbon dioxide and hydrogen sulfide. Hydrogen sulfide is toxic, with unpleasant smell and it reacts with vapor water, creating sulfuric acid, which can create corrosion problems. Hence, drying and desulfurizing the biogas produced from the digester is necessary.

Desulfurization will take place in a special device (rinsing column), through bio-chemical methods. The capacity of the column will be 80 m^3. H_2S is mixed with small air quantities and then, inside the column, is sprayed with water. It goes, then, through a biological filter is oxidized into sulfur. Sulfur precipitates at the bottom of the column. The produced S_2 is collected and mixed with the digested residue, in order to improve its properties. The desulfurized biogas enters the drying system. This includes cooling containers with temperatures lower than 10^o C. The concentrates are driven into the digested residue storage system.

After the drying system, biogas is transferred to a storage tank that is planned to have a volume capable of storing a biogas quantity, sufficient for the operation of the unit for 24 hours. This volume is estimated to be about 1,240 m^3. The biogas storage tank will be at an overpressure state. It will include a special membrane (air balloon) and will be equipped with safety valves. A safety torch will also be a part of the biogas storage system, which will be activated if the pressure in the tank exceeds certain limits.

Biogas combustion, electricity and heat production

The biogas is feeding an internal combustion engine, suitably designed for burning gaseous fuels, with properties similar to the ones of biogas. The engine will be a four-stroke one, it will have at least six cylinders and its indicative operating rotational speed will be 1,500 rpm.

Electrical energy will be produced by an electricity generator connected to the engine. The generator will be an asynchronous, 3-phase one, with a horizontal axis. The engine-generator system will be purchased as a single system from the manufacturer and will operate inside a special container. Some basic features of the generator are:

- Voltage: 400 V
- Frequency: 50 Hz
- Operational speed: 1,500 rpm
- Power: 180 kW
- Power factor (cosφ): 1

Apart from the electricity production, it is aimed to recover heat from the operation of the internal combustion engine. It is estimated that the recoverable heat can be about 270 kW. Thermal power will come from: (a) the exhaust gas (40%), (b) the cooling circuit (27%), (c) the lubrication circuit (11%) and (d) the intercooler (23%). High efficiency heat exchangers will be used for recovering thermal energy (plate exchangers for the (a), (b) and (c) systems and spiral exchanger for the (d) system). Water will be heated by the heat exchangers that will reach a temperature of at least 90^o C. The hot water will be driven into a storage tank with thick insulation. From this tank, by using pumps, it will be transferred to the district heating network and to the digester's heating system. The volumetric flow rate of the hot water is estimated to be 10 m^3/h. The storage tank could have a volume of 15 m^3 and it could be installed underground, in order to reduce further its thermal losses.

Storage and treatment of the digested residue

The digested residue is transferred through suitable ducts into the residue storage tank. This storage unit will have a capacity of 825 m^3. The storage tank will be equipped with a special system for separating the liquid part of the digested residue. The liquid part could be used as fertilizer. It could be loaded in tanker trucks from the storage tank and transferred to the plateau of Chrisovitsa (about 10 km from the unit), where extensive potato cultivation takes place. The sold part of the digested residue will be transferred to a building, where it could be ventilated. After this procedure it will be packed in sacks. The solid digested residue is an effective soil improver.

Connection with the wastewater treatment unit

The electrical energy produced by the biogas unit will be used for feeding with electricity the wastewater treatment unit of Metsovo, which has an average power demand of 120 kVA. The maximum power demand is 150 kVA. It is planned to connect the two units with an autonomous medium voltage gridline (20 kV), in order to avoid voltage drop greater than 4%, which is the maximum drop allowed by the relative legislation. The connection will include three main parts:

- A transformer for increasing voltage from 400 V to 20 kV
- An autonomous gridline

- A transformer for lowering voltage from 20 kV to 400 V

District heating system

The main parts of the district heating network are the pre-insulated pipes and the heat exchangers. The pipes will be from steel insulated by a layer of polyurethane. A cover from PVC will be positioned in the outer surface of the insulation, in order to protect it. The pipelines will be positioned underground, at a depth of at least 60 cm from the road surface. The quality of water in the district heating network will be regularly checked, in order to avoid corrosion of the pipes. A heat exchanger (water to water) will be installed in the primary school in order to transfer the heat from the district heating network to the internal hydraulic network of the school's heating system. The currently used oil-burner will remain connected to the system, through suitable modifications, in order to operate as a back-up system, in case any of problems in the district heating network.

