BECOOP

UNLOCKING THE COMMUNITY BIOENERGY POTENTIAL

Technical catalogue on biogas plants

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About

Over the last years, the EU has witnessed some remarkable steps in Renewable Energy (RE) deployment. However, at the same time, we see an increasingly uneven penetration of RE across the different energy sectors, with the heating and cooling sector lagging behind. Community bioenergy schemes can play a catalytic role in the market uptake of bioenergy heating technologies and can strongly support the increase of renewables penetration in the heating and cooling sector, contributing to the EU target for increasing renewable heat within this next decade. However, compared to other RES, bioenergy has a remarkably slower development pace in the decentralised energy production which is a model that is set to play a crucial role in the future of the energy transition in the EU.

The ambition of the EU-funded BECoop project is **to provide the necessary conditions and technical as well as business support tools for unlocking the underlying market potential of community bioenergy.** The project's goal is to make community bioenergy projects more appealing to potential interested actors and to foster new links and partnerships among the international bioenergy community.

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Project partners

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1. Introduction

Biogas production plants are the match between bioenergy production and waste management strategies, where organic waste streams or feedstocks undergo anaerobic digestion (biochemical reactions of microbial metabolism) to be transformed into biogas and other added-value by-products, contributing in an increasing degree of decarbonization through circular economy perspective. Biogas is a gaseous mixture mainly composed by methane (CH_4) and carbon dioxide (CO_2) which exhibits good heating values and potential to stablish renewable substitute to conventional natural gas when upgraded to enhance its methane content and injected to the grid. It can also supply electricity and heat when used along with co-generation units.

Due to its production, biogas generation facilities offer great opportunities for rural and country-side areas as well as for small-scale and self-consume energy production, thus suiting energy communities visions. Taking into account the BECoop audience (residential sector), these consumers could be municipalities, farmers, food-processing companies, community of neighbours, individual houses, swimming pools, local business, nursing home, hospitals, etc.

This specific catalogue will be focused on biogas production plant facilities, highlighting its main elements, CAPEX and OPEX trends, features, and profitability, as well as a brief roadmap for its assessment. To assess this goal, the information that can be found in this report are the following.

- A general overview of what an anaerobic digestion is in order to guarantee that this is the project that you want to promote.
- Technical considerations that should be known before contacting with stakeholders that can help you to develop your initiative. It should be known the main elements of the biogas plant, the information necessary to assess the power of the biogas plant, and the operational and maintenance requirements for this type of installation.
- Although, the best option (if you don´t have technical experience) is that an expert carried out a feasibility study, the point 4 explains how to assess a first estimation of the economic profitability of a biogas facility, but as indicated, this is just a starting point and then needs to be studied in more detail by an expert. Also, environmental and social benefits are mentioned in point 5.
- The point 6 indicates the group of stakeholders that can help you in the development of your initiative, and what kind of activities can be expected for each group of stakeholders. Not all of the stakeholders should be involved to develop a biogas production plant, it will depend of each particular case according to your necessities.
- The point 7 gives the general steps that should be carried out from the idea to the final implementations, with suggested stakeholders that can provide support if needed.
- Finally, some success cases are mentioned to provide some real examples of biogas plants owned by energy communities that are properly working or successful projects.

Important: This technical catalogue is based on general recommendations to be taking into account and facilitate the conversation at the time of establishing the first contact with the energy services /engineering companies that will carry out the project, being them finally, the ones that will decide

how the installation should be distributed and the type of equipment and technologies they will count on.

2. Anaerobic digestion concept

The concept of "anaerobic digestion" is related to the compilation of biochemical reaction (methane fermentation) that bacteria and several microorganisms carry out to degrade organic matter into simpler compounds and by-products for its metabolism [1]

Organic matter is decomposed into two different main fractions: a gaseous phase named **biogas** and a solid phase named **digestate**. Both fractions have been reported to offer various applications and both material and energetical valorisation as shown in Figure 1.

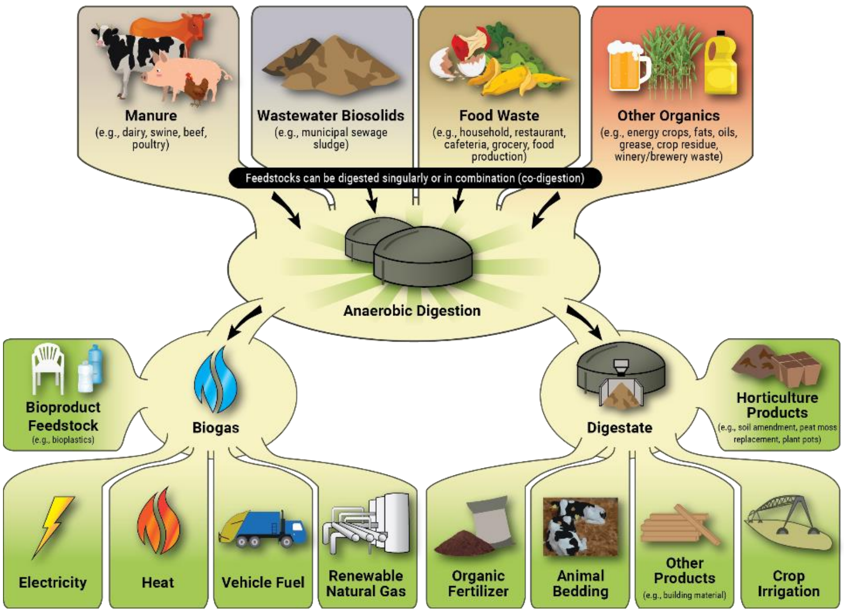

Figure 1: Anaerobic Digestion for waste valorisation. Source: EPA, [2]

Biogas is a mixture of gases like natural gas which exhibits high heating values ranging 16-28 MJ/m^3. Methane (CH_4) is the main compound with near 45-75% share of overall biogas content, whilst carbon dioxide is the second main product holding a 20-30% share. Carbon monoxide, hydrogen sulfide and other trace compounds/elements are also found in biogas.

Because of its similarities with natural gas, biogas thus shows great potential to directly substitute natural gas as an environmental-friendly fuel solution for heating and co-generation applications. On the other hand, biogas production also offers a promising opportunity for waste valorisation, landfill management and processes decarbonization. Table 1 shows main similarities between biogas and natural gas properties.

Table 1: Biogas and natural gas properties comparison [1,3–5]

Components	Units	Natural gas	Standard Biogas
CH_4	% vol.	70-90	45-75
CO_2	% vol.	0-8	47-25

N_2	% vol.	4-0	3-0
O_2	% vol.	0	< 0.5
H_2S	mg/m^3	2-20	3,000-10,000
NH_3	mg/m^3	-	50-100
HHV	kWh/m^3	11.3	6.6-7.5
Density	kg/m3	0.85-0.93	1.15-1.25

Biogas production enables efficient energy recovery from organic waste streams generated by domestic and/or industrial processes, producing carbon-neutral fuels that can be used to generate heat and/or electricity in facilities. Biogas is particularly promising as an energy solution for communities, as it allows for direct valorisation of community biomass waste streams.

