Bachelor Thesis

**Bachelor's Degree in Industrial Engineering and Economic Analysis**

# Environmental Impact Assessment of an Intensive Pig Farm

## THESIS

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# Abstract

Nowadays, the meet industry and intensive farming is in the crosshairs of environmentalists and organizations fighting climate change. In Spain, the controversy arose after the declarations of the minister of consumes, which explained in an interview that the meet sector contributes a 14.5% of the total emissions of $CO_2$ and that the consumption of animal-derived food should be reduced. Slurry, which is the combination of cleaning water, animal excretions, bedding, and food leftovers, has been used during many years as fertilizers, but in these times, the water pollution due to nitrates in some parts of Spain surpasses the allowed by the OMS.

Pigs are amenable to many different styles of farming, from intensive commercial units to commercial free-range enterprises, or extensive farming. Commercial farms house thousands of pigs in climate-controlled buildings. The goal of the present study is to assess the environmental impact of an intensive pig farm regarding odors, soil and groundwater pollution and waste treatment.

Hence, first, the dimensioning of the farm and the characterization of a treatment plant is performed to later, present different scenarios. This provides hints of specific requirements needed by policy makers to establish minimum requirements for the installation of new facilities.

# Index

# 1. Introduction

## 1.1. Motivation

Nowadays, intensive farming is a controversial topic in many countries due to its impact in the environment. Specially in Spain, after the declarations of the minister of consumes, Alberto Garzón, who explained that the meet sector contributes a 14.5% of the total emissions of $CO_2$ [1].

Since my childhood, climate change and environmental issues are something that have caught my attention and after coursing Environmental Engineering in the degree and understanding how the environment is affected by human actions, the intention to do a deeper study in this sector rose.

Therefore, adding these two factors gave me the idea of studying the impact of intensive farming in Spain.

## 1.2. Formulation and contextualization of the problem

After the declarations mentioned before, the president of Spain and many other Spanish politicians stood up against those declarations, which made this topic even more controversial. [2]

One of the affectations of intensive farming is the emission of nitrates into water. In fact, in June 2020, the European Commission sent a verdict pointing out Spain’s non-compliance with the dispositions about pollution due to nitrates. It has been studied that 22% of surface water bodies and 23% of groundwater bodies of Spain are contaminated by nitrates, exceeding 50mg/liter, which is the maximum level allowed by the WHO (World Health Organization).[3] This pollution

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[1] (RTVE, 2021)

[2] (Martin, 2021)

[3] (Tudela, 2021)

affects water destinated to the human consumption, having to bring tanker tanks to the most affected populations. Therefore, this is a problem that affects human beings, and it is desired to study in which way it affects, not only humans, but the rest of the ecosystem.

Moreover, in Figure 1 it can be seen that only 1,5% of the Spanish citizens with an age higher than 18 years old considered themselves vegetarian or vegan and a 6,3% consider themselves flexitarian, which means that they are reducing their consumption of products coming from animals, but still consume them punctually.

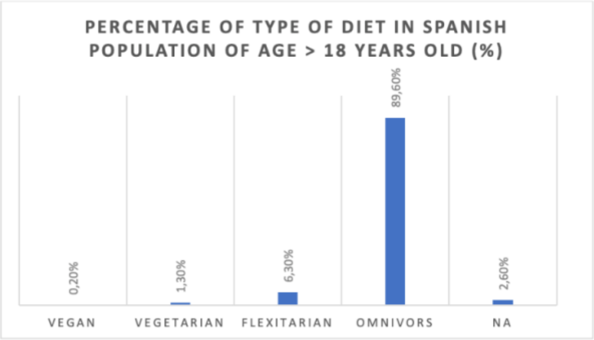

*Figure 1- Percentage of type of diet in Spanish population of age > 18 years old in 2017* [4]

Also, another fact is that the reason why people consume vegetarian or vegan products are usually not related to environmental issues but health or flavor. For example, from Figure 2 it can concluded that the main reason for Spanish people changing from cow milk to plant-based milk is that their digestion gets better, followed by the fact that they like more the flavor and that it is healthier. In addition, only 2% of the consumers choose this kind of milk due to sustainability reasons.

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[4] (Lantern Papers, 2017)

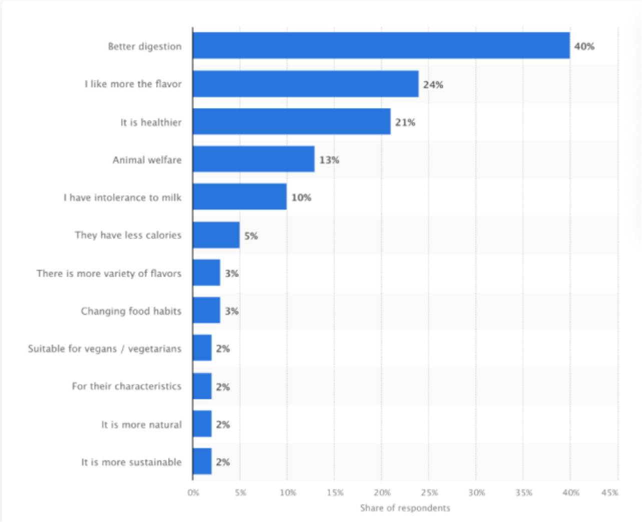

*Figure 2- Reasons of Spanish consumers to substitute milk for plant-based beverages in Spain in 2020* [5]

From these collected data, it can be concluded that Spanish citizens either do not know whether the animal products are bad for the environment or not, or they do not believe that pollution is a problem.

## 1.3. Objective and Methodology

After studying and contextualizing the problem, and seeing that Spanish citizens are not aware of the effects of the meat industry, although they are directly harmed by them, the objectives of the project can be stated.

The principal aim of the thesis is to study the impact that farming produces to the land that surrounds. To do so, a farm with the maximum allowed capacity of pigs stablished by the Spanish Law," *Real Decreto 306/2020 ",* which is considered intensive farming, is studied. By doing this, the quantity of pollutants the government is permitting to emit and the effects of them can be determined. The reason why the farm chosen to be studied hosts pigs is because Spain was in

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[5] (Statista, 2020)

2016 the second UE country with highest pig production, with 47.7 million pigs slaughtered. [6]

In Spain, the way of calculating the total amount of pollutants the farm is producing is determined in the document: "BASES *ZOOTÉCNICAS PARA EL CÁLCULO DEL BALANCE ALIMENTARIO DE NITRÓGENO Y FÓSFORO"*. It consists of a document containing the excreted matter and the emitted gases produced by different types of pigs and which depend on the alimentation they have. The number of pollutants excreted by one pig using the data of the Spanish government is calculated. However, for simplicity, real data obtained from a previous study [7] is used to calculate the output of the treatment plant and the implications on the ecosystem.

Therefore, in the section in which the environmental impact assessment different scenarios in which the outputs of farming get to the atmosphere, land or water-fields are presented to see the effects a bad management of slurry can have.

## 1.4. Scope of the project

The scope of the project is to perform the adequate equations studied in environmental engineering to determine the impact of an intensive pig farm to be able to study different scenarios and determine the measures that should be taken by the government or farmers to reduce their impact on the atmosphere, soil, and water.

However, studying the lifecycle of slurry has a chemical complexity due to the many transformations matter can suffer. Hence, studies already performed on slurry to calculate the efficiency of different treatments are used to get to the final conclusions, instead of going through all the chemical reactions.

At the end of the thesis, it is desired to get the emissions of an intensive pig farm, with the maximum dimensions stablished by the Spanish government, and

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[6] (Eurostat, 2017)

[7] (García)

compare different scenarios to predict the necessity of more restrictive law or treatments such as the bioremediation of soils.

## 1.5. Background

This section contains the definition of concepts that are used through the study aiming clarify their meaning.

First, the definition of intensive production system will be introduced. The definition used in the thesis comes from the Spanish royal decree [8], which says that the intensive production system is used by the farmers when pigs are hosted in the same installations where they are supplied food mainly based on fodder, also with a quantity of pigs higher than 15 fattening pigs per hectare, or its equivalent according to the values found in Annex I.

In some calculations the term UGM (major livestock unit) is used, which is also explained in the Spanish royal decree[9]. UGM is the equivalence for each type of animal present on a farm, in accordance with the values established in Annex I, which serves to establish the maximum capacity of an exploitation, for the application of the different requirements established by this royal decree, and to establish its classification by size.

The concepts of production in phases and manure, are also defined in the Spanish royal decree[10] and it is important to clarify their meaning. Production in phases is the system of production that gazes at periods of breeding, rearing or transition and/or bait of animals in installations situated in different geographic locations.

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[8] (Ministerio de agricultura y pesca, 2017)

[9] (Ministerio de agricultura y pesca, 2017)

[10] (Ministerio de agricultura y pesca, 2017)

Lastly, when talking about manure, it should be considered that it includes all excrement and urine of swine, with or without bedding.

# 2. Theoretical environmental impact of manure

The excrements and urine of pigs have always been used, mixed with litter or any other vegetal residue to produce solid manure, as a fertilizer given its important amount of nutrients, such as nitrogen, phosphorous, copper, potassium, and zinc. Although these elements have been used during many years as fertilizers for crops, if the land is oversaturated it might be prejudicial. The problem arises in the past years, due to the increase in production, since in many cases there does not exist enough solid surface to pour them. Manure is mixed with water in farms; therefore, its composition is mainly water.

## 2.1. Environmental effects of nitrogen

It is demonstrated that the clue element for the nutrition of corps is nitrogen, and generally if nitrogen is contributed to the land, production increases. However, this increase is remarkable at a low dose and as this dose is increased, the efficiency is reduced until getting to a point at which production is reduced, as it can be seen in Figure 3. Therefore, it is proved that an excessive amount of nitrogen affects production.

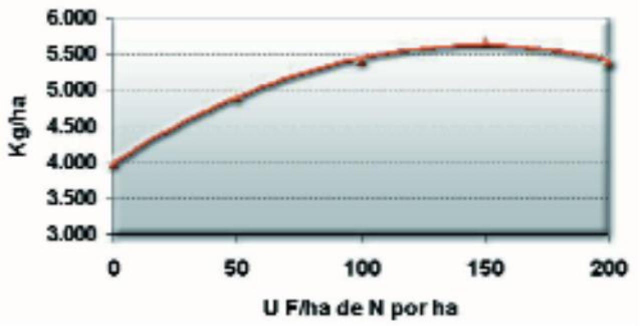

*Figure 3- Response of corps production to nitrogen* [11]

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[11] (Santos, 2002)

Moreover, the excess of nitrogen can also produce a negative environmental effect in two possible ways:

- Nitrogen is found in manure as ammonium ($NH_4$) and if it is not covered correctly and after a short period of time, it is released to the air as ammonia emissions ($NH_3$). Great amounts of ammonia can cause irritation of the throat and eyes, and even damage the lungs. Also, as ammonia is released to the atmosphere, it might transform into nitrogen oxide ($N_2O$), which contributes to global warming and to the destruction of the ozone layer.
- When manure is left on the land, ammonium is transformed into nitrate ($NO_3^-$). This component is soluble and, therefore, it is susceptible to being absorbed by corps but also to be leached, contaminating aquifers and underground water currents. This causes the eutrophication, which consists of an enrichment with nutrients of lakes and rafts that provoke an uncontrolled growth of algae and other vegetation. Once these organisms die, they get accumulated at the deepens, which in decomposition provoke a diminishment of the dissolved oxygen, affecting the wildlife of the environment.

Another problem generated by manure is the sedimentation in storage rafts. Slurry is formed by a liquid fraction and matter in suspension that tend to precipitate creating strata in the pits. This provokes a natural decantation that consists of three parts: a layer of sedimented matter, a liquid part on the center and a crust formed by cellulosic materials (Figure 4).

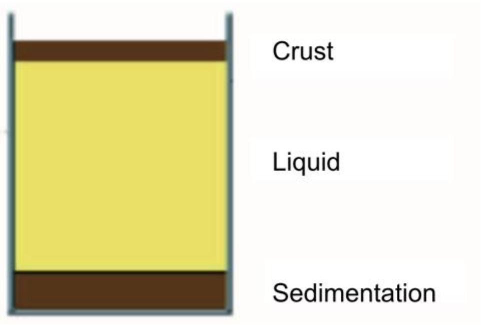

*Figure 4- Manure's natural decantation* [12]

Consequently, due to this decantation, manure results in a heterogeneous mixture, making it harder to distribute components homogeneously. This might lead to an oversaturation or undersaturation of land.

## 2.2. Other environmental effects of manure

Moreover, the emission of gases and bad smells is related to intensive pig farming. When manure is stored, it creates an enabling anaerobic environment for the growth of bacteria which produce methane ($CH_4$), which is a short-lived climate pollutant ten of times more powerful than carbon dioxide at warming the atmosphere.[13] Furthermore, another emitted gas is hydrogen sulfide ($H_2S$), a toxic gas and with an unpleasant smell, which is the result of the result of the transformation, in an anaerobic medium, of the sulfur contained in some amino acids.

Lastly, other impacts are that manure helps to the dispersion of microorganism's pathogens for human health and accumulation of heavy metals such as copper and zinc can be phytotoxic, being prejudicial for vegetables.

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[12] (García)

[13] (Climate & Clean Air Coalition, 2021)

# 3. Formulation of the intensive pig farm

In order to study the environmental impact of intensive pig farms, the characteristics of a hypothetical farm will be introduced, including the type of livestock and its dimensions. All the calculations done to determine these characteristics use the maximum number of pigs permitted in a farm in Spain, stablished by the Spanish government. [14]

## 3.1. Characteristics of the farm

### 3.1.1. Type of lifestock, equivalent UGM and manure production

The farm consists of an intensive production system that dedicates to the fattening of piggies with the slaughterhouse as destination, with animals from 20 to 120 kilograms. As the BOE[15] states, the maximum quantity of pigs in a farm is dependent on the parameter UGM, which determines the quantity of manure per place per year and its value is of 720 UGM ($UGM_{Max}$). So, using the data found in Annex I, the number of pigs in the farm and the theoretical manure production can be determined. For fattening pigs:

$$\text{Equivalent UGM} \equiv 0.12\text{pig}$$

$$Total\ number\ of\ pigs = \frac{UGM_{Max}}{Equivalent\ UGM} = \frac{720}{0.12} = 6{,}000\ pigs$$

$$Equivalent\ manure\ production\ (Theoretical\ maximum) \equiv 2.15 \frac{m^3}{place \times year}$$

$$Q_{manure} = 6000 \times 2.15 = 12{,}900 \frac{m3}{year}$$

Therefore, the studied farm will have $6{,}000$ fattening pigs, which will create a total manure production of $12{,}900 \frac{m3}{year}$.

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[14] (Ministerio de la Presidencia, 2020)

[15] (Ministerio de la Presidencia, 2020)

### 3.1.2. Dimensions of the farm

The structure of the farm will consist of rectangular pens of 3 meters wide and 7 meters long, including the area of the pond. The pens are made of concrete and have a 5% slope in order to facilitate the washing of the pens. The pond has the objective of being the defecation area for the pigs so that the pens stay cleaner, as shown in Figure 3. Usually, its dimensions are 1mx3m with a depth from 12 to 15 centimeters.

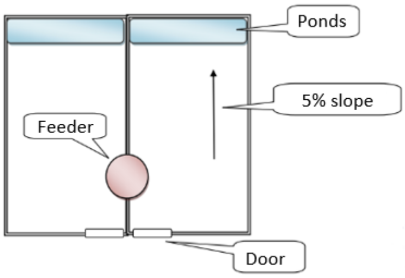

*Figure 5- Plan view of the pens of the farm* [16]

Therefore, the final top view of the inside of the farm can be seen in Figure 4. The main corridor is 1.2 meters wide.