3.3 Cost estimation and cost-benefit analysis

The energy unit presented in this paper is a pilot-unit, which will operate with non-commercial criteria. In particular, both the electricity and the thermal energy produced will be directed so as to cover the needs of two (2) municipal buildings (e.g. Primary School and Wastewater Treatment Facility). This means that there will be no direct revenues from the generated energy supply. Hence, the evaluation of its techno-economic feasibility cannot be based only on a simple financial analysis.

The financial analysis of a project has to be executed in relevance to the needs of the final user. Furthermore, there are three (3) general categories of final users [13]:

- Private Investors
- Banks
- Public Bodies

Each one of the abovementioned users assess an investment with different financial criteria and tools. Generally, there are two (2) main approaches as far as the financial analysis of an investment; namely the financial investment analysis and the social cost-benefit analysis [14]. Under this framework, there will be executed a social cost benefit analysis so as to evaluate the feasibility of the proposed unit. Through this analysis there will be assessed the change of the economic welfare of the Municipality of Metsovo due to the operation of this unit.

The socio-economic analysis aims at correcting the economic magnitudes of financial investment analysis, according to the externalities of the project (positive and negative), i.e. costs and benefits not valued by the conventional market mechanism. This approach evaluates the contribution of the investment plan to the economic welfare of a region or the whole country. Therefore, the evaluation is carried out for the entire society and not just for the private investor. The starting point of the social cost-benefit analysis is the financial data of the investment plan. Based on these data, a series of corrective interventions are made in the investment's Cash Flow Table (CFT), related to the economic, social and environmental impacts of the project. Since, the CFT prices are corrected with the shadow values so as the first to reflect the real cost and benefit for the society; the final step for compiling the CFT is to integrate the external economies of the project. The valuation of the environmental goods and services affected by the investment plan is carried out with the help of methods of the Environmental Economy, such as the Contingent Valuation Method, the Dependent Valuation Method, the Market Analysis of Beneficial Characteristics, the Avoidance Cost Assessment, etc.

Investment Cost

The estimation of the capital costs needed for the creation of the biomass unit, the district heating network and the electrical connection has been based on an extensive survey in the Greek energy market, as well as the cost tables of the Greek General Secretariat of Infrastructure. Table 7 includes the basic costs.

Table 7. Short budget analysis of the biogas energy utilization system in Metsovo

Expenses Categories	**Cost (€)**
Design Studies/ Licensing	**80,000**
Main Equipment	**800,000**
Digester	240,000
Raw material storage tanks	205,000
Residues storage tanks	95,000
Biogas storage system	100,000
Internal Combustion Engine	160,000
District Heating System	**280,000**
Heating network/ pipelines	250,000
Heating exchangers	30,000
Electrical connection with the Wastewater treatment Unit	**200,000**
Infrastructure	**510,000**
Buildings	320,000
Surrounding space formation and roadworks	190,000
Unforseen Costs (8% of the main equipment costs)	**80,000**
TOTAL	**1,950,000**

Financial benefits from the unit's operation

According to the data provided by the Municipality of Metsovo, an amount of 100,000 €/ year could be saved, if the Primary School is provided with thermal energy from the unit and the Wastewater treatment unit is provided with electrical energy from the biogas energy system.

