LIFE + MANEV
LIFE09 ENV/ES/000453

Evaluation of manure management systems in Europe

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Evaluation of manure management and treatment technology for environmental protection and sustainable livestock farming in Europe (LIFE09 ENV/ES/000453).

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Aragonese Society of Agro-environmental Management - SARGA (Spain) – Coordinating
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University of Milan (Italy)
Research Centre on Animal Production - CRPA (Italy)
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We want to thank everyone who has collaborated and worked on the project, especially Arturo Daudén and Christian Siegler, two pillars at the beginning and subsequent execution of the project, Reyes Fernandez for financial management and all the staff of the treatment plants evaluated for their involvement.

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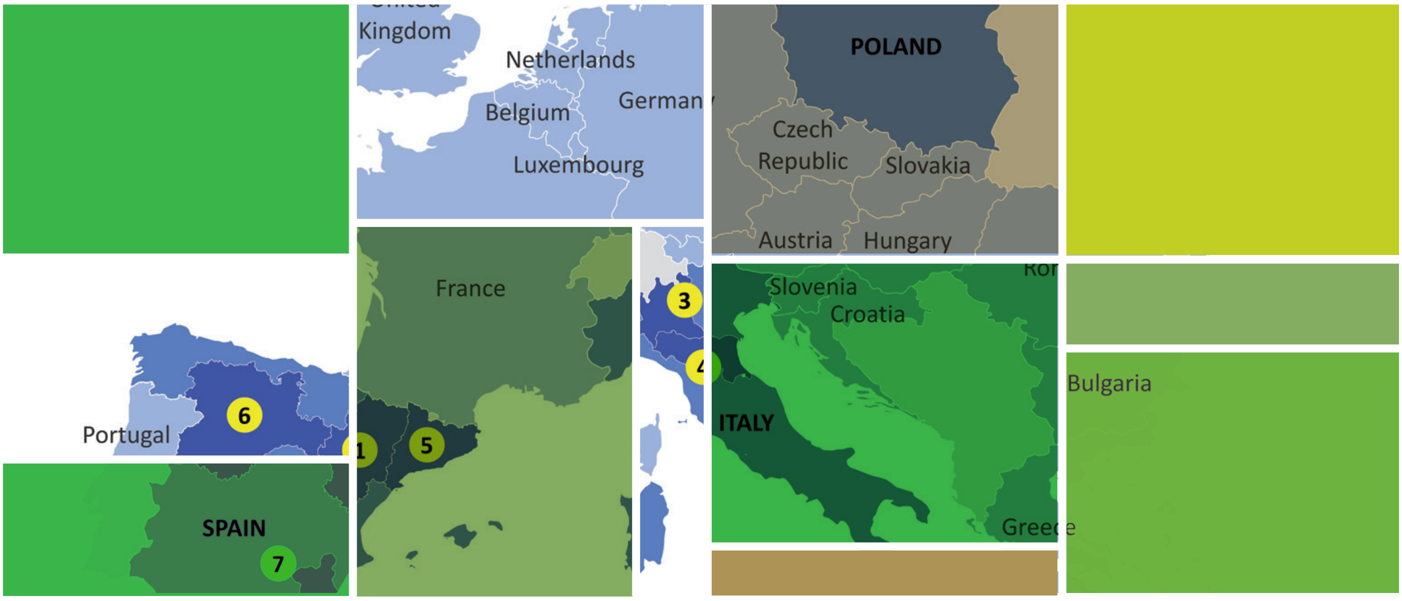

1. MANEV PROJECT: EVALUATION OF THE MANURE MANAGEMENT SYSTEMS IN EUROPE

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Marta Teresa, Eva Herrero and Berta Bescós
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INTRODUCTION

Did you know that agriculture is one of the most important economic sectors in Europe? The gross value of the agricultural goods in 2014 amounted up to 370 billion Euros. Almost 50% of all agricultural production is provided by livestock farming. The European Union is one of the world's leading producers of goods from this sector.

Yet, do you know the possible environmental problems derived from their breeding? The livestock population in Europe generates 1,400 million tonnes of manure per year; to have an idea, with this quantity, more than 650 million Olympic-size swimming pools could be filled. This large volume of manure generated is one of the aspects that most concerns public opinion, as it affects pollution and, therefore, people's health.

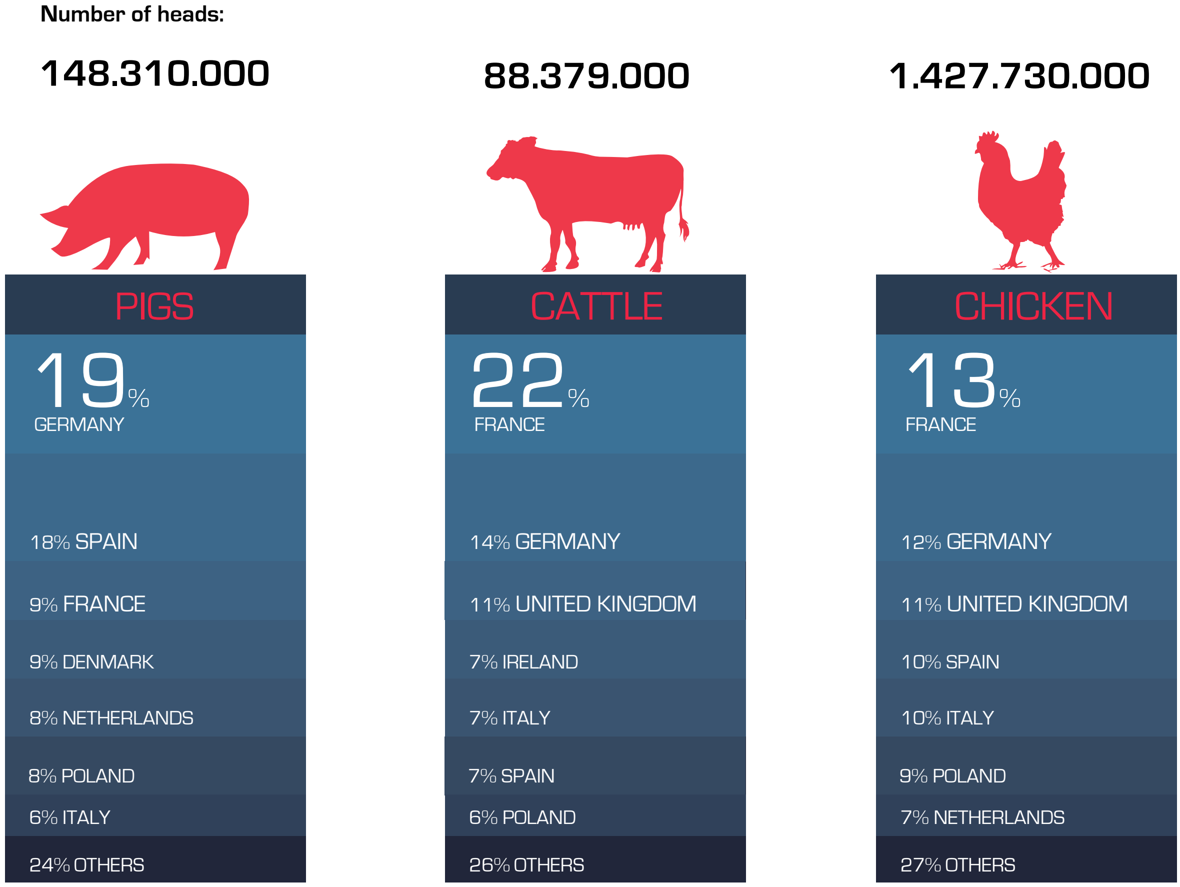


Figure 1.1. Main countries of livestock production in Europe (Eurostat and Faostat, 2014).

THE ENVIRONMENTAL PROBLEM OF MANAGING THE MANURE PRODUCED

Manure has a high potential as organic fertiliser in agriculture, due to its composition of nitrogen, phosphorus, potassium and organic matter among others.

However, the major intensification that livestock farming has undergone in the last few decades has generated large amounts of manure located in very specific areas, making it difficult to manage.

This unbalance, combined with the bad management of the manure may cause environmental problems such as groundwater nitrate contamination, eutrophication of surface waters, accumulation of metals and phosphorous in soils, spreading of pathogens, not to mention the public's dislike of its use because of the bad smell or the emissions of ammonia and greenhouse gases released into the atmosphere.

Do you know that the manure produced in Europe contains 7 million tonnes of nitrogen (N) (Leip 2011)? Nowadays 11 millions of tN of mineral fertiliser are applied to crops in Europe. If we were able to substitute part of this mineral fertiliser for manure, the environmental impact would be decreased.

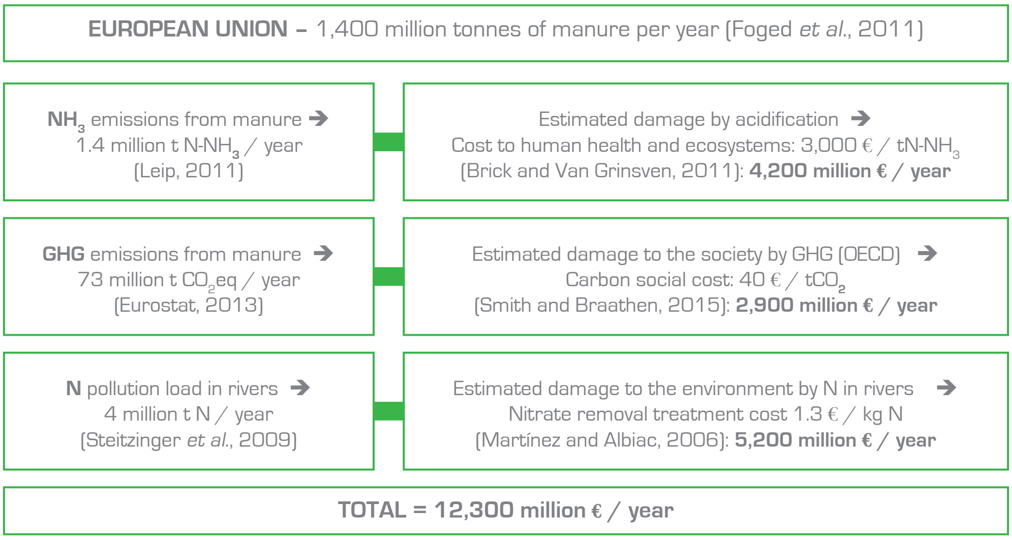
In addition, global population is increasing and it is expected that the world food demand will double by 2050. So, the challenge of reducing the environmental and economic impact of the manure management will be increasingly more important and decisive.

Do you have an idea of how important it is to carry out a proper manure management to avoid this environmental issue? To make it more understandable, it has been translated into economic data (Figure 1.2). The damage of ammonia and greenhouse gas (GHG) emissions into the atmosphere and the nitrogen that reaches the rivers has been calculated in Euros.

The pollution cost derived from manure management in Europe has been estimated in 12,300 million €/year. It is too much, isn't it? We really have to do something.

But, how can I know which is the management I can carry out on my farm? Before investing money, it is important to identify the most suitable strategy for my scenario.

Currently in Europe, there is a wide variety of manure treatments available in the market. Each one has its advantages and disadvantages. However, there is a lack of unified criteria for their implementation and, although wide scientific researches exist, there are few studies at real and large scale. Besides, the scope of these studies does not include all the aspects involved.



EUROPEAN UNION – 1,400 million tonnes of manure per year (Foged *et al.*, 2011)

NH_3 emissions from manure →
1.4 million t N-NH_3 / year
(Leip, 2011)

Estimated damage by acidification →
Cost to human health and ecosystems: 3,000 € / tN-NH_3
(Brick and Van Grinsven, 2011): **4,200 million € / year**

GHG emissions from manure →
73 million t CO_2eq / year
(Eurostat, 2013)

Estimated damage to the society by GHG (OECD) →
Carbon social cost: 40 € / tCO_2
(Smith and Braathen, 2015): **2,900 million € / year**

N pollution load in rivers →
4 million t N / year
(Steitzinger *et al.*, 2009)

Estimated damage to the environment by N in rivers →
Nitrate removal treatment cost 1.3 € / kg N
(Martínez and Albiac, 2006): **5,200 million € / year**

TOTAL = 12,300 million € / year

Figure 1.2. Estimation of the environmental impact cost derived from manure management.

LIFE+ MANEV PROJECT

With the aim of contributing to solving this situation, the LIFE+ MANEV project emerged within the framework of the European **LIFE+ Programme**. It started in 2011 and it was developed over 5 years.

The LIFE PROGRAMME is the EU's financial instrument supporting environmental and nature conservation projects throughout the EU. The general objective of LIFE is to contribute to the implementation, updating and development of the Community environment policy and legislation, in particular as regards the integration of the environment into other policies, and to its sustainable development in the Community.

European Commission

The project involves the participation of **eight partners** coming from European regions (Figure 1.3) with a major livestock production, coordinated by the Spanish public company Sarga, attached to the Department of Rural Development and Sustainability of the Government of Aragon.

1. Aragonese Society of Agro-environmental Management - SARGA (Spain) (Coordinating)
2. Aarhus University (Denmark)
3. University of Milan (Italy)
4. Research Centre on Animal Production - CRPA (Italy)
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7. Spanish National Research Council - CEBAS-CSIC (Spain)
8. Office of the Marshal of the Warmińsko-Mazurskie Voivodeship (Poland)

Figure 1.3. Partners involved in the project and their regions.

The purpose of this project is to improve the protection of the environment and the sustainability of livestock farming. In what way? Gathering the available knowledge and expertise in manure management at European level and putting it at the disposal of the stakeholders. This way, users are guided in choosing the system that better fits every agricultural scenario.

What tasks have been done to achieve this purpose within the project?

First of all, the studies on manure treatment technologies carried out in the different European regions were collected with the objective of gathering all the knowledge and expertise available so far.

Thereafter, it was necessary to create a protocol that unified the criteria and parameters in order to be able to evaluate and compare different manure treatment plants and management systems.

The Common Evaluation and Monitoring Protocol (CEMP) is a guideline that establishes the methodology for the assessment of different manure management systems in a defined scenario with the objective of obtaining comparable data around Europe. The assessment includes environmental, agronomic, energetic, economic, social, sanitary and legislative criteria (Figure 1.4) to determine the impact from a global point of view.

Figure 1.4. The 7 criteria established in the CEMP

Based on this protocol, thirteen operating treatment plants were assessed in different European scenarios. These evaluations enabled to understand better the performance of each technology and its different possible impacts.

The results have been widely disseminated not just in the regions where the project was developed, but also in other European zones through local, regional and international seminars and conferences focused on farmers, technicians, local administration and scientists. At the same time, numerous disseminative material of the project was created in different languages and is available on the web page of the project www.lifemanev.eu.

And what is the final outcome of the project?

With all this information, the MANEV tool was developed, which has the aim of supporting decision-making when implementing the best manure management system in a specific area, adapted to its needs, at European level.

MANEV is intended to be used by all the agents involved in the management of manure (Figure 1.5): Livestock breeders concerned about complying with the current legislation reducing management costs; farmers interested in obtaining a quality organic fertiliser; the local and regional administrations that work on protecting the environment, health and safety and sustainability of the agriculture and livestock sector; and the engineering companies that are focused on developing and marketing treatment technologies.

Figure 1.5. Stakeholders involved in the manure management.

The MANEV tool, available in the web page of the project, simulates the implementation of a management strategy in a scenario. A detailed report provides indicative results that let the user compare different alternatives according to the main features involved in manure management (Figure 1.4).

There are two ways of using the tool according to the user profile, the guided and the advanced mode.

1 2 3	If the user does not have technical expertise in manure treatment technologies, a guided mode will help him in the selection of the management system through a questionnaire.
⚙	The users that have the knowledge and technical expertise in manure treatment technologies can design the management system to be evaluated using the advanced mode.

What technologies can be assessed with the tool?

The tool includes more than 20 treatment technologies currently available on the market.

We have divided the technologies into four groups according to their main objectives.

TREATMENT TECHNOLOGIES
Facilitate the handling of the manure
Recovery treatments
Nutrient concentration
Nutrient removal

The **treatments that facilitate handling the manure** are the SEPARATION technologies (Figure 1.6). Manure is divided into a liquid and a solid fraction to facilitate the transport of the nutrients and its application on the field as organic fertiliser. It is also used as a step prior to other subsequent more complex treatments. There are different separation systems according to their efficiency, energy consumption and investment and maintenance costs. Choosing one or the other will depend upon the use intended for the liquid and solid fraction after the separation.

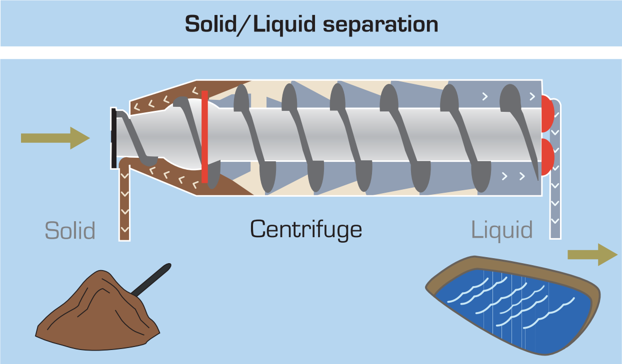

Figure 1.6. Scheme of a separation treatment.

By means of **recovery treatments**, a final product is obtained from manure with an added value in the market. One of them is COMPOSTING, a biological process in which the organic matter is stabilised and degrades into carbon dioxide and water in an aerated medium. The purpose is to obtain a stable organic and quality fertiliser for its agronomic recovery. On the other hand, biogas is obtained in the ANAEROBIC DIGESTION with the decomposition of the organic matter of the manure, in the absence of oxygen. The methane of this biogas is used to produce heat and electric energy in cogeneration engines.

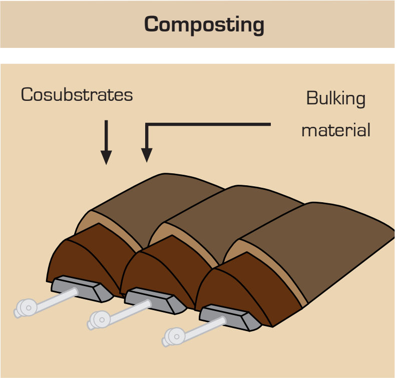

Figure 1.7. Scheme of composting treatment.

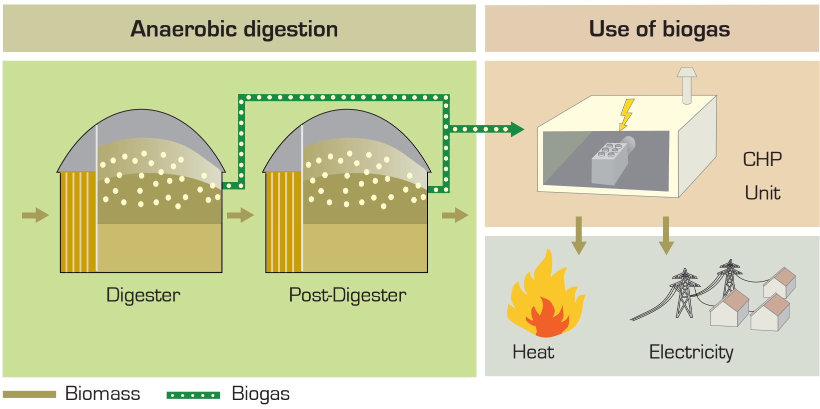

Figure 1.8. Scheme of anaerobic digestion treatment.

In **nutrient removal treatments**, part of the nitrogen contained in the liquid fraction of the manure is eliminated to reduce the nutrient load in the area. Through aeration and anoxia cycles nitrification/denitrification (N/DN), the ammoniacal nitrogen is transformed into nitrogen gas (N_2) that is naturally found in the air (Figure 1.9).

Nitrification-Denitrification

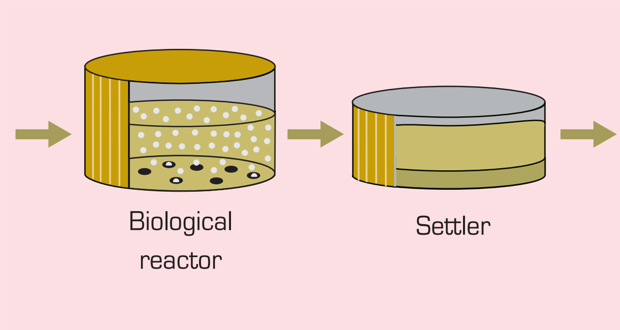

Figure 1.9. Scheme of N/DN treatment.