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[16] (Castellanos, 2012)

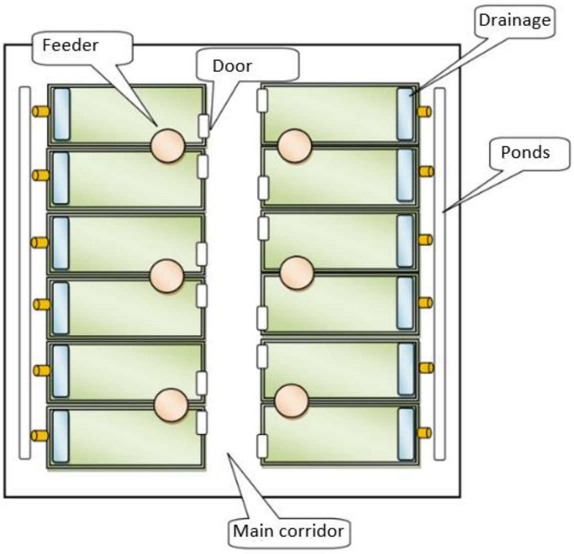

*Figure 6- Figure 4- Plan view of the inside of the farm* [17]

The number of pigs recommended for one pen is from 15-20 pigs [2], therefore, to find out the number of pens necessary in the farm, the arithmetic mean between the different values of recommended pigs has been calculated, as it can be seen below.

$$Arithmetic\ mean\ of\ pigs\ per\ pen = 15 + 16 + 17 + 18 + 19 + 20 = 17.5\ \frac{pigs}{pen}$$

$$Total\ number\ of\ pins = \frac{6{,}000\ pigs}{17{,}5\ \frac{pigs}{pen}} = 342.8571\ pens$$

Due to the structure of the farm and in order to optimize space, the number of pens must be 340, since with this value the farm will have two rows of 170 pens each. Considering the dimensions for the pens stated before, the total area of the farm is the following:

$$Total\ length\ of\ farm = \ 170\ pens\ \times (7 + 7 + 1.2) = 2618\ \ m$$

$$Total\ width\ of\ the\ farm = 170\ pens \times 3m = 510\ m$$

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[17] (Castellanos, 2012)

$Total\ dimensions\ of\ the\ fattening\ area = 2618 \times 510 = 1{,}335{,}180\ m^2 \equiv 133.52\ ha$

## 3.2. Theoretical quantity of pollutants found in pigs' manure

After finding the characteristics of the farm, now it is possible to compute the environmental impact produced. To do so, the formulas and data found in the official document emitted by the Spanish Government used to regulate the pollution of farms in Spain is used during the different subsections. [18]

As it is explained afterwards, there exist four main pollutants emitted from pigs' farming through manure: Nitrogen (N), Phosphorous (P), Volatile Solids (VS) and Methane ($CH_4$). The quantity emitted depends on what the pigs are fed, and this depends on their weight and their purpose. As it has been stablished in the previous section where the characteristics of the farm have been introduced, the pigs in our farm are fattening pigs from 20 to 120 kg. Therefore, the emissions for categories $k_2$, $k_3$, $k_4$, $k_5$, which correspond to pigs from 20 to 49, from 50 to 79, from 80 to 109 and more than 109 kilograms, respectively, are being calculated. Then, by doing the mean of all the values obtained, the total yearly emissions of pollutants are obtained.

### 3.2.1. Excretion of Nitrogen

The nitrogen from food that is not absorbed is excreted through urine and stool, therefore, the excreted nitrogen is the sum of both. With the aim of computing the total excreted quantity of Nitrogen by the different categories of pigs, the data seen in Table 1 and the equations presented afterward are used.

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[18] (Ministerio de agricultura y pesca, 2017)

| | $Frac_{fat}$ | $Frac_{protein}$ | $GMD_{\mathrm{j}}\left(\frac{g}{day}\right)$ | $\alpha$ | $Coef_m$ | $W_j$ (kg) | $EM_{portion,\mathrm{j}}\left(\frac{kcal}{kg}\right)$ | $PB_{portion,k_2}$ (%) |
|---|---|---|---|---|---|---|---|---|
| $k_2$ | 0.266 | 0.153 | 0.6418 | 0.6 | 206.0 | 33.99 | 3,724.7 | 18.22 |
| $k_3$ | 0.266 | 0.153 | 0.6922 | 0.6 | 206.0 | 65.00 | 3,703.6 | 17.37 |
| $k_4$ | 0.266 | 0.153 | 0.7142 | 0.6 | 206.0 | 93.60 | 3,693.8 | 16.55 |
| $k_5$ | 0.300 | 0.153 | 0.7142 | 0.6 | 206.0 | 116.10 | 3,674.9 | 15.16 |

*Table 1- Data Used for calculation of excreted nitrogen* [19]

$$Excreted\ N_j\left(\frac{kg}{year}\right) = N_{ingested,j}\left(\frac{kg}{year}\right) - N_{detained,j}\left(\frac{kg}{year}\right)$$

$N_{ingested,j}\left(\frac{kg}{year}\right)$: Nitrogen ingested by category j

$N_{detained,j}\left(\frac{kg}{year}\right)$: Nitrogen detained by category j

$$N_{ingested,j}\left(\frac{kg}{year}\right) = PB_{ingested,\mathrm{j}}\left(\frac{kg}{year}\right) \times 0.16$$

$$PB_{ingested,\mathrm{j}}\left(\frac{kg}{year}\right) = MS_{ingested,\mathrm{j}}\left(\frac{kg}{year}\right) \times PB_{portion,\mathrm{j}}$$

$$MS_{ingested,\mathrm{j}}\left(\frac{kg}{year}\right) = \frac{EM_{needed,\mathrm{j}}\left(\frac{kcal}{year}\right)}{EM_{portion,j}\left(\frac{kcal}{kg}\right)}$$

$$EM_{needed,\mathrm{j}}\left(\frac{kcal}{year}\right) = 365 \times \left(EM_{mant.} + EM_{fat,\mathrm{j}} + EM_{protein,\mathrm{j}}\right)$$

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[19] (Ministerio de agricultura y pesca, 2017)

$$EM_{mant.} = Coef_m \times W_j^{\alpha}$$

$$EM_{protein,\mathrm{j}}\left(\frac{kcal}{day}\right) = 12.1\left(\frac{kcal}{g} \times g_{protein}\right) \times Frac_{protein} \times GMD\left(\frac{g}{day}\right)$$

$$EM_{fat,\mathrm{j}}\left(\frac{kcal}{day}\right) = 12.8\left(\frac{kcal}{g_{fat}}\right) \times Frac_{fat} \times GMD\left(\frac{g}{day}\right)$$

For further calculations, it is also necessary to calculate the amount of nitrogen excreted through the stool and the one excreted through the urine. To compute these values, the data in Table 2 and the following equations are applied.

| | $\boldsymbol{DPB_{portion}}$ |
|---|---|
| $\boldsymbol{k_2}$ | 0.266 |
| $\boldsymbol{k_3}$ | 0.266 |
| $\boldsymbol{k_4}$ | 0.266 |
| $\boldsymbol{k_5}$ | 0.300 |

*Table 2- Data used for the calculation of excreted Nitrogen through stool and urine* [20]

*Figure 6- Data used for the calculation of excreted Nitrogen through stool and urine*

$$N_{Stool,j}\left(\frac{kg}{year}\right) = PB_{ingested,j} \times \left(1 - DPB_{portion,j}\right) \times 0.16$$

$PB_{ingested,j}$: ingested gross nitrogen by category j

$DPB_{portion,j}$: digestibility of the PB taken by category j

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[20] (Ministerio de agricultura y pesca, 2017)

$$N_{Urine,j} = Excreted\ N_{k_4}\left(\frac{kg}{year}\right) - N_{manure}\left(\frac{kg}{year}\right)$$

In order to compute all values, all the formulas and data have been introduced in a Matlab script and the results can be found in the Table 3.

| | $Excreted\ N_j\left(\frac{kg}{year}\right)$ | $N_{Stool,j}\left(\frac{kg}{year}\right)$ | $N_{Urine,j}$ |
|---|---|---|---|
| $k_2$ | 4.8853 | 4.8842 | 0.0011 |
| $k_3$ | 6.9094 | 6.9059 | 0.0035 |
| $k_4$ | 8.214 | 8.2088 | 0.0051 |
| $k_5$ | 8.6061 | 8.6004 | 0.0057 |
| **Mean** | 7.1537 | 7.1499 | 0.0038 |

*Table 3- Results for the calculation of excreted Nitrogen*[21]

### 3.2.2. Excretion of Volatile Solids

Volatile Solids or composts are chemical substances that contain carbon and are easily converted to gas at room temperatures, therefore, they are pollutants [22]. The formulas and data used [2] are described in this section, also the yearly excretion for each category and the mean value are computed. Therefore, the data, in Table 4, and formulas are:

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[21] Table of own creation

[22] (Greenteach, 2022)

| | $MS_{ingested}$ | $N_{Urine,j}$ | $D_{MSingested}$ (%) | $EB_{portion}$ |
|---|---|---|---|---|
| $k_2$ | 167.7787 | 0.0011 | 68.72 | 5,071.4 |
| $k_3$ | 248.8343 | 0.0035 | 65.56 | 5,060.8 |
| $k_4$ | 310.4356 | 0.0051 | 66.38 | 5,039.4 |
| $k_5$ | 355.0651 | 0.0057 | 63.38 | 6,061.2 |

*Table 4- Data used for calculation of excreted volatile solids*[23]

$$VS(kg\ \frac{m.s}{year}) = MS_{ingested}(kg/year) \times [(1 - D_{MSingested}) + EU_{EB}] \times (1 - Ceniza)]$$

$$EU_{EB} = \frac{\left(0.192 + 31 \times \frac{N_{urine}}{MS_{ingested}}\right)}{EB_{portion}}$$

$$D_{MSingested} = DE_{portion} = 68.72\%$$

$$EB_{portion} = \frac{5{,}071.4kcal}{kg}$$

$$Ashes \simeq 2\%$$

In the Table 5 the final results of excreted volatile solids per category and the mean value are introduced.

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[23] (Ministerio de agricultura y pesca, 2017)

| | $VS\left(kg\ \frac{m.s}{year}\right)$ |
|---|---|
| $k_2$ | 51.4378 |
| $k_3$ | 83.9938 |
| $k_4$ | 102.2927 |
| $k_5$ | 127.4354 |
| **Mean** | 91.2899 |

*Table 5- Results for the calculation of excreted volatile solids*[24]

### 3.2.3. Excretion of Phosphorous

Phosphorus is an essential element for our organism since it is part of the bones' composition. [25] Therefore, in order to compute the quantity excreted of this element, it is assumed that pigs ingest the needed phosphorus established in "*BASES ZOOTÉCNICAS PARA EL CÁLCULO DEL BALANCE ALIMENTARIO DE NITRÓGENO Y FÓSFORO*". Moreover, the formulas and data needed to compute the detained phosphorus for each category used are found in the Spanish legislation. Therefore, after doing the following calculations, the mean value of excreted phosphorus is found, Table 6.

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[24] (Ministerio de agricultura y pesca, 2017)

[25] (Ministerio de agricultura y pesca, 2017)

$$Excreted\ P_j\left(\frac{kg}{year}\right) = P_{needed,j}\left(\frac{kg}{year}\right) - P_{detained,j}\left(\frac{kg}{year}\right)$$

$P_{needed,j}\left(\frac{kg}{year}\right)$: Phosphorous taken by category j

$P_{detained,j}\left(\frac{kg}{year}\right)$: Phosphorous detained by category j

$$P_{needed,j}\left(\frac{kg}{year}\right) = \frac{P_{detained,j} + 10^{-5} \times W_j \times 365}{0.95}$$

$$P_{detained,j}\left(\frac{g}{day}\right) = \frac{5.4199 \times \left(W_{f-j} - W_{o-j}\right) - 0.002857 \times \left(W_{f-j}^2 - W_{o-j}^2\right)}{p_j}$$

$W_{f-j}(kg)$: final weight of category j

$W_{o-j}(kg)$: initial weight of category j

$W_j(kg)$: average weight of category j

$p_j$: period of category j

| | **Excreted $\mathbf{P_j}\left(\frac{\mathbf{kg}}{\mathbf{year}}\right)$** |
|---|---|
| $\boldsymbol{k_2}$ | 0.1949 |
| $\boldsymbol{k_3}$ | 0.3174 |
| $\boldsymbol{k_4}$ | 0.4190 |
| $\boldsymbol{k_5}$ | 0.4839 |
| **Mean** | 0.3538 |

*Table 6- Results for the calculations of excreted phosphorous*[26]

### 3.2.4. Emissions of Methane

The emissions of methane in pigs are due to the monogastric fermentations of the digestive system, also called enteric fermentation. The formulas and data used are described in this section, Table 7, also the yearly emissions for each category and the mean value are computed, in Table 8.

| | $MS_{ingested}$ | $\beta_{CH_4}$ | $MFB$ | $\alpha_{CH_4}$ |
|---|---|---|---|---|
| $k_2$ | 167.7787 | 0.02 | 75.89 | 0 |
| $k_3$ | 248.8343 | 0.02 | 75.66 | 0 |
| $k_4$ | 310.4356 | 0.02 | 75.77 | 0 |
| $k_5$ | 355.0651 | 0.02 | 75.11 | 0 |

*Table 7- Data used for the calculation of emissions of methane* [27]

$$FE\left(\frac{kg\,\frac{CH_4}{animal}}{year}\right) = 365 \times \left(\alpha_{CH_4} + \beta_{CH_4} \times MS_{ingested} \times MFB\right)$$

$\alpha_{CH_4}$: adjustment constant (kg of methane per day)

$\beta_{CH_4}$: methane emission coefficient for fermentable matter by bacteria

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[26] Table of own creation

[27] (Ministerio de agricultura y pesca, 2017)

MFB: fermentable matter per bacteria of the portion (kg/ kg of ingested dried matter)

| | $FE\left(\frac{kg\frac{CH_4}{animal}}{year}\right)$ |
|---|---|
| $k_2$ | 9.2949e+04 |
| $k_3$ | 1.3744e+05 |
| $k_4$ | 1.7171e+05 |
| $k_5$ | 1.9468e+05 |
| **Mean** | 1.4927e+05 |

*Table 8- Results of the calculation of emitted methane* [28]

### 3.2.5. Total quantity of pollutants emitted by pigs

The values obtained in the previous calculations determine the quantity of elements excreted by a pig. These amounts are gross values, the elements might suffer transformations before arriving to the outside. The firs

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[28] Table of own creation

## 3.3. Characteristics of slurry

### 3.3.1. Slurry composition

As seen in previously section 3, the chemical composition of manure depends on some factors that vary for each cattle farm such as: the category of the animal, its feeding, the environmental conditions, the cleaning system, etc. During the sanitation of farms manure is mixed with cleaning water creating slurry. This includes all the fermentable organic waste that is generated on farms. From the chemical point of view, it can be described as an aqueous solution of organic matter with solids in suspension, part of them settleable. On one hand, the liquid phase, which consists of pigs' urine and the water used to wash the animals and, on the other hand, the solid phase, that is made of excrements, food leftovers and the material that covers the soil. Therefore, to study the environmental impact of a farm, the chemical composition of manure must be determined.

