Cost analysis of energy production from anaerobic digestion in an intensive swine livestock farm

Filipe Charrua da Costa Lopes Rodrigues

Instituto Superior Técnico, Technical University of Lisbon, Lisbon, Portugal
filipe.charrua@tecnico.ulisboa.pt

ABSTRACT

Large amounts of agriculture waste generated, like animal manure, have caused major environmental problems throughout the world. Following the 20-20-20 objectives set by the European Union, and under the scope of the cooperation programme Galp 20-20-20 the work was aimed at finding energy cost reduction solutions for the intensive swine livestock farm Herdade do Gamoal, by increasing the energy efficiency and reducing the environmental footprint. Energy inefficiencies, attitudes and consumptions are identified through an energy audit, from which several solutions are suggested and evaluated, namely: adjustments to the water pump’s operational periods; replacement and maintenance to lightning and ventilation systems; a biogas plant; a photovoltaic plant for self-consumption; a biogas upgrading plant and implementation of a “green farm” attitude. The work covers the use of financial assessments to the proposed solutions, with focus on cash flow evolutions, payback periods and environmental advantages. The complete set of solutions studied provides significant room for cost reduction, energy saving, efficiency growth and emissions reduction. Upgrading biogas to BioM revealed to be the solution in this study with the greatest impact on cost reduction and energy re-purposing.

Keywords: Anaerobic Digestion, Swine Manure, Biogas, Biomethane, Photovoltaic, Energy, Efficiency.

1. Introduction

Our planet’s environmental problems have been studied by leading nations of the world since the 1990s. The greenhouse effect, caused by greenhouse gases (GHG) like carbon dioxide (CO₂) and methane (CH₄), leads to global warming and subsequent melting polar ice caps and rising sea levels. Therefore, it is imperative to take actions to reduce greenhouse effect. The European Union has been in this topic’s forefront, thus the 20-20-20 objectives were born, which are: reduce GHG emissions to at least 20% less than 1990 levels; improve 20% energy efficiency; increase the share of renewable energy consumption to an average of 20% and an increase of 10% in the share of biofuels in the transportation sector, all before 2020.

In 2007 Galp Energia created the Galp 20-20-20 cooperation programme inspired by the 20-20-20 Objectives defined by the European Commission, which each year supports 21 studies conducted by undergraduate and master’s students aimed at identifying rational energy attitudes, applicable in industry, as in the case of Raporal, S.A. and to find improvement actions that enhance energy efficiency and reduce operational costs. Raporal is a Portuguese company positioned in the whole chain of pork and beef production. The study took place at two of Raporal’s swine farms in “Herdade do Gamoal”, Alentejo.

Public policy puts Portugal among the countries that are at the forefront of climate policy. Policies like QEPiC, PNAC and ENAAC 2020 makes it possible to achieve national objectives; 31% share of renewable sources of energy on total consumption by 2020 and 40% by 2030. In 2014, of the 31% share 45% originated from biomass, 26% from hydro energy, 20% from wind energy and 6% from biofuels.

Electricity generation from renewable sources in mainland Portugal in 2014 was responsible for 62.7% of total electricity generation [1], [2], [3], [4].

Until 2015, decentralized electricity production from renewable sources was aimed at selling electricity at relatively high prices. On October 2014 Decree-Law 153/2014 was published which created new legal framework that came into force in January 2015. The new regime covers the generation of electricity for self-consumption in a usage installation connected to the respective generation unit, with or without a connection to the public energy grid, (referred to as UPP units); and through small generation units from renewable energy sources and exclusively intended for sale to the public electric grid (referred to as UPP units). The electricity generated by UPACs is remunerated in accordance with market prices, since it is savings oriented. UPPs – remuneration of electricity generated is calculated through a bidding system in which producers offer discounts to a reference tariff. The applicable tariff for each UPP will be the highest amount resulting from the highest discount offered and for 2015 was 85.5 €/MWh [5], [6].

Global swine production has been increasing for the last years. In Brazil, swine production is the second biggest livestock activity in terms of livestock population, in April 2015 there were 2 038 253 pigs [7]. The livestock sector is responsible for 61.8% of agricultural gas emissions, attributable mainly to swine (14.6%) and bovine (28.4 %) livestock. Regarding methane, most livestock emissions result from swine manure, with 83% of emissions in 2012.