Nutrient concentration treatments, such as ammonia stripping, that captures the nitrogen of the liquid fraction of manure and concentrates it by means of a chemical process, turning it into a fertiliser of great value and easy to transport (Figure 1.10).

Stripping treatment

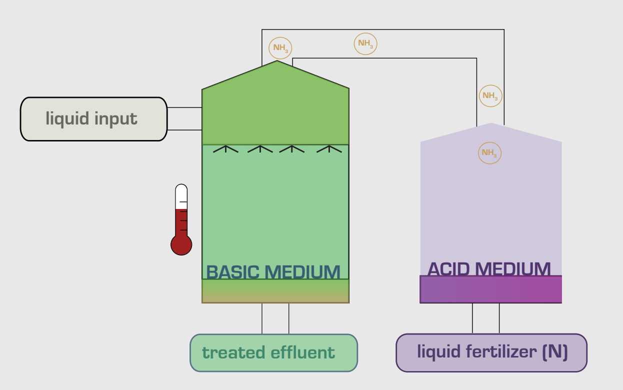

Figure 1.10. Scheme of ammonia stripping treatment.

The MANEV tool also includes **other treatments** available for the user. ACIDIFICATION, which adds an acid product to the manure that reduces the emissions of gases into the atmosphere. EVAPORATION AND THERMAL DRYING reduce the volume of manure with a thermal treatment to be subsequently managed. To treat effluents that have already been treated, there are treatments such as PHYTODEPURATION and REVERSE OSMOSIS. Manure or the products resulting from these treatments may be AGRICULTURALLY RECOVERED when applying them on the fields.

OUTLOOK OF THE LIFE+ MANEV PROJECT

Is this tool ready to evolve and be transferred to other areas?

The MANEV tool has been designed and programmed so that it can be updated and adapted to the latest technological developments in order to be operative with the passage of the time. For that reason, it is open to incorporate new treatment technologies, improve the existing ones or eliminate those which are outdated.

The configuration of the tool allows its use in all the EU member countries, as the databases that feed the system cover all this geographical area. To transfer the MANEV tool to other areas out of EU, it is necessary to update the databases, including geographic, economic and environmental data, and agronomic and social requirements implied in the new area of action.

Which is the potential of the results of the MANEV project?

The LIFE+ MANEV project intends to be a link between the scientific knowledge, the technology market and the agricultural and livestock sector. Manure management knowledge and expertise are made available to the final users to help them to improve the strategy in order to improve environmental impact in a sustainable way.

The potential of benefits from the MANEV project depends on the uptake of these technologies by the different regions and countries in the EU. However, the potential of use of the MANEV tool is very large, being able to carry out different actions which include:

- ➔ Comparative assessment in the same scenario, simulating different management systems.
- ➔ Comparative assessment for the same treatment with different quantity of manure managed, to determine economy of scale according to the unit cost of operation.
- ➔ Comparative assessment in similar scenarios but located in different countries, in order to determine how the different legal restrictions impact in the manure management options. This may result that some of the treatments are more developed in some areas than in others (i.e. biogas treatment plants).

- Comparative assessment between centralised and individual management systems.

- Assessment of the impact of a Vulnerable Zone Declaration in a new area.

- Assessment of how the market prices of the end products (compost, energy, etc.) may affect the sustainability of the management.

Which one are you interested in?

On the other hand, and bearing in mind these alternatives, the MANEV tool can be used to support policy making on sustainable agriculture and livestock at all scales (European, national, regional and/or local) as an instrument to achieve reducing pollutant emissions into the atmosphere, soil and water. The European Policies directly involved in this area are, basically, the Common Agricultural Policy (CAP), Industrial Emissions Directive (IED, 2010/75/EV), Framework Water Directive, Nitrate Directive and the Rural Development Policy 2014 -2020 of the European Commission (EC, 2013).

CONCLUSIONS

Although there are different technological options to treat manure, the selection of one or other will depend on the characteristics of the agro-farming scenario.

A deep knowledge of the technologies leads to a better identification of a correct manure management. Consequently, the implementation of these management alternatives will improve the environment and enhance the sustainability of the sector fulfilling the legal requirements.

The MANEV project unifies the know-how of the main technologies available for manure management currently working at full scale by means of homogeneous assessment based on a common protocol (CEMP). The MANEV tool gathers the state of the art of the different technologies and manure treatment systems, putting all this knowledge at the disposal of every stakeholder for their profit with the aim of minimising the environmental impacts and strengthening the livestock sector in Europe.

The manure management has **no unique solution**. The solutions should be **tailored to local conditions** and must ensure the financial viability by covering the costs of the selected combination of technologies.
The manure **land application** as an organic fertiliser is the first management option, if possible.
Substituting part of the mineral fertilisers used in Europe with organic fertiliser (manure), the environmental impact of the agriculture would be decreased.
The different **treatment technologies** are a good management strategy for the surplus areas, as they allow reducing the nitrogen and phosphorus quantity.
The **nutrient removal treatments** are an option only if there is no reuse or recycling alternative.
The **anaerobic digestion** can support the feasibility of nutrient removal treatments.
The treatment of the manure is not a solution in itself, but it is part of a proper **management system**.
The manure management system has to **be balanced** between the costs and the environmental benefits, ensuring its sustainability.
Further works in the **development and optimisation** of the treatment technologies are necessaries from the **economic** point of view, rather than to improve the treatment efficiency, which has already been demonstrated.
Successful management is achieved with the **collaboration and cooperation** of all the **stakeholders**.
It is of paramount importance for the **technology and innovation to reach the final users**.

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2. MANURE MANAGEMENT ACROSS EUROPE

2.1. CURRENT SITUATION OF THE LIVESTOCK PRODUCTION

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INTRODUCTION

The gross value added (GVA) of the agriculture in the European Union (EU-28), that in 2014 amounted to 160 billion euro, represents about 1.3% of total EU-28 gross domestic production (GDP)–(Table 2.1.1). In the same year, total agricultural goods output (gross of input) accounted a value of 369 billion euro at current producer prices. With 168 billion euro, livestock production covers a central role in the agricultural economy of the EU, totaling 45.5% of the whole value of the agricultural output. The relative importance of different animal productions varies widely among Member States, depending on pedoclimatic, economic conditions and consumption habits. However, the EU on the whole is one of the world's leading producers regarding pork, beef, poultry, milk and dairy products (Figure 2.1.1).

An overview of cattle, pigs and poultry population is provided in the major Member States and at the EU-28 level, assuming that those are the most relevant animal species when estimating the livestock sector and manure production.

	Million EUR	% total
Pigs	35,613.7	9.6
Cattle	30,559.2	8.3
Poultry	21,254.3	5.8
Other animals	8,733.2	2.4
Milk	60,884.0	16.5
Eggs	8,396.8	2.3
Other animal products	2,605.4	0.7
Animal goods products	168,046.6	45.5
Crop output	201,025.4	54.5
Agricultural goods output	369,072.0	100.0

Agricultural GVA at basic prices	159,742.1	43.2

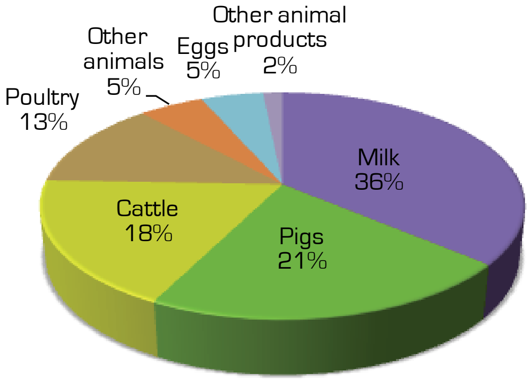

Figure 2.1.1. Distribution of the Animal goods products in the EU (Eurostat, 2014).

CATTLE

The EU has a bovine herd of around 88.38 million heads (Dec. 2014), which includes 23.57 million dairy cows and 12.09 million beef cows. Nearly 70% of the total cattle is concentrated in six **Member States** (France, Germany, UK, Ireland, Italy and Spain) that are the main beef and milk producers throughout the EU (Figure 2.1.2).

Total yearly beef production is of about 7.5 million tonnes (Figure 2.1.3) and the self-sufficiency is close to 100%. As beef and veal are concerned, the EU is the third producers worldwide, behind the USA and Brazil.

Also the dairy sector is of great importance to the EU representing a significant proportion of value of its agricultural output (16.5%). Total EU-28 milk production is estimated around 160 million tonnes (2014). Despite the steady rise of milk production in last years (Figure 2.1.4), the EU dairy herd has not been increasing proportionally as the milk yield per cow has improved.

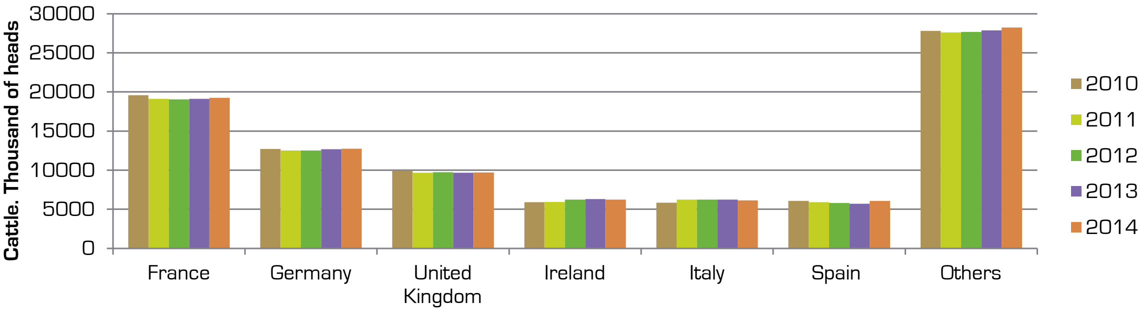

Figure 2.1.2. Cattle population in the EU-28 (,000 heads) (Eurostat).

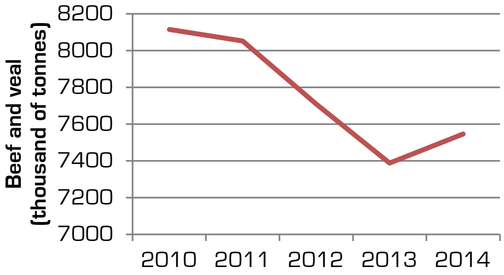

Figure 2.1.3. Beef and veal production in the EU-28 (thousand tonnes) (Eurostat).

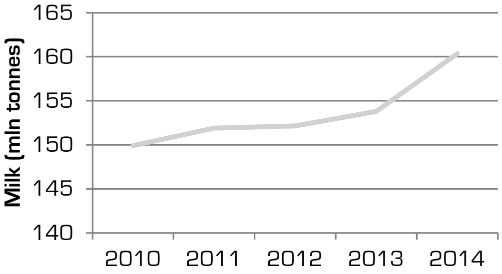

Figure 2.1.4. Milk production in the EU-28 (million tonnes) (Eurostat).

PIGS

With 150 million pigs and a yearly production of about 22 million tonnes carcass weight the EU is the world's second biggest producer of pigmeat after China and the biggest exporter of pigmeat and pigmeat products

Over the last five years, pigs livestock had decreased due primarily to the impact of the rules on animal welfare that led to a significant reduction of breeding sows herd (Figure 2.1.5).

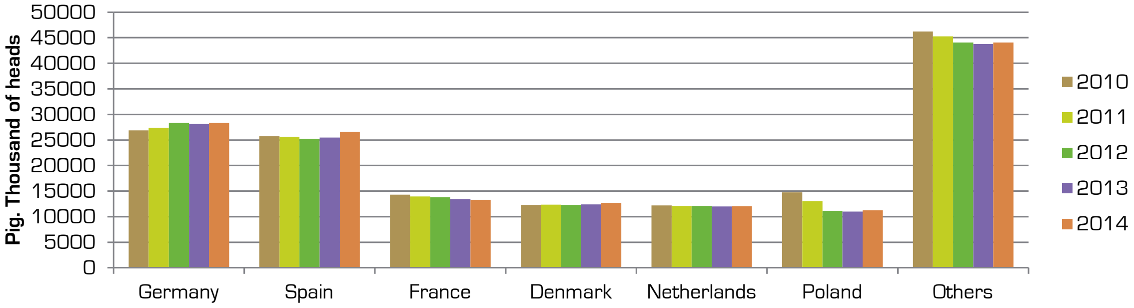

Figure 2.1.5. Pig population in the EU-28 (thousand heads) (Eurostat).

However, pigmeat production has remained stable for the productivity improvement of breeding farms (Figure 2.1.6). Main producers are Germany, Spain, France, Denmark, Netherlands and Poland which account for 70% of total pig population and pork production.

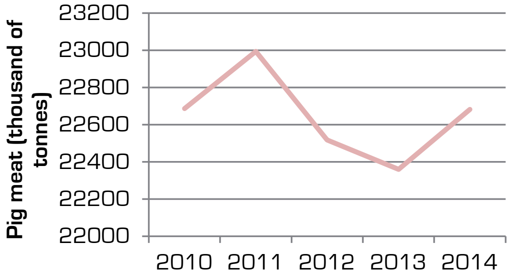

Figure 2.1.6. Pig meat production in the EU-28 (thousand heads) (Eurostat).

POULTRY

The EU is also one of the world's top producers in poultry meat (chickens and turkey), with USA, China and Brazil. Estimated production in 2014 was 12.76 million tonnes. The leading countries in this sector are France, Germany, UK, Spain, Italy and Poland, which ensure 70% of the EU production of poultry meat and 65% of the poultry flock (Figure 2.1.7).

European eggs production is an important amount of poultry economy with an average production of about 6.5 million tonnes per year. The EU-28 laying hens population in 2014 is 383 million of head (28.6% of chickens flock).

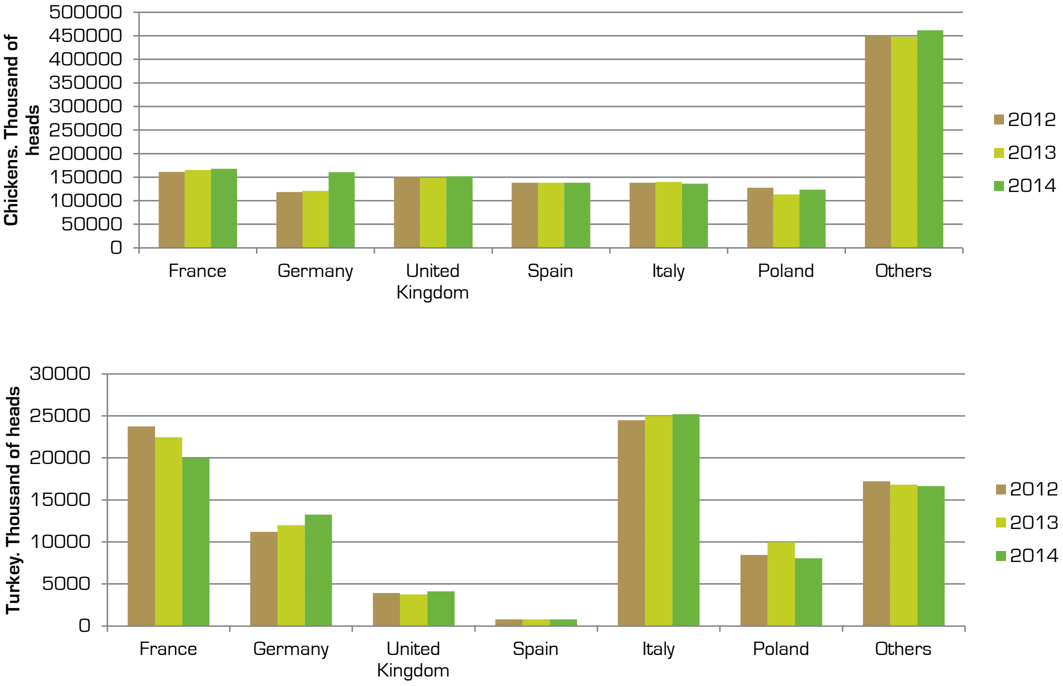

Figure 2.1.7. Poultry (sup.) and turkey (inf.) population in the EU-28 (thousand heads) (Eurostat and Faostat).

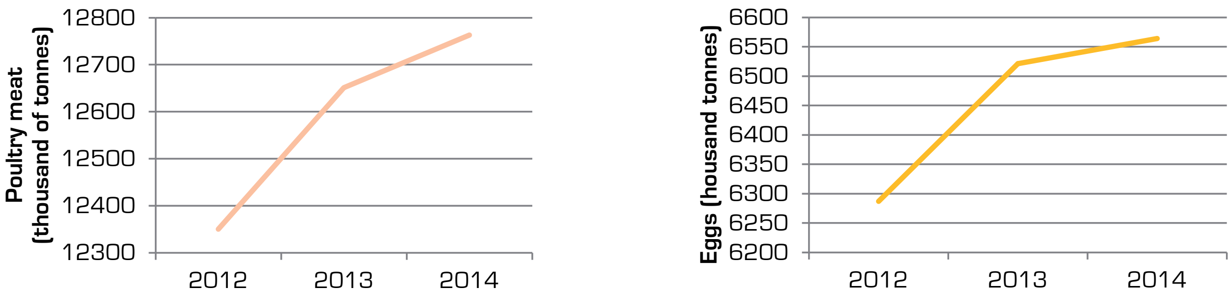

Figure 2.1.8. Eggs production (left) and poultry meat production (right) in the EU-28 (Faostat and Eurostat).

Country	Pigs	Cattle	Chicken
Austria	2,868	1,961	16,300
Belgium	6,350	2,477	36,219
Bulgaria	553	562	13,837
Croatia	1,156	441	8,716
Cyprus	342	60	3,150
Czech Republic	1,607	1,373	23,265
Denmark	12,709	1,553	14,241
Estonia	358	265	2,103
Finland	1,223	907	6,861
France	13,293	19,253	167,635
Germany	28,339	12,742	160,774
Greece	1,046	659	34,000
Hungary	3,136	802	30,075
Ireland	1,506	6,243	15,000
Italy	8,676	6,125	136,000
Latvia	349	422	4,100
Lithuania	714	737	8,820
Luxembourg	93	201	111
Malta	47	15	1,000
Netherlands	12,065	4,169	97,719
Poland	11,266	5,660	123,512
Portugal	2,127	1,549	43,000
Romania	5,042	2,069	80,136
Slovakia	642	466	11,365
Slovenia	282	468	3,172
Spain	26,568	6,079	138,000
Sweden	1,469	1,436	8,582
United Kingdom	4,486	9,693	152,000
TOTAL:	**148,311**	**88,388**	**1,339,693**

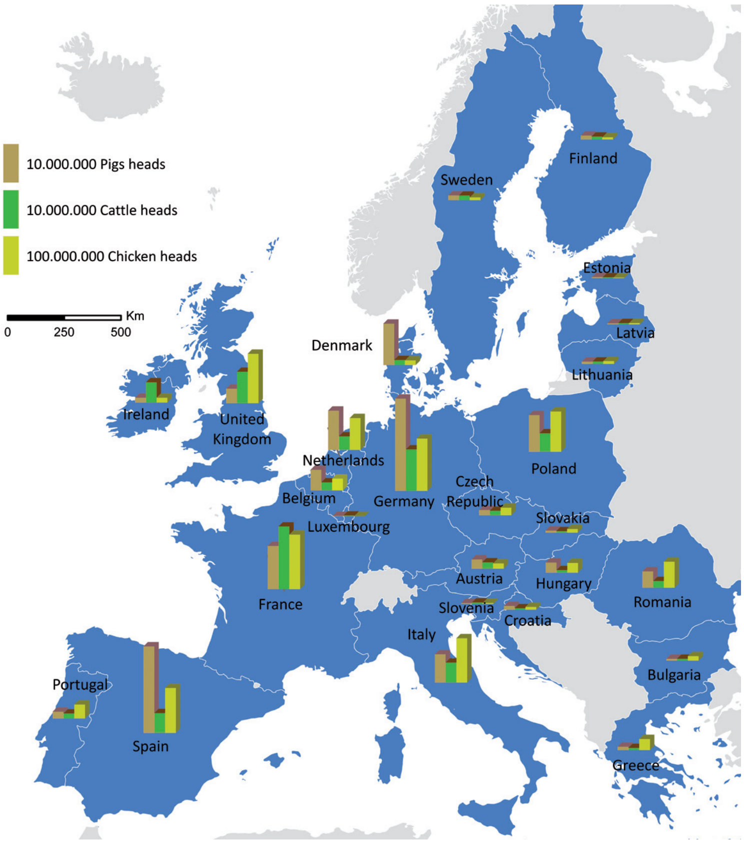

Figure 2.1.9. Overview of cattle, pigs and poultry population in the major European member states (Eurostat and Faostat, 2014).

