

# The Problem of Utilization of Agricultural Enterprises' Biowaste: The LLC "Leader" Case Study (Zaporizhzhya Region, Ukraine)

Olena Borzenko (Slozko)\*, Oleksandr Rogach<sup>†</sup>,  
Oleksandr Pidchosa<sup>‡</sup> and Olexiy Kravchun<sup>§</sup>

\*Doctor Habil.oec., Professor, Head of the Department of International Financial Research Institute of Economics and Forecasting National Academy of Sciences of Ukraine

<sup>†</sup>Doctor of Economics, Professor, Head of the Department of International Finance, Institute of International Relations of Taras Shevchenko National University of Kyiv

<sup>‡</sup>PhD (Economics), Assistant Professor, Department of International Finance, Institute of International Relations of Taras Shevchenko National University of Kyiv

<sup>§</sup>PhD (Public Administration)

## Introduction

The problem of management and utilization of the agricultural enterprises' biowaste in Ukraine is rather urgent given the increase in agricultural production and the absence of an integrated approach to solving the current problem. Other important factors are the lack or complexity of financing of these projects, as well as the incomprehension on the part of the owners of the enterprises on the benefits of biowaste recycling.

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Taking the above mentioned into consideration, the main objective of the proposed case study is to develop the project of constructing and commissioning a biogas collection and utilization complex, followed by production of electricity and heat on the LLC “Lider” pig farm. It also should be noted that in this case study we used the actual data of the enterprise and the developed project could be implemented in practice.

### General Description of the Pig Farm

LLC “Lider” is a full-cycle livestock complex (Table 1) of 1100 breeding sows with the capacity of about 26 thousand commercial pigs annually (*LLC Lider, n.d.*).

#### *Pig Farm Product Characteristic*

The farm produces meat and breed pigs of salable live weight of 105–110 kg.

Landrace and Duroc breeds are presented on a pig farm, they are characterized by high feeding quality, high fleshiness and good reproductive capacity.

#### *Location of the Project*

The pig company “Lider” is located near the village of Veselyi Gai (farm geographical coordinates are 47°59’10” N 35°48’24 E), which is the administrative center of Veselogaitsky Village Council, Zaporizhzhya region in the south-eastern part of Ukraine (Figure 1).



**Fig. 1:** Location of the pig farm LLC “Lider” on the map of Ukraine.

Source: developed by the authors.

**Table 1:** Key Features of the Pig Farm.

<b>Facilities in the Structure of the Pig Farm</b>	<b>Key Features</b>
<p><b>Pig farm:</b></p> <ol style="list-style-type: none"> <li>1. Pigsty No.1. The breed shed</li> <li>2. Pigsty No. 2. Completing of growing shop</li> <li>3. Pigsty No. 3. Feeding shop</li> <li>4. Pigsty No. 4. Feeding shop</li> <li>5. Pigsty No. 5. Feeding shop</li> <li>6. Pigsty No. 6. Feeding shop</li> <li>7. Pigsty No. 7. Feeding shop</li> <li>8. Sanitary inspection room</li> <li>9. Sanitary slaughter</li> <li>10. Manure pit with cage</li> <li>11. Manure liquid fraction pit</li> <li>12. Manure solids pit</li> <li>13. Storage of solid manure</li> <li>14. 440 kWt Transformer substation</li> </ol>	<ul style="list-style-type: none"> <li>• Land plot area – 6 hectares</li> <li>• The total number of pigs on daily maintenance – 12,000, sows – 1200</li> <li>• Built-up area – 10600 m<sup>2</sup></li> <li>• The number of employees – 27 people</li> </ul>
<b>Emergency power supply system</b>	<ul style="list-style-type: none"> <li>• Diesel Generator – Power 300 kW</li> <li>• Fan-load switching system</li> </ul>
<b>Boiler room</b>	<ul style="list-style-type: none"> <li>• Fuel Type – mainly agricultural pellets (sunflower husks)</li> <li>• Thermal power – 500 kW (can consume wood pellets and coal)</li> </ul>
<b>Water treatment system</b>	<ul style="list-style-type: none"> <li>• Artesian wells – (total debit up to 10 m<sup>3</sup>/h)</li> <li>• Reverse osmosis (water treatment) – capacity up to 100 m<sup>3</sup>/day</li> </ul>
<b>Warehouses for storage of fodder ingredients</b>	<ul style="list-style-type: none"> <li>• Land plot area – 2.5 hectares</li> <li>• Grain storage area – 5720 m<sup>2</sup></li> <li>• The volume of grain storage – 6 thousand tons</li> <li>• Technological equipment for cleaning of grain</li> </ul>
<b>Fodder production shop</b>	<ul style="list-style-type: none"> <li>• High-tech complex for production of premixes, AMVA, and complete fodder</li> <li>• Production capacity – up to 5 t/h</li> </ul>
<b>Agricultural fleet</b>	<ul style="list-style-type: none"> <li>• Tractors – 2</li> <li>• Feed carriers – 2</li> <li>• Universal loaders (3 ton) – 2</li> </ul>

Source: developed by the authors.