In the previous section, the composition of manure using the data provided by the Spanish government for a fattening pig is found out. However, the results give only the proportion of elements in manure, not taking into account that this is mixed with water creating the final dissolution, slurry. To do the environmental impact assesment, the information given in Table 9 is used, since it provides real data of the typical characteristics of waste waters fro pig farms.

| **Parameters** | **Units** | **Source 1** | **Source 2** | **Source 3** | **Source 4** | **Mean values** |
|---|---|---|---|---|---|---|
| Total solids (ST) | g/kg | - | 42.33 | - | - | 42.33 |
| Total Volatile Solids (STV) | g/kg | - | 62.16 | - | - | 62.16 |
| Density (**$\rho$**) | kg/$m^3$ | - | - | 1,023 | 1,015 | 1,019 |
| Total Nitrogen | g/kg | 5.62 | 5.95 | 3.70 | 2.45 | 4.43 |

| | | | | | | |
|---|---|---|---|---|---|---|
| Ammonia nitrogen (N-$\mathbf{NH_4^+}$) | g/kg | 3.18 | 4.54 | 2.16 | 1.56 | 2.86 |
| Total Chemical Demand of Oxygen $(\boldsymbol{COD_{total}})$ | g/kg | 65.60 | 73.02 | 52.14 | 39.95 | 57.68 |
| Phosphorous (P) | g/kg | 6.23 | 1.38 | 3.18 | 1.83 | 3.16 |
| Potassium (K) | g/kg | 2.81 | 4.83 | 2.75 | 1.70 | 3.02 |
| Sodium (Na) | g/l | 0.57 | - | 0.41 | 0.36 | 0.45 |
| Magnesium (Mg) | g/l | 1.30 | - | - | - | 1.3 |
| Calcium (Ca) | g/l | 3.96 | - | - | - | 3.96 |

*Table 9- Chemical composition of slurry* [29]

### 3.3.2. Slurry production

With the information of Table 9, the final quantity of elements excreted can be determined. In section 2, the total production of manure is calculated. However, as explained previously, it does not include the water added to it during the cleaning processes. Therefore, in this section the total slurry production that is going into the waste treatment installation is calculated.

In this section it is assumed that in the farm a corresponding amount of water is used for cleaning so that the final percentage of dry matter is $DM_{slurry} = 6.7\%$ and that the density of slurry is $\rho_{slurry} = 1050\,\frac{kg}{m^3}$. This data is collected from the *Use*

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[29] (Guzzo, 2017)

*of livestock as fertilizer* [30], a study performed by the agricultural engineer Joan Parera I Pous. Thus, the total flux per day can be found by using this data and the results obtained in section 2.

$$Q_{slurry} = \frac{Q_{manure}}{DM} = 192{,}537.3134\,\frac{m^3}{year} = 527.5\,\frac{m^3}{day}$$

Hence, using the principle of conservation of mass in steady-state and without generation nor accumulation [1], the flux of water is found and the density of manure [2], which is the solid part, are found:

$$Q_{manure} = 12{,}900\,\frac{m^3}{year} = 35.342\,\frac{m^3}{day}$$

$$Q_{in} = Q_{out} \rightarrow Q_{manure} + Q_{water} = Q_{slurry}\ [1]$$

$$Q_{water} = Q_{slurry} - Q_{manure} = 492.158\,\frac{m^3}{day}$$

$$\dot{m}_{slurry} = \dot{m}_{manure} + \dot{m}_{water} \rightarrow \rho_{slurry} \times Q_{slurry} = \rho_{manure} \times Q_{manure} + \rho_{water} \times Q_{water}\ \ [2]$$

$$\rho_{manure} = \frac{\rho_{slurry} \times Q_{slurry} - \rho_{water} \times Q_{water}}{Q_{manure}} = 1788.16\,\frac{kg}{m^3}$$

The environmental impact assessment is performed using this flow rate per day as the input of the waste treatment plant.

# 4. Study of alternatives for the manure management plan

From section 2 it is proved that pollution appears because of an inefficient or an incomplete management process that does not use appropriately the sources that it generates. A pollutant, from this point of view, is a source placed incorrectly. A

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[30] (Pous, 2014)

wrong manure management leads to pollution. It is important to create a plan, usually called integrated slurry management plan, that includes all the processes of farming, going from the origin (animals feeding) until the management of manure, with the aim of reducing the environmental impact on the atmosphere, the ground, and the water. Therefore, an integrated slurry management plan must include, at least the following four scopes:

- Measures in order to reduce production of the contaminant components at the origin, by adopting new diets and techniques during the farming.
- Application plan on grounds and crops. This plan must be done by considering the surroundings of the farm as well as the climate and hydrologic characteristics.
- Strategy of the treatment to apply. This strategy consists of a combination of processes with the objective of modifying the characteristics of manure so that it satisfies the characteristics demanded.
- Calculation of the volume of the storage rafts. As it is explained ahead, it is important that the storage rafts have the correct volume and is made of the correct materials and with the correct structure.

Therefore, in this section the project, not only facts about the importance of having a good manure management are presented but also a study, in economic and efficiency terms, of manure treatment alternatives is done to select the final solution.

## 4.1. Implementation of the integral slurry management plan

It is important to be methodic and go step by step in order to study all the alternatives and to take appropriate decisions.

The first step of this plan is to minimize the origin, by controlling the nutrients given to the animals, as well as other environmental conditions such as the pH and the temperature. In this case, for simplicity and since it is not desired to inquire about the creation of a farm, it is considered that these measures are correctly imposed.

Nowadays, there exist three alternatives to manage the waste produced in farms. The first, consists of having an outside company handling the management of manure. In the case studied, since it consists of an intensive farming, it is expected to have a great waste production, therefore, the cost of paying for an external company to manage it is really high. For this reason, it is discarded. transporting the manure to a field used to cultivate and use it as a fertilizer. In the next section it is explained with more extension. The second alternative is to have transporting the manure to a field used to cultivate and use it as a fertilizer. In the next section it is explained with more extension. The third, and last option, is to have a treatment plant nearby the farm. Although this includes an initial investment, it reduces the transportation costs, makes it possible to reuse waste and avoids having to pay an external company for their services. In the next sections, the two remaining options are studied, and a final management solution is presented.

### 4.1.1. Fertilizing plan

The easiest way to valorize manure is using them as fertilizers. It implies applying them into the ground in the right moment to obtain the maximum efficiency as fertilizers and to prevent the use of chemical fertilizers. This plan depends on the type of crop and the geographic zone or its climate.

It is recommended that the dose of components applied into the land is the same as that found in the corps. Therefore, the dose to apply depends on the type of plant. Another fact to keep in mind is that in the ground there might be nutrient residues from other applications, so the new application should be lowered.

In addition, the moment of application is also limited, since it is forbidden to do so when there are no corps, the floor is frozen, there are heavy rains, etc. To sum up, the appliance must be performed when the ground is dry. It is also stated in the Spanish Legislation[31] the following:

- The slurry with a humidity lower than 40%, cannot be applied at less than 5m of the banks of surface watercourses, lakes, standing bodies of water, the beginning of beaches and marine coasts, subway water catchments for human consumption, wells and springs.

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[31] (España, 2020)

- The slurry with a humidity higher than 40%, cannot be applied at less than 5m of the banks of surface watercourses, lakes, standing bodies of water, the beginning of beaches and marine coasts, subway water catchments for human consumption, wells and springs.

Hence, although manure has been used during many years without any previous treatment as fertilizers, taking into account the current regulations and with the farming capacity of the studied farm, this alternative is discarded. As explained before, there are many regulations that would make it almost impossible for an intensive farm to apply directly manure as a fertilizer. For this reason, in the following sections the characteristics of treatment plants are presented, and moreover, a comparison between different alternatives is presented with the objective of choosing the most adequate for this case.

## 4.2. Slurry treatment plant alternatives

As explained in the previous section, for an intensive pig farming it is almost mandatory to treat slurry due to the regulations given by the Spanish government. However, this treatment might also benefit the farm since the output obtained has more value as a fertilizer, being able to sell it at a higher price. The treatments also help facilitate the subsequent management since the output is more stable, homogeneous, less odors and more hygienic.

It is common for different farms to join together to create plants to reduce installation costs. However, and for simplicity, it is assumed that in this case the plant is created specifically for the treatment of the slurry of the farm. The installation can consist of a single treatment plant or a combination of different treatments. In this section, different alternatives are presented and also the combination of them.

Also, after leaving the farm and before going into the treatment plant, slurry is kept in a lagoon or raft. To calculate the minimum capacity of it, the treatment capacity should also be determined, therefore, the minimum volume of it is determined later on. Nevertheless, there are some facts that must be given a thought to. Firstly, it should prevent water accumulations, by avoiding water losses from drinkers and minimizing the water used for cleaning. It is also highly recommended to cover the pit to avoid rainwater to get into it and to minimize the greenhouse gas emissions provoked by manure. Secondly, pits must be waterproof and periodically cleaned.

### 4.2.1. Solid/Liquid Separation

This technique allows to separate between the solid part and the liquid part of slurry. The main function is to improve its handling, with the possibility of recycling the cleaning water, reduce the organic matter of the liquid fraction, concentrating the nutrients in the solid fraction, facilitating its management and transportation, reducing at the same time the emission of odors. The remaining liquid fraction can be used for the irrigation of crops. It should also be kept in mind that the efficiency of this treatment depends on the lifetime of the manure at which it is performed, since as time passes by, many solid components solubilize due to decomposition, and this makes them impossible to separate in a mechanical way.

There exist different separation systems, and although they all do the same function, the ideal system depends on the needed efficiency and on the size of the solid particles. The systems can be divided into natural decantation and the mechanical systems, and inside the mechanical systems there are mechanical separation systems by gravity, by centrifugation and by pressure. In Figure 7 different techniques of separation are classified.

The greatest cost of composting is the land occupied and the transportation costs. Given the quantities of slurry produced in an intensive farm, and taking into account that the composting process takes about 2 months and a half, using this technique

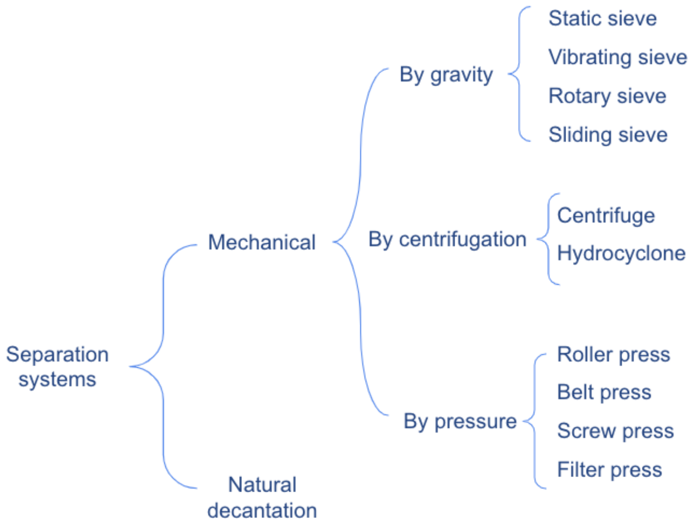

*Figure 7- Classification of solid/liquid separation systems* [32]

In the process of natural decantation, different strata are produced: an upper layer with solid remains (crust), an intermediate liquid layer and a lower layer with sediments. In the case of mechanical systems, there are two outlets, one consisting of the liquid part of slurry and the other containing the solid part. Therefore, costs are relatively low, its accuracy cannot be determined since it might depend on many environmental factors such as the temperature, manure characteristics… Hence, this alternative is discarded for the final design.

In Table 10 the efficiency of separation of nitrogen and phosphorous in the solid fraction are presented for each mechanical technique, as well as the consumption, cost of operation and the value of the initial investment.

| **S/L Separator** | **Nitrogen in solid fraction (%)** | **Phosphorous in solid fraction (%)** | **Energy consumption ($\frac{kWh}{m^3}$)** | **Investment (€)** | **Cost of operation ($€/m^3$)** |
|---|---|---|---|---|---|
| By gravity | 5-15 | 5-15 | $\cong 0$ | 3,500-15,000 | $\cong 0$ |

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[32] (Pous, 2014)

| | | | | | |
|---|---|---|---|---|---|
| By centrifugation | 5-20 | 10-30 | 0.1-0.5 | 17,000-21,000 | 0.5-0.9 |
| By pressure | 30 | 70 | 0.5 | 25,000-125,000 | $\cong 0$ |

*Table 10- Characteristics of solid/liquid separation systems* [33]

### 4.2.2. Composting

When manure is decomposed by the action of microorganisms, useful subproducts can be obtained. The type of subproduct obtained depends on the conditions at which decomposition happens. In this case, composting consists of an aerobic process, in which oxygen is used for the decomposition of organic matter. The objective of composting is to transform organic matter into a stable biological product (compost), reducing the volume of the original waste and eliminating pathogens, insect larvae and seeds. The chemical reaction is the following:

$$\text{Organic matter} + \text{Bacteria} + O_2 \longrightarrow \text{Compost} + \text{New bacteria} + CO_2 + H_2O + NH_3$$

*Equation 1- Chemical reaction of aerobic digestion* [34]

The process is developed in four phases:

1. Decomposition phase, characterized by high temperatures.
    a. Mesophilic bacteria (20-55 ºC, optimum 35 ºC): As a consequence of the metabolic activity, temperature rises and organic acids are produced, reducing the pH.
    b. Thermophilic bacteria (45-75 ºC, optimum 55 ºC): When temperature reaches 40 ºC, microorganism act by transforming nitrogen into ammonia and the pH becomes alkaline. At 60 ºC these microorganisms

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[33] (Pous, 2014)

[34] (Recíclame, 2022)

disappear and sporogeneses and actinomycetes bacteria appear and break down waxes, proteins, and hemicellulose.

2. Cooling phase, lowering temperature. When temperature is lower than 60 ºC, thermophilic bacteria appear and decompose the cellulose. Also, when temperature is lower than 40 ºC, the mesophilic bacteria also appear, lowering pH.
3. Maturation phase. At atmospheric temperature. This phase requires from 1 to 2 months since fungi assimilate the carbonate composts that did not degrade during the decomposition phase.
4. Stabilization phase. At atmospheric temperature. During this phase, the excess of heat is removed, the humidity is controlled, and the porosity of the compost is increased.

One of the disadvantages of composting is that it depends on many factors of the input organic matter, specially, on the ratio of carbon and nitrogen. The optimal relation is of 25-35, since for higher values decomposition is slower and for lower ones, it can cause loss of nitrogen and bad odors. Also, during aerobic digestions, $CO_2$ is emitted, which is one of the greenhouse gases. Nutrients need to be added to slurry for aerobic digestion to happen, therefore, there is a need to find some suppliers.

Composing has been used during many years due to its simplicity. The main costs of this technique are due to the land occupation since it is a process of about two months. Therefore, a good management plan is needed to determine the capacity of the lagoon and the amount of digestors needed. Also, the value of the transportation costs can be high. However, in our case, if it is considered that the composting is performed next to the farm, this cost is almost null.

### 4.2.3. Anaerobic digestion

As explained in the previous section, when organic matter is decomposed by the action of bacteria, useful products can be obtained. Anaerobic processes of decomposition are those in which oxygen are not used. In this case, the outputs are ammonia, sulfate, hummus, and biogas, which is composed mainly of methane and carbon dioxide. This process consists of a combination of reactions, which can be divided in three steps.

1. Acidogenesis. In this first stage polymers and other complex substances are hydrolyzed and fermented, transforming into simpler chemical components such as acetate, ethanol, hydrogen, and other organic acids.
2. Acetogenesis. In this second phase, the fatty acids are transformed into acetic acid and hydrogen.
3. Methanogenesis. Two different reactions happen, the first one is called acetolactic and consists of the decarboxylation of the acetic acid. The second is hydrogenotrophic reaction, in which carbon dioxide is reduced with hydrogen.

The output of the anaerobic digestion is mainly biogas, but there exists a part that consists of bacterium biomass. This is usually treated to obtain fertilizers, since it is an homogeneous and stabilized matter. Therefore, in this technique almost all the output is used.