Biogas production facilities may not be economically feasible unless they undergo a thorough assessment. The processes that involve biological reactions and microorganism, are susceptible to suffer from various difficulties, such as unaffordable capital expenditures and technical barriers that may hinder the techno-economic viability. Furthermore, while anaerobic digestion parameters can be optimized to maximize biogas potential within feedstocks, the supply of biomass may be subject to intermittent availability throughout the year or changes in chemical composition over time. In consequence, biogas production performances are usually very sensitive to feedstock (batch) changes, hindering its viability. As result, it is important to assess the supply chain, as well as the biomass providers and storage units, when proposing a project.

The use of biomass, waste streams and biogas facilities installation enable the use of autochthonous and renewable energy resources while contributing to create local employment in the municipalities where the valorisation initiative is implemented. From an economic perspective, organic waste streams usually have a lower price than conventional fuels and, additionally, environmental benefit derived in terms of forest cleaning, contributing to reduce forest fire risk, prevention of open-fires (as for instance of agricultural pruning) and the reduction of CO_2 emissions, due to the substitution of conventional fuels by biomass.

From the users' point of view, biogas production facilities could offer economic and technical benefits. It could contribute to reducing fossil fuel dependence, local energy safety, raising energy savings as well as solving domestic and industrial waste management issues.

3. Technical considerations

3.1 Main elements of a biogas production facility

The main goal of this chapter is to provide a general overview of the main technical elements of a biogas production plant in order to facilitate the conversation and the agreements with the energy service/engineering company in charge of the design and development of the installation. The main elements to consider are:

- Feedstock: The feedstock is the organic material that is fed into the biogas plant. It can be a variety of organic materials, such as agricultural waste, food waste, and animal manure.
- Anaerobic digester: The anaerobic digester is the main vessel where the anaerobic digestion process takes place under controlled conditions. It is a sealed tank that is designed to create an environment where microorganisms can break down the organic matter and produce biogas.
- Storage or Gas holder unit: The gas holder is a tank that stores the biogas produced by the anaerobic digester. It is designed to hold the gas at a constant pressure so that it can be used as a fuel whenever there is a high energy demand.
- Sludge treatment: The sludge treatment system is used to process the sludge that is produced as a by product of the anaerobic digestion process. The sludge is treated and stabilized, and then it can be used as an organic fertilizer or a soil conditioner.
- Upgrading unit: Such as gas scrubber units, devices that removes impurities from the biogas, such as hydrogen sulphide and moisture.
- CHP unit: The gas engine is a device that converts the biogas into electricity and heat. It is typically fuelled by natural gas or propane, but it can also be fuelled by biogas.
- Control and management of biogas plant.

3.2 Biogas plant

Biogas plant main features different elements to perform acceptable production efficiencies. When establishing the technical requirements to be met by the installation to optimise its production, it is important not to focus only on the digester unit, but also on the entire biomass and biogas storage system as well as the further biogas application since many times it is where the greatest source of oversizing issues.

3.2.1 Biomass storage

The properties, nature, and mass flow of the feedstock are key parameters for the proper operation of biogas plants. For this reason, it is essential to ensure a continuous, safe, and homogenous supply.

One way to address this issue is through biomass storage, which can provide a direct solution. More information about feedstock's importance will be assessed on following sections.

Next to the biogas plant, it is essential to have enough space to store at least the amount of material necessary to regularly supply the digester needs. Indeed, the storage technology will depend on biomass' properties, especially its water contents. In biogas applications, target biomass is usually with a high moisture content, as livestock manure. Hence, wet storage systems are commonly employed. However, special measures must be ensured with storage times control, as possible fermentation and excessive degradations could take place, reducing its biogas potential. On the other hand, dry biomass must be protected from combustion and decomposition effects (see Figure 2).

Anyway, the cost of storage is also one important parameter to assess the overall economic viability of the plant. Additionally, the storage is often necessary due to stationary characteristic on the feedstock or to avoid any possible intermittence of supply during the year.

Figure 2: Biomass storage options for different types of biomass: Solid crop waste (top left), sludge (top right) and liquid live stock (bottom)

In conclusion, biomass storage units may be assessed to protect the biogas production from uncontrollable or seasonal issues, but its required investment may increase with capacity, for that reason a proper size must be estimated.

The volume of the storage area will be defined considering the following aspects:

- Amount of biomass to be stored, where it has to be considered the self-sufficient target of the plant for a certain period of time.
- Bulk density of the biomass to be stored, which depends on the biomass selected and the size distribution of this biomass.
- Average consumption of biomass per day. For this, digester retention times must be assessed.

Taking into account the previous considerations, the approximate storage area can be calculated by means of the following formula:

$$\text{Usable volume needed} = \frac{\text{consumption of biomass per day}\left(\frac{\text{kg}}{\text{day}}\right) \times \text{ number of days to be self} - \text{sufficient (days)}}{\text{bulk density of the biomass }(\frac{\text{kg}}{m^3})}$$

Even though, the final surface needed will depend upon the equipment selected for biomass storage. This final decision must be made by the energy services company that carries out the installation, considering the final location of the generation plant, the biomass selected and the available space.

3.2.2 Digester

The digester represents the core of the biogas production plant. It is the main unit where biochemical anaerobic digestion processes take place, which involves the action of different microorganisms that decompose and break down the organic matter (in an oxygen-free atmosphere) to produce methane (CH_4) and carbon dioxide (CO_2) as primary products and main components in biogas. Furthermore, solid residue is also obtained - commonly named digestate - which can offer several further applications. The configuration of a digester, which is essentially a chemical reactor, depends on the feedstock and operation conditions, and can impact the particular purposes for which the produced biogas is used [6]

One of the most important parameters for digester operation regards its temperature. As anaerobic digestion comprehends a multi-step and multi-phase biological reaction system, biogas production is greatly dependent upon temperature. Two main broad categories of methanogens bacteria are found: Medium-temperature, mostly identified as **mesophilic**, which thrive anaerobic digestion between 30-38ºC; and high temperature bacteria, mostly known as **thermophilic**, which find optimum gas-producing temperatures ranging 49-57ºC. Furthermore, there are recent studies suggesting that psychrophilic bacteria operating in a temperature range of 5-15 ºC can bring an efficient as well as an economically positive imprint on the anaerobic digestion processes [7].

Moreover, different configurations design can be found in Figure 3, highlighting their main features:

- **Batch technologies:** These are the most common and simple ones, often used for small-scale plants. It is the most economical option as its construction and operation is simpler, able to suit different type of feedstocks. However, it is also the least sophisticated one. Batch digester usually need of mechanical mixing and lacks proper control of fermentation process, thus yielding lower biogas rates. Regarding its operation, feedstocks are introduced at the beginning into the reactor and remains closed for the overall duration of digestion process.

- **Plug flow technologies:** These types of digesters are usually long tube tanks in which waste flows through. They are typically used for industrial and large-scale, as they are highly efficient regarding biogas production yield, but its construction is quite complex, thus requiring high initial investments.

- **Complete mix:** Enclosed heated tanks with mechanical or gas mixing systems that are more suitable for highly wet feedstocks.

- **Hybrids:** There are also some hybrid technologies that combine features from both batch or continuous digester reactor, making them suitable for wider ranges of applications, but they still may require skilled operators and higher maintenance costs.