## The Project Base Line (Current Situation)

### *Overview of the current situation with waste on the pig farm and waste management system*

Removal of manure from the “Lider” pigsty is carried out through the use of a water wash system followed by separation of manure (moisture content of about 93.7%) into the solid fraction (about 40.7% moisture) and a liquid fraction (90–100% humidity).

The water wash system on the pig farm involves the accumulation of pig faeces (dung and urine) through the trash gaps in a separate bath, followed by the periodic supply of industrial water and gravity flush of faeces into a separate underground tank. Manure from the underground tank is sent to the “SEP-COM” separator, where it is subsequently separated into liquid and solid fractions (*SEPCOM Horizontal, n.d.*).

The solid fraction after separation is transported to a storage tank in a tractor trailer and applied into the fields after 8–10 months of fermentation.

The liquid fraction after separation is transferred from the separator into the rubber bladder (anaerobic pond/tank), from which it is taken out to the field in barrels after 6 months of fermentation.

The distemper is frozen and transported to the recycling plant, where the pig farm obtains a certificate of the delivered distemper weight.

In case of the absence of the proposed project:

- a. The manure from the farm will be kept in the anaerobic pond and storage tank. In this case, the storage of manure in such conditions, the pig farm will have problems associated with the storage and handling of waste, which will lead to different kinds of penalties in the framework of the Ukrainian legislation. In addition, the waste will result in the emission of methane into the atmosphere, thus having a negative impact on the environment.
- b. The pig farm will spend funds for waste disposal, as well as energy, thermal and electric power whose production and consumption leads to emissions of greenhouse gases into the atmosphere.

## Summary and Scope of the Project

This section provides a detailed description of the proposed concept and design for the production of biogas and its combustion technology for power generation, which are widely used on pig farms around the world (the process of anaerobic digestion in digesters of methane tanks) and describes the approaches and modes of project equipment.

In many of the EU countries (Germany, Austria, the Netherlands etc.), the problem of disposing of manure is solved by biogas plants (Holm-Nielsen *et al.*,2007; 2009). The output of these plants provides farmers with environmentally friendly liquid or solid bio-fertilizers without unpleasant odors, helminth eggs, weed seeds and nitrates.

In Ukraine, the introduction of biogas technology is associated with high capital costs and does not have a systemic nature. However, this problem can be solved by production of heat and electricity from biogas at cogeneration plants, as well as sale of electricity to the electric power network of Ukraine under the special “green tariff”<sup>1</sup>, which is 2.07 times as expensive as the cost of electricity for businesses.

Large pig farms with capacity of 5000 heads or more or dairy farms built on modern technology with the number of cows from 1000 heads are attractive in terms of implementation of such projects. These farms usually store manure in anaerobic lagoons or pits, which contributes to production of the greenhouse gas methane. The raw material for the production of biogas are encouraged to use liquid manure, death loss, as well as such other organic additives/ coenzymes (additional substrates) as maize silage, sunflower production waste, sugar beet pulp etc. to increase the productivity of biogas.