It is important to collect the biogas and use it in order to void the emission to the atmosphere, since it has an important impact on the greenhouse effect. Biogas has been mainly used to cook; nevertheless, it can be used for many other applications such as a heater, or fuel for motors. This technique also improves the quality of fertilizers, since it reduces its size and its viscosity, and it idles eggs, larvae, and parasites.

The main disadvantage of anaerobic digestion is that it depends on external factors and on the time that the slurry has been stored. If slurry is stored for a long time before entering the process, since it is a natural process, anaerobic digestion will happen in the raft, losing its energetic value.

### 4.2.4. NDN treatment

NDN treatments are used when it is desired to reuse the treated water inside the farms, and consists of eliminating the remaining elements, nitrogen and phosphorous. To be able to transform ammonia into nitrogen, it must go through different steps.

The first is based on transforming ammonia into nitrate using an aerobic process called nitrification. Two reactions, as it can be observed in Figure 8, happen during this phase.

$$NH_4^+ + O_2 \rightarrow NO_2^- + 4H^+ + 2e^-$$
$$NO_2^- + O_2 + 2H^+ + 2e^- \rightarrow NO_3^- + H_2O$$

*Figure 8- Chemical reactions of nitrification* [35]

Once nitrate is obtained, the next step is the denitrification. In this phase there are different intermediate reactions until pure nitrogen is obtained (Figure 9). The creation of these intermediate elements are undesired and therefore it has to be controlled. Some factors that facilitate the creation of this elements are the ratio C/N, the type of substrate, the pH, among others.

$$NO_3^- \rightarrow NO_2^- \rightarrow NO \rightarrow N_2O \rightarrow N_2$$

*Figure 9- Chemical reactions of denitrification*[36]

The efficiency is very variable since bacteria are really sensible to changes in temperature, but it can present a transformation of about the 60% of nitrogen in $N_2$. It must be taken into account that although this technique helps reducing the amount of ammonia helping not to saturate the land, it generates an output, gas nitrogen, that has no valorization and that is emitted directly to the atmosphere.

### 4.2.5. Combination of treatments

As explained at the beginning of this section, usually different techniques are used to treat slurry since one of them by itself might not be fully efficient. Depending on the legislations and characteristics of the farm, different options are considered. In Figure 10, the different possible combinations of the previously explained procedures are shown.

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[35] (Francisco J. Cervantes, 2007)

[36] (Francisco J. Cervantes, 2007)

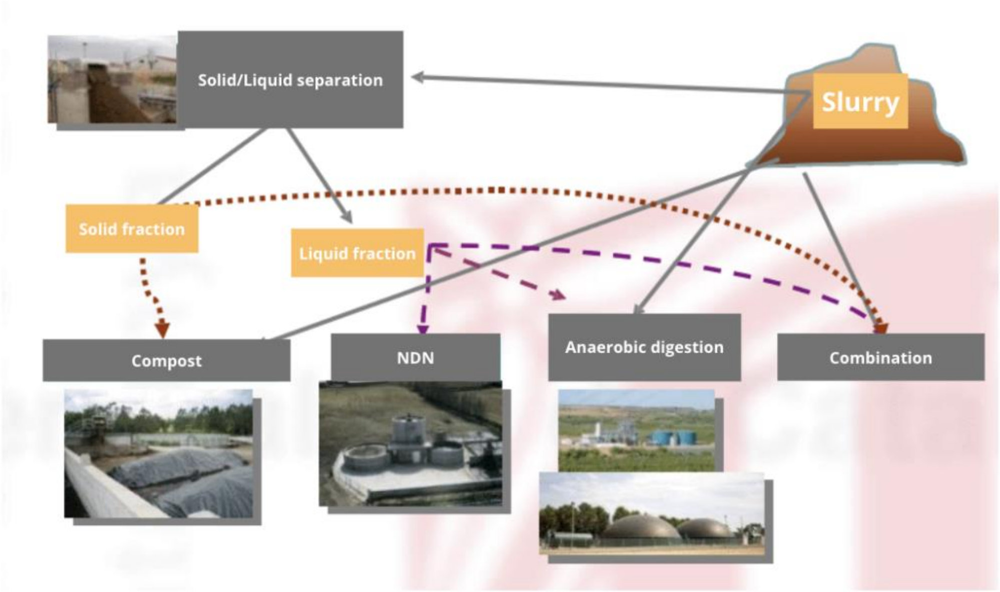

*Figure 10- Combination of slurry treatments*[37]

At the end of the processes, there are some outputs that are valued relying upon the use and treatment they are given. Therefore, the different fractions can have the following applications on the farm and its environment:

- The liquid fraction can be used as cleaning water for the farm, which helps the environment reusing a source, while reducing farming costs.
- The liquid fraction can be used as a fertilizer of greater agronomic efficiency, increasing its economic value.
- The liquid fraction might need depuration techniques to have the possibility of pour it into the sewer network, which increases the costs of the treatment.
- The liquid and solid fractions can also be used to produce energy in case anaerobic digestion is performed.
- The solid fraction can be used as a fertilizer, having less or more value depending on the nutrients of it.

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[37] (Pous, 2014)

Thus, in the next section, the more appropriate combination of treatments is selected using the multicriteria decision procedure.

## 4.3. Selection of the slurry treatment for the intensive pig farm

It should be borne in mind that, although the aim of this project is not to construct an intensive pig farm, the steps followed are necessary to get a realistic environmental impact assessment. That is to say that the decision making done during this section and previous ones is done thinking as if it was performed by a firm dedicated to farming. In this way, the results obtained resemble that at the present time. For this reason, in this section the selection of the slurry treatment for the intensive farming firm is performed with a project management technique called multicriteria decision.

The multicriteria decision analysis technique consists of using a decision matrix to provide a systematic analytical approach for establishing a criterion to evaluate and rank many alternatives. Therefore, it is needed to assign a weight to each of the criteria, for example a percentage, and a scale to rank the different alternatives, for example, from 1 to 5. Once the alternatives for each criterion are scored, they are added by weighing the value of each criterion, with which an overall score is obtained for each alternative. So, this methodology is used to select the treatment for the design of the treatment plant.

### 4.3.1. Selection of alternatives for the decision matrix

Given the scope of the thesis, and to simplify later calculations, the different combinations of treatments is limited to a maximum amount of three. This is also reasonable from an economical point of view given that it is assumed the investment is just performed for the farm studied.

Therefore, given the different combinations seen in Figure 10 and the characteristic of each of the treatments, five different alternatives are presented. The chosen alternatives to be studied have different objectives. Even though there will exist variations for the chosen alternatives, this is out of the scope of the project since the output of the treatment plant, which is what really is of interest for the thesis, are very similar for all the variations. Also, the S/L chosen to be used is determined afterwards, since there are many different separators. A commercial model is chosen in order to perform the calculations since the study of all the different options is out of the scope of the thesis.

The first alternative, does not include a pretreatment and implies a low initial investment, is to directly compost slurry, without any previous treatment. Although this alternative is the cheapest one, costs can increase due to the price of the property and the transportation costs. Also, the lagoon capacity might be higher than for other alternatives, increasing costs.

The second alternative, consists of a S/L pretreatment, composting the solid part and not treating the liquid part. This second alternative reduces de transportation costs and the lagoon volume, since the liquid and solid are separated from the beginning. The fact of not treating the liquid reduces costs but has the disadvantage that this liquid might not be greatly valued. Now there is an initial investment to reduce future costs, but compost is used again due to its simplicity. The third alternative is like this second one, but now instead of using compost to treat the solid part, anaerobic digestion is used. Therefore, the valued element is for this case the possibility to use biogas to generate energy. To be able to compare these two alternatives correctly, Table 11, which includes the differences between anaerobic and aerobic digestions is used.

| **Parameters** | **Aerobic digestion** | **Anaerobic digestion** |
|---|---|---|
| Heat generation (KJ/mol of glucose) | 2840 KJ/mol of glucose | 393 KJ/mol of glucose |
| Destination of carbon | 50% converted to $CO_2$<br>40-50% to the biomass | 95% converted to $CO_2$ and $CH_4$<br>5% to the biomass |
| Destination of energy | 60% in the biomass<br>40% is lost as heat | 90% retained in $CH_4$<br>3-5% is lost as heat<br>5-7% in the biomass |

| | | |
|---|---|---|
| Energy Consumption | High | Low |
| Nutrients addition | High | Almost null |
| Start-up time | Short | Large |
| Tolerance to temperature | Wide range | Higher than 25 ºC |

*Table 11- Comparison between aerobic and anaerobic treatment of wastewater* [38]

The fourth alternative consists of including, to the third treatment, the treatment of the liquid fraction coming out of the S/L separator by eliminating the nitrogen to make sure that the legislation is satisfied and then being able to throw this water into the sewer network. Biogas is still produced due to the anaerobic digestion. This alternative's objective is to just profit from the solid part by obtaining energy from it. It also reduces transportation costs since the liquid part can be directly thrown away.

The last alternative, and the more complex, is the same as the previous alternative but adding composting for the solid part coming out of the separator. The aim of this combination of processes is to obtain the maximum valorization of slurry, since all the parts are fully treated.

After presenting all the alternatives, in the next section the different criteria that are used in the decision matrix are presented, as well as weighted depending on their importance.

### 4.3.2. Selection of the criterion for the decision matrix

The decision matrix is used since there exist different good alternatives and it helps to not make the decision on cost alone. However, cost is an important criterion for the case studied as, to get a realistic approach, it must be as low as possible.

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[38] (Francisco J. Cervantes, 2007)

Hence, it should represent a 30% of the total. In this case, there are two types of costs, the operational cost, which is a variable cost that depends on the amount of matter treated, and the investment, which involves putting capital to use today to generate a future income. Then, the weight of each of the losses are 15% for the first, and 15% for the second. What should also be considered is that, as long as losses are compensated with gains, therefore, having a benefit, firms bear the costs. In section 4.2, outputs are explained, and they can be divided into the solid fraction, to which a 15% of weight is given, and the liquid fraction, which will include the other 15%.

Now that the economical concepts have been weighted, and add a total of 60% of the total, the other concepts are being considered. Another important concept is the environmental impact of the treatment plant. This is divided in different sub-criteria since there are different factors that should be considered. The first is the size of the treatment plant, since it is desired to reduce it as much as possible to have more flexibility to install it close to the farm, so it is given a 5% of importance. Moreover, the emissions of the installation should also be contemplated, including the gases or the leaching of pollutants into the ground, and it is given a 10% of weight since it is also related to the law compliance. The reliability of the process should also be considered since it is desired to have an effective process with low errors. This is the reason why it is weighted with a 15%.

The remaining 10% is divided into two criteria. 5% is given to management simplicity. This is related to the difficulty of coordinating the different steps of the process, as it can end up causing poor slurry management and therefore, more pollution and waste of resources. The other 5%, although it is related to the previous criterion, is the dependance on external suppliers. That is, if an additional input is needed to perform the treatment. It is always better to avoid depending on other suppliers since it might delay or increase the cost of the alternative.

In this decision-making technique, the alternative chosen is the one with the highest score. That is why when scoring aspects with a negative value, such as cost, they are given a low score when have a high value, i.e., for the alternative with higher costs, a 0 is given for this criterion. The opposite happens for positive aspects, they will be given high scores when their value is high.

### 4.3.3. Decision matrix

After presenting the criteria and alternatives, all the concepts are joined in the decision matrix. The table of annex II has been used to determine some factors that have been not clarified during the thesis for some of the treatments. An Excel file is used to compute the results of this project management technique, since manual computations are reduced. The decision matrix can be found in Annex III. The results of it are presented in Figure 11, in which the score for each alternative is shown.

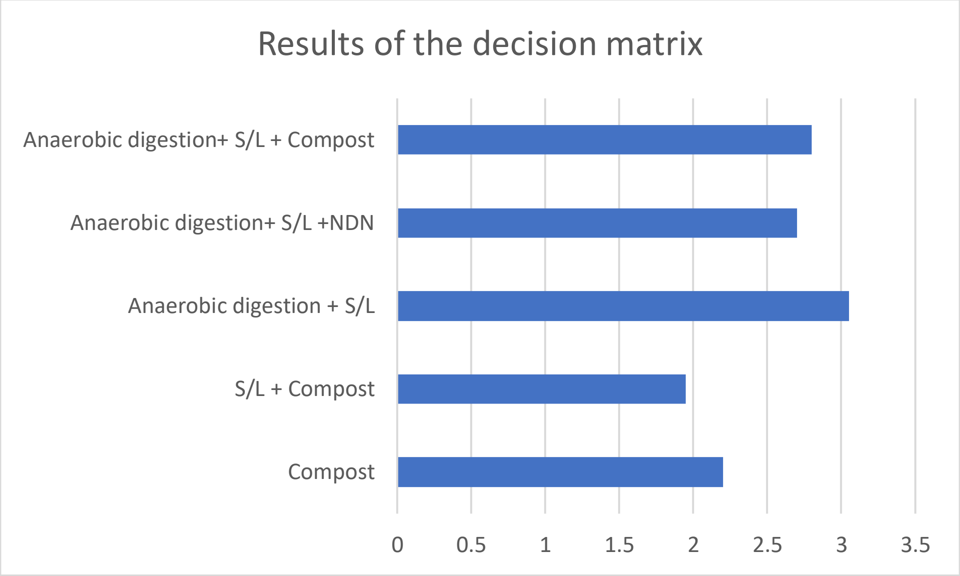

*Figure 11- Results obtained from the decision matrix* [39]

Finally, it can be concluded that the best alternative, given the necessities and desirable aspects of the thesis, is the combination of a solid liquid separator, and an anaerobic digestor. In the following parts of the project, the whole procedure of the slurry management plan is presented to be able to perform the final environmental impact assessment.

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[39] Own elaboration according to decision matrix

# 5. Slurry management plan for the studied pig farm

Until now, the functioning and the design of the final treatment plant has not been explained as a whole, but separately. Therefore, in this section of the thesis, everything is put together to be able to determine the final environmental impact of the process as a whole.

As a reminder of what is explained in previous sections, the process starts in the farm, where pigs produce excretions, and these are mixed with beds, which are usually formed of litter. The mix of litter, rests of food, excretions and other solids found in the farm is called manure. In section 2, the amount of manure produced in the studied intensive pig farm is calculated. Next, and with the aim of fulfilling the sanitary regulations, the floor of the farms is cleaned with water, which, thanks to the 5% slope included in farms, goes into the ponds. The mix of cleaning water and manure creates slurry.

Moreover, in section 4, the appropriate treatment of slurry is determined. By using the multicriteria procedure, it is concluded that the final alternative of treatment is the installation combining a S/L separator and an anaerobic bioreactor.

Thus, the connection between the slurry found in the farm ponds and the input of the treatment is the lagoon or raft, previously mentioned. It is assumed that the installation has the capacity to treat the daily amount of slurry produced. Thus, the buffer container is just a pass-through raft.

## 5.1. Block diagram of the installation

The slurry to be valorized is brought to the buffer container. Before starting the stabilization process, in this case, anaerobic digestion, sludge usually goes through a pretreatment with the aim of reducing its volume. Digestors have a hydraulic retention time (HRT), which indicates the time that the substrate spends inside the digestor. Therefore, the idea is to have a line connected to a valve and a flow meter to regulate and control the slurry flow into the separator. A pump or another mechanism capable to boost the flow is used to transport the slurry. Once the anaerobic digestion is performed, the digested biomass is then sent to the S/L separator in order to obtain a liquid fraction, which can be used to obtain an agricultural valorization, and a solid fraction which can be used as a fertilizer. In Figure 12, the whole process is presented in a schematic way.