Considering agricultural residues, 73 037 ton of waste were produced in Portugal in 2012 [8]. In the past, wastes ended up becoming a source of pollution, especially when discharged in the water, but waste policies are now aimed at transforming residues into resources. One alternative is to create renewable energy from waste products through anaerobic digestion (AD), which captures and utilizes methane, decreases organic load on receiving waters, and creates a high-nutrient, low-solid fertilizer. More importantly AD produces biogas, an important energy source and allows for energetic...
valorisation of wastes. Biogas is a product of the microbial decomposition of organic matter in a moist environment that excludes air and is basically composed by methane, carbon dioxide, and hydrogen sulphide (H₂S). The AD process encompasses four steps (hydrolysis, acidification, acetic acid formation, and methane formation), each respectively involving different groups of microorganism. Traditionally, AD was a single substrate treatment. Recently, it has been realized that AD becomes more stable and efficient when different substrates are applied at the same time in anaerobic co-digestion (AcoD). A large number of organic substrates can be used to obtain biogas, but using pig slurry (PS) form Heradade do Gamoal as a substrate or co-substrate is the main motivation for this study.

The objectives of this study encompass: identify energy inefficiencies in the productive system of the farm; draft solutions to improve or remove those inefficiencies; improve energy efficiency by increasing the utilization of renewable sources by 20%; reduce 20% of GHG emissions; evaluate the biogas potential from PS through AD and AcoD, and subsequently assess the feasibility of a biogas plant for different final purposes like feeding-in electricity and biogas upgrading to biomethane (BioM); evaluate electricity generation through photovoltaic conversion and adopting better practices of sustainable farming.

2. Materials and methods

The present work focuses on two swine farms located inside a 1000 ha property called “Heradade do Gamoal”, 70 km from Lisbon in the Alentejo region of Portugal. In this property, one farm is dedicated to pig breeding and weaning, “Heradade do Gamoal de Cima”, and the other is where piglets go through the finishing stage – “Engorda da Heradade do Gamoal” – prior to slaughterhouse. The energy audit starts with a survey of the farm, a mapping of the animal production processes, and is followed by a collection of data about all electrical and thermal equipment used in the farm. The farm’s current energy profile includes only electricity contracted through Iberdrola, and pellets used in two boilers providing the necessary heat. Regarding water consumption, each farm has its own water well, capable of providing enough drinking and cleaning water.

A single swine production centre comprises the farrowing facilities in Heradade do Gamoal de Cima, with a capacity for 1400 sows kept in intensive breeding and their young. The Finishing farm “Engorda da Heradade do Gamoal” has a simpler layout, characterised by four intensive breeding and their young. The Finishing farm “Engorda da Heradade do Gamoal” has a simpler layout, characterised by four

Mass and energy flows

Inside the control volume, mass exchanges occur at the productive and waste management level. Inputs are only food, water and pellets and regarding outputs, there are pigs leaving this farm to go to the finishing farm, agricultural waste that can be used as fertilizer and emissions from waste production. For both farms, waste generated inside comes from livestock production and social facilities. The livestock waste system is based on liquid manure (slurry), since a great volume of water is used. Slurry is removed periodically via channels and pipes to the outdoor cesspit unit where liquid-solid separation occurs. After separation, the liquid fraction is pumped to a lagoon system [9]. The current energy profile includes electricity and heat from two boilers burning pellets, thus, energy inputs are only the incident solar radiation, electricity and pellets.

Figure 1 – Farrowing farm’s mass flow.

Energy audit

An energy audit is performed based on the review of electricity bills for the period of 2014 and first months of 2015 and later on detailed measurement of the electricity consumed for the period of one week. Together both farms consumed a total of 572 194 kWh in electricity during the year of 2014, which corresponded to 54 485 €.

From electricity bills show it is possible to identify a consumption decrease of about 30% during the warmer months – July to October – and shows that 12% of yearly electricity is consumed during periods of Peak tariff, 44% during Mid-peak, 29% during Off-peak and only 15% during the less expensive period of Super Off-peak tariff (Chart 2). According to the company supplying electricity, 246 tons of CO₂ are emitted.