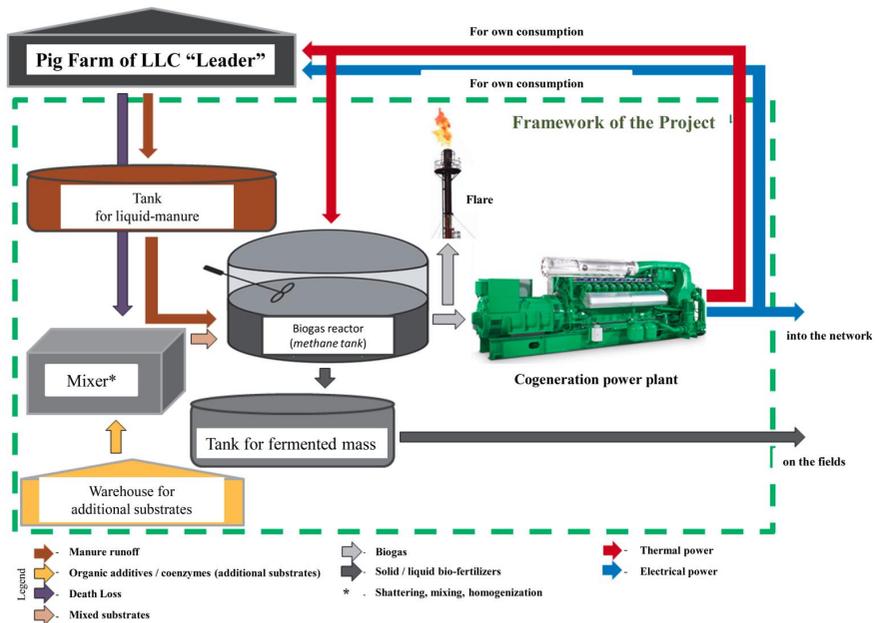


Fig. 2: The Framework of the project.

Source: developed by authors.

As part of the project, instead of manure storage in anaerobic ponds and storage tanks, we propose using the tried and proven biogas technology of anaerobic digestion in the biogas reactor (digester). The biogas digesters substrates will fermentate with the help of methanogenic bacteria at mesophilic temperature (20–40°C) or at thermophilic temperatures (50–60°C) (*Angelidaki & Ellegaard, 2003*). These temperature modes have their pros and cons, and they will be analyzed in detail in Section 5 “Optimum Modes and Configuration of the Project” in order to determine the optimal treatment for this pig farm.

Fermentation is carried out in a biogas reactor (digester) under a sealed gasholder, where methane will be accumulated as a component of biogas. The product obtained after the biogas fermentation (composed of 60% methane and 40% carbon dioxide) will be supplied to the cogeneration plant for heat and power and/or flared to reduce the emissions of greenhouse gases.

In addition to sale of electricity to the electric power network of Ukraine under the special “green tariff” (which is the main activity of the project), the pig farm will also be able to replace the consumption of heat and electricity, the energy produced from alternative sources, in particular, the energy of the resulting biogas in the cogeneration power plant.

As a complement to all the above, the pig farm will be able to use fermented substrate as fertilizer.

Based on the data of the pig farm provided by LLC “Lider”, we propose introducing a biogas plant processing about 36 thousand m<sup>3</sup> of substrate per year and providing the output:

		Unit of measurement	Amount
1	<b>Biogas total</b>	m <sup>3</sup>	<b>4 001 000</b>
2	<b>Liquid fertilizer total</b>	thousand ton	<b>46.25</b>

Under these terms the proposed biogas plant pays off for 5.7 years (9.7 years of the discounted payback period). This project solves the problem of recycling and efficient use of pig waste. The project pays for itself at the expense of what went to pay monthly bills for the power purchase, waste disposal costs and fines related to waste management in the enterprise. In addition, the profitable part of the project will be mainly provided by the sale of the produced biogas in the electricity network at “green tariff”, as well as through applying fermented substrate as fertilizer. These funds will go to repay the loan raised for the project.

The proposed basic project configuration consists of the reactor (volume of 2250 m<sup>3</sup>) with an additional supply of dry substrates (including death loss waste) and cogeneration power plant (capacity of 1000 kW of electrical power and 1500 kW of thermal power). The cost of such turnkey facilities is 3,200,000 EUR.

## Availability and Preparation of Raw Materials

### *Manure*

Liquid manure (moisture content of about 93.7%) from farm buildings is supplied by a water wash system through the receptacle to the fermentor, where the liquid manure, together with additional substrates, is kept with simultaneous heating and stirring to produce biogas.

### *Death loss*

Biogas production technology from death loss waste is already used on some pig farms around the world. The thermophilic mode should be used for slaughter waste, or the crushed waste should be pasteurized or sterilized before being fed to the fermenter.

### *Additional substrates*

Crops of wheat, barley, corn, sorghum, sunflower and soybean are grown on an area of 4000 hectares around the pig farm.

Barley, corn, sorghum, soybeans – these crops are used for production of animal fodder for pig farm. Wheat and sunflower seed are grown for sale. These agricultural areas are not under control of the pig farm. Livestock and crop management is clearly separated in the enterprise structure. Still, this agricultural waste can be used as additional substrate for biogas production.

*Corn silage.* Plant biomass (stems, leaves and cobs of corn, sorghum, and miscanthus, grains of cultures at the start of the grain maturation, when the plant is still green) is traditionally used, which does not require additional pre-treatment, except for silage.