POULTRY

The European livestock manure production has been evaluated for cattle, pigs and poultry, since these three categories produce the large majority all of the manure. Table 2.1.3 shows the estimated amount of manure produced using data on livestock population in EU-28 at 2014 and manure production factors per head and per year proposed in the *Inventory of manure processing activities in Europe* (Foged *et.al.*, 2011).

In EU-28 1,389 million tonnes of livestock manure are generated. France, Germany, United Kingdom and Spain, alone, are able to produce more than 50% of the total EU-28 manure. Eight countries produce near 80% of the total manure.

Table 2.1.3. Estimated amount of livestock manure produced in EU-28 (thousand tonnes per year) (Foget *et al.*, 2011; Eurostat).

	Pig manure	Cattle manure	Chickens manure	Total livestock manure	% on total manure	Cumulative
France	15,348	237,606	15,931	268,885	19.4%	19.4%
Germany	32,721	157,254	15,279	205,254	14.8%	34.1%
United Kingdom	5,180	119,623	14,445	139,248	10.0%	44.2%
Spain	30,675	74,907	13,115	118,697	8.5%	52.7%
Italy	10,018	75,595	12,925	98,537	7.1%	59.8%
Poland	13,007	69,855	11,738	94,600	6.8%	66.6%
Ireland	1,738	77,047	1,426	80,210	5.8%	72.4%
Netherlands	13,930	51,451	9,287	74,668	5.4%	77.7%
Belgium	7,332	30,572	3,442	41,346	3.0%	80.7%
Romania	5,821	25,533	7,616	38,970	2.8%	83.5%
Denmark	14,674	19,166	1,353	35,193	2.5%	86.1%
Others	20,796	152,091	20,761	193,648	13.9%	100.0%
TOTAL EU-28	**171,241**	**1,090,700**	**127,317**	**1,389,257**		

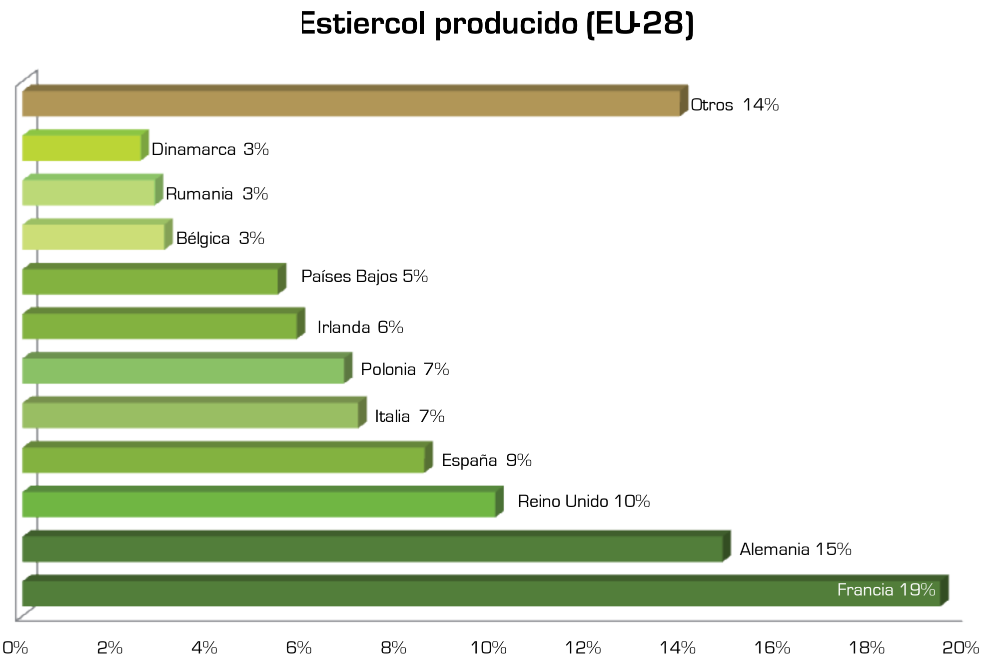

Table 2.1.10. Livestock manure produced in EU-28 (Foget et al., 2011; Eurostat).

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2.2. ENVIRONMENTAL IMPACT OF THE MANURE MANAGEMENT

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INTRODUCTION

Traditional farming was based on small installations where the environmental problems due to manure accumulation were minimal, since animal excreta were fertilizing the soil while animal were feeding from pasture, with the total integration between livestock and agriculture. The current intensive production systems have led to increase the size of the livestock farms in order to increase its production efficiency (Burton and Turner, 2003). The consequence is the generation of large amounts of waste within localized areas, where the available agricultural land for manure application is limited, which lead to an excess of manure that is not able to absorb the local agriculture.

The generation of excess of manure in specific areas, their accumulation and indiscriminate use in soils pose serious risks of contamination in soils, water and the atmosphere. The main problem at the environmental level focuses on different aspects: pollution of groundwaters; eutrophication of surface waters; accumulation of nutrients in the soil; dispersion of pathogens; accumulation of toxic compounds (heavy metals, etc.); ammonia acidification; greenhouse gas emissions; odours, dust and noise.

Figure 2.2.1. Spill of pig slurry in a ravine.

SOIL POLLUTION

The accidental spills and the places of manure storage in farms and the processing plants are the sources of soil contamination, but misuse of the manure in agricultural soils is considered to be the main cause. The accumulation of nutrients and organic matter in the soil is due to the inadequate or excessive use of manures in agricultural soils. Manures are not equilibrated fertiliser materials, then, their agronomical application based on the amount of an specific nutrient provided, can imply the application of other nutrients in excess to the crop requirements, which may be build up in the soil.

Nitrogen is one of the elements that can cause pollution by improper application of manures to the soil. The nitrogen from manures includes inorganic forms (mainly ammonium) and organic compounds which need to be mineralised for being available to plants. The mineralisation process implies the transformation of organic forms into ammonium and nitrate by the microorganisms, the size and extend depends on the manure characteristics, environmental factors (moisture and temperature), and characteristics and soil use. The main reactions can be summarised as:

- Ammonification: transformation of organic-N into ammonium through the action of a wide variety of microorganisms and enzymes.

- Nitrification: oxidation of ammonium into nitrate. The process occurs in two main steps by specialised microorganisms, mediated by nitrite formation.

A rapid and excessive formation of N-inorganic (exceeding the requirements of the plants) can cause loss of N, by volatilisation as ammonia (accumulation of ammonium to high soil pH), or by leaching of nitrates, with the consequent risk of water pollution.

The **phosphorus** in the manure is present in both organic and inorganic forms, but the organic fraction is hydrolysed rapidly, so the availability of P in the manure and slurry can reach 90-100 % of the total concentration. However, the inorganic P present or formed by mineralisation of the organic fraction can be easily precipitated in the soil, mostly calcareous, or adsorbed by the soil minerals. Although N and P concentrations of the manures can be considered as a valuable source of nutrients, however, their N/P ratio is generally lower than the required for plant nutrition. Then, the application of manures to soil according to N crop requirements can produce a relevant accumulation of P in the soil (Cabrera and Sims, 2000). Then, the P criteria should be also considered for the application of manures to agricultural soils to prevent excessive P accumulation. Phosphorus is one of the nutrients less mobile in the soil profile, since phosphates form insoluble iron and aluminum in acid soils and calcium in the alkaline soil, so the risk of leaching and contamination of waters by runoff, are generally lower than for nitrogen. In calcareous soils, 40 % of total P of pig manure can be fixed in the soil as non-available forms, such as insoluble calcium phosphate, which could reach 70 % at high doses of application (Bernal *et al*., 1993a). However, between 8-13 % of P from pig slurry can be infiltrated into the soil profile, reaching 90 cm depth in acid soils (Vetter and Steffens, 1981). The risk of contamination is related to the processes of surface runoff after application of slurry or manure in high proportions and associated with rainfall events. Then, excess application of manure for long period can build-up the P concentration in the soil, with high risk of surface waters pollution.

In the manures, **potassium** occurs mainly in soluble forms, which is often retained in the soil exchange complex and its dynamic is closely linked to the types of clays. In an agricultural system, the plant roots absorb potassium from the soil solution, shifting the equilibrium towards its solubilisation from the exchangeable forms. The application of manure and slurry provides this element in soluble form, which quickly interacts with the soil exchange complex, so it is often retained in the surface layer of the soil with low leaching, especially in clayey soils with illite type (Bernal *et al*., 1993b), which retains K in hardly exchangeable forms. However, in sandy soils, an over-application of manure or mainly slurries can cause an increase in soluble salts at the surface of the soil, due to the K and Na concentrations, and these soils are more susceptible to K leach.

The animal manures can be considered a source of **organic matter** improving soil fertility. The positive effect of the organic matter in the soil is due to the increase in the availability of nutrients, soil respiration, enzyme activities, microbial biomass and improvement of the structure of the soil, preventing erosion, and improving water holding capacity and soil water conditions. However, the incorporation into the soil of excessive amounts of organic matter from manures, can cause, if not previously stabilised, conditions of anoxia in the soil, due to its fast microbial degradation (O_2 consumption and CO_2 production). Under anaerobic conditions, the degradation of organic matter produces toxic compounds to plants (organic acids) or pollutants to the atmosphere. Then, the lack of oxygen in the soil and the presence of organic acids adversely affect the respiration of the roots, its growth and development. In addition there are various soil properties that are affected negatively: blockage of pores, limitation of the permeability, the water infiltration, etc., giving as a result a loss of physical soil fertility. Other risk of soil pollution associated to direct manure application is the heavy metal accumulation. The concentration of heavy metals in manures is highly variable and is related to the composition of the animal food. The highest concentrations are found for copper and zinc in pig manure (Moral *et al*., 2008), especially from piglets as these elements are frequently incorporated in the diet for avoiding digestion problems. Their potentially toxicity is due to their cumulative nature and their subsequent risk of entry into the food chain. The dynamics of heavy metals in the soil depends on the characteristics of the manure, of the soil, such as: pH, texture, organic matter, and the presence of oxides of iron, aluminum and manganese. Therefore, the risk associated with the soil application of **heavy metals** is greater in acid soils with low cation exchange capacity. The greater the retention of heavy metals in soil and the lower both the absorption by the plant and its leaching to groundwater.


Figure 2.2.2. Pig manure spread in a crop field.

The major soluble ions excreted in the urine are Na^+, K^+, Ca^{2+}, Mg^{2+}, Cl^- and SO_4^{2-}, which are especially available in slurries by their liquid character (Moral *et al*., 2008). Soil **salinisation** problems may be especially important when these wastes are applied to arid or semi-arid areas where climatic conditions, high evapotranspiration and scarce rainfall, lead to significant salt accumulation on the soil surface, after the application of high amount of slurry

(Bernal *et al.*, 1992). However, there is no risk of sodification, due to the higher proportion of K^+ to Na^+ in the manure, together with the favourable retention of K in the soil exchange complex. All this favours the retention of K in the complex instead of Na^+, which mainly remains in the soil solution, and can be washed by rain water. Soil salinity problems not only affect the development of certain plant species, particularly salt sensitive, but also the biological activity of the soil and the soil structure by the dispersing effect of sodium which causes soil compaction.

There are **other problems** associated with the soil application of manure, such as seeds of weeds that compete with crops; traces of xenobiotic compounds (remains of additives and medications) can be found in manures which can accumulate in the soil causing pollution problems. Also, manure and slurry, are not sterile materials microbiologically and contain a typical bacterial flora of the digestive tract of animals. Contain vegetative pathogenic bacteria, as well as spores, viruses with different chemical and thermal resistance as well as parasites in different infectious states, all of them represent high **epidemiological risk** (Martens and Böhm, 2009). The main parameters that determine the risk of pathogens dispersion from manure are: the amount of animal excreta; the number of bacteria present in the manure; the degree of dilution; and the capacity of the microorganisms to survive in manure, soil, water or environment (Burton and Turner, 2003).

WATER POLLUTION

The pollution of water bodies occurs primarily by infiltration and runoff, resulting in contamination of groundwater and surface waters, respectively. The runoff is produced by the contribution of large volumes of waste in saturated or impermeable soils, or the overflow and leakage from the storage system. Surface runoff pollution happens mainly in the first days after the application of manure, during large rainfall events. The organic fraction of the waste reach surface waters; then, in most countries specific legislation regulates the application times of manures and slurries. To avoid infiltrations, solid manure should be stored on a waterproof surface with leachate collection system. After soil application, the risk of nitrate leaching exists during the year and cumulatively in subsequent years. Indeed, animal effluent can cause degradation of water resources, both surface and deep, if not handled properly. The use of farming systems that maximize the use of nutrients from the soil can reduce potential contamination of the waters.

Nitrate accumulation is the main problem of groundwater pollution, due to nitrate leaching as a consequence to the high mobility of this anion in the soil profile. In certain specific areas the concentration can exceed the limit established for human consumption (50 mg/l). The amount of manure that is applied, the type of soil and its physical properties which might influence the mobility of ions in the profile (permeability, texture), the climatology of the place of application and the agronomic practices (crop type and the time of application) will condition the risk of nitrate leaching. In addition, the mineralisation dynamics of the manure determines the formation of the highly mobile forms of N, nitrate. In spring, the high plant growth requires great absorption of water and nitrogen, which reduces the nitrogen content in the soil, also, less rainfall during the summer makes to progressively decrease the water flow from drains and surface aquifers, reducing the pollution of groundwater. The reverse situation occurs in autumn: abundant surface water flow and low nitrogen uptake by crops which, together with the mineralisation of crop residues, can cause an increase in the concentration of nitrates in the soil (Cann, 1993).

With respect to the risk of **eutrophication** of surface waters due to runoff, both organic matter and nutrients (especially nitrogen and phosphorus) from manure and slurry are responsible for this pollution. Events of heavy rain immediately after the application of manure or slurry to soil are mainly associated with nutrient loss by surface runoff, instead of leaching. In addition, the input of organic matter from the manure and slurry in water courses can cause lack of oxygen in the aquatic environment with the consequent development of odours and reduction of biodiversity. Contamination by runoff happens mainly through the drag of particulate material, so the concentrations of soluble N in suspension and the type of manure are particularly important in this risk of contamination. Similarly to the contamination by nitrate leaching, surface runoff is greater in winter than in spring and tilla-

Figure 2.2.3. Eutrophication in surface water.

ge practices can minimise the risk of water pollution by surface runoff. Thus, strategies to reduce the risk of N pollution by surface runoff included limiting the amount of manure in each application (50 m^3/ha) and applying the manure through injection or immediate incorporation (Sørensen and Jensen, 2013). In addition, some manure treatments reduce the concentration of NH_4-N, such as composting, with a partial immobilization in organic-N forms, or the solid-liquid separation, whose solid fraction with low particulate content facilitates its incorporation into the soil (Sørensen and Jensen, 2013).

AIR POLLUTION

Within the main environmental impacts result of livestock production are the emissions of ammonia and GHG (methane, nitrous oxide and carbon dioxide), as well as of odours, dust, volatile organic compounds and microorganisms in the form of aerosols.

Figure 2.2.3. . Slurry splash-plate application.

In addition to being an atmospheric pollutant, **ammonia** contributes significantly to the acid rain. The loss of ammonia to the atmosphere occurs from animal housing, manure storage facilities and from the manure application to land. Approximately 50 % of the ammonia emissions from pig production originate from the shelter and the slurry storage, while the other 50 % is emitted following soil application (Martínez *et al.*, 2009). The emission of NH_3 from the soil after manure application depends on the NH_4^+ adsorption processes in the soil and in the organic fraction of manure, in addition to the physical processes that control the movement of the liquid in the soil fraction and its interaction with the cation exchange capacity of the soil. Emissions vary from virtually non-existent, to more than 50% of the NH_4+-N added, depending on the type of manure, the environmental conditions (temperature, wind, and rain) and the properties of the soil ($CaCO_3$, cation exchange capacity, pH, etc.). Biological processes of N transformation have low influence, due to the short duration of the NH_3 emissions after the application of manure.

The livestock sector represents a significant source of **greenhouse gas** (GHG) emissions worldwide, generating carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O) throughout the production process. GHG are emitted either directly (e.g. from enteric fermentation and manure management) or indirectly (e.g. from feed-production activities and conversion of forest into pasture); the contribution of the livestock supply chain amounts to 7.1 Gt CO_2-eq, with the direct emissions have been estimated to contribute with 5.4 Gt CO_2-eq to the global emissions (FAO, 2013a; FAO 2013b). Cattle (beef and dairy) are considered the dominant livestock sector contributing to GHG emissions (4.6 Gt), the value drops to a still significant 3.3 Gt (71 % of the total) when only the direct CH_4 and N_2O emissions from enteric fermentation and manure are considered; 25 % correspond to N2O emissions and 4 % to CH_4 from manure (FAO, 2013b). Other livestock species have much lower levels of emissions, such as pigs (0.7 Gt CO_2-eq) and poultry (0.7 Gt CO_2-eq), even when considering the full lifecycle of emissions (FAO, 2013a and 2013b).

The GHG balance of manure management reflects a multitude of microbial activities: emissions of methane (CH_4) are the net result of methanogenesis and CH_4 oxidation; nitrous oxide (N_2O) is a product of several processes, but may also be consumed via denitrification before escaping to the atmosphere; and the carbon dioxide (CO_2) balance is influenced by manures via (net) soil carbon stock changes upon field deposition and any production of bioenergy. Animal feed (fibre and protein contents); the animal livestock; the animal housing; the manure storage system; manure characteristics; and the environmental conditions are factors affecting CH_4 and N_2O emissions. Whereas CH_4 production and oxidation processes are associated with anoxic and oxic conditions, respectively, emissions of N_2O are stimulated under O_2-limited conditions (Sommer *et al.*, 2013). Then the mitigation strategies should be developed in all the stages of the livestock production system, from the animal feed, manure storage and treatment to soil application strategies.

Emissions of **odours** and **dust** are the most sensitive for the population due to their direct perception. Its origin can be clearly identified (stationary sources) from the houses and storage, or they can be temporal, such as those produced during the agricultural application of manure and slurries or during their treatment. Odours originated primarily from biological degradation of the substances contained in the excretions of livestock by formation of different gases and very different quantity (Batlló, 1993). The emissions of smells depend on the composition of the manure, the characteristics of the farm, the climatic conditions of the area and the distribution and application procedures of the manures.

Transmission of **pathogens** from the manure by airway occurs through aerosols (Millner, 2009), arising on farms, and during land manure application. Under specific conditions (wind and rain) the microorganisms may disperse over large distances (Salmonella can survive for 2 hours in aerosols). The application of slurry by soil injection drastically reduces the formation of aerosols and thus the spread of pathogenic microorganisms and odours in the air.

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2.3. OVERVIEW OF THE CURRENT SITUATION OF THE MANURE MANAGEMENT ACROSS EUROPE

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INTRODUCTION

Manure produced by animal in confined environment has to be removed from the animal area and then can be processed, stored, transported and applied to the soil.

Manure management include all the phases from manure generation to final use (Figure 2.3.1). Therefore also feeding strategies to limit nutrient excretion are generally included in manure management. Most of the solid and liquid manure produced is then stored. Requirement for storage capacities for liquid slurry is frequently six months but there are variations according to the country and the environmental risks. In some northern European countries, the storage capacity rises to nine months and in other situations is reduced to 3 months.

- To obtain a product easier to manage, for example by separating the solid fraction from liquid slurry;

- To stabilise the manure and obtain better fertiliser and reduce odours, for example by composting the solid manure;

- To reduce the nutrient content of the manure and comply with regulation, for example with aerobic process for nitrogen removal;

- To produce energy, for example with anaerobic digestion and biogas recovery.

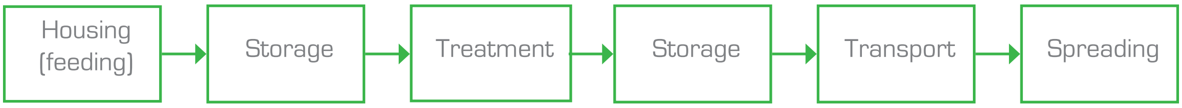

Figure 2.3.1. Different phases of manure management.

The type of storage can be very different according to the animal type, the housing system and the climatic conditions. Thus in some area internal pit under slatted floor is a common storage although new buildings should limit this solution due to the high ammonia emissions. Many farms use a liquid manure store outside farm buildings, but the shape, the building material and the presence of a coverage are variable. In southern countries lagoons and lining ponds are used, but the most common systems are tanks that can be built above ground, partly submerged or they could be completely underground.