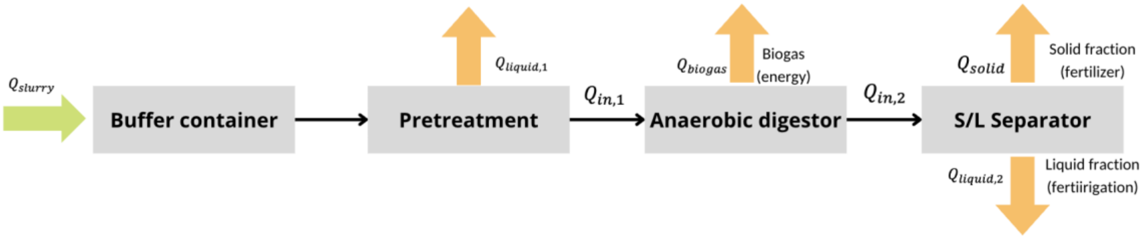

*Figure 12- Block diagram of manure treatment process*[40]

## 5.2. Pretreatment of slurry

The aim of the pretreatment is to reduce the volume of the flux that goes into the anaerobic digestor in order to reduce costs and time. The process is called sludge thickening. There are various processes used in sludge thickening. In this case, since the aim of it is to obtain a more compact and homogeneous flux, gravity thickening is used.

Gravity thickening involves using specially designed circular tanks that concentrate thin sludges to a more-dense sludge product. Thickening tanks have slow-moving vertical paddles. Sludge is usually pumped continuously from the settling tank to the thickener which has a low overflow rate so that the excess water overflows and the sludge solids concentrate at the bottom (Figure 13).

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[40] Diagram of own creation

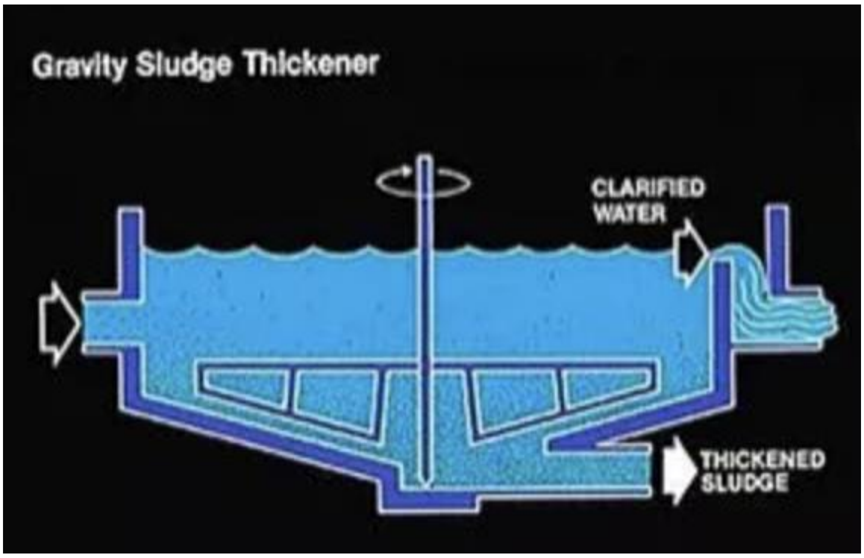

*Figure 13- Design of a gravity thickener* [41]

This sedimentation-like process can concentrate the sludge from about 1% to about 8-10%. Therefore, since the slurry entering the thickener has a concentration of 6.3%, it can be considered that a final concentration of 10% is achieved. Hence, using this information, knowing the flux of manure from previous sections, and using the mass conservation principle, $Q_{liquid,1}$ and $Q_{in,1}$ can be found.

$$C_{mixture} = \frac{Q_{solid}}{Q_{Total}} \rightarrow Q_{in,1} = \frac{Q_{manure}}{0.1} = 343.42 \frac{m^3}{day}$$

$$Q_{slurry} = Q_{in,1} + Q_{liquid,1} \rightarrow Q_{liquid,1} = Q_{slurry} - Q_{in,1} = 174.08 \frac{m^3}{day}$$

For the calculation of the volume of the thickener, the time of residence ($t_r$) has to be taken into account. For a thickening process, the residence time is usually of about 6-7 hours. Therefore, the needed volume of the gravity sludge thickener is:

$$V_{thickener=} t_r \times Q_{slurry} = 142.865\ m^3$$

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[41] (American Water Chemicals, Inc.)

## 5.3. Anaerobic digestion of slurry

To proceed to do the calculations of the outputs of the anerobic digestor and to obtain the amount of biogas produced, the model of Chen and Hashimoto (1978)[42] is used, since it simplifies the equations. This is possible thanks to the studies performed about anaerobic reactions from organic waste. Hence, the process to obtain the output of the anaerobic process is explained above.

$$S_1 = \frac{K}{\mu_m \vartheta - 1 + K} S_0 \quad (2)$$

The data of Table 9 is used to determine the amount of total volatile solids ($S_0$), and again, conservation of mass at the inlet of the anerobic digestor is used to determine the density of the inlet flow, and therefore, the total volatile solids entering the digestor in g/l. The calculations performed are the following:

$$Q_{in,1} = Q_{manure} + Q_{water,digestor} \rightarrow Q_{water,digestor} = 308.09 \ \frac{m^3}{day}$$

$$Q_{in,1} \times \ \rho_{in,1} = Q_{manure} \times \ \rho_{manure} + Q_{water,digestor} \times \ \rho_{water} \rightarrow \ \rho_{in,1} = 1{,}077.43 \frac{kg}{m^3}$$

$$S_0 = STV \times \ \rho_{in,1} = \frac{45.61 g_{STV}}{l_{slurry}}$$

In equation (2) parameter K is an inhibition constant of Chen and Hashimoto. In the model, they proved that the parameter K increase as the concentration of volatile solids does, using equations 4 to quantify it. Parameter $\mu_m$ determines the growth of microorganisms and increases with temperature, as shown in equation 3. Using the data of Table 9 to determine the amount of total volatile solids ($S_0$), considering a temperature of 35 ºC and a hydraulic residence time (HRT) of 20 days, the parameters can be given a value.

---

[42] (Azhari, 2017)

$$\mu_m = 0.013 \times T - 0.129 = 0.326 \quad (3)$$

$$K = 0.6 + 0.021 \times e^{0.05 \times S_0} = 0.8054 \quad (4)$$

Hence, the efficiency of elimination of substrate (E) can be determined using formula 5, and the final production of methane per unit of time and volume of the reactor ($P_v$) is determined in equation 6. $G_0$ determines the production of gas per unity of substrate eliminated, which in the case of purine residues, has a value of $0.45\ l\frac{CH_4}{gSV}$.

$$E = 1 - \frac{K}{\mu_m \vartheta - 1 + K} \quad (5)$$

$$P_v = G_0 \times \frac{S_0 - S_1}{\vartheta} = \frac{G_0 \times S_0}{\vartheta} \times \left(1 - \frac{K}{\mu_m \vartheta - 1 + K}\right) = 0.89556\ \frac{l_{CH_4CN}}{day \times l_{reactor}} \quad (6)$$

Now that the production of methane of the anaerobic digestor has been calculated, the volume of the reactor must be determined in order to find the total production of methane per day. Due to the big dimensions of the farm, the volume of the digestor might be higher than what would be recommended. This could be solved by installing more than one digestor. However, it is out of the scope of the project since the objective of it is to get the final environmental assessment and not to dig in the improvements of the treatment plant. Hence, the size of the biodigester ($V_T$) is calculated in a form that the useful volume ($V_u$) represents a 90% of the total one (Equation 8). The useful volume is the product of the HRT and the flow at the inlet of the digestor (Equation 7). Thus, with the total volume of the reactor the emissions of methane are found.

$$V_u = \vartheta \times Q_{in,1} = 7068.4 \quad (7)$$

$$V_T = \frac{V_u}{0.9} = 7853.78\ m^3 \quad (8)$$

$$Q_{biogas} = P_v \times V_u = 6330.18\ \frac{m_3}{day} \quad (9)$$

Hence, computing the balance of matter in the biodigester, knowing that the density of biogas is of 1.11 kg/$m^3$[43], the amount of digestate produced per day can be determined.

$$I_2 = Q_{in,2} \times \rho_{in,2}$$

$$Q_{in,1} \times \rho_{in,1} = Q_{biogas} \times \rho_{biogas} + I_2 \rightarrow I_2 = 359{,}677.92 \frac{kg}{day}$$

As explained in previous sections, biogas from anaerobic digestion must be reused to avoid the emission of methane into the atmosphere, since it is one of the gases that contributes most to the greenhouse effect. As shown in Figure 14, biogas can be used to generate heat or energy, which could be consumed in the same facility to create a circular model, or it could be converted into biomethane to be used later as a fuel or gas. It is out of the scope of the project to analyze the different ways of the treatment of biogas, however, for the further environmental study, in this section the amount of energy obtained from the biogas and the elements produced are determined. Moreover, these results are used in different scenario to see the impact of bad slurry management.

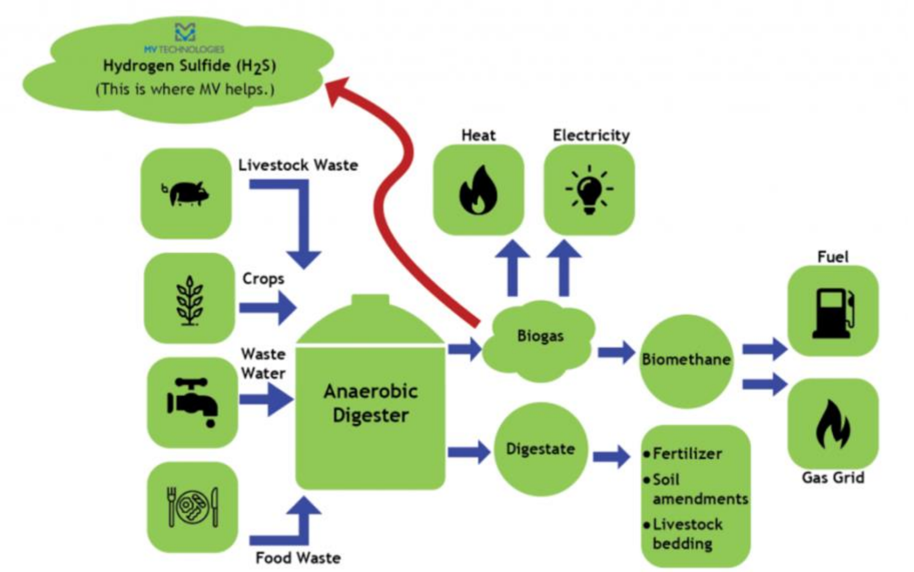

*Figure 14- Treatments options for the outputs of an anaerobic digester*

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[43] (Naskeo Envrionment, 2009)

### 5.3.1. Combustion of biogas to produce heat or electricity

In the Anaerobic respiration requires external electron acceptors for the disposal of electrons released during the degradation of organic matter. The electron acceptors can be $CO_2$, which is reduced to methane; sulfate ($SO_4^{-2}$) which is transformed to hydrogen sulfide ($H_2S$), a gas that gives off bas smells; and nitrate ($NO_3^-$) which is reduced to nitrogen gas ($N_2$). Hence, although almost all the output of the digester consists of methane and carbon dioxide, it also has to be considered that a low percentage of biogas is formed by gas nitrogen and hydrogen sulfide, which at atmospheric temperature is also a gas.

To produce energy from biogas, it is mixed with air to activate the combustion equation of methane, seen in equation 10. The output of the combustion is carbon dioxide and water. However, biogas is also formed by small percentages of other gases.

$$CH_4 + 2O_2 \rightarrow CO_2 + 2H_2O \text{ (10)}$$

The study of all the reactions happening in the combustion chamber where methane is burned are out of the scope, however, since the number of components emitted are of interest, the composition of biogas is of importance to know the whole emissions produced by anaerobic reactions. In Table 12, the percentage in volume of each of the components that form biogas is determined. From here, the total emissions to the atmosphere can be calculated and the power delivered. With the information about the produced biogas from the anaerobic digestor, knowing its combustion equation and the percentage of the rest of the components that form it, the amount of components emitted to the atmosphere are calculated. To find the emissions after combustion, the density of methane ( $\rho_{methane} = 0.657\frac{kg}{m^3}$) and carbon dioxide ( $\rho_{carbon\ dioxide} = 1.976\frac{kg}{m^3}$) are needed. It is assumed that a treatment to eliminate hydrogen sulfide is performed after or before combustion, since it can be prejudicial for people.

$$4468.36\ \frac{m^3\ methane}{day} \times \frac{0.657kg\ methane \times 44.01g\frac{CO2}{mol}}{1\ m^3\ methane \times 16{,}04\frac{gmethane}{mol}} = 8054.91\frac{kgCO_2}{day} = 4076.37\frac{m^3\ CO_2}{day}$$

$$4468.36\ \frac{m^3\ methane}{day} \times \frac{0.657kg\ methane \times 2 \times 18.015\frac{H2o}{mol}}{1\ m^3\ methane \times 16{,}04\frac{gmethane}{mol}} = 6594.37\ \frac{kgH_2O}{day} = 6.883\ \frac{m^3\ H_2O}{day}$$

| **Component** | **Quantity per $m^3$** | **Quantity produced (biogas)** | **Quantity produced (after combustion)** [44] |
|---|---|---|---|
| $CH_4$ | 68% vol | 4468.36 $\frac{m^3}{day}$ | - |
| $CO_2$ | 26% vol | 2420.36 $\frac{m^3}{day}$ | 6496.73 $\frac{m^3}{day}$ |
| $N_2$ | 1% vol | 93.091 $\frac{m^3}{day}$ | 93.091 $\frac{m^3}{day}$ |
| $O_2$ | 0% | 0 | -8197.04 $\frac{m^3}{day}$ |
| $H_2O$ | 5% vol | 465.45 $\frac{m^3}{day}$ | 472.33 $\frac{m^3}{day}$ |
| $H_2S$ | 400 mg/$m^3$ | 2.5321 $\frac{\mathrm{kg}}{\mathrm{day}}$ | - |
| PCI | 6.8 kWh/$m^3$ | - | 63301.812 $\frac{kWh}{day}$ |
| PCS | 7.5 kWh/$m^3$ | - | 69818.175 $\frac{kWh}{day}$ |

*Table 12- Composition of biogas and final emissions to the atmosphere* [45]

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[44] Column of the Table of own creation

[45] (Naskeo Envrionment, 2009)

### 5.3.2. Composition of digestate from the biodigester

Again, it is out of the scope of the thesis to study the whole of reactions happening in the biodigester. It is known, however, that the process affects the composition of the organic matter of the inlet and the transformation of organic nitrogen to ammonia. In Table 13, the typical efficiency that can be obtained in an anaerobic digestor of pigs' slurry at 35 ºC and with an HRT of 20 days is determined. Hence, with the efficiencies of Table 13 and the initial chemical composition of manure found in Table 9, the final composition after the anaerobic treatment of the digestate is obtained in the second column of Table 13. [46]

| Parameter | Outlet of digestor (% of inlet value) | Chemical digestate composition |
|---|---|---|
| Total Solids | 20-45 | 13.757 g/kg |
| Volatile solids | 40-60 | 31.075 g/kg |
| Organic Nitrogen | 60-40 | 0.785 g/kg |
| Ammonia Nitrogen | 140-160 | 4.29 g/kg |
| Nitric Nitrogen | 0 | 0 |
| Phosphorous | 100 | 3.16 g/kg |
| DQO | 40-60 | 28.84 g/kg |
| $\boldsymbol{Q_{manure,2}}$ | 95-98 | $34.28\ \frac{m^3}{day}$ |

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[46] The value of the final composition of the digestate is of own creation and is obtained doing the product between the elimination rate and the initial concentration.