As for corn, its harvest technology now common in Ukraine does not provide for the collection of plant residue. Leafy mass is crushed and scattered across the fields. In this case, the following options can be suggested: collection of shredded residue in vehicles and/or stationary cob threshing. After that, the collected waste is used for biogas production.

Despite this, there is low efficiency of raw vegetable fermentation after maturation because of the too-high carbon-to-nitrogen ratio and some micronutrient deficiencies. Most often, the plant biomass is fermented with animal manure wastes and this positively affects both the efficiency of biogas formation and qualitative characteristics of fertilizers (Li et al. 2009; Pöschl et al. 2010).

*Sunflower production waste.* As in the case of corn, given the high natural moisture content of waste, sunflower stalk silage can be recommended as the strategic direction with certain restrictions, followed by the production of

biogas. It is necessary to collect the crushed sunflower residue to be able to use sunflower production wastes for biogas production.

There are no examples of use of sunflower plant residues for biogas production in Ukraine yet, but it is practiced abroad.

## Optimum Modes and Configuration of the Project

### *Main Technological Aspects*

Anaerobic fermentation technology is developed for organic substances, but its use is limited to organic wood substrates as lignocellulose cannot be processed using anaerobic processes. Anaerobic digestion technologies have the following advantages:

- 1) Sustainable energy production through biogas production and reduction of CO<sub>2</sub> emissions on a continuous basis;
- 2) The low level of odor emission (completely closed fermentation systems, mechanical machining in the halls) and low overall emissions into the environment; and
- 3) Compact units.

A wide range of technologies is offered for anaerobic digestion of waste. The main part of the biogas plant is an anaerobic digester (or reactor /methane tank) and it has various operating modes. Furthermore, all the components required for the anaerobic digester are chosen in accordance with the particular fermentation technology and operating mode. As a result, mass balances, energy balances and installation diagrams are specific to each project.

Regardless of this, the biogas plant comprises the following main components, which are discussed in detail below:

- 1) Reception (including measurement) and storage of raw materials
- 2) Pretreatment (in some cases), depending on the type of raw material
- 3) The anaerobic digester (or reactor / methane tank) including:
  - Equipment for feed supply
  - Stirring equipment
  - Heating equipment
- 4) Storage and use of biogas
- 5) Access to the electricity network
- 6) Pumping equipment and pipelines for liquids and sludge
- 7) Equipment for the transportation of solid waste (in some cases), such as conveyor belts and wheel loaders
- 8) The equipment for process control
- 9) Storage, processing and sometimes further processing of the fermented product

To ensure the smooth flow of the anaerobic digestion process the biogas plant, as well as a fermenter, the components described below are needed. The requirements for these components depend on the type of substrates (*De Bere, 2000*).

### *Reception area and warehouse for storage of additional substrates*

*Additional substrate reception.* Reception includes the appropriate measurement of the amount of the delivered substrates (corn silage, other silos, beets etc.), by weighing them (for hard substrates) or by flow measurement (for liquid substrates). In addition, quality control of raw materials should be applied.

*Storage of substrates.* Storage volumes should be sufficient to ensure a continuous digester load balancing daily and seasonal volume fluctuations if they occur for each substrate. Depending on the substrates, storage includes the following:

- tanks for storage of liquids and sludge (above or below the ground level);
- receiving hopper for solid substrates; and
- sites for storage of solid substrates (open, covered or closed).

*Pre-treatment of substrates and fodder.* Sometimes pre-processing is necessary in order to:

- 1) remove contaminants and inert materials; and
- 2) decompose, crush and/or mix different substrates (special installations for mixing and supplying additional substrates), including addition of water (if necessary) to ensure the substrate bioavailability and constant fermenter load. Liquid substrates can act as solvents for solid substrates.

To follow sanitary standards (for example, in treatment of animal waste), the respective substrate is pretreated by pasteurization. Pasteurization of the substrate can be achieved by heating to 70°C for at least 60 minutes. Anaerobic digestion at thermophilic temperatures can also ensure that the hygiene requirements set for substrates are met.

Areas for receiving a substrate and pretreatment have to be separated.

### *Anaerobic digestion in the bioreactor (digester)*

Anaerobic technology is varied depending on general parameters of the process, operating conditions and types of fermenters, which have their own individual advantages and disadvantages, but none of them has been recognized as a technology leader. Substrate characteristics also affect the choice of anaerobic technology (*Vandevivere, et al., 2002*).