To better understand the energetic demands at each different stage of animal production, both current and active power were measured in each building for the period of one week to allow to disaggregate the electricity demand and find which stages of production are more relevant to the electricity costs, using equipment that connects to different segments of the farm’s electrical switchboard. One important output from the measurements is the Week Load Diagram for the entire farm. A daily pattern for the demanded active power shows two power peaks taking place every day (Chart 1). The pump used to pump water from the borehole into the tank was found to be the responsible agent of the power peaks, twice a day the level gets lower than the refill point the pump is switched on and refills it. 55% of electricity consumption comes from the farrowing sector due to 294 infrared lamps and 23 ventilation fans running 24/7, and can represent more than 310 MWh on an annual basis.

Suggestions for improvement

The energy audit allows identifying simple and inexpensive approaches to decrease consumption.
A methane yield evaluation is conducted to motivate and assess the advantages of such promising technology. AD (Anaerobic Digestion) biogas production can integrate waste management with renewable energy in a sustainable manner. Carbon dioxide emissions should decrease from the practice of cleaning all ventilation systems, electricity consumption, and cost savings, more precisely. Payback is 2 years and 3 months.

Ventilation blades and ducts were found to be covered with dust and dirt, causing the emission of 0.7% through mid-peak periods, 6% through off-peak periods, and 16% through Super Off-peak periods. Therefore, it's possible to use the entire Super Off-peak available time and causes the emission of 6.7% through peak periods, 23% through mid-periods of expensive electricity tariffs, and 34% through Super Off-peak periods, eliminating the need to use expensive periods. Operational intervals can be shifted into less expensive periods. Operational intervals can be shifted into less expensive periods. This is this work's major motivation and to assess the advantages of such promising technology a methane yield evaluation is conducted to both farms in “Herdade do Gamoal” together. For this analysis, PS formed by manure and water was used as substrate. PS was obtained in the cesspit unit fed with slurry from the breeding farm “Herdade do Gamoal de Cima” on December 1st 2015. Three different 1 litre samples were collected: one from the cesspit itself containing continuously mixed slurry coming directly from the underground sewage system; a second one collected from the resulting solid fraction after slurry has gone trough the separation unit and a third sample collected from the remaining liquid fraction.

pH, electrical conductivity (EC), total solids (TS), volatile solids (VS), chemical oxygen demand (COD), total Kjeldahl nitrogen (TKN), organic nitrogen (NORG), ammonium nitrogen (NH₄⁺ – N) and total phosphorus (TP) were determined according to standard methods [13] (Table 1). The methane yield is estimated using Chen and Hashimoto’s (1978) adaptation of Contois (1959) model to describe the kinetics of methane production from organic wastes under steady-state condition [14], [15].

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Raw slurry</th>
<th>Solid fraction</th>
<th>Liquid fraction</th>
</tr>
</thead>
<tbody>
<tr>
<td>pH</td>
<td>7.41</td>
<td>8.29</td>
<td>7.77</td>
</tr>
<tr>
<td>EC (mS cm⁻¹)</td>
<td>12.51</td>
<td>2.11</td>
<td>10.18</td>
</tr>
<tr>
<td>TS (g L⁻¹)</td>
<td>38.98</td>
<td>27.58%</td>
<td>5.65</td>
</tr>
<tr>
<td>VS (g L⁻¹)</td>
<td>22.31</td>
<td>24.15%</td>
<td>2.57</td>
</tr>
<tr>
<td>VS/TS (%)</td>
<td>59.80</td>
<td>87.56%</td>
<td>45.49</td>
</tr>
<tr>
<td>COD (g L⁻¹)</td>
<td>36260</td>
<td>-</td>
<td>3479</td>
</tr>
<tr>
<td>TKN (g L⁻¹)</td>
<td>1.82</td>
<td>-</td>
<td>0.742</td>
</tr>
<tr>
<td>NH₄⁺ – N (g L⁻¹)</td>
<td>1.11</td>
<td>-</td>
<td>0.625</td>
</tr>
<tr>
<td>NORG (g L⁻¹)</td>
<td>0.11</td>
<td>-</td>
<td>0.117</td>
</tr>
<tr>
<td>N₅Total (g L⁻¹)</td>
<td>1.82</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>PT (g L⁻¹)</td>
<td>178.7</td>
<td>-</td>
<td>11.42</td>
</tr>
</tbody>
</table>