*Table 13- Efficiency obtained for an anaerobic digestor of slurry at 35ºC and with an HRT of 20 days* [47]

## 5.4. S/L Separation of the digestate

In this process, the aim is to dehydratase the digestate in order to reduce its volume and facilitate its transport to the agricultural land o a controlled landfill. This is possible by eliminating part of the water of the digestate. In section 4, different alternatives of S/L separators are studied. In this case, the most effective separator is by centrifugation.

It is based in the centripetal action to separate the solid-liquid due to the differences in density. It consists of a closed system that has a cylindrical rotor with a screw turning in the same way but at different velocities to allow the sludge to be dragged until the outlet. An example of a centrifugate machine is seen in Figure 15.

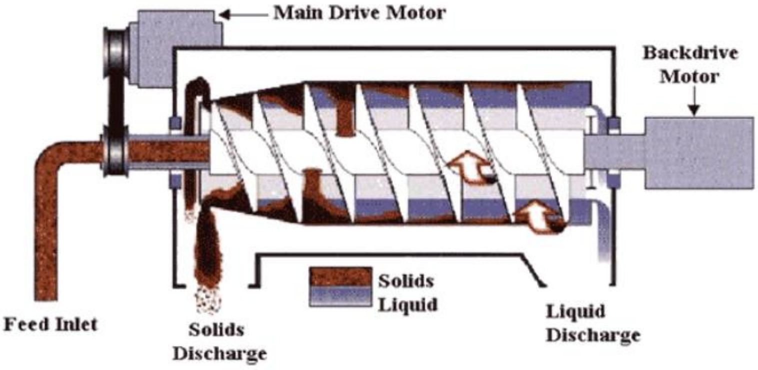

*Figure 15- Example of a centrifugate machine*[48]

The liquid obtained is called sludge liquor and has a similar composition to that obtained from the first solid/liquid separation. This technique dehydrates enough to obtain pasty products, with solids concentrations between 20 and 30%. From the Table 13 the flux of manure after the anaerobic digestion is calculated. Using

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[47] (arc-cat, 2002)

[48] (ALFA LAVAL, s.f.)

conservation of mass and considering that the final concentration of solids at outlet of the centrifugate machine is 25%, the final liquid and solid fractions are determined.

$$C_{mixture} = \frac{Q_{solid}}{Q_{Total}} \rightarrow \; Q_{solid} = \frac{Q_{manure,2}}{0.25} = 137.127\,\frac{m^3}{day}$$

$$Q_{solid} = Q_{manure,2} + Q_{liquid,manure} \rightarrow Q_{liquid,manure} = 102.847\;\frac{m^3}{day}$$

$$I_2 = Q_{manure,2} \times \; \rho_{manure} + \; \rho_{water} \times \left(Q_{liquid,manure} + Q_{liquid,2}\right) \rightarrow Q_{liquid,2} = 196.43\,\frac{m^3}{day}$$

In the following section, different situations are presented to determine the possible damages on the environment.

# 6. Environmental impact assessment

To perform the environmental impact assessment of an intensive pig farm different scenarios are presented. Waste management includes the collection, transport, recovery, and the disposal of waste. Thus, after the treatment plant, slurry is to be valorized and when there is no other alternative, to be disposed in the landfill.

With the objective of determining the effect of slurry on different scenarios, these are classified depending on the part of the ecosystem they penetrate: soil or atmosphere. Hence, some scenarios are presented to study the effect of the gases emitted by slurry and others to see how matter, in solid and liquid phase, affect the soil.

## 6.1. Environmental impact on the soil

Previously on the project it has been explained that the impact on soil is mainly due to high concentrations of elements, and mainly nitrogen. Slurry has been shown to have a high content of nitrogen in ammonia and organic nitrogen, hence being used as fertilizer since it is essential for plants growth. The concept of eutrophication and its consequences is also introduced. Therefore, in this section of the project it is desired to show how nitrogen affects the soil by presenting different scenarios, depending on the treatment previously performed on slurry.

First of all, the cycle of Nitrogen is presented in Figure 17 to get a better understanding of the different transformation and ways in which Nitrogen can be found.

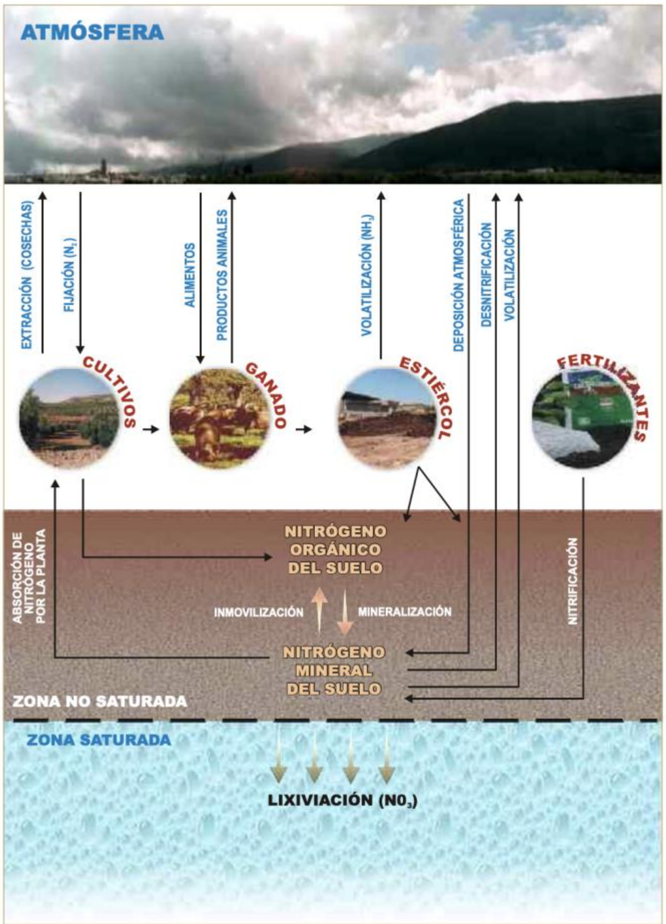

*Figure 16- Cycle of Nitrogen* [49]

The different transformations Nitrogen suffer are:

- Mineralization. Transformation of N organic into N inorganic. $NH_2 \rightarrow NH_4^+$

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[49] (IGME)

- Immobilization. Transformation of mineral nitrogen into organic nitrogen. $NO_3^- + NH_4^+ \rightarrow NH_2$
- Nitrification. Oxidation of ammonia into nitrite and nitrate due to the aerobic bacteria in the soil. $NH_4^+ \rightarrow NO_2^- \rightarrow NO_3^-$
- Denitrification. Transformation of nitrate to gas nitrogen or nitrogen oxides due to the anaerobic bacteria. $NO_3^- + NO_2^- \rightarrow N_2O \rightarrow N_2$
- Volatilization. Emission of gas ammonia to the atmosphere. If manure is not incorporated into the ground, a great part is lost due to this phenomenon. $NH_4^+ + OH^- \rightarrow NH_3 + H_2O$
- Lixiviation of nitrate is the process in which nitrate is loss from the soil due to a flux of water through it. Nitrate is not absorbed by particles in the ground, only if the soil generates a positive charge, such as acid volcanic soils and humid soils.

If the objective is to study the pollution of groundwaters, the quantities of nitrogen lost in each of the before mentioned transformations must be studied. Since it is out of the scope of the project to study all the chemical reactions that nitrogen suffer and the conditions in which they are produced, the data in Table 14 is used.

| Parameter | % |
|---|---|
| Absorbed by crop | 40-60 |
| Incorporated in organic matter of soil | 20-50 |
| In mineral form on ground | 5-20 |
| Losses due to denitrification and volatilization | 2-30 |
| Losses due to lixiviation | 2-10 |

*Table 14- Balance of N in a system soil-plant (%)*[50]

### 6.1.1. Characterization of the study of the impact on the soil

Although the liquid and solid fractions ideally are used as a fertilizer, so that the valorization of waste also provides an economical gain, to study its environmental impact it is considered that they end up in a landfill such as the one presented in Figure 17. Moreover, at 50 meters depth from the landfill, there is a groundwater that gets to a lake. In Figure 18 the total transportation nitrogen suffers is represented. The dimensions and the characteristics of the soil, the landfill and the ground water are presented.

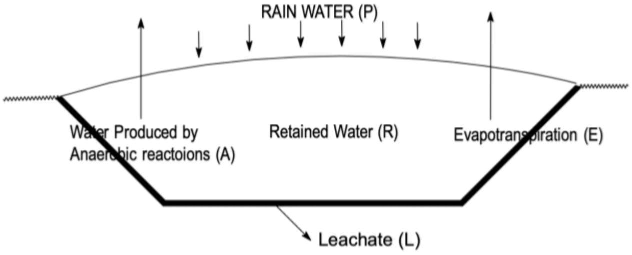

*Figure 17-Landfill water balance scheme* [51]

Characteristics of the landfill

- Field capacity (FC): 60% by mass
- Average rainfall in Lleida [52]: $P_{average} = 304 \frac{l}{m^2 \times year}$
- Evapotranspiration and anaerobic water consumption: 3 $\frac{l}{m^3 \times year}$
- Depth: d=2m

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[50] (Agroforestería, 2011)

[51] Representation obtained from an exercise of UPC lectures

[52] (Weather Spark, 2021)

Characteristics of the waste pulled into the landfill

- $Q_{waste} = Q_{liquid,1} + Q_{liquid,2} + Q_{solid} = 507.637\ \frac{m^3}{day}$
- Waste moisture content: 6.75 % by mass
- $\rho_{waste} = 1050.145\ \frac{kg}{m^3}$
- Content of Ammonia Nitrogen: 4.469 $\frac{kg\ Ammonia}{m^3\ liquid}$
- Content of Organic Nitrogen: 1.09 $\frac{kg\ Ammonia}{m^3\ liquid}$

Characteristics of soil: The soil considered for this scenario is fine sand.

- Hydraulic conductivity: $K_i = 2 \times 10^{-5}\frac{m}{s}$
- Porosity: $n = 0.38$
- Density: $\rho_{soil} = 1800\frac{kg}{m^3}$
- Depth: $Z_1 = 50m$

Characteristics of groundwater:

- Hydraulic conductivity: $K_i = 4.67 \times 10^{-4}\frac{m}{s}$
- Porosity: $n = 0.6$
- Density: $\rho_{aquifer} = 1800\frac{kg}{m^3}$
- Distance: X=2000m; $Z_2 = 35m$

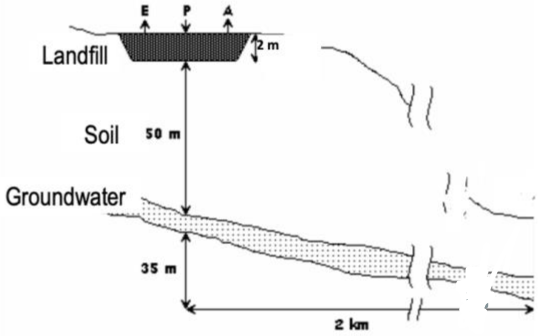

*Figure 18- Representation of Scenario 4: Lixiviation of liquid fraction of slurry* [53]

### 6.1.2. Explanation of different scenarios studied for the calculation of the pollution of soils

Four different scenarios are presented in order to see the different effects of nitrogen on the soil and how treatments might attenuate or not these effects. In this subsection, the four scenarios are presented.

Scenario 1: Slurry is not treated and is thrown in the uncontrolled landfill

Although this scenario is illegal, it is used to perform a study on the efficiency of treatments and legislations. Therefore, the flow arriving to the landfill is the one produced by pigs in the studied intensive farm once it is mixed with water, and the concentrations are the mean values of the concentrations obtained in Table 9

By using both concentrations, what it is desired is to compare the theoretical values stablished by the Spanish government and real values obtained in previous studies.

Scenario 2: The solid fraction obtained after the S/L separator is thrown in the uncontrolled landfill

In this scenario, the flux obtained from the S/L separator is thrown in the uncontrolled landfill. This scenario is hypothesized due to the transportation costs

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[53] Representation obtained from an exercise of UPC lectures

that might cause having to move to an appropriate agricultural land the solid fraction obtained from the treatment. The liquid fraction is used for cleaning means.

Scenario 3: The solid fraction is used correctly as a fertilizer in an agricultural land

In this scenario, the flux obtained from the S/L separator is valorized and used in an agricultural land, thus, a part of the nitrogen deposited to the soil is absorbed by corps. This scenario is the one approved and recommended by the Spanish government. Although the liquid fraction should also be valorized, to reduce the number of scenarios, it is assumed that it is also used for cleaning reasons.

### 6.1.3. Explanation of the calculations performed

All the calculations for the different situations have been obtained using Matlab, since with it human errors are reduced, and calculations can be performed faster.

#### *6.1.3.1. Time at which leachate starts to appear*

The following calculations are performed to find the time at which leachate start to appear, that in fact, corresponds to the time at which L=0. Using a water balance on the landfill (Equation 11), this time can be found.

$$L = P - E - A - R = 0\ (11) \rightarrow t_1 = \frac{R}{P - (E + A)}$$

- Amount of rainwater accumulated in the landfill: $P = \frac{P_{average}}{d}$
- Evaporation and water for anaerobic metabolism are assumed in the characteristics of the landfill: $E + A = 3\frac{l}{year \times m^3}$
- Water already in the sample: $w_{sample} = \frac{(100 - \%solid)}{100} \times \rho_{waste}$
- Water that can be retained: $FC = \frac{w}{w + w_{sample}} \rightarrow w$
- Retained water: $R = w - w_{sample}$

#### 6.1.3.2. Calculation of time needed for pollutant achieve the groundwater

With the aim of calculate the time needed for nitrate to achieve the groundwater, the different dispersion mechanisms of nitrate through the soil and the groundwater must be determined.

It is considered that nitrate, which is found dissolved in water, moves with the flow of water at its speed in the porous medium. This phenomenon is called advection and to perform the calculation of the velocity of the flow the Darcy's Law equation (Equation 12) is used.

$$v_{fz} = -\frac{K_i}{n} \times \frac{\Delta h}{\Delta L} \quad (12)$$

Nitrate does not suffer from adsorption and after leaching, the only process that modify the pollutant concentration is due to anaerobic degradation. However, since this degradation needs very specific conditions to happen, then the assumption that the concentration of nitrate that leaches does not suffer any modification is done. Therefore, the retardation factor is 1, meaning that the velocity of the pollutant is the same as that of the water flux. Therefore, knowing the distance between the landfill and the groundwater, and the velocity at which the contaminant flows through the soil, the time it takes to get to the groundwater is calculated with the following formula ahead:

$$v_{fz} = \frac{Z_1}{t_2} \rightarrow t_2$$

#### 6.1.3.3. Calculation of time needed for pollutant to achieve the lake

To calculate the time needed for the pollutant to achieve the lake, the same assumptions as for section 6.1.3.2. are used, but in this case the porosity and hydraulic conductivity are different. This is because, even assumed the same type of soil, in groundwaters usually the porosity is higher since there are more voids through which the liquid can move. Thus, using Darcy's law (Equation 12) and knowing the distance until the lake, the time spent until the pollutant reaches the lake is calculated.

$$v_{fx} = -\frac{K_x}{n} \times \frac{\Delta h}{\Delta L}$$

$$v_{fx} = \frac{X}{t_3} \rightarrow t_3$$

#### 6.1.3.4. *Calculation of the total time of the transportation and concentration penetrating the lake*

To find the total time of the transportation of nitrate in this scenario, the times obtained in the previous subsections must be added. Hence, the total time is of 7.92 years. The final concentration can be calculated using Table 14 and the flux and the total concentrations of Nitrogen from the waste obtained in the plant. The percentage of the initial concentration that leachate depends on each scenario.