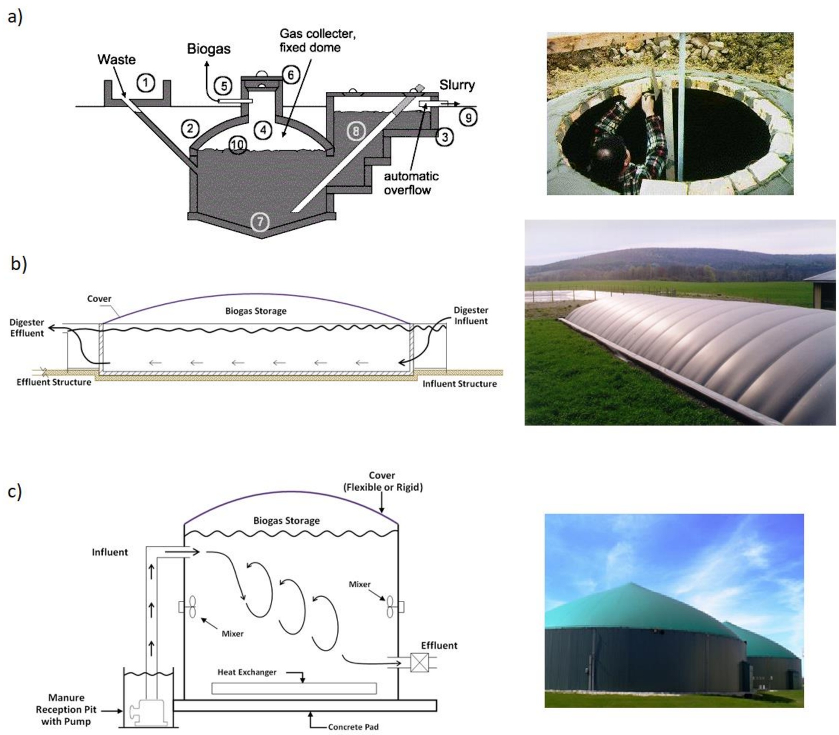

Figure 3: Biogas digester main technologies: a) Batch overflowing digester b) Plug-flow digester c) Gas mixing system digester. Source: U.S. Environmental Protection Agency

Table 2 summarizes the main features of most common digesters.

Table 2: Main digester operational features and characteristics [6]

Factors	Fixed dome	Floating drum	Tubular design	Plastic containers
Gas storage	Internal Gas storage up to 20 m³ (large)	Internal Gas storage drum size (small)	Internal eventually external plastic bags	Internal Gas storage drum sizes (small)
Gas pressure	Between 60 and 120 mbar	Up to 20 mbar	Low, around 2 mbar	Low around 2mbar
Skills of contractor	High	High	Medium	Low
Availability of Material	yes	yes	yes	yes
Durability	Very high >20 years	High; drum is weakness	Medium; Depending on chosen liner	Medium
Agitation	Self agitated by Biogas pressure	Manual steering	Not possible; plug flow type	Evtl Manual steering
Sizing	6 to 124 m³ digester vol	Up to 20 m³	Combination possible	Up to 6 m³ digester vol
Methane emission	High	Medium	Low	Medium

It is important to carefully consider the main purpose of biogas application, as well as the daily amount of biomass entering the process and the acceptable range of biogas yield. These factors are key to estimating the sizes of other units, such as biogas storage and use facilities, and should be taken into account by both the constructor and the designer.

3.2.3 Biogas storage units

After anaerobic digestion, the produced biogas will likely be stored in the short or medium term for further application. This may include direct use for on-site cogeneration or transport to an off-site application or distribution point.

The storage tank for biogas can either be located inside the digester or downstream as an independent unit. Additionally, it is important to consider the pressure ranges for the storage system, which will depend on the expected production outcome and storage needs [8]:

- Low-pressure Biogas Storage: The most common are flexible membrane materials which offer the least trouble with H_2S corrosion under less than 2 psi pressure (Figure 4).

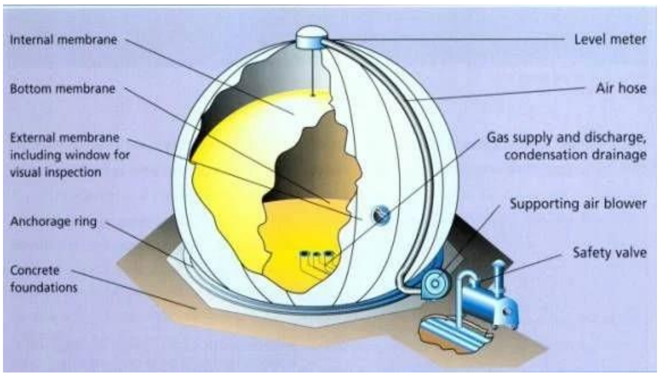

Figure 4: Low pressure storage system. Source: BioEnergy Consult [4]

- Medium-pressure Biogas Storage: Prior to its storage, biogas should be cleaned and compressed to assess these types of units and to ensure operation and avoid corrosion In this case biogas is stored in 2 – 200 psi pressure range.
- High-pressure Biogas Storage: This type of unit is mostly assessed for higher applications as biogas upgrading and biomethane off-site uses, where biomethane must be compressed or liquefied to save space and facilitate its further transportation. The gas is stored in steel cylinders or bottles as for other commercial gases. Storage facilities must be adequately fitted with safety devices such as rupture disks and pressure relief valves. Pressure is compressed between 2,000 and 5,000 psi, which cost is much greater than other storage units (Figure 5).

Figure 5: High pressure biogas storage system. Source: AtmosPower Pvt. Ltd. [9]

3.2.4 Sludge Treatment

Sludge treatment refers to the processes that involve the treatment of solid by-products of anaerobic digestion. With these, different purposes might be considered, as simply as its volume reduction, weight, or toxicity. As expected, the treatment will be different depending on the characteristics of the sludge, the desired end-product and the available possibilities. Summing-up, the purposes for sludge (or digestate) semi solid by-product are:

- Volume reduction: easing transport, handling or storing.
- Pathogen reduction: the disposal of anaerobic digestion sludge increases risks for health due to elevated potentials of pathogens, thus its treatment is mandatory to reduce those risk when disposed or handled.
- Nutrient recovery: sludge or "digestate" is a promising strategy for recovering phosphorus and nitrogen inorganic compounds, which can be potentially used as fertilizers. In fact, currently most potential application of digestate pathway is its processing as fertilizer or soil amendment.
- Energy recovery: as any other end-waste, sludge and digestate can be energetically valorised by incineration to produce heat and electricity when coupled to a combined cycle plant.

Figure 6 shows various strategies and treatment methods that can be taken into account for the sludge treatment. While composting is currently the preferred method for converting digestates into a soil amendment product that benefits soil structure, other less effective methods focus on decreasing the amount of digestate generated rather than producing valuable by products. Drying and thickening digestate streams are simpler and more cost-effective ways to reduce the volume of solid or liquid digestate after anaerobic digestion, making it easier to dispose of. Lastly, the least efficient and ecological route followed by biogas producers is incineration of residual digestate streams. However, it is still the most common pathway after biogas production when no market or further application is assessed.