The method to obtain the annual methane and biogas production volumes through anaerobic digestion is presented below, from Equation 1 to Equation 10. B₅ for pig manure is set at 0.48 m³CH₄/kgTS, which matches the feeding conditions and manure collection techniques used in “Herdade do Gamoal”; digestion temperature is set at 38 °C; influent total solids concentration (CTS) of the substrate is equal to 38.98 kgTS/m³manure and influent volatile solids (CVS) is equal to 23.31 kgVS/m³manure, representing 59.8% of TS (Table 1).
Cost analysis of energy production from anaerobic digestion in an intensive swine livestock farm

An hydraulic retention time of 20 days is assumed [14]. The effluent feedstock for methane production is the livestock waste from Herdale do Gamou, which is 113 m³/day, hence 2.634 kgs VS/day [16], [17].

Maximise specific growth \[ \mu_m = 0.5 \frac{1 + 110 \exp(-0.187 \times 30)}{1 - 0.367 \times 30} \] (Equation 1)

Loading rate \[ \frac{S}{L} = 1.15 \frac{b}{d} \] (Equation 2)

Kinetic parameter \[ K = 0.6 + 0.0005 \cdot e^{0.1501 \cdot 30} = 0.610 \] (Equation 3)

Methane yield \[ B = 0.441 \frac{m_\text{CH}_4}{kgs} \] (Equation 4)

Volumetric methane production rate \[ \gamma = 0.514 \frac{m_\text{CH}_4}{b/m³ \text{digester, day}} \] (Equation 5)

Digester volume \[ V_{\text{dig}} = 20 \times 1.10 = 2.20 \text{ m}^3 \] (Equation 6)

VS per day \[ V_{\text{dig}} = 11.30 \times 23.31 = 2.634 \frac{kgs}{day} \] (Equation 7)

Daily methane production \[ V_{\text{meth}} = 0.441 \times 2.634 = 1.162 \frac{m_\text{CH}_4}{day} \] (Equation 8)

Annual methane production \[ V_{\text{meth}} = 1.162 \times 365 = 424.262 \frac{m_\text{CH}_4}{year} \] (Equation 9)

Annual biogas production \[ \frac{m_\text{CH}_4}{year} = 424.262 \times 5.60 = 707.104 \frac{m_\text{CH}_4}{year} \] (Equation 10)

Considering the annual volume of methane produced through AD the annual energy production is 4.219 057.4 kWh available in the form of gas [18]. With an electric efficiency of 40% and thermal efficiency of 45% for the CHP plant [19], the resulting overall efficiency is 85%, wherefore the annual electrical and thermal energy productions can reach 1.687 622.97 kWh (electric) and 1.898 575.84 kWh (thermal) respectively.

For a volume of 2.280 m³ (a cylinder with a diameter of 22 m and 6 m deep) he heat loss through the tops, walls and floors is determined in Equation 11 [15], [14], [20], [21].

The total thermal power required to maintain the digestion process at a desired temperature is 1.30 746.47 W, therefore, the amount of heat demanded during one day can be determined as shown below:

\[ Q_{\text{heat}} = Q_{\text{loss}}(1 + \alpha) \times 24 	imes 3600 \text{ sec} = 3.1384 \text{ kWH} \] (Equation 11)

Subtracting the heat demands from the available energy, the remaining is 2.282.9 kWh, which shows that it is possible to maintain the digestion process using only the remaining heat, 29%. The excess energy can be used in the breeding facilities, as a substitute or as a complement to the existing heat source, for instance to heat the farrowing nests.