*Types of fermenters.* Various types of fermenters (or reactors) may be classified according to the types of structures, namely:

- vertical or horizontal reactor design
- reactors made of concrete or steel
- reactors built above or below ground

Thermal insulation requirements for reactors depend on the type of fermenters and heating system designs.

The concept of the biogas plant is designed for fermenter volume of 2250 m<sup>3</sup> (reservoir of round shape, which has an inner diameter of 22 m and an internal height of 6 m) with daily volumes of loading the substrate at the level of 98.74 m<sup>3</sup> per day.

### *Various technological options of anaerobic digestion process.*

#### Temperature

Depending on the range of operating temperatures, the anaerobic digestion process can be done in different temperature conditions, among which are:

- 1) psychrophilic mode – fermentation at a temperature below 20°C, but this is hardly used in practice (used in landfills).
- 2) mesophilic mode – fermentation at temperatures of 20–40°C (optimum temperature 35–37°C), which is characterized by a high level of process stability, however, a longer fermentation process (30–60 days) than in thermophilic mode (long retention time in the digester).
- 3) thermophilic mode – fermentation at temperatures of 50–60°C, which is characterized by an accelerated fermentation process (15–30 days), has substrate disinfectant properties and uses a smaller volume of the reactor, but this mode is more sensitive to various fluctuations in the biogas formation process.

#### Water Content

For biological anaerobic decomposition of organic material, it is always necessary to have certain water content. A minimum of 60% water content ensures proper anaerobic digestion process.

There is no definite difference between the terms “wet” and “dry” anaerobic fermentation in practice. They differ depending on the solid content of the substrate. Thus, the substrate used for biogas formation (fermentation) can be in two consistencies depending on the dry solid content (moisture), among which are:

- 1) Dry texture – dry solids content of more than 20% (humidity less than 80%). Such consistency is rarely used in the biogas practice.

- 2) Wet texture – dry solids content below 15% (over 85% humidity). Such consistency is typically used in the practice of biogas production.

Most operating biogas fermenters use the wet method, when solid substrates are fermented together within certain limits. Accordingly, the dry method is used in certain fermentation processes for solid substrates, e.g. organic waste or energy crops (organic agricultural waste).

### Operating Modes

- 1) There are different modes of delivery (supply) of substrates<sup>2</sup>:
- a) in batches (technically used only with solid substrates in the mixing percolation system)
  - b) semicontinuous
  - c) non-stop

Supply systems differ depending on the consistency of the substrate:

- Liquid slurry substrates can be pumped from the pre-processing/mixing tanks or directly loaded into the fermenter;
- Solid substrates are loaded into the fermenter:
  - through a receiving hopper;
  - through the mixing tank as the joint substrate;
  - directly to an incoming pipeline of the fermenter;
  - by direct lateral loading to the fermenter using a membrane lid for biogas storage; or
  - by immediate top fermenter loading if it is equipped with a concrete cap.

- 2) There are different modes of mixing substrates:
- a) mechanical
  - b) hydraulical
  - c) pneumatic
  - d) percolation

In order to prevent formation of a crust on the surface of the fermented substrate and to maintain its uniformity, each fermenter is equipped with mixers at certain angles.

- 3) There are different modes of heating substrates: external and internal (heat exchanger in the fermenter). In practice, these solutions are used as heating:
- submerged heaters, through which the hot water runs (internal heat exchangers);
  - heaters mounted on the wall of the digester;
  - stirring hot water or steam; and
  - injection of the substrate through an external heat exchanger.

The necessary heat is obtained through the use of biogas.

### *The number of stages of fermentation process*

The substrate has to be fed into the fermenter in regular portions several times during the day, which ensures stable production of biogas. The biogas storage (gas tank) is located above the ceiling of the digester. The gas tank is a rubber dome (membrane) for the accumulation of biogas production. The biogas proceeds from the fermentation tank through the annular opening in the ceiling of the fermenter. To protect the rubber dome, the outer protective dome is installed.

With the single step of anaerobic fermentation, all four stages will simultaneously occur in the fermenter with their mandatory balance in order to ensure the overall stability of the process.

Some contractors perform the process in two steps, when the first step is focused on hydrolysis and the second on the formation of methane, where the conditions can be provided more accurately: for example, the optimal PH value for the acid phase is from 5.2 to 6.3 and it ranges from 6.8 to 7.2 for the methane phase. Two-stage processes are aimed at increasing the conversion yield and reducing the biogas reactor volumes (*Demirer & Chen, 2005*). However, one-step processes require less equipment.