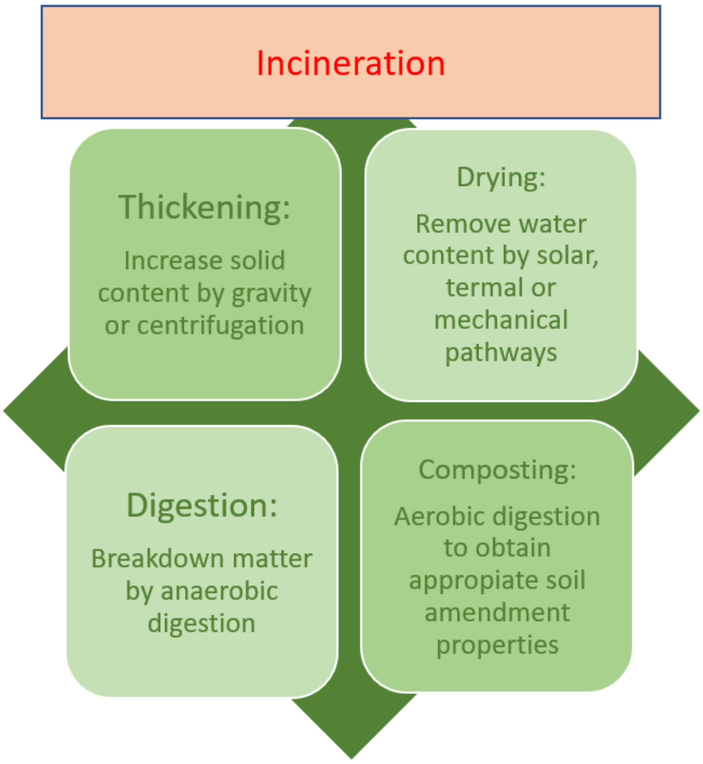

Figure 6: Anaerobic digestion sludge by-product treatment strategies

3.2.5 Biogas use: Boiler, CHP or upgrading unit

After production, biogas may be converted into other useful forms of energy as heat, electricity or upgraded into biomethane to applicate as natural gas substituent. The design of a biogas production plant should take into consideration the intended application of the produced biogas prior to construction, in order to ensure that all necessary units are incorporated into the design. For this, different units and strategies for valorisation are considered:

- **Combustion engine**: Most direct biogas application is as fuel for combustion engines or boilers with the goal of producing heat, mechanical power for any vehicle or equipment, or electricity when integrated into CHP unit (for more information about CH units, you can consult the BECoop technical catalogue “co-generation”).
- **Upgrading units:** Some upgrading units can convert biogas into biomethane by removing impurities as sulphur compounds and CO_2 and adding hydrogen. This biomethane can be injected into natural gas grid and sold as renewable fuel.
- **Fuel cell:** Biogas can be used as a fuel source for fuel cells, which convert the chemical energy of the gas into electricity through an electrochemical process. This application is rarer than the previous ones explained, as its economic feasibility remains much lower.

3.2.6 Control and management of biogas plants

The main objective of controlling a biogas plant is to regulate the generation of biogas, the feedstock stream fed into the digester, and the distribution, application, or storage of the produced biogas. Another important variable to regulate is the control operating temperatures, digestion retention times and/or pressures, which is usually based on the technical specifications of the different units.

Temperature is a defining parameter for the biogas plant and production. A biogas plant can operate at a range of temperatures, depending on the specific microorganisms used in the digestion process. These microorganisms and commonly classified as thermophilic (relatively high temperatures) and mesophilic (mild temperatures).

Mesophilic systems, which use microorganisms that thrive at moderate temperatures, can operate between 25-35°C. The optimal temperature range for most types of anaerobic digestion is between 35-40°C. However, some thermophilic systems, which use microorganisms that thrive at higher temperatures, can operate at temperatures between 55-60°C.

The control of the different parameters as digester temperature, feeding rates, biogas pressures and feedstock retention times are usually managed through a "supervisory control and data acquisition" (SCADA), this supervision will allow the optimization of the operation and will increase the safety of its operation. The control and monitoring of the installations include the elements of the biogas generation and power plant.

3.3 Power of Biogas Plant

To assess the power of the installation, the user should provide some preliminary input data such as their energy requirements, biomass potential, and availability.

Biogas plant facilities represent a remarkable investment whose margins shall be properly calculated. Once the primary energy potential is defined, it is possible to start considering its supply format (heat and/or power). However, results must be compared to match energy requirements and investment capacities. It should be considered that any overestimation may arise the risk of expensive project payback rates, threatening the economic feasibility of the project.

For these reasons, it is important to perfectly acknowledge community energy demands and necessities to avoid overestimated plant volumes and facilities leading to unaffordable projects. It is recommended to address the aid of expert companies to satisfy those calculations.

3.3.1 Feedstock's biogas potential and performance efficiency

The maximum power output of a biogas plant can be estimated using several methods. One common method is to use the amount of feedstock that will be used by the plant as a starting point. By knowing the composition of the feedstock, you can estimate the potential amount of biogas that will be produced by the plant.

The biogas potential of feedstocks is an important factor when considering biogas production activity. A proper biogas production rate can be assessed through feedstock's biogas potential, which results will also impact on other considerations, such as economics, regulatory issues, feedstock availability on and off the facility, and end use of the biogas, that should also be evaluated. This data can be easily collected online, whereas expert companies are used to manage these technical concepts.

It is necessary to identify the biogas potential range that our chosen feedstocks can offer. For these:

- 1st stage: This step refers to the potential and availability of all suitable feedstock in the surrounding area that may be applied to biogas plant (e.g. manure, crop residues, organic waste etc.) and its biogas potential. Feedstocks from outside purchases or supplies may suffer from intermittences or supply issues. It should be ensured to have the most homogeneous feedstock supply to ensure anaerobic digestion stability.
- 2nd stage: Once the overall annual feedstock capacity is defined, it would be possible to estimate the overall maximum biogas potential for the available feedstock. For example, after considering a total available amount of 300 tons of pig manure per year, and considering pig manure BMP[1], a maximum annually biogas potential of 6,000 m^3 could be estimated.

Another important factor that can be used to estimate the maximum power output of a biogas plant is the efficiency of the plant's anaerobic digestion process. The efficiency of the process can be affected by a number of factors, including the temperature, pH, and pressure of the digester, as well as the type of microorganisms that are used. If an efficient coefficient of 60% is considered for the previous examples, a total annual biogas potential of 3600 m^3 should be finally inferred.

Table 3: Various feedstock's biogas potential.

Feedstock Type	Biogas Potential (m^3/ton)
Industry waste	457
Wood residues	225
Food organic waste	281
Sugar beet	321
Wheat	202
Soybeans	229
Rice	229
Sugar cane	202
Pig slurry	20
Sewage Sludge	15

Once you have an estimation of the potential biogas production and the efficiency of the anaerobic digestion process, you can use that information to estimate the maximum power output of the plant. It's important to keep in mind that these are just estimates and that actual performance may differ. Many site-specific factors like feedstock quality, digester design, and process monitoring and control

[1] *BMP, Biomethane Potential test: The biomethane potential (BMP) test is a laboratory analysis used to determine the potential amount of methane that can be produced from a given organic substrate, such as agricultural waste, sewage sludge or manure.*

also have a large impact on the performance of the plant. It is always recommended to consult with experienced biogas plant designers or operator for accurate estimation and effective plant operation.

3.3.2 Biogas end-use application

During the conception phase of any biogas production facility, it should be addressed which would be the final application of the produced biogas based on the community's objectives.