Solid manure is often kept in heaps on a contained concrete pad, although in some countries temporary field heaps are allowed. Deep-litter manure is often stored in the animal house until it can be spread, but in some case, it has to be stored on an external platform for some months.

Manure before being stored can be processed for several purposes. The main objectives of manure treatments are:

There are several technologies available to process solid and liquid manure and their diffusion is often limited to some country. A good overview of the manure treatment systems used in Europe can be found in the reports of the project “Manure Processing Activities in Europe” (Foged *et al.*, 2011) that contains the results of a survey in different countries about the application of different techniques.

Generally, the amount of manure treated by a single technology in Europe is limited and well below the 10% of the total manure produced.

One of the most common technologies is the separation of solids from liquid manure (Figure 2.3.2).

Separation comprises mechanical, chemical and other technologies for active separation of slurries. Altogether, the report estimate more than 11,000 installations treating around the 3% of the entire livestock manure production in EU. The most used technology is separation

Figure 2.3.2. Phase separation (screw press). View of solid fraction.

by drum filters. The survey reports that the separation is most used in Italy where this technique is used to treat 24% of livestock manure produced.Use of additives and other pre/1st treatments is not often used (0.5% of the entire livestock manure production in EU).

Anaerobic treatment comprises mesophile and thermophile processes. According to the cited survey, anaerobic treatment happens on 5,256 installations the 6.4% of the entire livestock manure production in EU. The share increases in some countries and in Germany reach the 19% of the manure produced in the country. In these cases legislation and incentives applied in every country are a key factor.

Treatment of the solid fraction comprises composting, drying and combustion. Altogether these processes apply to 0.8% of the entire livestock manure production in EU. They are mostly used in Spain where 3 % of the manure production in the country is processed.

The liquid fraction of the manure after separation, as well as diluted slurries, can be processed with technologies to obtain a volume reduction (reverse osmosis, concentration), a more stabilised product (aeration, ozonisation), and/or, a reduction of nitrogen content in the liquid (ammonia stripping and absorption, nitrification-denitrification). The amount of manure treated with these technologies reported by the survey is the 0.7% of the entire livestock manure production in EU. These treatments seems to be applied to the 3.9% of the livestock manure production in Spain, but with a relative limited number of plants (87) while the higher number of installations are in France (215). The most common process of this group is nitrification-denitrification. In total it is being processed 7.8% of the livestock manure production in the EU. The different processes are often combined in an installation and a separation step is often present at the beginning of the process chain and in some cases after anaerobic digestion.

The survey highlights how the anaerobic digestion and the consequent biogas production give often the possibility to introduce other manure processing technologies. In fact, the benefit of energy production can compensate the investments for other technologies that can convert digestate in products with more suitable properties for land spreading (reduction of nitrogen, stabilisation) or with characteristics more accepted by the market (composting).

Some of the treatment plants process manure produced by different farms. The aggregation of farms in a consortium or cooperative facility have the advantage of achieving reductions of costs and allowing a more effective operation of the plant (Figure 2.3.3). By contrast, the transfer of the effluents from and towards farms is an operation that must be carefully evaluated also for the

Figure 2.3.3. View of a collective treatment plant in Bergamo province (Martinengo, Lombardy, Italy).

possible emissions to the environment.Transport of manure can be carried out with different systems: i) tractors and slurry tankers or trailers, ii) trucks, iii) pipeline. The system more frequently used is road transportation.

Land spreading (or exportation to other farms or enterprises) is the final step of manure management. Application to soil is an operation that can be carried out with different technologies according to the soil type and condition, the period of the year and the cropping system used. Also if it has not been possible to find suitable statistics, there is a clear trend towards techniques that incorporate the manure directly or soon after spreading, in order to minimise the ammonia and odour emissions, increasing the efficiency of the nutrients applied.

Regarding nutrient use, it has to be emphasized that inefficient use of fertilisers leads to the accumulation of nutrients in areas of intense agricultural activities and can cause serious environmental problems in these areas and beyond. As highlighted during the final conference of the project "Resource Efficiency in Practice - Closing Mineral Cycles" (http://mineral-cycles.eu), to close mineral cycles there is a need for: i) an integrated and holistic approach, taking all environmental media into account, ii) an increased use of innovative practices and solutions, and iii) the enhanced implementation of existing policies, aiming at reducing pollution at its source.

The adoption of suitable treatments is getting an increasing attention as a possible mean to reduce nutrient surplus and to better balance nutrient application considering the possibility to extract nutrients (especially nitrogen and phosphorus) when they are exceeding crop requirement of the farm and export them to other areas where there is a lack of nutrients and organic matter. However, it has to be emphasized that manure processing cannot be the solutions of the problem but it is a component of a management system that must have a whole-farm approach.

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"Resource Efficiency in Practice - Closing Mineral Cycles" (http://mineral-cycles.eu)

3. COMMON EVALUATION AND MONITORING PROTOCOL

3. COMMON EVALUATION AND MONITORING PROTOCOL

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1. INTRODUCTION

The strategies and technologies used across Europe aimed at improving the manure management are numerous and diverse. Therefore, it is necessary to evaluate objectively the different management alternatives that could be implemented in an agricultural scenario. This assessment requires a unification of criteria that provides a deep insight into the impact of every management system in order to obtain comparable results.

Thus, a Common Evaluation and Monitoring Protocol (CEMP) was developed within the LIFE+ MANEV project. CEMP is a guideline that establishes the parameters, evaluation procedures and functional units unifying the methodology for the assessment of different manure management systems in a defined scenario with the objective of obtaining comparable data around Europe. The assessment includes environmental, agronomic, energetic, economic, social, sanitary and legislative criteria to determine the impact from a global point of view.

This protocol was the basis for the evaluation of the treatment plants monitored by the partners of the project and for the development of the MANEV tool.

The whole document can be downloaded from the website of the LIFE+ MANEV project (www.lifemanev.eu).

2. SCENARIO AND BOUNDARIES OF THE EVALUATED SYSTEM

A scenario is the representation of a real situation where a management system is simulated and evaluated. The boundaries of the assessed scenario should be established according to every local circumstance under a geographic and temporal framework.

The GEOGRAPHICAL BOUNDARIES of the system assessed range from the external storage of the farm to the final destination of the end products: cropland fertilisation, exportation to other areas or discharge into watercourses (if possible) (Figure 3.1).

- **Step 1. External farm storage:** external storage of the manure in the facilities of the livestock farm.

- **Step 2. Transport + Intermediate storage:** intermediate storage including the transport from the livestock farms to the centralised storage facility.

- **Step 3. Treatment** of the manure whether at the farm or the centralised facility. This step includes the sequence of the different processing units or technologies that makes up the plant.

- **Step 4. End-products management:** transport and land application for fertilising the crop land located within the scenario, exportation of the end products to other areas out of the scenario or discharge into the watercourses if compliant with the local regulations.

In the case of the exportation of the end products, the incomes obtained from the selling are the only aspect included in the evaluation. Transport and subsequent management are not taken into account.

The construction of any of the facilities, either storage or treatment plant, as well as the co-substrates or additional materials included in the process are borne in mind just for the economic assessment based on local costs. Other issues are considered to belong to their manufacturing system.

These boundaries can vary from a single farm and the crops related to this farm to a whole influence area of a centralised treatment plant including more than one municipality.

Related to the **TEMPORAL BOUNDARIES**, the evaluation of a system includes a whole work period of **15 years,** which is the average lifetime estimated for a common treatment facility, while the monitoring assessment of the scenario or treatment system should include data of at least a **whole natural year** in order to evaluate how the variation of local climatology, livestock manure production and composition and farm activities, among other effects, concern the process.

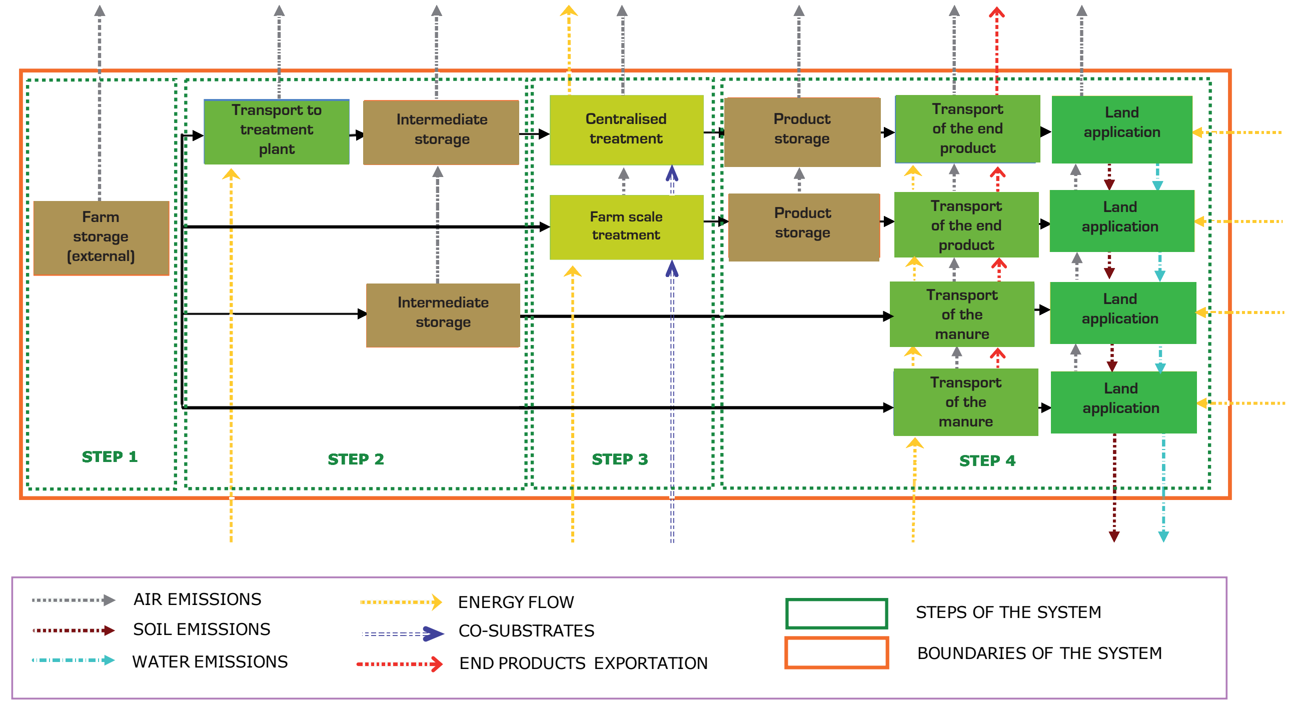

Figure 3.1. Geographical boundaries of the system to be assessed.

3. CRITERIA, PARAMETERS AND INDICATORS FOR THE ASSESSMENT

The CEMP considers seven criteria necessary for the global evaluation of any manure management system or treatment technology: environment, energy, economy, agronomy, social, biosecurity and legislation (Table 3.1). Each criterion includes a list of indicators that are quantified through specific parameters and are homogenised on the basis of reference units with characterisation factors.

The functional unit in which all the calculations are based on is the **tonne of manure.**

Table 3.1. Criteria, indicators and parameters established in the CEMP.

CRITERIA	INDICATORS	PARAMETERS
Environment	WATER: Eutrophication	N balance, P balance
	AIR: Acidification	NH_3, SO_2, NO_x emissions
	AIR: Global warming	CO_2, CH_4, N_2O, emissions
	SOIL: Salinity	Electrical Conductivity
	SOIL: Metals	Cu, Zn
Energy	Energy production	Electricity and heat
	Energy consumption	Electricity, heat and fuel
Economy	Incomes	Energy production; end-products
	Expenses	Depreciation, energy consumption, chemicals, maintenance, manpower
Agronomy	Fertilising units NPK[1]	NPK[1] Balance
Social impact	Odour	Reference values
	Noise	Reference values
	Visual impact	Height, distances, population…
	Impact in local activity	Jobs created
Biosecurity	*E. Coli*	Reduction / No reduction
	Salmonella	Reduction / No reduction
Legislation	European legislation	Compliance
	National legislation	Compliance
	Local legislation	Compliance

[1] NPK: Nitrogen, Phosphorus, Potassium

3.1. ENVIRONMENT CRITERION

The bad practices in the management of the manure may cause environmental problems such as groundwater nitrate pollution, eutrophication of surface waters, acidification of the ecosystems due to ammonia emissions and global warming because of greenhouse gases released into the atmosphere. The application of high doses of manure over the years may lead to the accumulation of metals and phosphorus in soils.

The environmental criterion of the CEMP covers all these aspects and determines the representative parameters and the reference units for its assessment (Table 3.2).

A) WATER POLLUTION: EUTROPHICATION RISK POTENTIAL

Total nitrogen (N) and total phosphorus (P) are analysed in manure or end-products in order to calculate the mass nutrient balance related to the crop requirements and application doses. The kg of N and P that are in surplus determine the eutrophication risk potential.

B) AIR POLLUTION: ACIDIFICATION

Acidification is measured with the **ammonia (NH_3), sulphur dioxide (SO_2) and nitrogen oxides (NO_x) emission**. Standard default emission factors for those parameters provided by an official organism are used for the assessment of the acidification potential. If any local or experimental data, as well as more accurate references, are available, the use of this information will be prioritised.

The acidification reference unit is **kg SO_2 equivalent** (Basset-Mens and van der Werf, 2005; López-Ridaura, 2009).

The characterisation factors agreed to be used for acidification are the Average European factors shown in Table 3.3 (López-Ridaura, 2009; Basset-Mens and van der Werf, 2005; Guinée, 2002; Huijbregts, 1999).

NH_3 EMISSIONS take place in all those activities in which **manure is in contact with air** (storage, land application and the uncovered tanks of the treatment plants) and transport activities (Table 3.4).

Nitrogen emission calculations are related to TAN content of manure or end products before and after the storage period (EMEP/EEA 2009).

Table 3.2. Indicators and parameters established in the CEMP for the environmental assessment.

	Sub-criteria	Indicators	Parameters	Unit	Characterisation factor	Reference units
ENVIRONMENT	**WATER POLLUTION**	**Eutrophication**	**N**	kg N	N balance	kg/ha
			P	kg P	P balance	
	AIR POLLUTION	**Acidification**	**NH_3 emission**	kg NH_3	1.6	kg SO_2 eq.
			SO_2 emission	kg SO_2	1.2	
			NO_x	kg NO_x	0.5	
		Global Warming Potential	**CO_2 emissions**	kg CO_2	1	kg CO_2 eq.
			CH_4 emissions	kg CH_4	25	
			N_2O emissions	kg N_2O	298	
	SOIL POLLUTION	**Salinisation**	**EC**	dS/m	dS/m	dS/m
		Metals	**Cu**	mg/kg Cu	-	Legal restrictions
			Zn	mg/kg Zn	-	

Table 3.3. Characterisation factors for the acidification potential.

	NH_3	SO_2	NO_X
kg SO_2 eq.	1,6	1,2	0,5

Table 3.4. Methodology to determine ammonia emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 1	
Farm storage	EMEP/EEA 2009 – Chap. 4.B - Tier 2 methodology
Step 2	
Intermediate storage	EMEP/EEA 2009 – Chap. 4.B. - Tier 2 methodology
Transport	EMEP/EEA 2009 1.A.3.b Road transport update June 2010.pdf - Tier 2 methodology.
Step 3	
Treatment Direct emissions from aerobic treatments and storage tanks within the treatment plant facilities.	Scientific references: (Loyon, 2007; Balsari, 2007; Blanes-Vidal, 2009; Balsari, 2006; Sommer, 2003; Paillat, 2005; Sogaard 2002). Experimental data – Direct measurements
Step 4	
End-products management Intermediate storage until its end use Land application.	EMEP/EEA 2009 – Chap. 4B. - Tier 2 methodology
End-products management Transport of the end-products Off-road emission of the mobile sources and machinery	EMEP/EEA 2009 –1.A.3.b Road transport update June 2010.pdf - Tier 2 methodology.

SO_2 EMISSIONS take place in all those activities in which manure, intermediate products or end-products are **transported**. Table 3.5 shows the methodology and the parameters required for its determination. In all cases, it is assumed that all sulphur in the fuel is transformed completely into SO_2.

Table 3.5. Methodology to determine SO_2 emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 2	
Transport	EMEP/EEA 2009 - 1.A.3.b Road transport update June 2010.pdf - Tier 1 methodology
Step 4	
End-products management Transport of the end-products Off-road emission of the mobile sources and machinery	EMEP/EEA 2009 – Chap. 4.B. - Tier 2 methodology

NO_x is a generic term for the mono-nitrogen oxides NO and NO2. Nitric oxide (NO) is formed through nitrification in the surface layers of stored manure or in manure aerated to reduce odour or to promote composting. At present, few data are available describing NO emissions from manure management. Nitric oxide emission from soils is generally considered to be a product of nitrification. Increased nitrification is likely to occur following application of manures and deposition of excreta during grazing (EMEP/EEA, 2009).

The activities that generate NO emissions in the scenario boundaries are the **storage, transport** and **land application** of manures (Table 3.6).

C) AIR CLIMATE CHANGE: GLOBAL WARMING POLLUTION (GWP)

The main greenhouse gas (GHG) parameters that determine the GWP are methane (CH_4), nitrous oxide (N_2O) and carbon dioxide (CO_2) emissions. Standard default emission factors specified by an official organism are proposed for the assessment. Nevertheless, the use of local-specific emission factors or data will have priority due to the fact that default values are not comprehensive

Table 3.6. Methodology to determine NO_x emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 1	
Farm storage	EMEP/EEA 2009 - Chap. 4.B - Tier 2 methodology
Step 2	
Transport	EMEP/EEA 2009 1.A.3.b Road transport update June 2010.pdf - Tier 2 methodology.
Intermediate storage	EMEP/EEA 2009 - Chap. 4.B - Tier 2 methodology
Step 3	
Treatment Emissions related to direct emissions from aerobic treatments and storage tanks within the treatment plant facilities.	EMEP/EEA 2009 – Chap. 4.B - Tier 2 methodology Experimental data – Direct emissions Scientific references – (Loyon, 2007; Hansen, 2006; Brown, 2008).
Step 4	
End-products management Intermediate storage until its end use. Land application.	EMEP/EEA 2009 - Chap. 4.B - Tier 2 methodology
End-products management Transport of the end-products, off-road emission of the mobile sources and machinery.	EMEP/EEA 2009 - 1.A.3.b Road transport update June 2010.pdf - Tier 2 methodology.

in terms of attributing emission reductions to some indirect measures that can be undertaken in the sector and they do not take into account local circumstances.

The climate change reference unit is kg CO_2 equivalent according to IPCC guidelines.

Characterisation factors are those linked to a global warming potential horizon of 100 years according to IPCC data (IPCC, 2007) (Table 3.7).

CO_2 EMISSIONS are produced in the steps that require energy, whether in the transport activity (fuel) or in the **treatment** plants (electricity and heat) (Table 3.8).

CH_4 EMISSIONS are emitted in anaerobic conditions. The activities related to manure management system that cause CH_4 emissions are storage, transport and treatment (Table 3.9).

Table 3.7. Characterization factors for the GWP.

		CO_2	CH_4	N_2O
Lifetime (years)			12	114
GWP time horizon kg CO_2 eq.	20 years	1	72	289
	100 years	1	25	298
	500 years	1	7,6	153

Table 3.8. Methodology to determine CO_2 emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 2	
Transport	IPCC 2006 Vol. 2 Chap. 3 - Tier 2 methodology
Step 3	
Treatment Energy balance, anaerobic digestion (biogas composition).	EU-27 fossil fuel mix Experimental data – Direct measurements Scientific references (biogas composition)
Step 4	
End-products management Off-road emission of the mobile sources and machinery and/or end-products transport.	IPCC 2006 Vol. 2 Chap. 3 - Tier 2 methodology

Table 3.9. Methodology to determine CH_4 emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 1	
Farm storage	IPCC 2006 Vol. 4 Chap. 10 - Tier 2 methodology.
Step 2	
Intermediate storage **Transport**	IPCC 2006 Vol. 4 Chap. 10 - Tier 2 methodology. IPCC 2006 Vol. 2 Chap 3 - Tier 3 methodology IPCC 2006 Vol. 2 Chap 3 - Tier 2 methodology
Step 3	
Treatment Anaerobic digestion (biogas composition) and direct emissions from aerobic treatments and storage tanks within treatment plant facilities.	IPCC 2006 Vol. 4 Chap 10 - Tier 2 methodology Experimental data – direct measurements Scientific references – (Loyon, 2006; Hansen, 2006; Brown, 2008).
Step 4	
End-products management Transport of the end-products, off road emission of the mobile sources and machinery and their intermediate storage until its end use.	IPCC 2006 Vol. 2 Chap 3 - Tier 3 methodology IPCC 2006 Vol. 2 Chap 3 - Tier 2 methodology

N_2O EMISSIONS are produced in nitrification/denitrification processes, whether in the aeration storage periods, in NDN treatment plants or in the biological process of NDN that occurs in the soil under aerobic conditions (Table 3.10).