In addition, it is possible to use the storage tank for further fermentation of the substrate and storage of biogas in a separate gas holder.

Biogas has the following content of gases:

- methane – 55–75%;
- carbon dioxide – 21–41%;
- nitrogen – 1–3%;
- hydrogen – 0.01–0.03%;
- hydrogen sulphide – 0–3%.

The calorific value of biogas is 5000–6500 kcal/m<sup>3</sup>.

### *Storage tank for fermented substrate*

Fermentation is 20% dry and 15% wet. With wet fermentation, substrates are pumped.

Two-reactor biogas plants (post-fermenter with the storage of the fermented substrate – two stages of fermentation) are used very rarely in the world. Biogas plants with one reactor (digester) where the fermentation process is carried out are mainly used. Despite this, the fermented substrate is usually sent into a special tank for its storage; it can also work for further eventual fermentation. In this case, a tank is equipped with a stirrer, and biogas is drawn here similarly to a biogas reactor (digester).

The fermented substrate is separated into solid and liquid fractions or used as a liquid fertilizer without fractionation through direct additional substrate transportation from the tank to the fields.

### *Fertilisers*

The organic wastes contain the necessary elements for plant growth; their correct processing transforms toxic waste into expensive fertilizer. The company can use these fertilizers both for their needs (at their farmland) and sale.

The fermented mass is brought to fields using liquid-manure tankers. The liquid mass is poured over the surface of the soil proportionally and then the soil is re-plowed.

### *Cogeneration power plant*

The produced biogas (after desulfurization in the desulfurization system and drying) enters the cogeneration plant. Cogeneration plants convert the biogas energy in electrical and thermal power using generators that are powered by internal combustion engines. The cogeneration plant consists of a gas engine and electric generator. The generated heat is used to heat the biogas plant and for other purposes, and the generated electricity is sold to the national Ukrainian electricity network on a “green tariff” and is also used for their own needs.

The mechanism of stimulation by a “green tariff” is the world incentive of the energy use of biogas by means of electricity production in mini-BPP (cogeneration plants).

## **The Potential of Production of Biogas, Electricity and Heat**

### *Biogas production*

Based on the LLC “Lider” pig farm data, we propose building a biogas plant that processes about 36 thousand m<sup>3</sup> of substrates per year and provides the following output:

	<b>Unit of measurement</b>	<b>Amount</b>
Biogas total	m <sup>3</sup>	<b>4,001,000</b>

*Manure runoff.* The pig farm of 1100 sows and 26,000 fattening pigs produces 26,000 tons (71.3 tons/day) of manure annually.

In accordance with the physical and chemical analysis of the farm, the dry matter content of manure is 6.3% (with a moisture content of 93.7%). The dry content of the organic matter in dry matter of manure at the entrance to the biogas installation is 74.4% (respectively, the ash content is 25.6% of the total dry matter of manure).

Accordingly, the pig farm produces 1638 tons per year (4.5 tons/day) of manure, based on dry matter and 1218 tons (3.3 tons/day), based on the organic dry matter, respectively.

Only 49% of dry matter decomposes, forming biogas and biogas output level of 0.748 m<sup>3</sup> of biogas per 1 kg of the decomposing dry matter. On this basis, the level of output of biogas from manure runoff is estimated at 600,350 m<sup>3</sup> per year.

*Mortality loss.* The average annual mortality is estimated at the level of 42 tons (115 kg/day).

In accordance with the average content of bone at 11% for one pig carcass, waste from the sanitary slaughter is estimated at 37.4 tons per year (102 kg/day).

The yield of biogas is estimated at 0.3 m<sup>3</sup> of biogas per 1 kg of slaughter waste (mortality without bones). On this basis, the level of output of biogas from pig mortality is estimated at 11,217 m<sup>3</sup> per year.

The dry matter content in the slaughterhouse waste is 12% (at 88% humidity). The dry content of organic matter in dry matter of slaughterhouse waste at biogas plant inlet is 80% (respectively, the ash content is 20% of the total dry matter of slaughterhouse waste). Based on this, as well as a minor amount of mortality waste compared with the volume of manure, mortality loss can be mixed/homogenized with manure wastewater without additional water while maintaining the required level of dry matter content of maximum 5–15% in the total substrate weight for the process of fermentation and biogas production.

*Additional substrates: The case of corn silage.* The amount of necessary additional substrate is calculated based on the need to achieve the installed cogeneration plant capacity to 1000 kW with a view to further attraction of international funding for the project.