Some of the most common applications for biogas production include:

1. Energy generation: Biogas can be used as a source of energy for heat and electricity production in power plants. It is often used to fuel internal combustion engines or gas turbines to generate electricity.
2. Off-grid or on-grid: Most biogas production facilities are aimed to satisfy off-grid energy requirements as for self-consumption heating and electricity production. However, bigger anaerobic digestion projects also aim the conversion of organic waste into electricity with selling purposes to the electrical grid system. Biogas production applications could also aim both in-site heating and to-grid electricity sells.
3. Biomethane upgrading: Biogas can be purified to remove carbon dioxide and other impurities to produce biomethane, which is almost pure methane, it can be used as fuel for natural gas vehicles (NGV) and for injection into the natural gas grid.

It is crucial to define the intended application of the produced biogas, as it will impact the design and estimation of output power and capital expenditures. For instance, if the final application is electricity generation, there may be a need to purchase biogas upgrading units or combined heat and power (CHP) units. Many small-scale biogas plant facilities are designed for off-grid applications to increase energy savings for heating or other uses.

3.3.3 Power output estimation

There are several ways to estimate the maximum power output of a biogas plant, but the most common method is to use the lower heating value[2] (LHV) of the biogas and the maximum biogas production potential. This estimation allows to identify the highest theoretical power that the plant could produce taking into account that all the energy contained in feedstock is transformed into biogas. It needs to be highlighted then, that anaerobic digestion performance will define real conversion rates and biogas yields.

As LHV may vary from one biogas to another, due to possible differences on their composition and from different feedstocks, typical average values can be used for estimating the total primary energy of the biogas potential input. The following formula may help to estimate the primary maximum power output of the biogas plant depending on the amount of feedstock used:

$$Maximum\ Power\ Output\ (kW) = \frac{V_{biogas\ (m^3/year)} \times LHV_{(MWh/m^3)}}{h} \times\ C_i$$

[2] *The lower heating value (LHV) of biogas is the amount of energy released when the biogas is burned and is typically measured in units of energy per volume. LHV of biogas can vary depending on the composition of the biogas, but it is typically around 55 MJ/m*^{3}

Whereas:

- V_{biogas} refers to estimated annual maximum biogas potential for the specific case
- LHV refers to chosen standard or specific biogas lower heating value
- *h* refers to the expected annual total running hours for the plant
- C_i refers to the different efficiency coefficients that must be applied for the boiler, co-generation or other biogas application unit.

  **E.g. Biogas used for heat production by boiler unit shows typical efficiencies C_{boiler}=0.75 for most commercial equipments. Biogas used for electricity production by co-generation unit shows typical efficiencies C_{boiler}=0.45 for most commercial equipments*

It should be noted that this method is just a rough estimation and real power output performance will depend on many factors including the design and operation of the biogas plant.

Additionally, you may also refer to other inputs and outputs of the plant such as feedstock, digester volume, and type, mixing method, temperature control, pre-treatment, etc; to get a more accurate estimation.

3.4 Operational and maintenance of the installation

Even though biomass and waste feedstocks are more cost-effective than fossil fuels, the operation and maintenance costs of biomass valorisation technologies are slightly higher to ensure proper operation and service life of the installation. This is due to the significant amount of inorganics and impurities that remain after biomass digestion, necessitating more frequent maintenance operations:

- The frequency of sludge and digestate removal will depend upon the installation characteristics and the biomass to be consumed. Biogas plant constructors and operators are expected to have experience and a background in maintenance of digesters and other units, particularly with regard to the retention and digestion times specified in the technical specifications of the units.

- When considering boilers or CHP for biogas use, removing the contaminants that can be located in the heat exchangers tubes and other auxiliary/cleaning emissions systems, can be done automatically by means of a pneumatic system (or other technologies). It is noteworthy to remark that biogas may contain small quantities of sulphurous compounds and other contaminants that may produce corrosion of the units, thus it is also recommended maintenance to be performed at least once per year, (normally after the winter season) and invest additional time to deeply clean all the installation.

Normally these operations are carried out by the company in charge of the operation of the installation. If these maintenance operations are being done and the design of the installations is based on the biomass resource to be fed, no malfunctions should arise.

Sometimes the bad experiences associated to the use of biomass, are due to the following issues:

- The biogas plant has been oversized and therefore the installation usually operates at very low capacity.

- The installation may encounter issues when the biomass fed is significantly different from the design specifications, as for instance: (i) different moisture content, (ii) size distribution (this can cause problems in the feeding system), (iii) chemical composition (be careful with that since it cannot be visually identified, high alkali and chlorine content, if the digester it is not designed properly, can considerably decrease the service life of the installation), (iv) low biomethane potential, (v) ash content, etc.

4. Capital expenditure and Operational Costs

4.1 CAPEX Estimation

Estimating the capital expenditure (CAPEX) for a biogas production plant can be a complex process, as it will depend on a variety of factors such as the size and location of the plant, the type of feedstock and digester to be used, and the desired rate of biogas production. As commented on previous section, once defined the main parameters that match feedstock's availability, biogas end-use application and the specific circumstances for the case scenario, the following tips could be followed to have preliminary estimations of capital expenditures (CAPEX).

A common approach to estimate the CAPEX is to break it down into different component costs. These costs can be broadly categorized into four main areas: land, construction, equipment, and contingencies:

$$CAPEX = Land\ costs + Constructions\ Costs + Units\ Purchases + Contingencies$$

Where:

- **Land cost:** This will include the cost of acquiring or leasing the land on which the plant will be built, as well as any site preparation or development costs.
- **Construction cost:** This will include the cost of building the structures and facilities required for the plant, such as the digester, gas storage unit, and power generation equipment. It also includes costs of installation and commissioning of the equipment and civil work like excavation, foundation, and building.
- **Equipment cost:** This will include the cost of purchasing and installing the equipment required for the plant, such as the digester, gas storage unit, gas treatment and compression equipment, pumps, and control systems. As explained, a previous estimation has been developed to properly sized the volumes and capacities of these units. Here is the key to the project successful achievement, as overestimation of these units could lead to unoptimized biogas production performances and thus to unaffordable projects.
- **Contingencies:** This will include any additional costs that may be incurred during the project, such as permitting fees, legal fees, and unforeseen contingencies that may arise during the construction process.

The cost of building a biogas production plant, also known as an anaerobic digestion plant, can vary significantly depending on a number of factors, including the size of the plant, the type of feedstock it will use, the location of the plant, and the specific technologies and equipment that are employed. In general, the cost of building a biogas production plant is primarily driven by the cost of the anaerobic digester, which can be a significant portion of the total nearly 40-50%, as well as the cost of other equipment such as gas engines, gas holders, and sludge treatment systems. In addition, there may be costs associated with site preparation, utility connections, and other infrastructure work. A common estimation of Capital Expenditure breakdown for off-site cogeneration is referred to in Figure 7 [10]

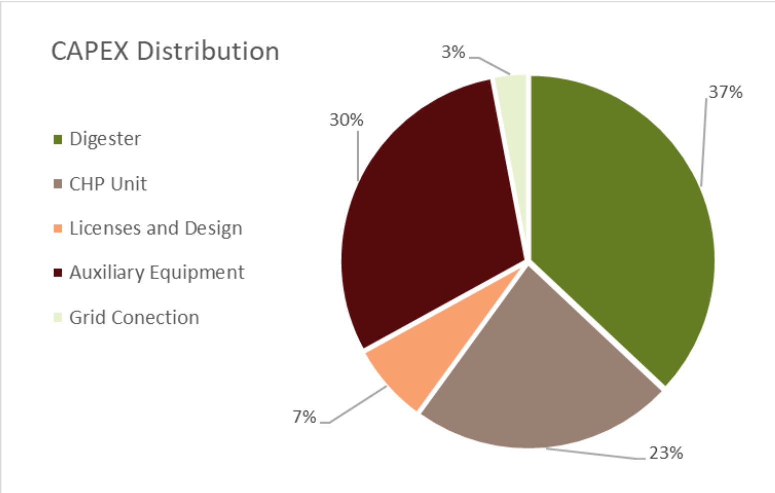

Figure 7: CAPEX Distribution [10]

The costs for each of these categories will depend on a variety of factors specific to the project, and estimates can be made using historical data, industry standards and guidelines, and consulting with experienced engineers. It's also important to consider any government subsidies or tax breaks, which may be available to support a biogas project.