Financial instruments

Parameters for the project’s economic assessment are exposed by means of NPV (Net Present Value), IRR (Internal Rate of Return) and Payback Period. A positive NPV indicates that the projected earnings generated by a project or investment exceed anticipated costs (in present euros). The discount rate used for NPV calculation is 7% per year. The following is the formula for calculating NPV:

\[ \text{NPV} = \sum_{t=0}^{t=T} \frac{C_t}{(1+r)^t} - C_0 \] (Equation 13)

where \( C_t \) is the net cash inflow during period \( t \); \( C_0 \) represents total initial investment costs; \( r \) the discount rate and \( T \) the number of time periods. Internal Rate of Return calculation relies on the same formula as NPV does, and is a metric used to measure and compare the profitability of investments. The higher a project’s IRR, the more desirable it is to undertake it, and is defined as the rate of return that makes NPV of all cash flows, of an investment, equal to zero. The Payback Period is also an important determinant of whether to undertake the project. It is the period of time required to recover the cost of an investment.

Capital costs include the digester’s construction and both CHP technology and related equipment acquisition. A budget price quotation was requested to Wolf Systembau Gesellschaft m.b.H., a well-experienced German company, and includes several options that most of the biogas developers are currently requiring. The price for concrete was set at 75 €/m³. Cost values for CHP technology varies with the installed power, and was set to 2 000 €/kW [22], [23]. The initial investment of the biogas plant is:

\[ \text{Invest} = C_{\text{costbiogas}} + C_{\text{costchp}} = 586 067 € \] (Equation 14)

Depreciation is calculated over the investment costs, for a period of 25 years in the case of the digester (4%) and 10 years for the technology (10%). It was assumed that the project would have a financing support of 50% with an interest rate of 4% and a yearly cost of 0.5% of total initial investment for insurance [22]. Operational costs include all expenses related to maintenance, repairs and labour. Every year, 2% of CostCHP to cover any damage and any repairs; 0.01 €/kWh, for maintenance due to corrosive elements within biogas and lastly 17.65 €/h is contemplated for labour costs [22]. Table 2 presents all annual costs for biogas production in a 50% financing scenario for the first 15 years.

The sources considered to forecast the income generated from the biogas production were electricity and agricultural fertiliser, with the biogas plant operating with no restrictions to the electricity injected into the grid. Assuming that the established tariff discount is 2 €/MWh and that 10% of the electricity production is consumed by the plant itself at a cost of 0.0956 €/kWh [22] and that the ton of Nitrogen is valued at 10 €/ton N. Thus, the annual revenue is determined as in Equation 15.

\[ \text{Revenue/ year} = 132 377.15 + 1 501.32 = 133 878.46 € \] (Equation 15)

It is important to perform a cash flow analysis to evaluate the project’s feasibility, using NPV, IRR and Payback Period indicators. From Chart 4 it is possible to perceive that after 11.6 years the cumulated cash flow becomes positive, with an IRR of 9% and NPV equal to 94 499 € after 15 years. If the analysis were extended to 25 years – lifetime of the equipment – the investment would have an IRR of 12% and a NPV of 274 881 €.

Another major environmental benefit is related to the methane conversion into CO₂. The CO₂ emissions from producing and burning biogas are \(-4 779 780 \text{ k}(\text{CO}_2) \text{/year}\) meaning that, overall, CO₂ is being captured instead of being emitted, which is beneficial.

3. Cost reduction options

Co-digestion

Anaerobic Co-digestion (AcOd) consists in the digestion of two or more substrates simultaneously and offers a higher biogas production as well as major cost reduction advantages. Manures are often associated with poor methane yields. AcOd of manures with other substrates simultaneously and offers a higher biogas production, with the digestion process efficiency and consequently make plants economically feasible. In the scope of this study, and in order to compare the performance of mono digestion and co-digestion plants one more financial analysis was made for the co-digestion of PS with...
The photovoltaic plant is dimensioned considering the use of mono-crystalline modules Q-Peak-G3 280W, with 1.67 m², manufactured by the German company Q CELLS for its good value for money. These units have a power of 280 W and the overall power to be fitted is 56 000 W, thus the number of modules to form the panel was found to be 200. Hence, the calculations for PV energy conversion are performed as in Equation 22 to Equation 25.

\[ P_{\text{overall}} = 200 \text{ mod} \times 280 \text{ W} = 56 \text{ 000 W} \]

Equation 22

\[ A_{\text{overall}} = 200 \text{ mod} \times 1.67 \text{ m}^2 = 334 \text{ m}^2 \]