Socioeconomic benefits from the unit's operation

The importance of such a pilot unit for the broader area of Metsovo produces important benefits:

- Reduction in gaseous pollutants and greenhouse gas emissions, because of the replacement of fossil fuels in the Primary School
- Reduction in greenhouse gas emissions, because of the use of biogas energy in the Wastewater treatment
- Reduction in soil and water pollution due to uncontrolled organic waste disposal

These positive environmental impacts need to be takin into account, in order to gain an integrated view on the viability and feasibility of the biogas unit. This can be done through the incorporation of external costs/ benefits in the cost-benefit analysis. Through environmental valuation methodologies the external costs and benefits of various activities can be assessed. So, a social cost-benefit analysis becomes possible, which allows to have a clearer view of true dimensions of investments/ technologies/ policies [15], [16], [17]. For the social cost-benefit analysis of the biogas unit in Metsovo, a table of fixed cash flows is used. The analysis is made for 20 years and the discount rate has been considered to be 5%, a typical value for non-commercial energy projects [18]. The table includes the following data:

For calculating the external benefits due to emissions' reduction, assessments based on the damage function approach have been used [19], [20], [21]. This approach takes into account the total environmental impacts, which are caused in the whole "fuel cycle", from its extraction till its end use. The external cost of diesel oil use is estimated to be 13.50 €/MWh and the external cost of electricity from the Greek Interconnected System is 40.70 €/MWh [22]. Taking into account the energy quantities saved by the operation of the biogas unit (287,420 kWh of thermal energy in the Primary School and 353.210 kWh of electricity in the Wastewater treatment unit), the external benefit is 18,256 €/year.

As regards the external benefit from the reduction of soil and water pollution, an innovative element of the study presented, is that a specialised primary survey was conducted, in order to directly assess this external benefit. The methodology of Contingent Valuation (CVM) was applied. This method draws data from hypothetical markets, which are described by the people conducting the surveys. The population sample is asked to express its preferences regarding changes in the quality of the environment, in order to, finally, translate the environmental goods into monetary terms. So, a survey based on the CVM method is realized through interviews and completion of suitable questionnaires. The core question of these questionnaires is the question, in which the respondents are asked to answer whether they are willing to offer an amount of money for protecting an element of the environment. The respondents are also asked to determine how much money they are willing to offer. In the case presented in this paper, the questionnaire included 16 questions, in total, together with 8 demographic questions. The core question was composed as follows:

> "Lets consider that a solution to the problem of agricultural, livestock and food production waste in Metsovo is going to be given by the creation of a biogas production unit. The construction of the unit will be financed by the Central Government. However, the operation of the unit demands some expenses, which should be covered by the Municipality of Metsovo. In this case, all the citizens of the Municipality of Metsovo will pay an extra amount of municipal taxes. How much money do you find to be a reasonable extra charge in the municipal taxes for operating the biogas unit?"

Then a tab with money amounts was presented to the respondents and they were asked to choose the amount of money they are willing to pay.

The reference population for conducting the CVM study is the population of the Municipality of Metsovo, which amounts about 6,200 permanent inhabitants. The necessary sample for a confidence interval of 95% and with an error margin of 5% was calculated to be 330 people. The sampling method was chosen to be the one of random sampling. The questionnaires were completed through personal interviews.

The analysis of the results showed that the inhabitants of Metsovo are willing to pay about 22,000 €/month for contributing to the operation of the biogas unit. This cost expresses the external benefit from avoiding the pollution of soil and water from organic waste. It should be noted that 64% of the respondents were willing to pay. Since, the external benefit calculate corresponds to the utilization of the total quantity of organic waste in the area, it is reduced by 50%, since the unit under study will utilize about half of the residues produced in the Municipality of Metsovo. Hence, the annual external benefit from the organic pollution reduction is 132,000 €.