Once the costs have been estimated, they can be grouped together to give an overall estimate of the CAPEX for the project. It's important to remember that this is just an estimate, and the actual costs may differ based on a variety of factors. It's also a good idea to consult with experienced engineers and financiers to ensure that the estimate is accurate and to help with the planning and execution of the project.

4.2 OPEX Estimation

Operational expenditure (OPEX) refers to the ongoing costs associated with operating and maintaining a biogas production plant. These costs can vary widely depending on the size and location of the plant, as well as the type of feedstock and technology used.

Some of the most common operational expenditure items for a biogas production plant include:

- **Feedstock:** This is likely to be the largest operational expenditure item for a biogas plant, as it represents the raw material that will be used to produce the biogas. The cost of feedstock will depend on factors such as the type and volume of feedstock used, as well as any transportation and handling costs.
- **Labour:** This includes the cost of hiring and training employees to operate and maintain the plant.

- **Maintenance:** This includes the cost of regular maintenance and repairs to the plant and its equipment, as well as any spare parts that may be required.
- **Utilities:** This includes the cost of electricity, water, and other utilities that are needed to operate the plant.
- **Chemicals:** Some biogas plants may require the use of chemicals to optimize the anaerobic digestion process or to treat the biogas before it is used or sold.
- **Taxes and fees:** This include any taxes or fees that are required to operate the plant, such as property taxes, environmental fees, or permits.

Figure 8 shows a compilation of typical biogas production total cost (capital investment, operational and feedstock supply are inferred) correlating main factors: production capacity, feedstock, and biogas valorisation technology. Production cost for biogas co-generation are plotted for the range lower values whilst biomethane upgrading and grid-injection facilities are plotted for range higher values [11]

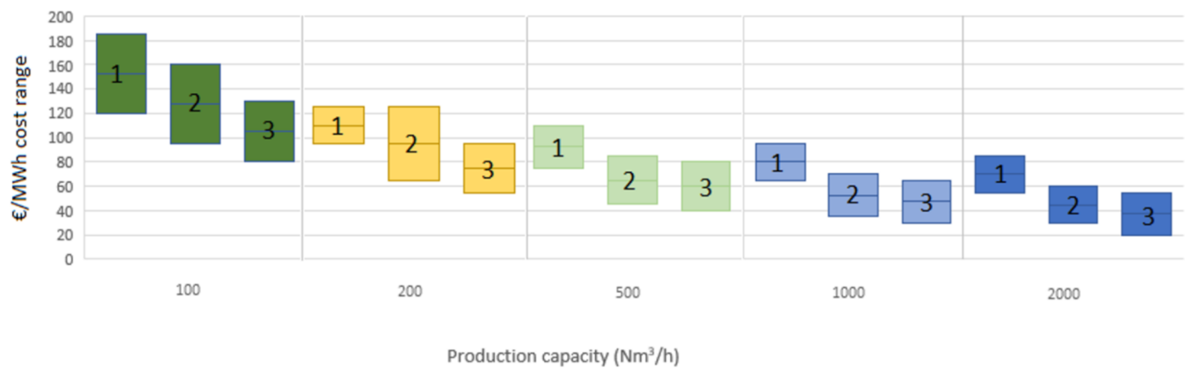

Figure 8: Range of total cost per energy produced correlation with production capacity and type of feedstock. 1: Energy Crops; 2: Manure; 3: Organic Waste

It's important to keep in mind that these are just some examples of common operational expenditure items, and the specific costs will depend on the project.

5. Profitability of biogas plants

Biogas plant profitability is greater than just economic issues. In first term, environmental challenges are roughly tackled by anaerobic digestion. Methane is one of the most contaminant greenhouse gases, thus its profitability as an energy carrier is further than only economic, but climate change mitigation. Moreover, anaerobic digestion emerges as a great application for the improvement of waste management strategies, otherwise, most waste streams end up disposed in landfills and contribute to pathogenic threats and environmental disasters.

In social terms, biogas plants also profit from great benefits regarding the economy and activities in rural areas, which are indeed the ones that hold the biggest potential for biogas explorations. Biogas plants create jobs that satisfy their construction, operation, maintenance, and supply, in addition to promoting local development, agricultural waste, and food waste management, reducing farm industry odours and health risks. In fact, rural areas may offer suitable symbiosis with biogas plants providing valuable local feedstock in exchange for cheaper and greener energy and waste management. All these facts result in cost savings for both the biogas plant and the agroindustry involved.

When biogas is involved in self-consumption or heat and electricity co-generation, savings on facility heating or electricity consumptions may have positive effects on the amortization of the installations and payback periods.

At this point, it could be considered not just the current annual price of fuels, but also the tendency in the future years since the stability of the prices will not be the same for all the fuels. Also, if the current fuels used are fossil fuels, it should be considered that they have an extra tax according to the specific emission factor of the fuels used, which can lead to a significant increase of the final price of the fossil fuels used. This price increase will make more and more attractive the potential savings from a biogas plant.

Figure 9: Evolution of the price of CO_2 emission in the last 5 years [12]

Once the current situation is well analysed, it should be compared with the future installation, and thus, two main aspect should be considered:

- Investment (CAPEX) of the new biogas plant installation: it includes the investment cost, the assembly and the transportation of all of the equipment required, together with the civil engineering costs. This number is very sensitive to the specificities of each case (location where the initiative will be implemented, expertise of the company in charge of the operations, the equipment selected, the biomass fed, etc).
- Operational and maintenance cost of the installation (OPEX): it includes the raw materials cost, labour cost, maintenance cost, energy cost, etc.
- Once, the CAPEX and OPEX of the new installation are estimated, in order to assess the economic profitability, the annual savings and/or energy sales of the new installation should be calculated. After having estimated all the investment and operating costs along with the potential savings or

revenues regarding heat or power sales, a simple way to calculate the payback period (this parameter indicates the necessary years to obtain the return of the investment carried out), is obtained through the division of CAPEX and profit of the operation (the annual savings and/or revenues discounted with OPEX costs) associated with the new installation. The lower the payback, the lower the risk associated with the new installation. It should always be lower than the service life of the new biogas facility (an average service life is between 20-30 years) for being economically profitable.

$$Payback = \frac{CAPEX}{\left(Annual\ savings\ \left(\frac{€}{year}\right) + Energy\ Sales\ \left(\frac{€}{year}\right)\right) - OPEX}$$

- Annual savings refers to the substitution of heat and or electricity consumptions by biogas valorisation.
- Energy sales refers to the revenues obtained by biogas, biomethane, electricity, heat or by products sold to other consumers or injected to the grid.