Equation 23

Equation 24

\[ \eta_{\text{panel}} = 0.15 \]

Equation 25

The three loss factors add up to 4.5 % [25] and, assuming an efficiency of 97.7 % for the inverters, the yearly amount of energy delivered to the farm grid was found to be:

\[ E_{\text{tot}} = E_{\text{inv}} (1 - \eta_{\text{arr}} \eta_{\text{inves}} \eta_{\text{ip}}) \]

Equation 26

Since both farms consumed a total of around 600 000 kWh of electricity during the year of 2014, the contribution from the PV plant would represent 15.1 %. The price selected for the mono-crystalline module Q-Peak-G3 280W is 200 €/mod plus an assembly cost of 30€/mod, which results on a total initial investment of 68 960 €. During daylight hours each MWh the farm consumes costs 84.9 €. Hence, this is the cost per MWh that the photovoltaic plant would have delivered to the grid was found to be:

\[ E_{\text{tot}} = E_{\text{inv}} (1 - \eta_{\text{arr}} \eta_{\text{inves}} \eta_{\text{ip}}) \]

Equation 26

Since both farms consumed a total of around 600 000 kWh of electricity during the year of 2014, the contribution from the PV plant would represent 15.1 %. The price selected for the mono-crystalline module Q-Peak-G3 280W is 200 €/mod plus an assembly cost of 30€/mod, which results on a total initial investment of 68 960 €. During daylight hours each MWh the farm consumes costs 84.9 €. Hence, this is the cost per MWh that the photovoltaic plant would have delivered to the grid was found to be:

\[ E_{\text{tot}} = E_{\text{inv}} (1 - \eta_{\text{arr}} \eta_{\text{inves}} \eta_{\text{ip}}) \]

Equation 26

Since both farms consumed a total of around 600 000 kWh of electricity during the year of 2014, the contribution from the PV plant would represent 15.1 %. The price selected for the mono-crystalline module Q-Peak-G3 280W is 200 €/mod plus an assembly cost of 30€/mod, which results on a total initial investment of 68 960 €. During daylight hours each MWh the farm consumes costs 84.9 €. Hence, this is the cost per MWh that the photovoltaic plant would have delivered to the grid was found to be:

\[ E_{\text{tot}} = E_{\text{inv}} (1 - \eta_{\text{arr}} \eta_{\text{inves}} \eta_{\text{ip}}) \]

Equation 26

Since both farms consumed a total of around 600 000 kWh of electricity during the year of 2014, the contribution from the PV plant would represent 15.1 %. The price selected for the mono-crystalline module Q-Peak-G3 280W is 200 €/mod plus an assembly cost of 30€/mod, which results on a total initial investment of 68 960 €. During daylight hours each MWh the farm consumes costs 84.9 €. Hence, this is the cost per MWh that the photovoltaic plant would have delivered to the grid was found to be:

\[ E_{\text{tot}} = E_{\text{inv}} (1 - \eta_{\text{arr}} \eta_{\text{inves}} \eta_{\text{ip}}) \]

Equation 26

Since both farms consumed a total of around 600 000 kWh of electricity during the year of 2014, the contribution from the PV plant would represent 15.1 %. The price selected for the mono-crystalline module Q-Peak-G3 280W is 200 €/mod plus an assembly cost of 30€/mod, which results on a total initial investment of 68 960 €. During daylight hours each MWh the farm consumes costs 84.9 €. Hence, this is the cost per MWh that the photovoltaic plant would have delivered to the grid was found to be:
Cost analysis of energy production from anaerobic digestion in an intensive swine livestock farm

methane from carbon dioxide and other impurities, produce a gas with up to 99% methane content called biomethane (BioM), which can be made compatible with Natural Gas (NG) in any of its typical applications, both for industry and also for public and private energy consumers. It can be used in the coupled production of electricity and heat (CHP), as fuel in natural gas vehicles and also as a natural gas substitute in natural gas burners used for heating. In addition, there is the possibility to use BioM as a raw material for the chemical industry.

Based on the study done by A. C. Jardim (2013) the BioM production calculations are made considering the membrane separation technology (MS), where various degrees of permeability of polymer membrane materials are used to separate unwanted constituent parts of gas from the biogas.