Raw manure and end-products intended to be applied on the land as organic fertilisers (EC, 2001) should comply with the regulation established in every place related to their composition and maximum levels of metal application allowed.

Table 3.10. Methodology to determine N_2O emissions in the boundary of the system.

ACTIVITIES	METHODOLOGY
Step 1	
Farm storage	IPCC 2006. Vol. 4 Chap. 10 - Tier 2 methodology.
Step 2	
Intermediate storage	IPCC 2006. Vol. 4 Chap. 10 - Tier 2 methodology.
Transport	IPCC 2006 Vol. 2 Chap 3 -Tier 3 methodology IPCC 2006 Vol. 2 Chap 3 -Tier 2 methodology
Step 3	
Treatment Emissions related to anaerobic digestion (biogas composition) and direct emissions from aerobic treatments within the treatment plant facilities.	IPCC 2006 Vol. 4 Chap. 10 - Tier 2 methodology. Scientific references (biogas composition and direct emission measurements). Bibliographic references (Loyon, 2006; Hansen, 2006; Brown, 2008).
Step 4	
End-products management Transport of the end-products	IPCC 2006 Vol. 2 Chap 3 - Tier 3 methodology
End-products management Off-road emission of the mobile sources and machinery	IPCC 2006 Vol. 2 Chap 3 - Tier 2 methodology
End-products management Intermediate storage until its end use	IPCC 2006. Vol. 4 Chap. 10 - Tier 2 methodology.
End-products management Land application	IPCC 2006 Vol. 4 Chap. 11 - Tier 2 methodology.

E) SOIL POLLUTION: SALINISATION

The electrical conductivity (EC) of manure and end-products is considered the risk factor for salinity but only in those areas that are identified as a risk of salinisation by the European Soil Data Centre (ESDAC) of the European Commission (Tóth *et al.* 2008).

http://esdac.jrc.ec.europa.eu/public_path/salinisation.png

F) SOIL POLLUTION: METALS (COPPER AND ZINC)

The concentration of copper (Cu) and zinc (Zn) in the end-products is also monitored.

As there is no specific European regulation for organic fertiliser metal content, **Council Directive** 86/278/EEC *on the protection of the environment, and in particular of the soil, when sewage sludge is used in agriculture*, is used as a default reference.

Nevertheless, in those cases in which a national or local regulation is available, this one should have priority, i.e.: Real Decreto 824/2005 and Orden PRE/630/2011 in the case of Spain.

3.2. ENERGY CRITERION

The energy criterion is assessed by the overall energy balance, which comprises both **energy consumption** (E_{cons}) and production (E_{pr}) and the reference unit is **kWh**.

$$\boxed{E = E_{pr} - E_{cons}.}$$

Table 3.11 shows the parameters and reference units determined to unify its assessment.

Table 3.11. Indicators and parameters established in the CEMP for the energy assessment.

	INDICATORS	PARAMETERS	UNIT	CHARACTERIZATION FACTOR	REFERENCE UNITS
ENERGY	ENERGY CONSUMPTION	**Electricity consumption**	kWh/t	1	kWh/t
		Heat consumption	kWh/t	1	
		Fuel consumption	kWh/t	1	
	ENERGY PRODUCTION	**Energy potential** - Energy content of biogas production (Obtained from CH_4 measurements)	kWh/t	1	
		Electricity production –Electrical energy produced after transformation	kWh/t	1	
		Heat production - Heat produced after transformation	kWh/t	1	

A) ENERGY CONSUMPTION

The energy consumption is the addition of the electricity (Ee), heat (Eh) and fuel (Efuel) consumed in a management system.

$$E_{cons} = E_h + E_e + E_{fuel}$$

Electricity and heat are the energies consumed for the functioning of **treatment technologies**. Their assessment is made measuring and recording directly the real energy consumption in every main processing unit.

During **transport**, vehicle fuel is consumed. The type of fuel consumed has to be specified in every case, although it is usually diesel. In any case, the non-renewable energy consumption in transport should be calculated using the Lower Heating Values (LHV) of the specified fuel (López-Ridaura, 2009; Goedkoop, 2010; Basset-Mens and van der Wert, 2005).

If the acquisition of daily records is not possible in any way, technical data should be used.

B) ENERGY PRODUCTION

In manure management systems the energy is produced in anaerobic digestion treatment plants, where biogas is generated for the production of energy. It is assessed from both points of view: the potential and the real production of energy. The real production or renewable energy leads to GHG emission savings.

The **POTENTIAL ENERGY (E_{POT})** is estimated according to the content or methane yield in biogas produced. It is estimated according to the lower heating value (LHV) of the produced biogas so that a quantity of biogas (or methane) is expressed as **kWh_p**. (V= volume of biogas).

$$E_{pot} = V\,[m^3] \bullet LHV\,[kWh/m^3]$$

The biogas can be used for different purposes: feeding a combined heat and power unit (CHP unit), injection to the natural gas grid, vehicle fuel and its energy production efficiency will depend on it.

The **REAL ENERGY PRODUCED (E_{prod})** is the sum of produced electricity ($E_{prod\ e}$) and heat ($E_{prod\ h}$).

$$E_{prod} = E_{prod\ e} + E_{prod\ h}$$

The **electricity and heat production efficiency** is obtained by the specifications from technical data of the equipment.

The **electricity production** includes the electricity sold to the grid and the electricity self-consumed by the plant without selling.

$$E_{\text{prod total e}} = E_{\text{prod e losses}} - E_{\text{prod e selling}} - E_{\text{prod e self-consumed}}$$

The **heat production** includes the heat sold or used in any nearby facilities, heat losses and the thermal energy self-consumed by the plant.

$$E_{\text{prod total h}} = E_{\text{prod h losses}} - E_{\text{prod h selling}} - E_{\text{prod h self consumed}}$$

3.3. ECONOMY CRITERION

The balance of incomes and expenses are the indicators of the economy criteria (Table 3.12). The reference unit of this criterion is € per tonne of manure.

Table 3.12. Indicators and parameters established in the CEMP for the economy assessment.

	INDICATORS	PARAMETERS	UNIT	CHARACTERISATION FACTOR	REFERENCE UNITS
ECONOMY	Incomes	Energy production (electricity + heat) End-products sale – Market potential Others	€/t	1	€/t
	Expenses	Depreciation Energy consumption (electricity + heat + fuel) Consumables Co-substrates Maintenance Manpower Other	€/t	1	€/t

A) INCOMES

In a manure management system, the incomes can be generated by the sale of the different added-value products obtained in the process: energy, organic fertiliser and others.

The incomes obtained for the **ENERGY PRODUCTION** depend on the feed-in-tariff and subsidises of the electricity production with renewable energy, as well as on the price of the heat on the local market.

The assessment of the market potential of the **ORGANIC FERTILISER** can be calculated in two ways:

- According to the value of the product in the local market (if possible).

- According to the value of product composition (NPK) and its efficiency regarding the average prices of the most usual mineral fertilisers in Europe.

There are **OTHER** incomes to be taken into account that will depend on the particularities of the areas, such as local subsidies.

B) EXPENSES

The expenses are determined by the cost per tonne of manure managed within the system **(€/t of manure).** Those expenses include:

- The **DEPRECIATION** of the equipment and facilities integrated into the system bearing in mind the total investment and the expected life. Residual value is always considered zero and the depreciation is considered straight-line.

- The cost of the **ENERGY CONSUMPTION** (electricity, heat and fuel) in the system.

- The cost of all the reagents used in the operation of the plant (flocculants, coagulants, antifoaming, etc.) and those required for the daily analysis to control the process: **CONSUMABLES.**

- The cost of some **CO-SUBSTRATES** that will improve the efficiency of the plant.

- The **MAINTENANCE** cost that includes replacements of any devices, changes of oil, etc. If no specific data are available, a % of the total investment cost could be used.

- The expenses in personal staff according to the qualification (operator or technician) and the number of employees to run the treatment plant: **MANPOWER** cost.

- **OTHER** costs not considered under other categories.

3.4. AGRONOMY CRITERION

Manure and the treatment end-products have a high potential as organic fertiliser in agriculture. An efficiency coefficient is applied to determine their nutrient availability measured in a fertilising unit on N, P and K. The sources of these coefficients are the decay series, assumed worldwide as a reference of nutrient mineralisation (Pratt *et al.*, 1973; USDA 2012) (Table 3.13).

The nutrient balance is carried out bearing in mind the crop requirements (and the composition of the manure or end-products quantified in fertilising units of NPK). The agronomic balance considers losses and gains from the soil and, in the case of N, also the losses due to the spreading system and the time of spreading.

Table 3.13. Indicators and parameters established in the CEMP for social impact.

	Indicators	Parameters	Unit	Characterisation factor	Reference units
SOCIAL	**Odour**	**Odour nuisance**	Dimensionless scale (range 1-4; 1: no odour; 4: maximum odour nuisance).	Dimensionless	Dimensionless - Linear combination of weighted standardised values
	Noise	**Noise nuisance**	Yes/No	Dimensionless	
	Visual impact	**Parameters based on environmental impact assessment methodologies**	Low/Moderate/High	Dimensionless	
	Impact on local activity	**Jobs created**	Number of operators and number of specialised technicians required	Dimensionless	

3.5. SOCIAL IMPACT

Other important criterion included in the evaluation is how manure management systems impacts on society (Table 3.14).

This criterion is dimensionless and every parameter is assessed individually.

Table 3.14. Indicators and parameters established in the CEMP for social impact.

	Indicators	Parameters	Unit	Characterisation factor	Reference units
SOCIAL	Odour	Odour nuisance	Dimensionless scale (range 1-4; 1: no odour; 4: maximum odour nuisance).	Dimensionless	Dimensionless - Linear combination of weighted standardised values
	Noise	Noise nuisance	Yes/No	Dimensionless	
	Visual impact	Parameters based on environmental impact assessment methodologies	Low/Moderate/High	Dimensionless	
	Impact on local activity	Jobs created	Number of operators and number of specialised technicians required	Dimensionless	

A) ODOUR

The odour is measured through a dimensionless scale ranging from 1 to 4 of the intensity of the nuisance caused by the manure management system (1: minimum and 4: maximum).

Whenever possible, direct measurements are carried out following dynamic olfactometry standardised method by EN-13725 (Air quality – Determination of odour concentration by dynamic olfactometry 2006).

B) NOISE

Whenever possible, noise is assessed directly following the standardised methodology and reference limits specified by Directive 2002/49/CE or local regulations (i.e. in the case of Spain, it is regulated by RD 1367/2007).

When no other option is available, it is indicated whether noise generation of the management system causes nuisance in the surrounding area or not.

C) VISUAL IMPACT

Visual impact is measured following a simplified general guideline based on environmental impact assessment methodologies and categorising this impact as low, medium or high according to following factors:

1. Number of potential observers

Visual range: Distance affected by the visual impact. It is assessed with the distance to the closest town or urban area and regarding the number of inhabitants:

- 0-2.5 km – 0-500 inhabitants.............................+1
- 0-2.5 km – 500-1,000 inhabitants..................+2
- 0-2.5 km – + 1,000 inhabitants ....+3
- 2.5-5 km – 0-500 inhabitants.........................+0.5
- 2.5-5 km – 500-1.000 inhabitants..................+1
- 2.5–5 km – + 1,000 inhabitants..................+1.5
- 5-7.5 km – 0-500 inhabitants..................... +0.33
- 5-7.5 km – 500-1,000 inhabitants........... +0.66
- 5–7.5 km – + 1,000 inhabitants......................+1

Surface/Height ratio: surface and average height of the facilities related to the volume managed in the system (Table 3.15).

Surface references have been established after an assessment of the average farm surface according to the number of heads in pig farms. For farms between 0 and 1,000 heads, surface values ranged from 1,600 to 11,000 m^2; for farms with between 1,000 and 5,000 heads surface values ranged from 4,000 to 23,000 m^2 and for farms with over 5,000 heads surface values ranged from 6,500 to 30,000 m^2.

Average height references used for the assessment: 3 m (animal housing) – 12 m (anaerobic digester).

Presence of communication routes/roads:

- Distance:

  There is a road closer than 3.5 km ....+1
  There is not a road closer than 3.5 km......... +0

- Traffic intensity:

  High: ....+3
  Medium: ....+2
  Low: ....+1

2. Consistency of the visual elements of the environment regarding colours:

- The facility's colours are consistent with the natural environment: ....+0
- The facility's colours are not consistent with the natural environment: ....+1

3. Transport generated due to the activity in the facilities:

- High: ....+3
- Medium: ....+2
- Low: ....+1

Table 3.15. Information taken into account for weighting surface and height.

Surface [m^2]	Average Height	Volume	Weight
5.000	3	15.000	+1
	12	60.000	+3
15.000	3	45.000	+2
	12	180.000	+5
30.000	3	90.000	+4
	12	360.000	+6

4. Anthropisation level (level of transformation of spaces, landscapes or natural environments through human action).

- High: ....+3
- Medium: ....+2
- Low: ....+1

5. Are there any amendments carried out to palliate the impact

- There are amendments (i.e. vegetation) that palliate the impact: ....+0
- There aren't amendments that palliate the impact:...+1

D) IMPACT ON LOCAL ACTIVITY – JOBS CREATED

The number and qualification of the jobs created for the implementation of a manure management system are assessed bearing in mind:

- Total hours worked per year per person: 1700 h/year (Average values from the database of the Organisation for Economic Co-operation and Development (OECD) Stat. Data taken on November 26, 2014 12:08 UTC (GMT)).

- Qualification: operator or technician.

3.6. BIOSECURITY CRITERION

E. coli and Salmonella are characterised using periodical sample analyses in raw manure and in end-products of the treatment in a certified laboratory.

The final concentrations are compared with the legislation to comply with the by-products regulation (Table 3.16).

Table 3.16. Indicators and parameters established in the CEMP for biosecurity assessment.

	Indicators	Parameters	Unit	Characterisation factor	Reference units
BIOSECURITY	*E.coli*	*E. coli*	cfu/ml	1	cfu/ml
	Salmonella	*Salmonella*	presence/ absence	1	presence/ absence

3.7. LEGISLATION CRITERION

Legislation at all levels establishes the European, national and local restrictions to comply with in order to assess which management options could be considered.

In those areas already under special regulation (i.e. vulnerable zones, SCIs., etc.) the improvement that the introduction of a new management system will provide to the area must be highlighted.

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4. MANEV TOOL FOR THE ASSESSMENT OF THE MANURE MANAGEMENT SYSTEMS

4. MANEV TOOL FOR THE ASSESSMENT OF THE MANURE MANAGEMENT SYSTEMS

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INTRODUCTION

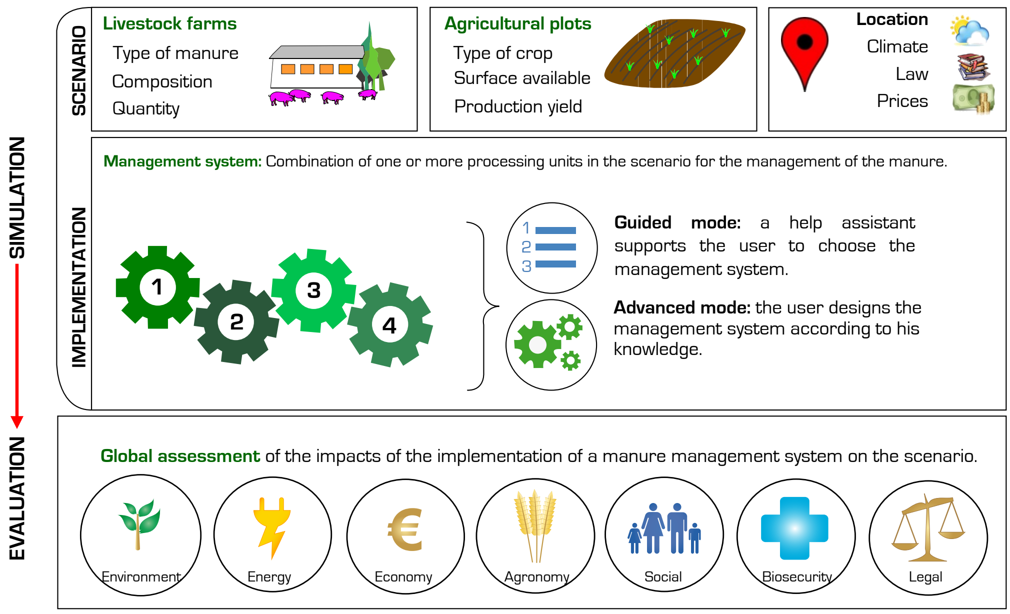
There are a wide number of technologies available in the market aiming at the improvement of manure management. Although there is not a universal solution to solve the environmental impact of manure management, treatments represent a good strategy in certain areas, especially in nitrate vulnerable zones (NZV) and nutrient surplus areas. The selection of one or another technology will depend on the farm size, local geography, land type, climate and production method that give rise to farms with highly individual features (García-González *et al*., 2015).

The use of an appropriate decision support system (DSS) could assist farmers, livestock operators, as well as public bodies, to identify manure management systems, including treatments that could have a positive impact on GHG emissions mitigation and other affections. It has been observed that most computer-based decision support systems for manure management are mainly focusing on nutrient management. Very few have considered the whole manure management environment impact, at the same time as social and economic issues. Thus, an overall evaluation of a manure management system based on defined criteria is required to help farmers to improve the management; it will also benefit society in general (Karmakar *et al*., 2007).

Within the frame of the LIFE+ MANEV project, a decision support tool has been developed with the aim of helping stakeholders to identify which manure management systems fulfil the requirements of their agricultural scenario. This software, named MANEV tool, gathers the available knowledge and expertise in technologies dealing with manure management at European level.

DESCRIPTION OF THE MANEV TOOL

Table 4.1. Scheme of the MANEV tool.



Management system: Combination of one or more processing units in the scenario for the management of the manure.

Guided mode: a help assistant supports the user to choose the management system.

Advanced mode: the user designs the management system according to his knowledge.

Global assessment of the impacts of the implementation of a manure management system on the scenario.

MANEV is a free tool available online (www.lifemanev.eu) which main target is to protect the environment and foster the livestock sector, helping users in the selection of the manure management system that fits better every agricultural scenario.

The software unifies and homogenises the knowledge and expertise in manure treatment technologies available in Europe to place them at the disposal of the stakeholders. It intends to be a link between the scientific knowledge, the technology market and the agricultural and livestock sector.

How does the MANEV tool work? The MANEV tool simulates and assesses the effects of the hypothetical implementation of a manure management system in a specific agricultural scenario: one or various livestock farms and related agricultural plots, according to its particular characteristics linked to the location (climate, regulation, economy, etc.). The assessment is carried out from a global point of view, taking into account seven criteria: environment, energy, economy, agronomy, social issues, biosecurity and legislation. The comparison of different simulations in the same scenario will help the user to choose the best option. Figure 4.1 shows the functioning scheme of the MANEV tool.

This tool is intended to be used by all the agents involved in manure management: livestock breeders, farmers, local and regional governments and engineering companies. In order to adapt the tool to the wide range of potential users, two different modes of use were established according to their technical knowledge on treatment technologies: guided mode and advanced mode.

HOW WAS THE MANEV TOOL CREATED?

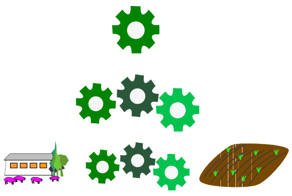
The MANEV tool was designed thanks to the expertise and experience of the project partners and the broad scientific bibliography review carried out on the manure treatment technologies available in Europe.

Its design and creation were based on the common evaluation and monitoring protocol (CEMP) developed within the project where the criteria, parameters and indicators were established to unify the data and make the different management systems comparable.

There are 32 different processing units included in the software based on the general management (mixing of the various inputs and transport of the products), the strategy that is looked for in the scenario (facilitate the handling of the manure, obtain end-products with added-value, remove nutrients, concentrate nutrients, reduce gas emissions) and the end use of the products (Table 4.1).