As mentioned, this is a simple way of doing a first estimation, but to be more accurate other parameters should be considered as the inflation or the tax rate. If the CAPEX is covered by own or external resources, loans, etc., in order to obtain more information about business and financial considerations, the BECoop Catalogue for the provision of business and financial support services can be consulted.

Table 41 summarises the information mentioned in this section, through an example of investing on a new small-scale biogas plant production replacing electricity household consumption[3] of an average 10,000 population community (16,000 MWh_e) producing 5,000 tons of urban organic waste[4] (biogas potential of 0.280 m^3/kg as shown in section 3.3.1). In this example an inflation rate of 2% has been considered for household electricity consumptions and 1% for OPEX increase annually, as a result a 10-year payback period is obtained.

Table 41. An example of a breakdown of savings, expenses and investment obtained for a biogas plant.

Items	Unit	Data year 1
Savings (Current situation)		
Consumption of electricity	MWh/year	16,000
Price of electricity considered	€/MWh	150
Annual electricity cost	€/year	2,400,000
Biogas production	MWh/year	5,800
Yield of electricity production	%	35
Useful electricity production	MWh/year	2,030

[3] Energy consumption per capita in the household's sector in the EU in 2020 was 1.6 MWh per capita

[4] When expressed in relation to population size, the EU generated, on average, 4 813 kg per capita of waste excluding major mineral waste in 2020, whereas household shares 9.15%. Thus, organic municipal waste is estimated on **500 kg per capita annually** [15]

Total energy satisfied by biogas		13%
Annual electricity savings	**€/year**	**304,500 €**
Expenses (future situation)		
Power of the installation (see section 3.3.3) with 7920h of work per year	MW	0.30
CAPEX cost (taking into account investment trends in bibliography [13]	**€**	**1,845,900**
Annual total cost: amortisation of investment cost, electricity consumption of the plant, feedstock costs, transport of feedstocks, salaries and maintenance costs (see section 4.2)	€/year	121,800
Total earning (Savings – OPEX)	**€/year**	**182,700**
Financial considerations		
Inflation of electricity	% of inflation per year	2
Inflation of OPEX	% of inflation per year	1
Grant	%	0
Loans	%	0
Payback		
Payback	**Years**	**9,3**

6. Stakeholders needed

In order to develop a biogas installation, the users, in the majority of the cases, would most likely need the support from other stakeholders, that sometimes can be integrated inside the community/RESCoop or in other cases they will provide external support by subcontracting. Some of the stakeholders that could be necessary are listed below:

Biomass producers/suppliers

It is very important to guaranty the supply of the raw material (biomass) that should feed the biogas installation. There are a huge range of biomass with different composition and size distribution, therefore the biomass purchased should guarantee the same range of properties since the installation it is designed for a specific biomass. It is recommended to consume local biomass, because it is more sustainable, and the transportation cost it is lower. These biomasses can be purchased from the biomass producers or from biomass suppliers, in any case it is important to carry out supply contract specifying who is in charge of transportation, the frequency of supply, and the quality of the biomass supplied. Furthermore, energy communities shall be formed by biomass producers that are willing to valorise its resources.

Energy Services/Engineering Company (ESCO)

A biogas production plant, it is an industrial plant, so therefore it is important to account with an expert company that will oversee the proper design of the installation. This step it is critical, since a bad design of the installation can jeopardise the viability of the project. It is recommended that these companies have a clear idea of the biogas to be produced, since the installation should be designed accordingly. Sometimes this lack of information entail problems in the future, so dedicating efforts to making the project fully understood is highly recommended.

Some energy services/engineering companies have in their business model to be part of an energy community while others do not, this fact should also be taken into account depending on the business model to be selected by the energy community to be formed.

Equipment manufacturers

The selection of the proper equipment for the installation to be designed it is important, even though this process normally it is being done by the previous stakeholder (energy services/engineering companies), since they have agreements with several equipment manufacturers, and they choose the best technology for each case.

Public/Local institutions

To develop biogas plants, generally, it implies the coordination between the different administrations for the processing of permits (e.g. licenses for waste management, production of energy, etc.) and the optimisation of the system in the case of supply to buildings or other facilities under different public ownership. Furthermore, if electricity sales or biomethane injection to the grid is forecasted, then the administration will play a fundamental roll to enable and give the license of connection to the public grid.

Consumers

Final consumers can be a wide variety of different stakeholders as: individual farms, community of neighbours, local industries, or even some of the stakeholders previously mentioned. They will be the "clients" of the biogas use or energy, and therefore, they will expect to achieve financial savings, and to contribute to the environmental and social aspects in the area by being part of this community based on biogas production and usage.

Transversal stakeholders (as research centre, biomass associations, investors)

In addition to the stakeholders previously indicated, which are the most necessary in this value chain, there are others, that in some cases, could help to assess/give advice/finance/etc the development of bioenergy communities based on biogas production, some of them are:

- Research centres: it could be interested to contact with this stakeholder if the promoter of the idea doesn´t account with the necessary technical information to assess if it could make sense to go further. The research centre can carry out a first feasibility study (being completely impartial) and if it is feasible to facilitate the contact with energy service companies or even being the technical expert (as representative of the promoter) in this communication with the ESCO. Additionally, it can provide support to prepare some documentation in order to obtain financial grants to develop the project.

- Biomass association/local action groups: this stakeholder can inform to the promoter about stakeholders that can help them in order to develops its initiative, can inform them about other success cases based on biogas plants, open financial grants, etc.
- Investors: a biogas plant requires a huge initial investment as it was mentioned before, so it is frequent to acquire some external funding. In this case, investors can provide support. Before contacting the investor, it is important to have a feasibility study, and the idea of the project well organized to capture its attention from the beginning.

In case the promotor of the idea needs to contact or find out a specific stakeholder, it is advisable to visit BECoop e-market platform where you can find useful information in this regard.

7. Steps to be followed

This section aims to summarize and establish a chronology order of general steps to be performed by the promoter of the idea of a biogas production plant unit starting from the beginning.

Table 5. General steps to be followed to develop a biogas facility from the beginning.

Order	Action	Description	Stakeholders that can help
1	To define the available amount of biomass for anaerobic digestion and the potential of biogas than can be produced with it.	The first step is to understand the dimensions of the biogas plant to be developed, which relies on the estimated production of biogas. See chapter 3.3.1	Biomass suppliers and producers are important stakeholders in determining the available amount of biomass. Additionally, other community members can also be involved in the process. In cases where support is needed, they can reach out to research centers or ESCOs to carry out estimations and provide guidance on the design and implementation of the biogas plant.
2	Biogas final use or application.	The way biogas is going to be valorised or used is very important to envision the type of technologies that will be implemented within the plant and its cost. See	Final consumers should provide the type of energy to be covered with the biogas (thermal, electricity, both, etc). Research Centres and ESCO

		chapter 3.3.2 about the information required	can provide support for the selection of the technology.
3	To do a pre-feasibility assessment about the implementation of a biogas plant	Based on the information described in chapters 3 and 4, it is key to evaluate the economical KPIs in order to decide whether to go further with this project or not.	It is recommended that the design and implementation of a biogas plant be carried out by an expert in the field, such as a research center or an Energy Service Company (ESCO).
4	To identify and contact different ESCOs and communicate the initiative.	Preliminary contact with ESCOs should be done with the goal of communicating the project and investigate if they are interested to collaborate.	It can be done by the promoter of the idea with the support of the company that will carry out the pre-feasibility assessment (if it wasn't previously done).
5	To carry out the design and the implementation of the biogas plant.	To develop the project of the biomass anaerobic digestion for biogas production and its implementation, selecting the biomass to be fed, the equipment needed, to obtain the administrative licenses, etc.	Usually done by the ESCO selected and/or an engineering company.
6	To guarantee the supply of the biomass.	The proper quality of biomass is crucial for the successful design and operation of a biogas installation. See risks in Section 3.2.1	It depends on the business model selected, and the role of each stakeholder of the community. Normally, the agreement with the biomass supplier is carried out by the same stakeholder that is in charge of the operation and maintenance of the biogas facility.
7	To start with the operation of the biogas plant	Guaranteeing the correct operation of the installation, securing the energy (biogas, biomethane, electricity or heat) supply to the final consumers and the correct maintenance of the installation to ensure its useful life.	ESCO, the community or other stakeholder selected to be in charge of the operation and distribution of the biogas application products should be responsible of this.