The annual BioM production is estimated to be 422,141.4 m³/year assuming 99.5% of methane recover. The MS technology implies a 35% reduction on the initial investment when compared to CHP equipment, hence, the initial investment of the BioM plant would be 416,067 €. Depreciation, interest and insurance were quantified using the same method as before, but according to A. C. Jardim (2013) an additional 5% over operational costs is taken into account. Income sources differ depending on the solution scheme, which are: BioM consumption in Raporal’s slaughterhouse, BioM injection in NG grid, BioM trading between different industries and BioM as fuel for a vehicle fleet.

For BioM consumption in Raporal’s slaughterhouse, BioM is considered as a substitute to the NG consumed in Raporal’s slaughterhouse/meat processing factory, which has a consumption of more than on million cubic meters, or 13.7 GWh per year. To quantify the saving created from using 422,141.4 cubic meters of BioM as part of the annual gas consumption it is necessary to find how much it costs to use the same volume of natural gas. The statistical data reported by Direção-Geral de Energia e Geologia (2016) in January 2016 indicates the NG price evolution where the average price for the last seven semesters was 41.789 €/MWh. The resulting annual saving form such tariff would be 175,427.1 €, 33% greater income when compared to the revenue from the electricity generated on the biogas CHP plant projected before. In Chart 6 it is possible to perceive that the estimated Payback Period is 5.1 years with an IRR of 23% and NPV equal to 540,571 €. If the analysis were extended to 25 years the investment would have an IRR of 24% and a NPV of 810,683 €.

Portugal doesn’t have NG reserves and therefore there is no NG production in national territory.

The NG that flows on the national NG grid needs to meet a series of parameters admissible by ERSE (2013). However, a uniform standard for the feed-in of biomethane does not yet exist in Europe, and neither in Portugal, other than guidelines from projects like Biogas max [29]. Portugal doesn’t have the legal framework for biomethane injection into the NG grid, so it is not defined how to compensate for that. It would also be interesting to consider direct contracts between BioM producers (in this case Raporal – supplier) and BioM users (e. g. nearby industry with heat requirements), or even the possibility of suppliers using traders to marketing the BioM. In a more macro perspective, BioM traders would purchase BioM from various producers and market it to a variety of customers/consumers.

Lastly, BioM can also play an important role regarding vehicular fuels, contributing to the share of biofuels in vehicular fuels, as required by the European legislation [30], [31]. BioM can already be used as a fuel for natural gas vehicles without any complications, and one possibility would be to feed the BioM into the NG network and afterwards make it available at NG fuelling stations, like what is happening at some German fuelling stations [32]. An alternative to this is the direct linking of a biogas production plant to a BioM upgrading plant, with a vehicle fleet being fuelled using BioM, for instance Raporal’s own fleet. However, the future market development of BioM as a fuel is crucially dependent on the degree of market take-up for natural gas vehicles, which is still hampered by the commodity nature of Portuguese population.

“Green farm”

The last solution concerns closing the phosphorus (P) cycle and manure processing, due to the increasing concerns about limited phosphate rock reserves. Phosphorus is an essential element that cannot be replaced. The most important aspect of management of animal waste is the prevention of CH₄ emissions due to storage. Processing animal waste preferably by using simple separation technologies can reduce this CH₄ emissions. These emission control interventions could be greatly profitable if the avoided emission was already being compensated. Some technical interventions can be made in order to better close the P cycle, such as reducing the P input, P-recovery and adopting the concept of Bio-refinery [33], [32].
4. Conclusions

The present study concerns the feasibility of energy and cost saving solutions for livestock breeding activities, and had Raporal’s swine farm as a case study. Major emphasis was given to the dimensioning of a biogas plant for energy generation through CHP or biomethane production through upgrading. Other solutions encompassed energy efficiency measures for electric equipment and a photovoltaic park. An energy audit was conducted to identify, disaggregate and understand the current paradigm of Raporal’s swine farm in “Herdade do Gamal”, as well as to expose potential energetic inefficiencies. Only then it was possible to introduce new attitudes for the pig-farming sector. The proposed attitudes include: adjustments to the water pump’s operational periods; replacement and maintenance to the lighting and ventilation systems; a biogas plant; a photovoltaic plant; biomethane production and implementation of a “green farm” attitude.