Operation and maintenance cost

The annual expenses for operating the biogas unit have been estimated as follows:

- Insurance costs: It has been taken equal to 1% of the main equipment cost, namely 8,000 €

- Regular maintenance costs: They are considered to be the sum of (a) 3% of the main equipment cost, (b) 2% of the district heating system cost and (c) 1% of the infrastructure cost, namely 34,700 €.
- Personnel costs: A small-scale biogas unit, such as the one under study, will need one person as permanent personnel. The supplementary needs will be covered by the current technical personnel of the Municipality of Metsovo. It is considered that the cost for one full-time worker in the unit will be 21,000 €/ year.
- Organic waste transport costs: Taking into account the distance between the potential position of the unit and the livestock farms, the necessary waste quantities, the fact that the waste can be transported through tanker trucks with a storage capacity of 20 m^3 and by considering that the diesel oil consumption of a truck is 20 lit/ 100 km, this category of costs amounts about 6,500 €/ year.

Hence, the total annual operation and maintenance costs are 70,200 €.

By combining the abovementioned data, the social cost-benefit analysis of the biogas utilization system shows that its construction and operation is feasible. The Societal Net Present Value is calculated to be 294,000 € (> 0) and the Societal Internal Rate of Return is 6.72% (> discount rate). The annual cash flow is positive for the Municipality of Metsovo and equal to about 30,000 €. So, the unit can be operated without burdening the municipal budget. Therefore, subsidizing the creation of such an energy utilization unit can be justified. In Table 8, the annual cash flows that construct the social cost benefit analysis are shown. It is noted that on an annual basis the cash flow is positive and reaches € 30,000, indicating that with appropriate management, the Municipality of Metsovo will be able to keep the unit in operation without burdening its budget. These results fully justify the grant / funding of the project. On the one hand, it turns out that it is an energy unit with positive socio-economic performance, which furthermore implies intangible advantages for the Municipality of Metsovo, such as:

- Operation of a technologically innovative project in a mountainous region
- Pilot implementation of an environmentally friendly technology that can help address the major social problem of energy poverty

Table 8. Annual cash flows of the biogas unit investment in Metsovo

Years	0	1	2	3	4	5	6	7	8	9	10
CAPEX (€)	-1.950.000										
Inflows (€)		250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256
Saving from electrical consumption of WWT (€)		*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*
Saving from thermal consumption of Primary School (€)		*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*
External Benefit from reduced emmissions (€)		*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*
External Benefit from reducing organic pollution (€)		*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*
OPEX (€)		70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200
Cash Flow (€)		180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056

Years	11	12	13	14	15	16	17	18	19	20
CAPEX (€)										
Inflows (€)	250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256	250.256
Saving from electrical consumption of WWT (€)	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*
Saving from thermal consumption of Primary School (€)	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*	*50.000*
External Benefit from reduced emmissions (€)	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*	*18.256*
External Benefit from reducing organic pollution (€)	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*	*132.000*
OPEX (€)	70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200	70.200
Cash Flow (€)	180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056	180.056

Discount Rate	5%
Social IRR	6,72%
Social NPV	293.896

4. Conclusions

Summarizing the findings presented in the previous sections, some main conclusion are pointed out below:

- The area of Metsovo has significant organic residues' potential that can be utilized for energy production, mainly due to the livestock breeding activities. The use of the residues can contribute towards producing "green" energy and reducing the organic pollution of water streams and soils.
- By utilizing about half of the exploitable biogas potential of the area, a biogas energy unit can be created, with an electrical power of 180 kW and a thermal power of 270 kW. The operation of such a unit allows the coverage of the electricity needs of the local wastewater treatment unit and the thermal needs of the town's primary school. The financial benefit from covering these energy needs amounts 100,000 €/ year.
- The environmental benefits caused by the operation of the unit are particularly positive. It can be noted that such a unit, which treats organic waste and simultaneously produces energy is an intervention that upgrades the environmental conditions in the area of Metsovo.
- The socioeconomic impact of the biogas unit is positive. Moreover, the annual cash-flow is positive. Hence, an investment that subsidizes its creation can be justified. The creation of such a pilot-unit in Metsovo will produce significant added value for Greek mountainous areas, in general.