To find the final concentration of nitrate that gets to the lake, this scenario is treated as a non-reactive dispersion mechanism. Following the continuity equation for the flow and taking considering that it is a continuous source of pollutant, the final concentration is calculated using equation 12.

$$\frac{C(x,t)}{C_o} = \frac{1}{2}\left( erfc\left[\frac{x - v_{fx}t}{2\sqrt{D_x t}}\right] + \exp\left(\frac{v_{fx} . x}{D_x}\right) erfc\left[\frac{x + v_{fx}t}{2\sqrt{D_x t}}\right]\right) \quad \textbf{(12)}$$

The longitudinal dispersion is assumed to be $\alpha_x = 7.5\, m$. Since $\left(\frac{v_{fx} \cdot x}{D_x}\right) \equiv \left(\frac{x}{\alpha_x}\right) \leq 500\ \forall\ x$, a simplification of equation 12 can be done, which results in equation 13, the one used in this scenario.

$$C(x,t) = \frac{C_0}{2} \times \left(erfc\left[\frac{x - v_{fx} \times t}{2\sqrt{(D_x \times t)}}\right]\right) \quad (13)$$

Since this formula is used for a continuous source of pollutant in 1-D and the scenario faced in this section is in 2-D, the calculations are divided into two steps. On the first step, the concentration arriving to the groundwater is calculated, using an initial constant concentration the one that gets to the sand soil after lixiviation. Therefore, with this concentration, the second step is to calculate the concentration of nitrate that gets to the lake. In this case, it is considered that the initial concentration is the one getting to the groundwater, calculated in step one.

Calculation of the concentration arriving to the groundwater

$$C_0 = \%Lixiviation \times (C_{ammonia} + C_{organic})$$

$$C(z, t_2) = \frac{C_0}{2} \times \left( erfc\left[\frac{z - v_{fz} \times t}{2\sqrt{(D_z \times t)}}\right]\right)$$

Calculation of the concentration arriving to the lake:

$$C_0 = C(50\ m, 913420.8\ s)$$

$$C(x, t_3\ ) = \frac{C_0}{2} \times \left( erfc\left[\frac{z - v_{fz} \times t}{2\sqrt{(D_z \times t)}}\right]\right)$$

### 6.1.4. Presentation and analysis of results

After performing the calculations, two different factors are analyzed. The first factor to analyze is the time needed for the pollutant to get to each stage of the situation. Hence, $t_1$ is the time until lixiviation starts, $t_2$ is the time the pollutant flux spends going from the floor of the landfill to the groundwater and $t_3$ is the time it spends going from the groundwater until the lake. In Figure 19 the results are observed.

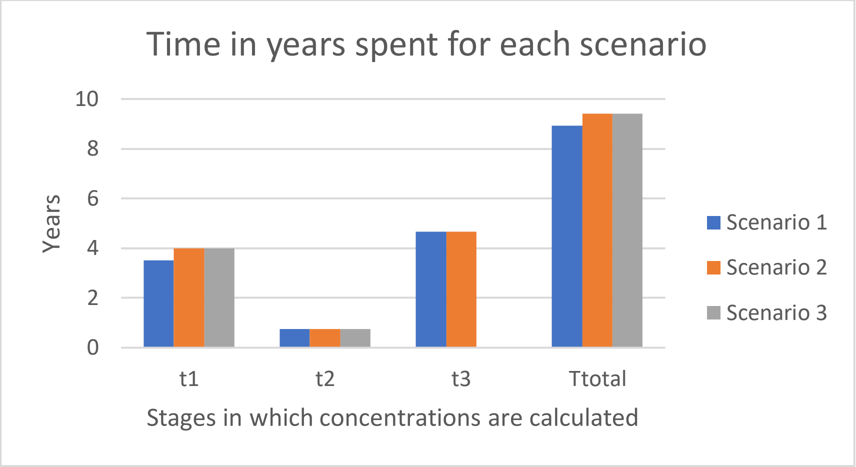

*Figure 19- Time in years spent for each scenario* [54]

The results satisfy what was expected, since for the first scenario, where the flux has lower solid fraction than for the other two, leachate appear sooner. However, difference between one case and the others are smaller than expected.

The other analyzed factor is the concentration of nitrate that achieves the groundwater $(C_1)$ and the one that gets to the lake $(C_1)$. On one hand, it can be clearly observed that in scenario 3 concentrations are the lowest since the percentage of nitrogen that leaches is lower. Therefore, there exists a notable difference between the use of slurry as a fertilizer, where a great part of the nitrogen is absorbed by plants or leaving it in a landfill.

On the other hand, it is also observed in Figure 20 that concentrations in scenario 2 are higher than in scenario 1, where no measures are taken. This can be explained with the fact that it is concentrations which are compared, and not total amounts of pollutants. Hence, since in scenario 2, separation between solid/liquid is performed, the output has a lower volume and the same amount of nitrogen, therefore, it is more concentrated. Separation is performed to reduce transportation costs but does not help eliminating nitrogen nor reducing pollution.

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[54] Graph of own creation using data in Annex IV

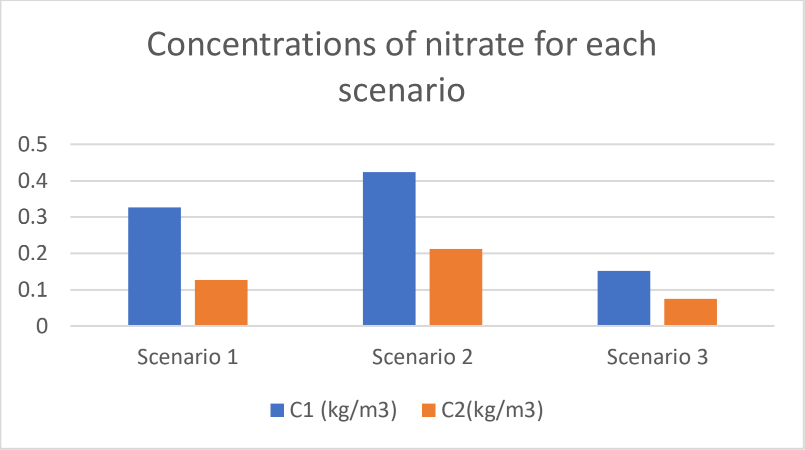

*Figure 20- Concentrations of nitrate for each scenario*[55]

Aiming to prove the aforementioned, the quantity of nitrate in kilograms per year that arrives into the lake for each scenario is calculated and embodied in Figure 21. To calculate the total quantity of nitrate, the concentration arriving to the lake has been multiplied by the flux going into the landfill.

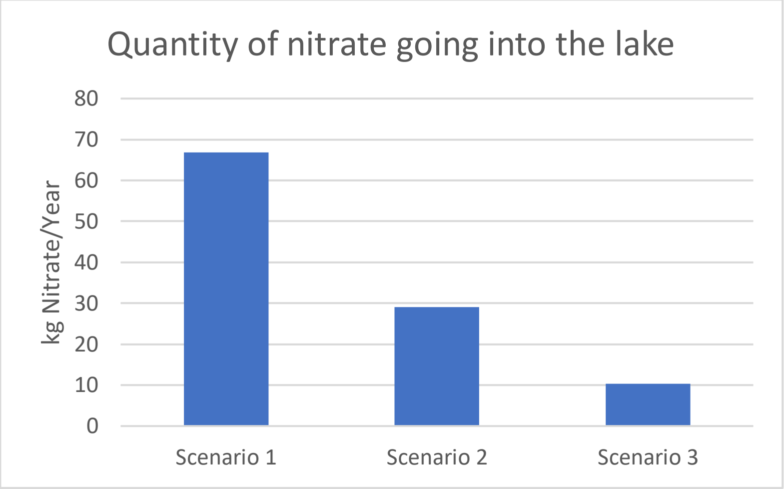

*Figure 21- Quantity of nitrate going into the lake for each scenario*[56]

As a conclusion of this section of the thesis, it can be stated that due to the time that is spent before nitrogen gets to the lake, it is possible that the groundwaters

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[55] Graph of own creation using data in Annex IV

[56] Graph of own creation using data in Annex IV

of Spain are more polluted than what it is indicated in the measures of tap water. Hence, given that in some populations the limit of nitrates is already exceeded, some additional measures for cleaning the soil should be taken.

In addition, if the study was performed with completely exactitude, the nitrogen absorbed from the atmosphere by plants should be also considered, and thus, the final concentration that leaches would be different. Therefore, the quantities obtained in the study cannot be compared to those stated on the legal frame since it is just an approximation of the reality. The solutions obtained in this section are useful to compare between treatments, and to see that in case there is a bad management of manure, leaving it into an uncontrolled landfill, cause a big pollution of aquifers. From Figure 20 it is seen that the most important factor to reduce the pollution due to nitrates is to use the digestate or the manure in lands where there are corps that will absorb part of the nitrogen.

## 6.2. Environmental impact on the atmosphere

Previously to the environmental impact assessment on the atmosphere, it has to be remarked that there exist two types of air pollutants. The primary pollutant is that emitted directly to the atmosphere through chimneys, vehicles, etc. Then the secondary pollutants are those that are created due to the chemical interaction between the primary contaminants and the natural components in the atmosphere.

Also, it is also necessary to distinguish between emission and inmission. Usually, contaminants are delivered through a source, and this process is known as emission. Once in the atmosphere, this are transported, transformed, etc. As a result of this processes, there exists a determined concentration of each pollutant. This concentration, which is independent of the source, is known as inmission level. The levels of inmission are those that determine the effect of a pollutant on health or the environment.

In the treatment plant, the biogas coming from the anaerobic digester is combusted in a charmed in order to get a valorization from slurry, which in this case gives energy. This energy can have many applications, and the most interesting from an economic point of view of an intensive farm is to use the energy produced to generate electricity or for the heating system of itself. The generation of electricity, for example, from biogas coming from slurry anaerobic digestion from an environmental point of view helps twice to the mitigation of generation of greenhouse gases: it captures methane that could flow directly to the atmosphere and replaces the use of fossil fuels to produce electricity. However, in case that the combustion chamber works correctly, there is a continuous emission of carbon dioxide to the atmosphere, which is also a pollutant gas. Therefore, to study the impact of the treatment chosen for the intensive pig farm different scenarios are presented.

### 6.2.1. Characterization of the study of the impact on the atmosphere

To perform the study, some characteristics of the environment are presented. To be consistent with the study of the impact on the soil, it is considered that the farm is in Lleida, since it is a province with a lot of farming and agricultural culture. Therefore, the average year conditions are:

- Average of wind velocity: $u = 3.11\frac{m}{s}$ [57]
- The level of radiation is usually low, and many days the sky is overcast [58]. Hence, to simplify the calculations, it is assumed that the sky completely covered.
- There is a population 5 km away from the farm and the treatment plant
- There are farmers at 20 meters from the combustion chamber
- The outlet of the smokestack is at 10 meters from the ground and has a diameter of 2 meters

It is also assumed that when the combustion of biogas is performed, there are other treatments performed to eliminate toxic elements on the gas.

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[57] (Weather Spark, 2021)

[58] (Weather Spark, 2021)

Taking into consideration the assumptions stated in this section, the different scenarios to be studied, the calculations performed, and the final results and analysis are performed.

### 6.2.2. Explanation of different scenarios studied for the calculation of the pollution of the atmosphere

Following the same procedures as for the study performed on section 6.1, different scenarios are presented to check the efficiency of the treatment plants and to study the permissiveness of the Spanish laws.

Scenario 4: Slurry is not treated and is left on an uncontrolled landfill

In this scenario, it is aimed to study the effect of not treating slurry in any way. In fact, it resembles the situations in which slurry is left on the top of agricultural lands to use them as fertilizers, when they do not go through any treatment. This causes the bacteria on the ground to decompose the matter, producing Organic Volatile Compounds, methane, and other gases in a composition found in the data on annex V.

Scenario 5: Biogas is burned in the combustion chamber to create energy

The combustion of biogas releases carbon dioxide and vapor to the atmosphere. This generates a continuous emission of carbon dioxide to the atmosphere, which is the gas that mostly contributes to the greenhouse effect given that high quantities of it are found nowadays in the atmosphere. Therefore, with this scenario a realistic point of view of the emissions produce by intensive farming are described, since the combustion of biogas is accepted and recommended by the Spanish government. In order to get a realistic comparison, the amount of carbon dioxide is compared to that of a diesel car performing the two ways trip from Tarragona to Barcelona (224 kilometers).

Air pollutants are those substances that are present in the atmosphere in higher concentrations than what it is natural. Nitrogen constitutes almost the 80% of the volume of air in normal conditions. The emissions of nitrogen from combustion are low ( $Q_{N_2} = 93.091\frac{m^3}{day}$) compared to its concentration in the atmosphere, thus, it is assumed that the gas nitrogen emissions have no impact on the environment.

Scenario 6: Biogas is generated in the installation but not burned

In this scenario, it is aimed to study the concentrations of hydrogen sulfide, that is an uncolored gas, with rotten egg smell and which can be poisonous in case it is found in high concentrations. Hence, it is assumed that it is released to the atmosphere as consequence of a leak of biogas. To do so, it is assumed that the leak happens for 24 hours. All the biogas is emitted, however, since hydrogen sulfide has toxic properties, its affectations are studied more deeply.

### 6.2.3. Explanation of the calculations performed

As for the previous subsection, where the effects of farming on soil are to be determined, all the calculations for the different situations have been obtained using Matlab, since with it human errors are reduced, and reduces the time of calculations.

#### 6.2.3.1. *Immission due to composting*

In annex V, the quantities of each pollutant delivered due to composting are shown. To see the concentration of this pollutants in the village and the farm, the Equation 16 explained before is used, but in this case, the effective height ($H_e$) is equal to zero since the emission of gases happens at the ground level. Also, Probit equation is used to check the affectations due to emissions of ammonia, which is one of the outputs of composting.

#### 6.2.3.2. *Emissions due to combustion*

From Table 12, it is known that the emission of carbon dioxide due to the combustion of biogas is $Q_{CO_2} = 6{,}496.73\ \frac{m^3}{day}$. To be able to compare it to a more palpable situation, it is compared to the emissions produced by a car (E=26.9

g/km de CO2) [59] going from Barcelona to Tarragona and back (x=224km). Hence, the equivalent number of cars doing this trajectory is:

$$N_{cars} = \frac{Q_{CO_2} \times \rho_{CO_2}}{E \times x}$$

#### 6.2.3.3. Immission due to a leak of biogas

To study the immission due to a leak of biogas, the atmospheric dispersion model is used, specifically, the gaussian model. In it, it is stated that pollutants are dispersed in the atmosphere due to the action of wind and the thermal and mechanical turbulence of the atmosphere. The atmospheric stability is the indicator of the global turbulence of the atmosphere. In the case studied, given the conditions on the environment, the atmospheric stability is of type D, since the sky is completely covered.

Since wind velocity is affected by height and the rugosity of the land. The velocity mentioned before is calculated at 10 meters height. However, as stated in the assumptions, the gases of the installation are emitted at a height of 15 meters. Then, the new velocity to be considered is calculated through equation 14. The exponent p is a factor that depends on the stability and the environment, which in the studied case is rural ($p = 0.15$).

$$u_z = u_{10} \times \left(\frac{z}{z_{10}}\right)^p \quad (14)$$

In addition, since the emission is performed through a pipe, the gas is emitted with a certain velocity and density that makes it win some height. To calculate this effective height ($H_e$) of the aigrette, the equation of Davidson and Briant (equation 15) is used.

$$\Delta H = H_e - H = D \times \left(\frac{u_f}{u}\right)^{1.4} \times \left(1 + \frac{T_f - T_a}{T_f}\right) \quad (15)$$

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[59] (Autobiz Ocasión, s.f.)