8. Success cases

This section describes an initiative that has already been implemented with the goal of raising awareness about the potential benefits of successfully developing a biogas plant, as well as gaining a better understanding of its average techno-economic performance.

8.1 Combination of Anaerobic digestion with composting in Girona, Spain

Pla de l'Estany is a poblation of Girona province (Catalonia, Spain) designed as vulnerable zone according to Government. In order to improve land fertilization and minimize environmental pollution when applying manure, it is compulsory to farmers to establish Nutrient Managing Plans (NMP) which farmers had to design and validate according to the dosage of nutrients applicable to their crops. Enhancements in animal feeding, manure transportation and treatments may be also considered. [14]

In this context, the dairy farm SAT Sant Mer, decided to build a biogas plant to process the manure produced together with other organic wastes.

The project of Apergas plant is the result of the synergy of three companies: SAT San Mer, EnErGi, and BIOVEC. The design of the plant was done in 2007, the construction during 2008 and the startup in 2009. It treated slurry from dairy farms of SAT San Mer altogether with organic wastes from other agribusiness facilities. A total of 18,771 m3 of cow slurry and 3,129 m3 of co-substrates were digested.

Figure 10: General view of Apergas biogas plant (left), anaerobic digesters (right)

Biogas at a flow rate of 322 ton per year was valorized in CHP unit of 500 kW with an electrical production of 4,000 MWh per year. A total of 1,100 tons CO_{2eq} per year savings were estimated for the operation of the plant during 2010 and 2011. Furthermore, CAPEX data were reported with a total of 1.4 M€, whereas main digesters and CHP units share a 50% of the investment. Also cost of operation

(OPEX) were reported regarding electrical consumptions, salaries, maintenance, and other costs as a total of 200 k€ per year.

Table 6: CAPEX and OPEX of the project.

CAPEX	
Unit Description	Cost (€)
Equipment (stirrers, pumps, valves, CHP engine, etc.)	522,800 €
Concrete works (Anaerobic digesters, composting platforms and trenches, etc.).	292,000 €
Facilities (gas, water, electricity)	132,000 €
Grid connection	136,200 €
Mechanical separator	28,300 €
Hydrogen sulphite control	18,000 €
Soil movement, levelling, etc.	89,500 €
Other (roads, fees, contingency, etc.)	63,000 €
Toilets, landscaping, etc.	15,000 €
Project engineering	114,000 €
Total Investment	**1,410,800 €**
OPEX	
Concept	Cost (€)
Salaries	33,100 € / y
Operational control (sampling, analysis, etc.)	27,830€ / y
Maintenance	61,200 € / y
Electricity	12,976 € / y
Other	70,000 € / y
Total operational cost	**205,106 € / y**

9. Conclusions

This document establish the main terms and elements that must be understood and considered when thinking on implementing a biogas production facility. For such assessment, it is clearly defined which are the key- parameters to develop for these kinds of projects: available biomass in the area, biogas capacity and potential, and a clean economic assessment to ensure the feasibility of the facility. Moreover, it also offers several examples of stakeholder's groups that may enable and offer synergies for the implementation of biogas production and valorisation projects. Some steps to follow are also given.

Finally, this catalogue may serve as a guide for promoters to enable their actions with stakeholders, energy communities and biomass owners. However, bioenergy projects require some technical knowledge and experience, thus it is highly recommended to further consult experts and engineering companies to facilitate the decision-making process prior to investing.

10. References

[1] An introduction to biogas and biomethane – Outlook for biogas and biomethane: Prospects for organic growth – Analysis - IEA n.d. https://www.iea.org/reports/outlook-for-biogas-and-biomethane-prospects-for-organic-growth/an-introduction-to-biogas-and-biomethane (accessed February 2, 2023).

[2] How Does Anaerobic Digestion Work? | US EPA n.d. https://www.epa.gov/agstar/how-does-anaerobic-digestion-work (accessed January 9, 2023).

[3] Rasi S, Veijanen A, Rintala J. Trace compounds of biogas from different biogas production plants. Energy 2007;32:1375–80. https://doi.org/10.1016/J.ENERGY.2006.10.018.

[4] BASIC DATA ON BIOGAS 2012.

[5] Jacob Jørgensen P, for Day R. Biogas-green energy. Process. Design. energy suPPly. environment Biogas-green energy Process • Design • Energy supply • Environment n.d.

[6] Anaerobic System Design and Technology | US EPA n.d. https://www.epa.gov/agstar/anaerobic-system-design-and-technology (accessed January 20, 2023).

[7] Akindolire MA, Rama H, Roopnarain A. Psychrophilic anaerobic digestion: A critical evaluation of microorganisms and enzymes to drive the process. Renewable and Sustainable Energy Reviews 2022;161:112394. https://doi.org/10.1016/J.RSER.2022.112394.

[8] Types of Biogas Storage Systems | BioEnergy Consult n.d. https://www.bioenergyconsult.com/biogas-storage/ (accessed January 19, 2023).

[9] Gas Plant & Biogas Manufacturing Company in Ahmedabad - Atmos Power Pvt. Ltd n.d. https://www.atmospower.in/ (accessed February 2, 2023).

[10] Biogas Plant Development Handbook | BiogasWorld n.d. https://www.biogasworld.com/biogas-plant-development-handbook/#economics_handbook (accessed February 2, 2023).

[11] El biogás. Actualidad y perspectivas de un gas renovable - Fundación Naturgy n.d. https://www.fundacionnaturgy.org/publicacion/articulo-el-biogas-actualidad-y-perspectivas-de-un-gas-renovable/ (accessed January 24, 2023).

[12] EU Carbon Permits - 2023 Data - 2005-2022 Historical - 2024 Forecast - Price - Quote n.d. https://tradingeconomics.com/commodity/carbon (accessed January 24, 2023).

[13] Biogas installations investments n.d. http://www.biogas-renewable-energy.info/biogas_installations_investments.html (accessed January 31, 2023).

[14] Foged R, Lyngsø H, Flotats X, Bonmati Blasi A, Martin Schelde K, Palatsi J, et al. Assessment of economic feasibility and environmental performance of manure processing technologies 2012.

[15] Waste statistics - Statistics Explained n.d. https://ec.europa.eu/eurostat/statistics-explained/index.php?oldid=503519 (accessed January 31, 2023).