The combination of one or more processing units implemented in a specific agricultural scenario will form a manure management system that will be simulated and assessed to determine its impact.

The assessments are calculated through the algorithms created by the partners of the project based on the data available in scientific papers, official reports from international bodies and experimental data. The design of the algorithms was structured according to a common template where the key parameters of the inputs (Table 4.2) and outputs (Table 4.3) were established. The main INPUTS could be manure from a single farm, a mixture of manure from several farms and/or cosubstrates or the output of a previous treatment unit. The OUTPUTS include the different end-products (output 1, 2...) obtained after the treatment, the biosecurity involvement, the economic and energy balance, the gas emissions and the social impact.



Processing units are each of the single phases of a management system that entail a change in terms of economy, energy or physical chemical properties of manure.

The combination of different processing units in a specific order forms the **processing lines**.

The implementation of a processing line in a specific scenario forms the **manure management system**.

Table 4.1. Scheme of the MANEV tool.

MAIN STRATEGY	PROCESS	TYPE
General management	MIXING	
	TRANSPORT	Tractor + slurry tank
		Tractor + container for solids
		Truck mounted tanker
Facilitate the handling	STORAGE	Uncovered
		Covered
	SEPARATION (S/L)	Centrifugation
		Chemical centrifugation
		Natural settling
		Chemical settling
		Screening
		Chemical screening
		Pressing
		Chemical pressing
	DRYING	
Reducing ammonia emissions	ACIDIFICATION	
Added- value end-products	ANAEROBIC DIGESTION	Mesophilic (T 38 – 40 ºC)
	COMPOSTING	Static pile
		Passive windrow
		Intensive windrow
Nutrient removal	AEROBIC BIOLOGICAL TREATMENT	Nitrification / denitrification (NDN)
		Sequential Batch Reactor (SBR)
	PHYTODEPURATION	Surface system
		Subsurface system
Nutrient concentration	STRIPPING	pH and/or T
	FILTRATION + REVERSE OSMOSIS	
	EVAPORATION	
End-use	LAND SPREADING	Broadcast application
		Band surface application
		Injection
		Solid spreading
	EXPORTATION	

The key operational parameters for the calculation and the constraints that limit a correct functioning of the treatment were established for each processing unit.

The data that feed the software come from different sources, prioritizing the databases available online from official organisms covering all the European regions and guaranteeing and allowing its periodical updating. Table 4.4 shows the main sources used for different information.

The algorithms were tested and validated with the experimental data obtained from the monitoring and evaluation of the 13 treatment plants included in the project.

The MANEV tool is a web application that was developed using C# language on .NET framework. Its availability online makes it more accessible to users although the programming can result more difficult to develop than a stand-alone application.

Table 4.2. Parameters established for the INPUT data.

INPUTS
INPUT 1
Type of manure
Flow rate (m^3/day)
Mass flow rate (t/day)
Total solids (kg/t)
Volatile solids (kg/t)
COD - Chemical Oxygen Demand (kg/t)
TKN - Total Kjeldahl Nitrogen (kg/t)
TAN - Total Ammoniacal Nitrogen (kg/t)
P - Total Phosphorous (kg/t)
K - Total Potassium (kg/t)
EC - Electrical conductivity (dS/m)
pH
Cu - Copper (g/t)
Zn - Zinc (g/t)
E. coli (CFU/100 ml)
Salmonella (presence/absence per litre)

Table 4.3. Criteria and parameters calculated in the OUTPUT data.

OUTPUTS	
OUTPUT 1, 2, 3	**ECONOMIC BALANCE**
Flow rate (m^3/day)	**Incomes**
Mass flow rate (t/day)	Energy production (electricity) (€/t and €/year)
Total solids (kg/t)	Energy production (heat) (€/t and €/year)
Volatile solids (kg/t)	End-products sale (€/t and €/year)
COD - Chemical Oxygen Demand (kg/t)	CO_2 emission rights (€/t and €/year)
N - Total Kjeldahl Nitrogen (kg/t)	TOTAL (€/t and €/year)
Nammoniacal - Total Ammoniacal Nitrogen (kg/t)	**Expenses**
P - Total Phosphorous (kg/t)	Investment cost (€)
K - Total Potassium (kg/t)	Expected plant life (years)
EC - Electrical conductivity (dS/m)	Depreciation (€/t and €/year)
pH	Energy consumption (€/t and €/year)
Cu - Copper (g/t)	Consumables (€/t and €/year)
Zn - Zinc (g/t)	Co-substrates (€/t and €/year)
E. coli (CFU/100 ml)	Maintenance (€/t and €/year)
Salmonella (presence/absence per litre)	Manpower (€/t and €/year)
	TOTAL (€/t and €/year)
EMISSIONS	**ENERGY BALANCE**
SO_2 eq. (kg/t)	**Energy production**
NH_3 (kg/t)	Fuel (kW·h/t)
SO_2 (kg/t)	Electricity (kW·h/t)
NO_x (kg/t)	Heat (kW·h/t)
CO_2 eq. (kg/t)	**Energy Consumption**
CH_4 (kg/t)	Fuel (kW·h/t)
N_2O (kg/t)	Electricity (kW·h/t)
CO_2 (kg/t)	Heat (kW·h/t)
SOCIAL	
Noise (Yes/No)	
Odour (Yes/No)	

Table 4.4. Main sources for the different information that feed the software.

INFORMATION	SOURCE
Input quantity and composition by animal type/heads	Bibliography review and legislation
Crop nutrient uptake (NPK)	Bibliography review
Nutrient availability factor (N_A, P_A and K_A)	U.S. Department of Agriculture
Emission factors	IPCC, EMEP & bibliography review
Maximum amount of nitrogen from organic fertilizers that can be applied	Legislation (Nitrate Directive)
Agricultural machinery costs	Agroscope
Nomenclature of Territorial Units for Statistics (NUTS) and Local Administrative units (LAU)	Eurostat database
Crop types and yields	
Prices of mineral fertilizer	
Fuel costs	
Hourly labour costs	
Climate data	European Climate Assessment and Dataset
Vulnerable zones in European Union	Directorate-General for Environment (European Commission)
Saline and Sodic Soils in the European Union	European Soil Data Centre (ESDAC) (Join Research Centre European Commission)

HOW TO USE THE MANEV TOOL

The MANEV tool is accessible from the website of the LIFE+ MANEV project (www.lifemanev.eu). It is available in seven languages: English, Spanish, Italian, Danish, Polish, French and German.

After registering in the tool, the user will create a personal account introducing the livestock farms and agricultural plots that will take part in the scenarios. To include them it is necessary to identify, locate and determine the type of livestock and number of animals on the one hand, and the type of crop and hectares on the other. The tool will provide values of manure composition and crop nutrient requirements by default in order to facilitate and streamline the management of the tool. However, those values can be modified if the user has a more accurate data.

The user will subsequently build a project firstly choosing the livestock farms and agricultural plots that will determine the scenario. In order to find an appropriate manure management system, the user has at his disposal two modes of use:

- If the user does not have technical expertise in manure treatment technologies, a GUIDED MODE will help him in the selection of the management system through a questionnaire:

Q1. What **management strategy** do you want to apply?

- Producing an organic fertilizer with added value

- Producing electricity and/or heat

- Reducing the volume

- Facilitating manure management by phase separation

- Obtaining a liquid fraction suitable for watercourse discharge

- Reducing the emission of gasses into the atmosphere

Q2. What level of **technological complexity** can you assume?

Q3. What is the maximum acceptable i**nvestment cost** (€)?

Q4. What is the maximum acceptable **operating cost** (€/t or €/m^3)?

Depending on the answers, the tool will filter the processing lines that fulfil the user's requirements. For this end, more than 1,000 different predefined processing lines were designed combining the technologies and covering a wide range of management strategy approaches, technological complexity levels and investment and operating costs. The direct land application is prioritised provided that the agricultural balance allows it (Figure 4.2). If there is a surplus in the balance and a reduction of nutrients is required, the predefined processing lines follow the scheme of the Figure 4.3.

- The users who have the knowledge and technical expertise in manure treatment technologies can design the management system to be evaluated using the ADVANCED MODE. The user will create a project selecting the livestock farms from his personal account and will add the different processing units in a specific order so that the output of the previous will be the input of the next. The value of the different key operational parameters and constraints can be modified at the user's discretion.

Finally, the project generates a detailed report with the main results of the evaluation including the environmental, economic, energetic, agronomic, social, sanitary and legal impact of the hypothetical implementation of the management system in the scenario.

The tool allows the user to compare different simulations with the aim of determining the management system that fits better into the scenario balancing the environmental improvements with the economic impact to the farmer.

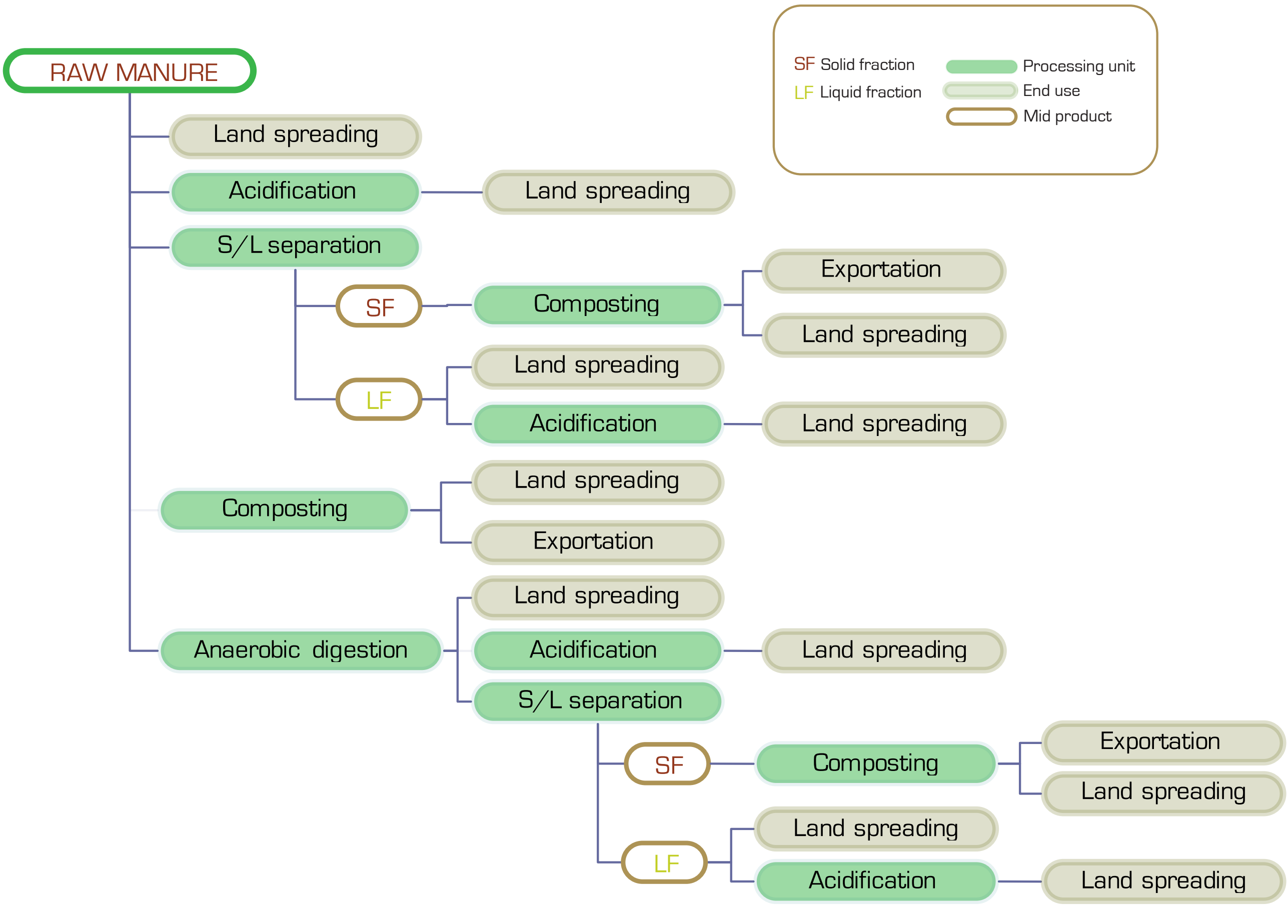


Figure 4.2. Tree diagram: scheme of process lines available in the Guided Mode for a balanced scenario.

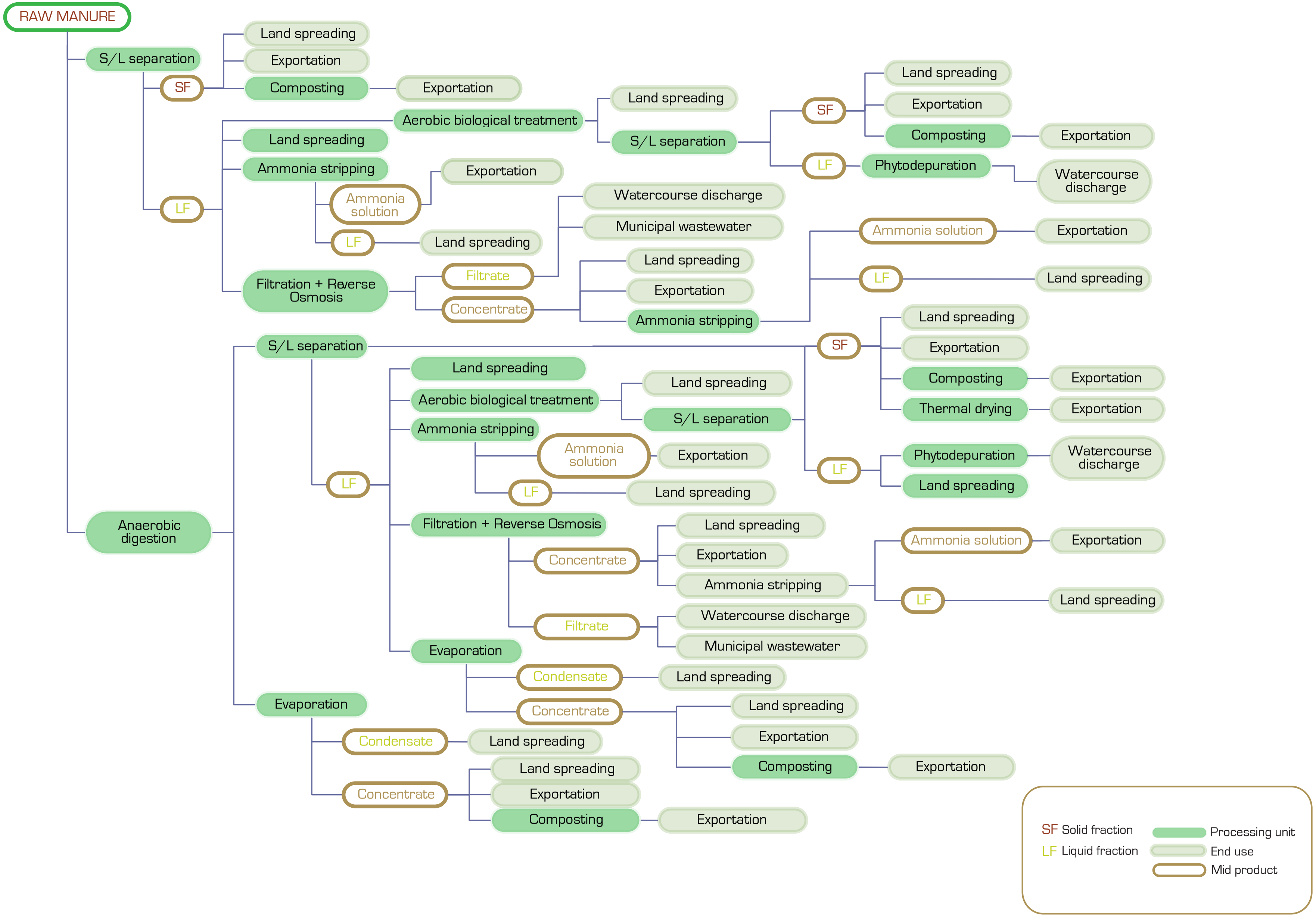


Figure 4.3. Tree diagram: scheme of process lines available in the Guided Mode for a surplus scenario.

MAIN CHALLENGES OF THE MANEV TOOL

This tool has faced different challenges to achieve its target:

- The use of treatment technologies is an ever-changing environment: the tool is modular and flexible and allows including or modifying new developments in treatment technologies in order to be updated.
- The European-wide approach of the tool unifies the knowledge and homogenizes the evaluation for the proper comparison among different scenarios. This big scope comes at the expense of the accuracy of the results. However, its target is to be able to compare different scenarios, not to obtain precise results.
- The on-line availability of the tool enables easy access and speeds up the dissemination of its use in Europe.
- The friendly design of the MANEV tool tries to counter its internal complexity. Practical functionalities such as geo-location using maps and default values help the user to manage the tool and reduce the data required.

CONCLUSIONS

The MANEV tool provides Europe with a common instrument to homogeneously assess different treatment technologies and manure management systems to minimise the environmental impact and improve the sustainability of the agriculture.

The software fits into the user's expertise on treatment technologies and management systems and responds to two basic needs when choosing a management scheme: obtaining a general view of the suitable techniques for a specific scenario and the assessment from a global point of view of specific treatment processing lines combining different technologies.

This tool showcases all the research work and experience acquired during the last years on the use of different technological solutions throughout Europe and enables easy access to all this information for the final users. This work intends to be a support tool for all the stakeholders, encompassing from policy makers to local farmers, and to lay the cornerstone for the foundation of a good practice learnt, showing the weaknesses and strengths of different management systems from a global point of view.

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5. MANURE TREATMENT TECHNOLOGIES

5. INTRODUCTION TO TREATMENT TECHNOLOGIES

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INTRODUCTION

In Europe, there are a wide number of technologies aiming at the improvement of manure management considering environmental aspects and the sustainability of the livestock sector.

Local circumstances determine the goal to pursue, and the suitability of the treatment technology. The type and size of the farm, pedoclimatic conditions, agricultural practices, as well as the legal framework, conditioned by its location, will determine the choice of the management strategy.

The MANEV tool (Chapter 4) divides the management system into processing units, understood as every single step of the process that represents a change, according to any of the criteria used in the evaluation, such as changes in the physical-chemical manure properties, transportation or end product management. Different technologies or processing units can be combined in many ways to configure suitable management systems.

The processing units included in the MANEV tool are technologies currently developed at large scale and available on the European market (Table 5.1). The most relevant technologies are described in Chapter 5.

Table 5.1. Processing units included in the MANEV tool (Teresa, *et al.* 2014) .

Process	Type	Description
Storage	Uncovered Covered	Manure storage and regulation to adjust the inputs to the subsequent process.
Acidification		Reducing NH_3 emissions.
Phase separation (solid / liquid)	Centrifugation Chemical centrifugation Natural settling Chemical settling Screening Chemical screening Pressing Chemical pressing Filtration + Reverse osmosis	Separation of the input material in a liquid fraction and a solid by physical or physico-chemical process. It facilitates subsequent management of the two fractions and concentrated nutrients in the solid fraction.
Anaerobic digestion	Mesophilic (T 38 – 40 ºC)	Manure valorisation to produce biogas, CH_4 emissions reduction, odor reduction, stabilization of organic matter and sanitation.
Composting	Static pile Passive windrow Intensive windrow	Slurry valorisation through aerobic decomposition of residual organic matter for producing compost.
Aerobic biological treatment	Nitrification / denitrification SBR	Reduction of N present in manures through its transformation to N atmospheric.
Stripping	pH and/or T	Reduction of N present in manures by recovering the ammonia nitrogen.
Phytodepuration	Surface system Subsurface system	Tertiary treatment reduction or elimination of pollutants by biological and physico-chemical processes involving the aquatic plants ecosystem itself.
Evaporation		Separation of the liquid fraction of manure by an evaporation process.
Drying		Drying of manure by thermal process.
Land spreading	Broadcast application Band surface application Injection Solid spreading	Agricultural valorisation of manure or end products of a treatment plant (organic fertilizer NPK).
Exportation		Valorization of end products outside of the study area.

5.1. ACIDIFICATION

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OVERVIEW

Manure acidification is a process by which the ammonia emission and production of nitrous oxide are reduced by lowering the pH of the manure. The process has been used in different ways to reduce ammonia emission and/or N losses in animal housing, storage and at the field. In this study, acidification during field application will not be discussed.