The water borehole pump adjustments regarding the operational timing was the measure with the least cost reduction impact, more specifically a decrease of €388 €/year, mainly because the pump’s functioning only represents 6% of the farm’s electricity costs, thus there was a small margin for improvement.

Exchanging the entire fluorescent lighting system for LED tubes doesn’t require an high initial investment and therefore makes the project valuable in a little more than two years. Not making regular maintenance interventions to avoid efficiency losses through the ventilation fans can translate into a great energy waste, not only concerning ambiance and climate conditions but also concerning energy bills. It was concluded that maintaining ventilation ducts and fans clean could save 42.9 MWh per or 3 334 €. Moreover, both solutions could avoid the emission of 37.44 ton CO₂.

This work also focused on using solar photovoltaic energy to enhance the energetic and financial performance of the livestock activities in “Herdade do Gamal”. A relatively small plant of 200 PV modules has proven to be a feasible and concrete solution regarding electrical energy. This way, it would be possible to generate satisfactory extra savings from unused areas outside the buildings, with comfortable investment and inviting payback period. Equally significant to the extra financial advantage is the environmental gain promoted by the non-emission of 877.78 ton CO₂ after 25 years.

Agricultural livestock production generates waste streams that are currently not completely taken care of. This can be achieved using anaerobic digestion techniques, thus using a significant portion of the waste stream in the form of biogas and even fertilizer. This paper evidences how the digester implementation for waste treatment and consequential energy and fertilizer generation in a swine farm, can help enhance its productivity and contribute to achieve a sustainable production and solve environmental subjects. The biogas plant was dimensioned to treat 113 m³ of waste manure per day. It would translate into a substantial initial investment with a low revenue income, hence the unattractive final NPV and long payback period of more than 11 years.

The combination of pig slurry with SHW was found to be a more suitable path. This route has proven to be a much more effective arrangement, both in financial and biogas production terms. It has been demonstrated the possibility of using biogas to generate electricity in a swine farm, in a greater amount than the consumed electricity, namely 2.8 and 8.9 times greater, for mono- and co-digestion respectively.

Another major advantage of anaerobic digestion is the environmental aspect, in this case related to the non-emission of methane through the conversion into CO₂. Burning biogas from anaerobic digestion only releases a small amount when compared to the removed figure, meaning that overall CO₂ is being captured instead of being emitted - this initiative would “remove” 779 780 kg CO₂eq/year from the atmosphere.

Upgrading biogas to BioM has revealed to be the solution in this study with the greatest impact on cost reduction and energy re-purposing. In financial terms, upgrading biogas instead of burning it in a CHP system has shown to be a much more attractive opportunity, essentially because the technology would imply significant lower investment. In the case of using BioM as 36.7% of Raporal’s slaughterhouse annual NG consumption annual savings could reach over 175 000 €, and consequently an enterprise like a BioM plant would become a profitable project after just over 5 years.

The legislation for feeding-in biogas into the NG network does not yet exist in Portugal, which makes Portugal one of the European countries that are developing this expertise at a slower rate. This slow developing rate is also an additional difficulty in reaching European energy and climate change targets, as defined in the European directives to incorporate 10% of renewable share in the transportation sector by 2020 demonstrate the important role that BioM can play as a vehicular fuel. The option that turned out to be motivating for decreasing swine farming costs was to consider using the produced BioM as fuel on the company’s own fleet of vehicles.

The last solution to be studied in this paper was the concept of the “Green farm”, where a significant source of income by revenue and savings can be achieved.

To summarize, the complete set of solutions studied in this work provides significant room for cost reduction, energy saving, efficiency growth and emissions reduction. Together, the water pump’s adjustments, lightning and ventilation procedures and the biogas plant can add up to more than 140 000 € of annual income, more than 1.6 GWh of energy production and more than 4 700 ton CO₂eq/year removal. Even greater results are achievable when BioM solutions and a PV plant are considered.

5. References

Cost analysis of energy production from anaerobic digestion in an intensive swine livestock farm