Reference list

[1] International Solid Waste Association: Waste Management Outlook for Mountain Regions: Sources and Solutions. https://www.grida.no/publications/157 (2016). Accessed 10 May 2017

[2] Gharfalkar, M., Court, R., Campbell, C., Ali, Z., & Hillier, G.: Analysis of waste hierarchy in the European waste directive 2008/98/EC. Waste Management, 39, 305-313 (2015)

[3] Liantinioti K.: Investigation of biogas production and exploitation potential in the area of Metsovo. MSc thesis. NTUA, Athens (2011)

[4] Biernat, K., Gis, W., & Samson-Bręk, I.: Review of technology for cleaning biogas to natural gas quality. Silniki Spalinowe, 51 (2012)

[5] Holm-Nielsen, J. B., Al Seadi, T., & Oleskowicz-Popiel, P: The future of anaerobic digestion and biogas utilization. Bioresource technology, 100 (22), 5478-5484 (2009)

[6] Persson, M., Jönsson, O., & Wellinger, A.: Biogas upgrading to vehicle fuel standards and grid injection. In IEA Bioenergy task, Vol. 37, pp. 1-34 (2006)

[7] Agapitidis, I., Zafiiris, X. Biogas upgrading to Biomethane, use as transport fuel or injection into the FA network, 3rd EEDSA Conference (2009)

[8] Wellinger A., Murphy J., Baxter D.: The Biogas Handbook, Science, production and application. IEA Bioenergy. Woodhead Publishing, Cambridge (2013)

[9] Al Seadi, T., Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk, S., & Janssen, R.: Biogas Handbook. University of Southern Denmark, Esbjerg (2008)

[10] Seadi, T. Al, Rutz, D., Prassl, H., Köttner, M., Finsterwalder, T., Volk S., Janssen R., Sioulas K.: Biogas Handbook. Center for Renewable Energy Sources, Pikermi (2008)

[11] Lo, K.V, Liao, P.H.: Methane production from fermentation of winery waste. Biomass vol 9, pp 17-29 (1985)

[12] National Technical University of Athens. Metsovion Interdisciplinary Research Center. Technical Assistance to the Municipality of Metsovo for creating a biomass energy unit. Research Project Results (2014)

[13] Torries, T.: Evaluating Mineral Projects: Applications and misconceptions. Society for Mining, Metallurgy and Exploration, USA (1998)

[14] Kaliampakos, D., Damigos, D.: Cost – Benefit analysis in the decision making process. National Technical University of Athens, Athens (2004)

[15] Diakoulaki, D., Mirasgedis, S., Tourkolias, C.: Assessment and exploitation of energy – related externalities in the industrial sector. Energy Policy, 35, 2925-2938 (2007)

[16] Longo, A., Markandya, A. & Petrucci, M.: The internalization of externalities in the production of externalities: Willingness to pay for the attributes of a policy for renewable energy. Ecological Economics, 67, 140-152 (2008)

[17] Koundouri, P., Kountouris, Y., & Remoundou, K.: Valuing a wind fam construction: A contingent valuation study in Greece. Energy Policy, 37, 1939-1944 (2009)

[18] Florio, M., Finzi, U., Genco, M., Levarlet, F., Maffii, S., Tracogna, A.: User guide for cost-benefit analysis of investment plans. European Regional Development Fund (2003)

[19] Butti, G., Papaemmanouil, A. & Andersson, G.: External Costs of Power Production in South Eastern Europe. 2nd WSEAS/IASME International Conference on Renewable Energy Sources, Corfu (2008)

[20] Georgakellos, D. A.: External Cost of air pollution from thermal power plants: case of Greece. International Journal of Energy Sector Management, 1, 257-272 (2007)

[21] Georgakellos, D. A.: Climate Change external cost appraisal of electricity generation from life cycle perspective: the case of Greece. Journal of Cleaner Production, 32, 124-140 (2012)

[22] Katsoulakos, N. Optimal use of renewable energy sources in mountainous areas. The case of Metsovo, Greece. Doctoral thesis. National Technical University of Athens, School of Mining and metallurgical Engineering, Athens (2013)