The main driving force behind acidification is reducing ammonia emissions. Reducing ammonia losses and gives a more stable ammoniacal nitrogen manure composition and greater certainty of the N applied to the field in situations where N is wished to be retained. However, low pH ammonia stripping will be made more difficult and would require greater consumption of base to raise pH, in situations where N is needed to be removed. The use of an acidification unit with animal housing is aimed to improve the animal's environment.

The low pH and more particularly the high sulphur content after acidification can cause problems when the manure is to be subsequently used for anaerobic digestion, although this also means that acidification will reduce CH_4 losses in storage. Finally the emission of H_2S will be increased at lower pH, although evidence suggests this is a short term effect that may be partly attributed to the stirring.

SCHEME

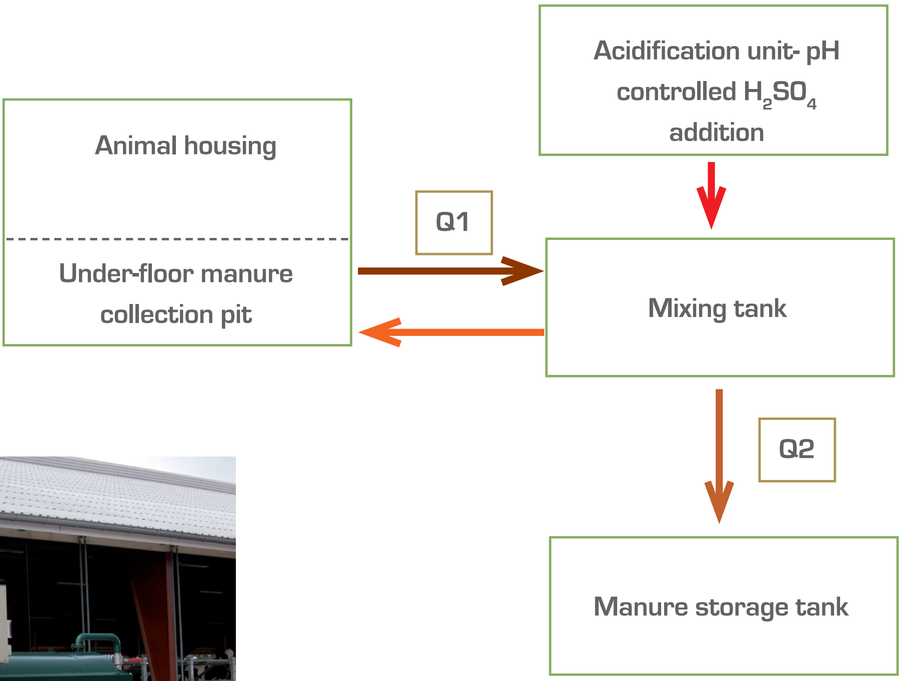

Figure 5.1.1. Scheme of acidification process.

Figure 5.1.2. Infarm acidification unit ©Infarm

TECHNICAL DESCRIPTION

Manure acidification has been considered for many years, initially with the addition of biomass to self-acidify through the production of volatile fatty acids during natural hydrolysis/fermentation processes. The addition of H_2SO_4 to artificially acidify manure had been considered but has been hampered by safety and foaming issues. These have been addressed in a recent commercially available product made by Infarm in Denmark.

These type of operate by a single unit located close to the animal stables. The technology relies on the simple equilibrium of NH_3/NH_4+ related to pH. Ammonia has a pka of 9.25 and thus at lower pH a greater part is in the NH_4+ state and thus complexes with other ions and is not lost as NH_3 gas. The principle of animal house acidification is that manure in stables with slatted floors or other underfloor manure storage systems is removed from the pits by pump and sent to the acidification unit. In the unit, pH is measured and 96% H_2SO_4 is added to the manure via a control system to achieve a pH of around 5.5 without foaming issues. The acid is added to the top of a process tank which is connected to the animal stable. The process tank is mixed gently to mix the acid and the process is aerated to prevent foaming before the acidified manure is sent back to the animal housing. Manure from the animal house is usually sent to the acidification unit daily or weekly. The manure is periodically removed to exterior storage as would be the case for the farm prior to mounting the acidification system. A similar system is used for acidification of manure storage tanks or the acid can be added directly to the tank, at the risk of foaming.

The system is a simple addition to an existing farm; the unit is a self-contained module requiring only connection to the manure pipelines and an electrical supply.

MAIN OPERATIONAL PARAMETERS

The main operational parameters are the initial manure pH (although manure alkalinity is also very important) to determine the quantity of acid required. Dry matter content is also important to ensure adequate mixing of the acid.

PERFORMANCES

The acidification of liquid manure to pH 5.5 affects many aspects of the manure. In terms of gaseous emissions the published data seems dependent on the type of acid used, although it is only H_2SO_4 that is known to be used commercially. The changes in gaseous emissions are not always fully documented and the large spread in values suggests it is difficult to measure. The changes are as follows:

- Reduced ammonia emissions by 50-70% in animal housing and 50-88% in storage facilities.
- Lower CH_4 emission during storage has been found, reduced by 17-90%.
- Increased H_2S emission during the acidification process, although this is temporary.

Acidification also has other effects including:

- Reduced nutrients in solid fraction following separation, for example struvite is dissolved at low pH and thus follows the liquid fraction.
- Increased plant growth, perhaps due to additional S.
- Reduced ammonia emission during subsequent composting of up to 70%.
- Greater retention of NH_4+ during filtration as the greater part of TAN is soluble at low pH.
- Slower production of TAN from protein due to reduced microbial action.

ENERGY CONSUMPTION

Energy consumption of the system is very low, calculated to be less than 0.001 kWh per head per day for the control system. This does not include energy for pumping of manure which is considered to be part of the existing manure facility.

ECONOMIC CONSIDERATIONS

In terms of economics the system requires service by skilled personnel but is a simple process that only requires 96% H_2SO_4 at a dose rate of approximately 5kg per ton of manure. An acidification unit has an investment cost of around 100,000 Euros for the cattle manure unit, with consumables (acid) at around 1,500 Euros per year and low energy consumption.

PATHOGENS

Studies regarding pathogens in acidified manure are few but there is evidence to suggest that the increased concentration of the protonated form of volatile fatty acids at low pH causes severe problems with microbial metabolism and thus all microbial activity, including that of pathogens, is limited.

CLIMATE CHANGE

The acidification process reduces the emission of ammonia in subsequent processes. The ammonia has the potential to be deposited after emission and oxidised to N_2O, thus greenhouse gas emissions downstream can be reduced as mentioned above. Also, the reduced emission of CH_4 in subsequent processes such as storage due to inhibition of methanogenesis can also make a substantial change on greenhouse gas emissions, but these are also rather specific to the storage method.

FUTURE TREND

The technology has been investigated academically in many institutions and has been demonstrated on an industrial scale in several north-west European countries but is only known to be applied commercially in Denmark at present where the proportion of acidified manure has grown from 2% in 2008 to 10% in 2012. This is due to national control of ammonia emissions and thus future growth in other countries will depend on national legislation.

5.2. SOLID-LIQUID SEPARATION

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OVERVIEW

The use of these techniques is widespread over livestock farms in Europe, as they are often relatively cheap and simple and require little attention. Solid-liquid separation technologies allows separating manure into a dry matter (DM) and nutrient-rich solid fraction and a liquid fraction that can be both managed separately. In particular, the solid fraction could be more easily exported for crop use in other arable farm areas, reducing cost of transportation (Burton, 2007). Otherwise, the liquid fraction is also easier to handle, reducing risk of blockages in pipelines.

However, solid-liquid separation processes do not remove the excess of ammoniacal nitrogen, do not reduce the biodegradable organic matter load and do not reduce pathogen content (Burton, 2007) and, therefore, both fractions have to be correctly managed. Moreover, solid-liquid separation does not deal with odour problems. Solid-liquid separation techniques cause an increase in heavy metal concentration, such as Cu and Zn, in the solid fraction which may pose an environmental problem if used as fertiliser (Hjorth *et al.*, 2010).

The application of a solid-liquid separation technique is crucial as pre-treatment for a further aerobic biological treatment of the liquid fraction or for solid fraction composting. It also can be used as post-treatment for digestate coming from anaerobic digesters.

SCHEME

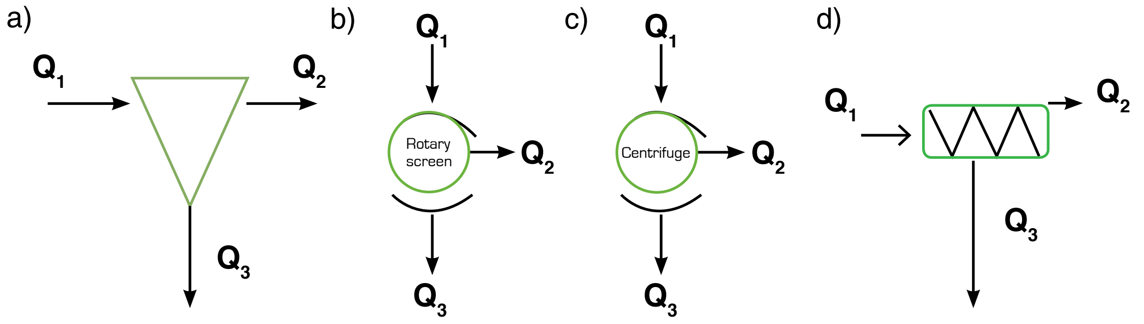

Figure 5.2.1. Scheme of solid-liquid separation technologies: a) sedimentation, b) screening, c) centrifugation and d) pressing. Q1: manure input, Q2: liquid fraction, Q3: solid fraction. In these mechanical processes, the addition of coagulants and flocculants increase separation efficiency.

TECHNICAL DESCRIPTION

The way by which the manure is dewatered will affect the possibilities for nutrient recovery, since different methods affect the ratios of nutrients in the liquid and in the solids (Hjorth, *et al.*, 2010). The different methods developed for solid-liquid separation can be divided into the following categories: sedimentation, screening, pressurized filtration and centrifugation and the combination of all of them with chemical addition.

SEDIMENTATION

Sedimentation is a physical process in which suspended solids are separated from the liquid fraction by gravity. Most thickeners consist of a container that is cylindrical at the top and conical at the bottom (Figure 5.2.2). In batch operation, slurry is added to the top of the thickener and the solids settle at the bottom of the conical part from where the solids can be removed. They are simple systems that require low investment and they are usually used for seasonal manure storage.

Table 5.2.1. Main factors affecting sedimentation efficiency.

Factor	Comment
Type of manure	Pig and cattle slurry and liquid pig and cattle manure (Flotats *et al.*, 2011)
Solid content	Separation efficiency considerably decreases for slurry with a solid content lower than 1% and higher than 4%. Within this range, separation efficiency increases when increasing the solid content (Ndegwa *et al.*, 2001). It is not recommended when total solid content in the influent manure is higher than 4% (Chastain, 2013).
Settling time	Increasing the settling time increases the separation efficiency although this process seems to have been completed during the first hour of retention time.

SCREENING

This separation technology involves a screen of a specific pore size that allows only solid particle smaller in size than the openings to pass through. The liquid fraction flows through the screen and is drained off.

The screen separators can be static, vibrant or rotary. The first type presents the simplest design: slurry is pumping to the top of the separator, liquid fraction flows through the screen whereas the solid fraction is retained in the screen and is retired by gravity and flow pressure (Figure 5.2.3 I, Figure 5.2.4). In vibrant separators, screens present a fast vibration, reducing clogging risks compared to static screens (Figure 5.2.3 II). Finally, rotary screens consist of a rotating perforated cylinder with a loading area at the top and a scraper to remove the solids (filter cake) (Figure 5.2.3 III). Separation by screens is usually used as pre-treatment to avoid sedimentation phenomena during storage, as conditioning process before pumping or coupled with more efficient separation systems (Flotats *et al.*, 2011).

Figure 5.2.2. Cylindrical settler with conical base.

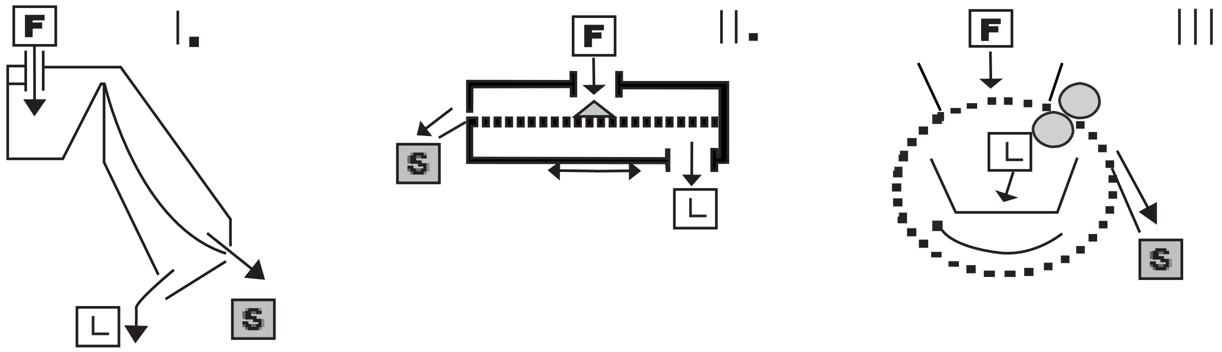

Figure 5.2.3. I: Static screen, II: Vibrant screen, III: Rotary screen. F: Influent slurry, L: liquid fraction, S: Solid fraction. Adapted from Burton and Turner (2003).

Figure 5.2.4. a) Static screen installed in a dairy farm; b) and c) rotary screens.

Table 5.2.2. Main factors affecting screening efficiency.

Factor	Comment
Type of manure	Pig and cattle slurry (Flotats *et al.*, 2011)
Solid content	This solid-liquid separation technology is not recommended when total solids in the influent manure are higher than 6% (Chastain, 2013).
Pore size screen	For swine manure, the use of screen openings lower than 0.5 mm causes continuous operating problems. For dairy manure, the most common screen size used is between 1.5-1.7 mm.

CENTRIFUGATION

In decanter centrifuges a centrifugal force is generated to cause the separation of solids from the liquid. There are vertical and horizontal types of decanter centrifuges. The horizontal decanter centrifuge consists of a closed cylinder rotating the conveyor at high speed that differs slightly for the speed of the bowl (outer conical shell) (Hjorth *et al.*, 2010). The solid particles are conveyed towards the conical end and let out through the solid discharge openings (Figure 5.2.5). The liquid fraction, containing a suspension of colloids, organic components and salts, is discharged through liquid-discharge openings at the wide end of the decanter centrifuge.

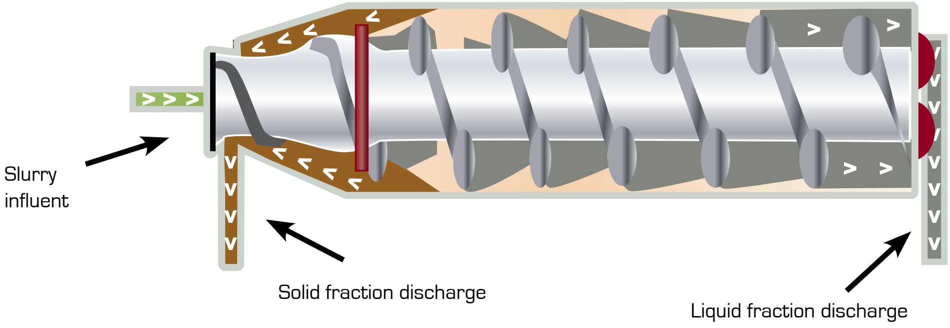

Figure 5.2.5. Typical decanter centrifuge. Adapted from Moller *et al.* (2007).

Table 5.2.3. Main factors affecting centrifugation efficiency.

Factor	Comment
Type of manure	Pig and cattle slurry and digestate from anaerobic digestion (Flotats *et al.*, 2011)
Solid content	The separation efficiency of dry matter increases at increasing dry matter content of the slurry (Flotats *et al.*, 2011). However, it is not recommended when total solids in the influent manure is higher than 10% (Chastain, 2013).
Velocity	Increasing the velocity of the decanter centrifuge will increase the DM content in the solid fraction, although this fact has no effect on the separation of P, K and N (Hjorth *et al.*, 2010).
Retention time	Increasing the retention time by reducing the volumetric feed rate has been observed to increase the efficiency of the separation of slurry.

PRESSURIZED FILTRATION

The most typical configuration is a screw press, in which slurry is transported in a cylindrical screen (0.5-1 mm) with a screw (Figure 5.2.6). As shown in Figure 5.2.7, the liquid passes through the screen and is collected in a container surrounding the screen whereas at the end of the axle the solid fraction is pressed against a plate, producing a filter cake with high dry matter content, often twice as high for gravity screening (Flotats *et al.*, 2011; Hjorth *et al.*, 2010).

Figure 5.2.6. Screw pressing in a pig farm.

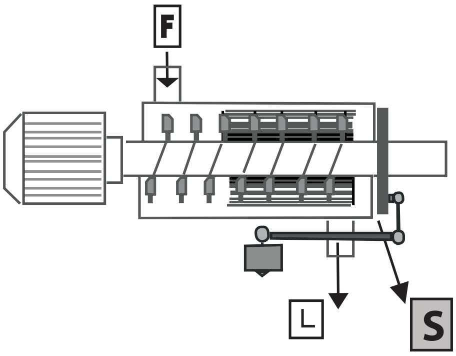

Figure 5.2.7. Scheme of a screw press. F: influent, L: liquid fraction, S: solid fraction. Adapted from Burton and Turner (2003).

Table 5.2.4. Main factors affecting the efficiency of pressurized filtration.

Factor	Comment
Type of manure	Pig and cattle slurry (Flotats *et al.*, 2011)
Solid content	This solid-liquid separation technology is not recommended when total solid content in the influent manure is lower than 2% (Chastain, 2013).
Pressure applied	Increasing the applied pressure will increased the dry matter content in the solid fraction (Hjorth *et al.*, 2010).

COAGULATION-FLOCCULATION

The use of chemical additives increases the efficiency of mechanical solid-liquid separation processes, reduces the phosphorous concentration in the liquid fraction and/or increases the dry matter content in solid fraction. In slurry, colloidal particles are not aggregated because they are negatively charged and repeal each other (Gregory, 1989). However, aggregation can be facilitated by adding multivalent cations (mainly aluminium and iron chlorides, aluminium and iron sulphates as well as calcium and magnesium oxides) that cause coagulation and/or polymers (such as chitosan and polyacrilamide –PAM), whereby flocculation occurs (García *et al.*, 2009; Hjorth *et al.*, 2010; Vanotti and Hunt, 1999). During the coagulation process, multivalent cations totally o partially neutralize negative surface charge by absorbing the oppositely charged ions to the particle ions, creating a double layer and thereby removing the electrostatic barrier that prevents aggregation (Figure 5.2.8a). During the flocculation, high-molecular weight polymers create local positively and negatively charged areas on the surface of the particles, resulting in a strong electrical attraction between the particles (Figure 5.2.8b). Long-chain polymers are absorbed to the surface of more than one particle, causing the formation of strong aggregates of large flocs that are easier to be separated (Figure 5.2.8c).

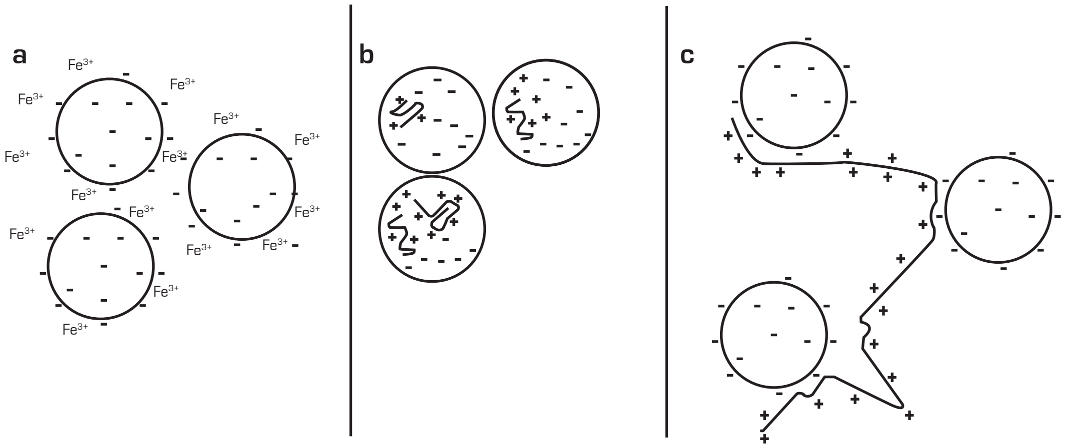

Figure 5.2.8. Schematic representations of a) coagulation, b) flocculation and c) aggregation (from Hjorth *et al.* 2008).