To study the damage on the population of the village close to the installations and on the farmers working there, the following equation (Equation 16), which determines the concentration of pollutant at ground level on x axis, is used:

$$C(x,0,0,H_e\ ) = \frac{Q}{(\pi\times u\times\sigma_y\times\sigma_z)}\times \exp\ (-\frac{1}{2}\times(\frac{H_e}{\sigma_z})^2 \quad (16)$$

Then, using the equation for the vulnerability to toxic substances (Equation 17) and the Probit Function (Equation 18). In Equation 18, parameters a and b depend on the toxic substance that is emitted. The percentage of affected population due to the exposition to a toxic substance can be calculated thanks to a table that relates it to the value of the Probit function.

$$V = \int_{ti}^{tf}[C(t)]^n\,dt \quad (17)$$

$$Y = a + b\times ln(V) \quad (18)$$

### 6.2.4. Presentation and analysis of results

To analyze the results obtained from the calculations, different graphs are presented in this section comparing the scenarios presented.

Firstly, the concentrations of the emissions of methane are compared in scenario 4, where there is uncontrolled composting, and in scenario 6, where biogas is accidentally emitted. These results are seen in Figure 22. The slope of the line is due to the height at which the emission happens. Therefore, for Scenario 4, the emissions are very high when close to the emitting source and decrease faster with distance. In scenario 6, where the effective height is of 10 meters, the concentration at ground level is higher at further distances due to the dispersion effect.

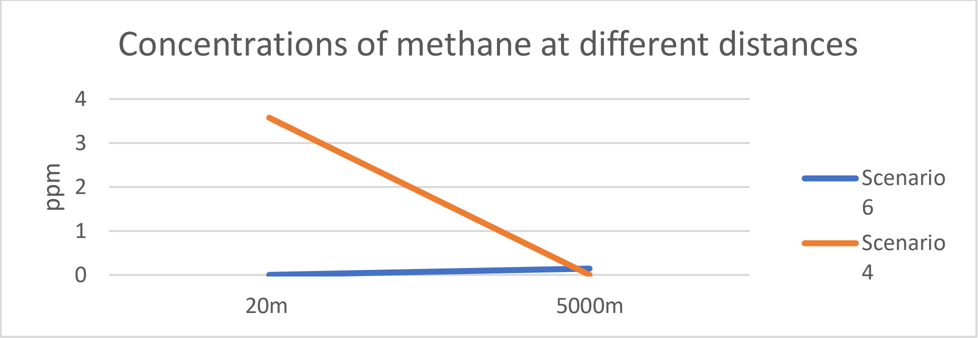

*Figure 22- Concentrations of Methane at different distances*[60]

It can be concluded that, in case composting is used, some distance measures from the source should be taken since its concentration of pollutants close to it can be dangerous for human health.

To study the emissions due to combustion of biogas, to be able to compare it to a more palpable situation, a comparison with the emissions produced by a car (26.9 g/km de CO2) [61] going from Barcelona to Tarragona and back (224km) is performed. Hence, using the formula explained in the calculation's section, it can be concluded that the emissions are equivalent to those of 2130.5 cars performing this journey. Moreover, to study the immissive power of the pollutants, concentrations emitted are compared to those in scenario 6, it can be concluded from Figure 23, that less concentrations of carbon dioxide arrive at all distances from the source. The explanation to these results is that, in scenario 6, gases are emitted in two forms, which are $CO_2$ and $CH_4$. Therefore, the concentration of carbon dioxide is less, but the total emissions, taking into account the contribution to the greenhouse effect, might be higher. In these two scenarios, both suffer from the dispersion effect since the source has a height.

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[60] Graph of own creation using data in Annex VI, VII, VIII

[61] (Autobiz Ocasión, s.f.)

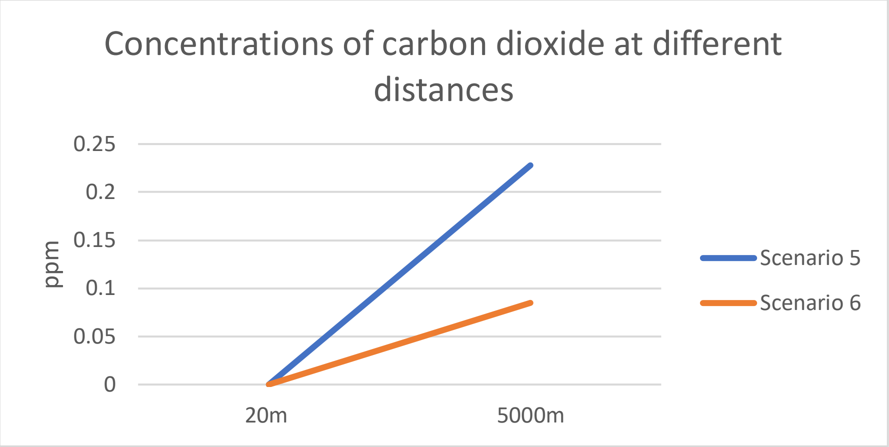

*Figure 23- Concentrations of carbon dioxide at different distances* [62]

Moreover, it is stated before that another study of interest is the concentrations in which toxic substances, such as ammonia and hydrogen sulfide are emitted. In both cases, the concentrations at which they are found in the atmosphere after its emission are not high enough to affect people. However, their emissions might contribute to other environmental effects such as acid rain and others that affect climate change. The ppms of these gases are seen in Table 15. Hydrogen sulfide is emitted in scenario 6 and ammonia in scenario 4. Hence, if combustion of biogas is performed, no toxic gases are emitted and, in any scenario, they have an immisive power.

| | **Concentration (ppm)** | |
|---|---|---|
| **Gas emitted** | 20 meters | 5000 meters |
| $H_2S$ | 3.03E-10 | 5.799E-05 |
| $NH_3$ | 153 | 0.0146 |

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[62] Graph of own creation using data in Annex VI, VII, VIII

*Table 15- Concentrations in ppm of toxic gases of different scenarios* [63]

To end up with the analysis, it also must be clarified that in composting, the concentration of Organic Volatile Compounds at 20 meters is of 78 ppm and at 5 km it is of 0,0079 ppm. Organic Volatile Compounds (OVC) can include toxic elements such as benzene, vinyl chloride and 1,2 dichloroethane. However, since the concentration of each of them cannot be determined, the toxicity of the OVC cannot be studied. Also, they have an environmental impact since they are ozone destroyers, such as carbon tetrachloride, thus affecting the phenomenon of ozone layer depletion.

As a final conclusion of the environmental impact on the atmosphere caused by intensive pig farming, it can be said that treatments performed to valorize the outputs, also help reducing the emissions of pollutants gases. By using biogas as an energetic source, the greenhouse gases emissions can be greatly reduced, since there exists a reutilization of slurry and no imported natural gas is needed. Nevertheless, this procedure still produces an amount of carbon dioxide equivalent to 2,030.5 cars doing a journey of 224 km.

# 7. Economic impact analysis of the thesis

The objective of the thesis is to do an environmental impact study of the impact of intensive farming and does not include any expected economic benefit from it.

Nevertheless, the results obtained could be sold to the government, environmental organizations or farms, especially intensive farms. Nowadays, due to digitalization, the best way to obtain profit from written papers is posting them in blogs or on Google and add advertisement on the website. Hence, from the thesis, a website can be created, and new information can be added as time passes. With this, the aim of raise awareness in-between the population can also be satisfied.

The basic expenses of creating a website are the domain, which is the unique name that identifies a web site on the Internet and hosing, that is the rental of

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[63] Graph of own creation using data in Annex VI, VII, VIII

space on the server to store the domain name of a web page. It is assumed, also, that the web site is created by a single person using WordPress, which a free web site creator[64].

Moreover, the benefits come from Google Adsense. Google Adsense pays depending on the number of clicks on banners on your website (or views on YouTube) that you get to generate these ads and the quality of them. An average income for a website that gets 100 visits per day is usually 10€ per month, about 0.1€ per click [65].

Another technique to get profit from a website is advertising firms' specialists in the sector of waste treatment, or farming techniques. In this case, since there exists high affinity between the blog and the advertiser's product, the cost for the client can exceed 1 euro CPT (Cost Per Thousand Impressions). [66]

Therefore, considering that the website is created by a designer, which asks for 1,100 € and that there is a half-time researcher working to get new studies, the Table 16 is performed to determine the cashflow of a 3-year period. It is assumed that every year the views of the website increase a 50% due to the increase in content. Also, on the second and third year, the researcher working time is reduced to 10 hours per week, which is a total of 440 hours per year. Moreover, it is chosen to work with Google Adsense for these three years, until the blog is known enough so that firms wish to advertise on it.

| | **Parameters** | **Duration** | **Y1** | **Duration** | **Y2** | **Duration** | **Y3** |
|---|---|---|---|---|---|---|---|
| **Salary of designer** | 1,100 € | Single payment | -1,100 € | | | | |

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[64] (Orbita Click, 2019)

[65] (Girón, 2022)

[66] (Bravo, s.f.)

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Salary of rescher** | 25 €/h | 880 hours | -22,250 € | 440 hours | -11,000 € | 440 hours | -11,000 € |
| **Google Adsense** | 0.1 €/click | 18,250 | 1,825 | 27,375 | 2,737.5 | 41063 | 4106.3 |
| **Cash flow (€)** | | | -21525 € | | -29787.5 € | | -36,681.3 € |

*Table 16- Net Present Value computations during time* [67]

From table 16, it can be concluded that creating a blog is not rentable in case there is a researcher working to create new content, since the cashflow tends to a more negative value. Thus, maybe the best option would be just to post the article in some free research blogs such as *ResearchGate* (https://www.researchgate.net) to spread the conclusion obtained.

# 8. Environmental and social impact analysis of the thesis

## 8.1. Environmental impact analysis of the thesis

Due to the ethics of the project, the development of the project has been thought of in order to reduce the environmental impact, but it is really difficult to make zero-waste and pollution in the lifeday. As the project consists of developing an environmental assessment, the carbon footprint of the final product is assumed to be zero. However, the carbon footprint of the process gone through to develop the analysis is not zero and has an environmental impact. In the economic study, it has been planned to have just one researcher working on it, and it is assumed that the researcher works from home since it is just a part-time work, performed in his/her extra time.

There exist two different scopes for calculating the carbon footprint for this project. The different actions, direct and indirect, from our project that might produce

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[67] Table of own creation

emissions are the heating system and the electric consumption. Hence, the indirect emissions of the project are calculated hereunder.

Electric consumption

The average electric consumption of an office is 52,5 Kwh/m².[68] Taking into account that the cubic meters that corresponds to each worker in an office is 10 and that there is only one person working on the assessment, and also that the commercializing company has a mixed electric factor of 0,45 kg CO2 /kWh [69], it can be concluded that the electric consumption is:

$$52.5\ \frac{kWh}{m^2} \times 10\ m^2 \times \frac{0.166\ kg\ CO2}{1kWh} = 87.15\ kg\frac{CO2}{year}$$

Heating system

In this case, and taking into account that this footprint is indirect, the pollution of a heating system is, in average, of 169 Kwh/m² [70] and being consistent with the working space of the researcher used for the previous calculation, the value of the heating system carbon footprint is:

$$169\ \frac{kWh}{m^2} \times 10\ m^2 \times \frac{0.2012\ kg\ CO2\ ^{71}}{1kWh} = 340.03\ kg\frac{CO2}{year}$$

Therefore, the total carbon footprint of the project per year is the sum of both, getting a total emission of $427.18\ kg\frac{CO2}{year}$.

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[68] Energía en edificios de oficinas (17th June 2015)

[69] (Valsaín, 2011)

[70] Energía en edificios de oficinas (17th June 2015)

[71] 71 (Valsaín, 2011)

## 8.2. Social impact analysis of the thesis

As stated in the introduction of the project, nowadays the meet industry is a controversial topic since there is a movement towards veganism and vegetarianism. One of the objectives of the thesis is to raise awareness of the effects on the environment that the production, in this case, of pigs' meat has.

As explained in the environmental impact, it is almost impossible to create a product with zero-waste. However, measures can be taken in order to reduce the impact. It is proved that limitations stablished by the government until now have helped reducing the waste produced by farming. Nevertheless, there still exists an important part of pollutants going into the soil, water, and atmosphere.

Thus, the objective of raising awareness is considered to be completed with the conclusions obtained in the environmental assessment. Therefore, from this project it is expected to get a reduction in the meat consumption or for the government to revise the laws in force. However, not all the social impact might be positive. This is because it is demonstrated that applying new treatments, different to the traditional ones, the impact on the environment can be reduced. These new treatments, tend to have a higher cost due to the use of new technologies and more digitalized machines. For this reason, farmers and firms working on the meat industry might not accept the results of the study.

# 9. Conclusions

In the aftermath of the calculations performed, the final conclusions of the thesis can be derived.

The first thing to conclude is that the excretions proposed by the government for the calculation of the environmental impact of farming in order to determine the measures to be taken resemble those obtained after comparing data from different experiments. The possible variations between real values and theoretical ones can be due to the different existent farming techniques, the alimentation given to the animals or the surrounding conditions.

Related to the different treatments to be performed to slurry, it has been seen that the obtention of biogas from it is the best way to valorize waste, since the economical gains are noteworthy. In fact, many sources from the government recommend this technique. However, the final outputs of this process are still prejudicial for the environment. This has helped to understand that, although a good management of waste is performed and the regulations are satisfied, there always exists an amount of substances that arrive to the environment, and which cause an imbalance equilibrium on the environment. Nevertheless, while looking for information and knowing the composition of manure and slurry it has been observed that it resembles that possibly found in food leftovers or other organic waste produced. Thus, what was thought to be a consequence of the meat industry, has turned out to be a consequence of overproduction fostered by consumerism.

One of the concerns of the thesis is due to the pollution of Spanish waters in regions in which there is a lot of livestock. After the study of the composition of the slurry and finding out that the time it takes to the pollutant to get to the superficial waters it has been concluded that the Spanish soil should be treated. The reasoning after this conclusion is that, since in the studied scenario, nitrate takes about nine years to get to the hypothesized lake, the actual pollution of Spanish soils and water is probably higher than what is measured in tap waters, and these consequences are observed years later. Therefore, to prevent future and worst scenarios, soil and water should be treated at present. The solution proposed is an in-situ heat treatment that consists of heating the polluted environment to provoke the controlled evaporation or degradation of pollutants to be later on sent to specific treatment plants. A study should previously be done to find the hot points for pollutants and therefore, apply the treatments in those zones.

Another topic for which a conclusion has been found is for the emission of gases to the atmosphere. It has been seen that although slurry goes through treatments such as anaerobic and aerobic digestion, gases that contribute to the greenhouse effect are emitted. However, the treatment applied does affect to the quantity of contribution, since in some processes methane is emitted, which has great pollution power. Therefore, the government should promote the installation of treatment plants such as the one presented on the thesis to take as much as possible profit from slurry. One proposal is to build public treatment plants so that farms that cannot afford to install an anaerobic digester or treatment process can deposit the manure produced in their farms.

Lastly, although the assessment does not have an economic benefit, it can help farmers, citizens or even the government to take right decisions about slurry management and to be conscious of the impact of not only intensive pig farming, but all types of farming.

# 10. Acknowledgements

Firstly, I would like to give a special thank you to the tutor of the thesis, Juan Jesús. Although having a lot to work, he has always had time to help me and guide me throughout the project.

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Lastly, I would like to thank my colleagues from the degree for supporting me during the whole thesis.

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