The pig farm will be able to additionally produce about 3,389,400 m<sup>3</sup> of biogas a year by the addition of 18,830 tons (6017 m<sup>3</sup>) of corn silage, which can be harvested at 401 hectares planted with corn (Table 2).

Besides, it is necessary to additionally add about 1384 m<sup>3</sup> of water a year to the total weight of the substrate in order to maintain the dry matter content at 10% level.

**Table 2:** Additional production.

Nº	Parameter	Value	Unit of measurement
1.	Corn silage yield of biogas	180	m <sup>3</sup> / ton of silo
2.	Biogas yield from 1 ha of silo corn	7800–9100	m <sup>3</sup> /ha
3.	Silo volume	10–20	m <sup>3</sup> of silo/ ha
4.	Dry matter content	33	%
5.	Dry organic matter content in the dry matter	95	%

Source: developed by the authors.

### *Power Generation*

The combustion of 1 m<sup>3</sup> of biogas can produce about 2 kW of electricity.

In this regard, the pig farm will be able to consume the produced biogas to produce 8,002,000 kW of electricity per year, and subject to the standard number of hours of operation of the cogeneration plant – 8000 hours/year – the required installed capacity of the cogeneration unit will just be at 1000 kW.

Our calculations show that the biogas plant installed on the pig farm will require the installation of an electricity generator in the range of 150–200 kW of installed capacity for the efficient utilization of existing waste (manure and death loss).

If about 20% of the processed product waste composition, providing a higher biogas yield (silage corn at this stage), the required installed electric power generator should be 1000 kW in this case. This capacity will provide a biogas plant and the pig farm with heat and electricity, as well as give an opportunity to sell electricity to the network at the “green tariff”.

### *Heat Production*

The combustion of 1 m<sup>3</sup> of biogas can produce about 3 kWh of thermal power. In this regard, the pig farm will be able to consume the produced biogas for additional production of 12,003,000 kWh (10,322 Gcal) of thermal power per year, and subject to the standard number of hours of operation of the cogeneration plant – 8000 hours/year – the established thermal power capacity of the cogeneration unit will be at the level of 1500 kW.

Heated production halls and office buildings, nearby manufacturing plants, drying plants, housing and social infrastructure buildings, and small towns can become potential consumers of heat, and the generated heat may even be used for refrigeration.

## **The Socio-economic Impact, Environmental Protection and Ecology**

The socio-economic impact of introduction of biogas plants includes:

- reduced dependence of national economy on imported power and increased energy security of the country;
- solving problems of sustainable energy supply for the agricultural sector of the economy with its own renewable energy source with high environmental and technical parameters of its consumer qualities;
- high levels of occupational safety and health;

- use of organic waste at agricultural enterprises;
- energy savings due to replacement of the electricity taken from the network by energy produced from alternative sources;
- improving the global environment (combating global climate change by reducing emissions of methane and carbon dioxide in the atmosphere);
- obtaining high-quality organic fertilizers, without helminth eggs, weed seeds and nitrates; and
- creating jobs in installation and construction of biogas plants as well as during their operation (3–4 workers for each unit).

## The Cost of the Project

### *Capital expenditures*

According to various estimates, the cost of capital expenditures may vary in the range of 250–900 euros per 1 m<sup>3</sup> of the installed reactor or 2000–6000 euros per 1 kW of installed capacity.

Capital expenditures cover the following units:

- 1) land;
- 2) construction work, including infrastructure;
- 3) mechanical components;
- 4) electrical components and process control;
- 5) accession to the electric power grid systems and the possible distribution of heat; and
- 6) design.

In addition, an important factor is the added capital expenditure following unforeseen capital expenditures related to the development and implementation of the project:

- 1) The pre-feasibility study stage. About 15–20% of capital expenditures.
- 2) The feasibility study stage. About 10–15% of capital expenditures.
- 3) The design stage. About 5–10% of the capital cost.

Accordingly, the average capital costs are at a level of EUR 3,200,000.

### *Operating Costs*

Annual cost of operation and maintenance includes the following components with indicative ranges:

- 1) Maintenance and repair;
- 2) Insurance and administration;
- 3) Purchase and delivery of additional substrates;
- 4) Feed water for additional substrates;
- 5) Start-up fuel to run the cogeneration plant;
- 6) Personnel; and
- 7) Selling fertilizers.

Accordingly, the average operating costs are at EUR 606,000 per year.

### **The Revenue Part of the Project**

The revenue part will be provided by:

- 1) sales of electricity of its own production;
- 2) saving power consumption from the network;
- 3) saving energy for heating a pig farm and ensuring its hot water supply; and
- 4) sales of liquid fertilizers.

The produced electricity can be sold in a network at a “green tariff” at a price 2.07 times higher than the market rate of electricity for businesses. With the deduction of energy required for the operation of the pig farm as a whole, as well as the biogas plant, the electricity sale on a “green tariff” will give 932,000 euros annually.

Substitution of network power consumption by electricity of its own production will lead to saving 71,000 euros annually.

Saving fuel (coal, pellets) for heating the pig farm and ensuring its hot water supply will lead to saving 63,660 euros annually.

Income from the sale of liquid fertilizer (based on the price of 6–7 euros per ton of liquid fertilizer) is estimated at 323,750 euros annually.

Accordingly, the income part is estimated at EUR 1,390,406 annually.

On top of that, the pig farm will receive additional benefits by reducing costs and penalties associated with waste disposal.

Under these terms, the proposed biogas plant pays off for 5.7 years (9.7 years of discounted payback period). This project solves the problem of recycling and efficient use of pig waste. The project pays for itself at the expense of what went to pay monthly bills for power purchase, waste disposal costs and fines related to waste management in the enterprise. In addition, the profitable part of the project will be mainly provided by the “green tariff” sale of electricity produced by the biogas plant, as well as through the implementation of fermented substrate as fertilizer. These funds will go to repay the loan raised for the project.

**Table 3:** Results of Financial Analysis.

Parameter	Unit of measurement	Value
Lifetime of the project	years	25
<b>Costs</b>		
Capital expenditures (CAPEX)	euro	3,200,000
Operating costs (OPEX)	euro/year	606,000
Depreciation costs (20 years)	euro/year	160,000
<b>Revenue</b>		
The profitable part	euro/year	1,390,406
<b>Additional Parameters</b>		
Credit (financing 60% of the project, 15 years, the rate of 5% per annum)	euro	1,920,000
Tax on profits	%	19
<b>Payback Indicators</b>		
Net profit	euro/year	557,581
Simple payback	years	5.7
Discounted payback period (10% discount rate)	years	9.7
Net present value (NPV)	euro	11,651,160
Internal rate of return (IRR)	%	17.30
Net Present Value (NPV), with discount	euro	1,995,111
Internal rate of return (IRR), discount taken into account	%	6.63

Source: calculated by the authors on the basis of the data provided by LLC "Lider".

Under aforementioned terms, the proposed biogas plant pays off for 5.7 years (9.7 years of discounted payback period). This project solves the problem of recycling and efficient use of pig waste.

The project pays for itself at the expense of what went to pay monthly bills for power purchase, waste disposal costs and fines related to waste management in the enterprise. In addition, the profitable part of the project will be mainly provided by the "green tariff" sale of electricity produced by the biogas plant, as well as through the implementation of fermented substrate as fertilizer. These funds will go to repay the loan raised for the project.

**Table 4:** Project Implementation Schedule.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
1	Development and preliminary feasibility study	█															
2	Feasibility study		█														
3	Development of the project implementation plan			█													
4	Development of design documentation				█												
5	Tracking and obtaining permits					█											
6	Earthwork						█										
7	Building of structures							█									
8	Insulation and cladding								█								
9	Laying pipelines									█							
10	Construction of machinery hangar										█						
11	Pumping and mixing equipment											█					
12	Heat distribution network												█				
13	Installation of a cogeneration unit													█			
14	Biomass supply system														█		
15	Monitor/control system															█	
16	Connecting to a network																█
17	Additional unforeseen work																█
18	Commissioning																█
19	Training																█

Source: developed by the authors.

## Notes

<sup>1</sup> “The Green Tariff” policy is a feed-in tariff (FIT) scheme for electricity generated from renewable energy sources, introduced in Ukraine in 2009. The scheme will be open until 1 January 2030. “The Law on Electrical Energy Industry” of 16 October 1997 created a legal framework for the “Green Tariff” scheme.

The National Commission for State Energy Regulation (NERC) is responsible for management of the scheme, modification of the tariffs, granting and distributing financial support to the eligible parties. Support from the “Green Tariff” scheme can only be obtained upon the completion of a power plant. **Technologies eligible for the support:** solar PV; wind; hydroenergy (with capacity no larger than 10MW); biomass energy (International Energy Agency 2016).

<sup>2</sup> The sharp and substantial increase in bioreactors loading is not good, since it can slow down the biological process and, in some cases, stop biogas emission. The same can happen with a substantial change in the quality characteristics of the raw materials.

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