Coagulation-flocculation processes are commonly used before solid-liquid separation, but can also be employed after separation. In this last case, the construction of coagulation-flocculation basins with a slight slope allows the solid fraction to be easily withdrawn using a payloader (Figure 5.2.9).

Figure 5.2.9. Coagulation-flocculation basins with a slope for withdrawing solids.

Table 5.2.5. Main factors affecting the efficiency of coagulation-flocculation.

Factor	Comment
Type of manure	Liquid pig and cattle manure and pig and cattle slurry (Flotats *et al.*, 2011).
Coagulant and flocculant doses	An optimum dose exists, and overdosing can cause the particles change positively, counteracting aggregation (Gregory, 1989; Hjorth *et al.*, 2010).
Solid content	Polymer-enhanced solid-liquid separation of flushed manure is more efficient with high solid content wastewater (Vanotti *et al.*, 2002).
Stirring applied (i.e. time and speed)	The stirring applied has a large impact on the formation of the aggregates; too low stirring causes the aggregates to be non-uniform and unstable with low particle catchment, while too high stirring causes the aggregates to be destroyed (Flotats *et al.*, 2011).

PERFORMANCES

Dry matter and nutrient separation efficiencies

Separation index is the ratio of the total mass recovery of a component (DM or nutrients) in the solid fraction as a proportion of the mass of that component in the original raw slurry (Table 5.2.6). The larger the separation index, the greater the amount of given component in the solid fraction.

Economical considerations and energy consumption

Approximate investment costs and energy consumption for each technology are shown in Table 5.2.7. In Figure 5.2.10, an estimation of the cost of each technology as a function of flow of manure treated is shown. This estimation includes depreciation, maintenance, manpower and energy consumption.

Table 5.2.6. Separation indexes for the each separation technology. Standard deviation is shown in brackets. Table adapted from Hjorth et al. (2010).

Separation technology	Separation index (%)				
	Volume	Dry matter	N	NH_4+-N	P
Sedimentation	22 (4)	56 (10)	33 (2)	28 (2)	52 (21)
Screening	23 (16)	44 (27)	27 (17)	23 (19)	34 (21)
Centrifugation	14 (7)	61 (16)	28 (10)	16 (8)	71 (14)
Pressurized filtration	11 (15)	37 (18)	15 (17)	2.6a	17 (14)
Coagulation-flocculation	22 (16)	70 (13)	43 (24)	20 (14)	79 (21)

*Own surce

Table 5.2.7. Investment costs and energy consumption for each separation technology.

Separation technology	Investment (€)	Energy consumption (kW/t)
Sedimentation	17,000a	0.0-0.1a
Screening	3,500-8,000 (sieve) 15,000 (vibrant)a	0.19b
Centrifugation	40,000-100,000a	2.90b
Pressing	30,000c	0.53b

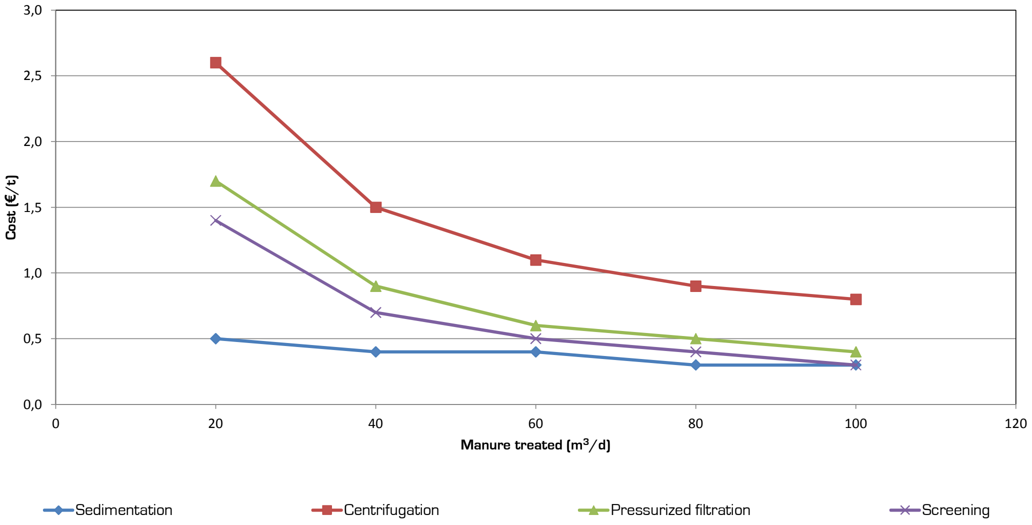

Figure 5.2.10. Estimated cost of the different solid-liquid technologies as a function of flow of manure treated.

Coagulation-flocculation coupled with mechanical solid-liquid separation can increase the overall cost of the process in 0.2-0.4 €/t, depending on the solid content of the manure treated, flow treated and type of chemical used.

OTHER INFORMATION

There is scarce information about pathogens removal and gas emissions in solid-liquid separation technologies. Other useful information is summarized in Table 5.2.8.

Table 5.2.8. Complexity, noise and odour in solid-liquid separation technologies.

Separation technology	Complexity	Noise	Odor (scale 1-4)
Sedimentation	Low	No	
Screening	Low	Yes	3
Centrifugation	Medium	Yes	3
Pressing	Low	Yes	3

CLIMATE CHANGE

Solid-liquid separation processes reduce manure volume while increasing nutrient concentration, thereby cutting transportation costs and its associated impact on the climate change, since greenhouse gas emissions derived from transportation are reduced (Riaño and García-González, 2015).

FUTURE TREND

Preferred technologies in the future should firstly aim at nutrient recycling (Foged *et al.*, 2011). In this vein, the implementation of solid-liquid separation will play an important role as a possible best technology in future farming scenarios. Future efforts should be focus on the optimization of the performance of solid-liquid separation technologies in order to reduce costs while increasing nutrient concentration of the separated solid fraction.

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5.3. ANAEROBIC DIGESTION

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OVERVIEW

Anaerobic digestion is a microbiological process following different reactions in a synergic scheme where organic matter is transformed into biogas, a flammable gas constituted mainly by methane (CH_4) and carbon dioxide (CO_2), with a CH_4 content ranging from 55% to 75% by volume. This process can be applied to sewage sludge, animal manure, organic industrial waste, organic fraction of municipal solid waste, energy crops and high strength organic wastewaters, converting all these material as resources for renewable energy production in the form of CH_4.

The primary energy production of biogas in Europe was 13.4 Mtoe (millions tonnes of oil equivalent), with an electrical production of 52.3 TWh during 2013 and with more than 14,000 biogas plants in the European Union (Eurobserver, 2014). Germany has around 7,000 biogas plants mainly processing energy crops and manure, as well as organic industrial and household wastes, with an estimated primary energy production of 6.7 Mtoe and electrical sells to the grid around 29 TWh during 2013.

Apart the classical uses of biogas for thermal or electrical energy production, the use as vehicles fuel or as natural gas substitute, after an upgrading process to produce biomethane, is gaining interest worldwide. The injection to the natural gas grid enables biomethane to be stocked and used remotely from the production site, in order to be consumed when and where the energy conversion efficiency will be higher, instead to be transformed to electricity onsite without a useful and efficient recovery of the wasted heat. This practice is thought to be the next developing industrial step of the biogas sector, with 258 biomethane plants at the end of 2014 in just 12 EU member states, and being Germany the leading country with more than 150 biomethane plants with a capacity around 93,650 Nm^3/h on 2014, practically doubling it since 2011. Sweden is leading the use of biogas as biofuel, with many buses in Stockholm city consuming biomethane.

SCHEME

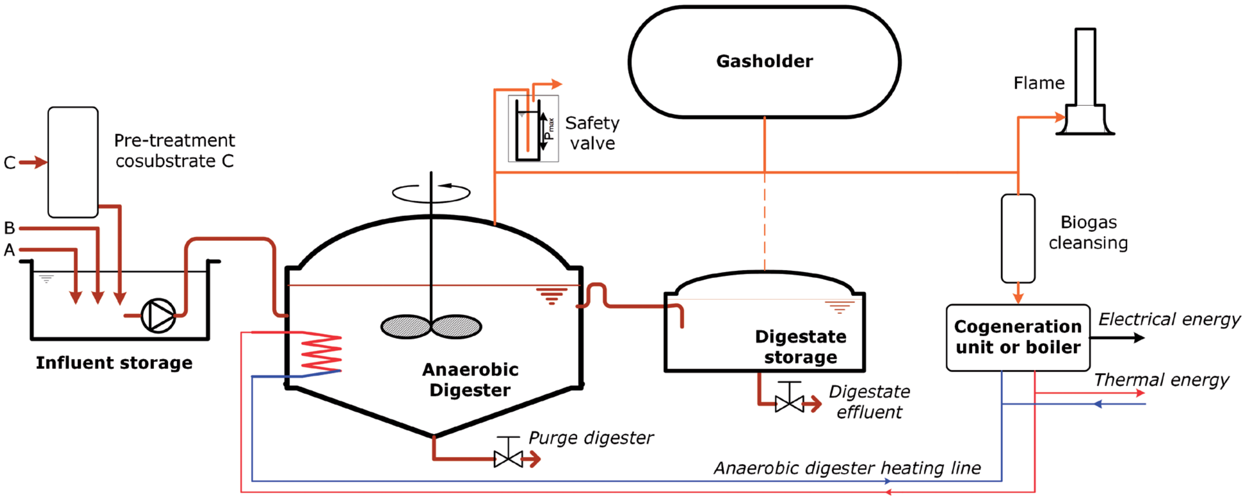

Figure 5.3.1. General scheme of a co-digestion plant.

TECHNICAL DESCRIPTION

Figure 5.3.2 depicts a scheme of the main reactions occurring during the anaerobic digestion process and microorganisms catalysing them. The detection of the rate limiting steps helps to understand the technological trends on reactors and facilities design developed to overcome these limitations. Considering that 0.35 m^3 CH_4 is equivalent to 1 kg COD (Chemical oxygen demand), the knowledge of the initial COD of an organic waste to be consumed by anaerobic microorganisms (anaerobic biodegradability) allows the estimation of the final methane potential. Some wastes, as the ligno-cellulosics, presents very low values, and a general trend of the biogas sector is to adopt methods to increase biodegradability of this kind of materials.

It can be appreciated in Figure 5.3.2 that all organic compounds are converted to different volatile fatty acids, which accumulation could decrease pH to low levels, inhibiting the microbial growth. pH also affects the equilibrium between ammonium and free ammonia, which is an inhibitor of the acetoclastic methanogens. The equilibrium between CO_2 and bicarbonate is important to maintain pH around neutrality, and the buffer capacity of a waste to be processed is a property to consider for a good anaerobic digestion process.

While animal manures have a high buffer capacity, although low methane production potential and high ammonium content, some industrial organic waste present the opposite characteristics, being the anaerobic digestion of mixtures of both substrates the way to have high biogas productions and a stable process. This practice, named co-digestion, consists on mixing wastes with complementary compositions in order to implement economically feasible plants, to unify management methods and to optimize investment costs, and is the base concept of the on-farm and centralized biogas plants in the agricultural sector. Figure 5.3.1 shows a scheme of a co-digestion plant.

The anaerobic digestion for the treatment of organic biomass finds application in animal farming because:

- accelerates the stabilization process of slurry and manure for future storing and agricultural use as fertilizer;
- allows a good odor removal and less methane emissions (greenhouse gases);
- allows removal of weed seeds, parasites and eggs and larvae of insects, which will be beneficial for the manure use as fertilizer;
- allows an energy and economic recovery from animal manure and slurry.

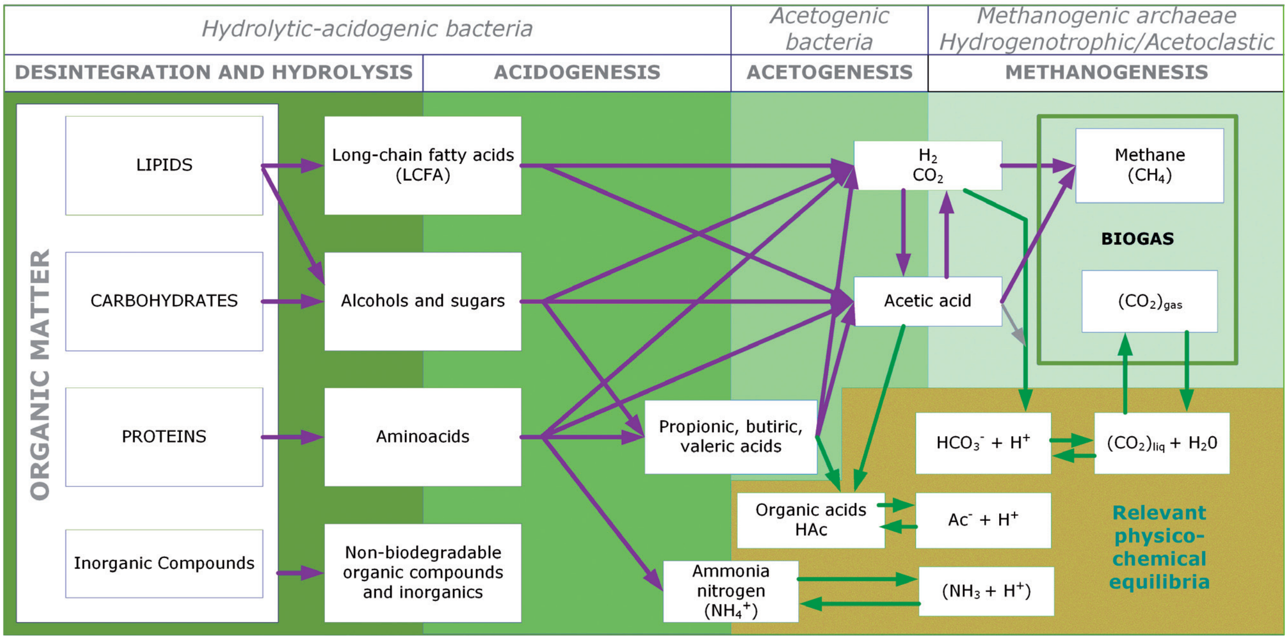

Figure 5.3.2. Steps of the anaerobic digestion process.

Figure 5.3.3. Anaerobic digestion plant at dairy cow farm (Catalonia, Spain)

Figure 5.3.4. CHP engine fuelled by biogas

PERFORMANCE

Following the biogas plant scheme of Figure 5.3.2, manure arrives to the influent storage where it is homogenized and mixed with co-substrates for increasing the biogas production of the plant. Biogas yields of manures are relatively low (around 10-15 m^3/tonne and 22-27 m^3/tonne for pig and cow manure, respectively), while some organic industrial wastes present much higher values (such as bentonite bound oil – 350-450 m^3/tonne – or concentrate whey – 100-130 m^3/tonne), allowing mixtures producing biogas enough to balance the economics of the plant, depending of the energy prizes and subsidy policies of every country. Some potential co-substrates requires thermal pre-treatments for sanitation purposes, such the slaughterhouse waste (70-100 m^3/tonne)

Usual anaerobic digester configuration for manure and co-digestion follows the CSTR design (Completely Stirred Tank Reactor), with a hydraulic retention time (HRT) comprised in the range 20-70 days. The higher HRT values can be found when some co-substrates are slowly biodegradable (e.g. crops) and/or an adaptation to high ammonia concentration or other inhibitors are required.

After the process, it is recommendable to maintain the effluent in a covered store before its agricultural use, in order to allow biogas release from the liquid and recover the biogas produced in this stage, which could reach around 10-15% of the total production.

Gas line must include its temporal storage in a gasholder, which can be the top of the digester, a security valve system with the objective to maintain the gas pressure into a secure pressure range when the active control systems do not work, a flare for combusting biogas when it cannot be used and the maximum biogas storage capacity is reached, a biogas treatment system for removing or reducing moisture, dust and hydrogen sulphide (H_2S), which can negatively affect the biogas to energy production unit, and the final energy production unit.

The transformation of biogas into usable energy may be by direct combustion in a boiler, producing only heat, or combustion in a CHP (Combined Heat and Power) unit to produce electrical and thermal energy. 1 m^3 of biogas produces 1.8 – 2.0 kWh of electric energy and 2-3 kWh of thermal energy, depending of the CHP power. For the use of biogas as biofuel or for natural gas grid injection, a further upgrading is required in order to obtain 95-98 % methane content (biomethane), which can be found in some large-scale biogas plants.

CLIMATE CHANGE

The process contributes to the mitigation of anthropogenic CO_2 emissions. It is considered to be around 90% reduction of the corresponding emission of the fossil fuel substituted by biogas. In the case of manures, this value can be almost doubled, since its controlled anaerobic digestion and subsequent energy use of biogas decreases the natural emissions of CH_4 to the atmosphere during manure storage and management. Typical farm-scale anaerobic digestion plant treating manure (together with 5% of co-substrate) reduces between 50-70 $kgCO_2eq$/tmanure, with respect a reference situation where the manure is used as fertilizer after 4-6 month of storage (Foged *et al.*, 2011).

CLIMATE CHANGE

General trends of anaerobic digestion for manure processing can be synthesized as:

a. To focus the research to increase biogas production from the fibres fraction of manure, mainly constituted by ligno-cellulosic compounds, by appropriate pre-treatments in order to decrease the economic dependence from other organic wastes as co-substrates, which could tend to increase its supply economical costs.

b. To integrate anaerobic digestion in global combined processes dealing with nutrients recovery and management, in order to build sustainable manure processing strategies.

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5.4. AERobic BIOLOGICAL TREATMENT

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OVERVIEW

The term “aerobic biological treatment” includes several different processes, namely all those processes where a decomposition of organic matter by aerobic microorganism occurs (Burton and Turner, 2003). However, in this context we will refer only to a specific aerobic process that involves aerobic nitrification followed by an anaerobic denitrification. This process is used to reduce organic matter but especially to remove nitrogen that is transformed in molecular nitrogen and released to air.

Nitrification-denitrification can be carried out with different technologies that share some elements and methods. This process is often, but not necessarily, preceded by the separation of coarse and fine solids entering the plant and followed by removal of excess biomass from the installation. In some cases the treatment can be completed by a further step for the removal of phosphorus by flocculation and sedimentation.

The goal of the treatment ranges from the simple reduction of the organic load and nitrogen to the complete removal of pollutants with discharge in surface water.

During treatment there are possible releases into the atmosphere of ammonia (NH_3) and nitrous oxide (N_2O) that can be contained by an appropriate setting and management of the plant (Béline and Martinez, 2002).

The treatment requires a dedicated structure and the plant can be, in some cases, very complex. The management of the system must be performed by trained personnel.

This type of treatment is suitable for farms who cannot find other solutions to the management of surplus nitrogen. It is the only technology that reduces the nitrogen content in the effluent in a form that does not present environmental problems (molecular nitrogen).

The high costs of investment and management make these systems expensive and their choice must be evaluated wisely and with qualified technical support.

Consequently, this process is not very diffuse. However, in some intensive livestock areas, like for example Britany, the technology is widespread and represent 90% of the farm treatment units (Béline *et al.*, 2004).

In addition, it should be noted that, from the environmental point of view, the biological treatment might not be considered a good solution because mineralize organic matter and release nitrogen, with a process conceptually opposite to that used for the synthesis of ammonia for the production of mineral fertilizers.

SCHEME

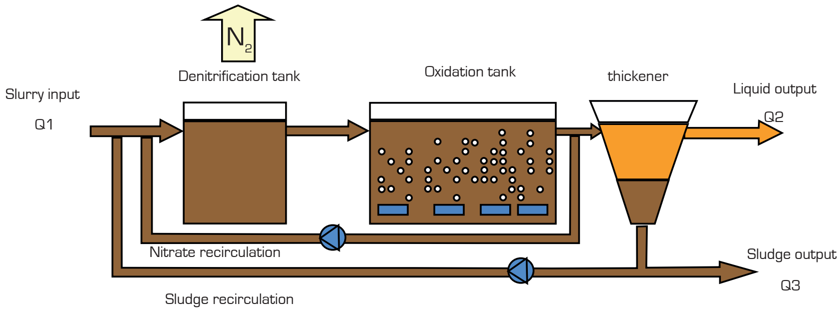

Figure 5.4.1. Scheme a: nitrification and denitrification in different tanks

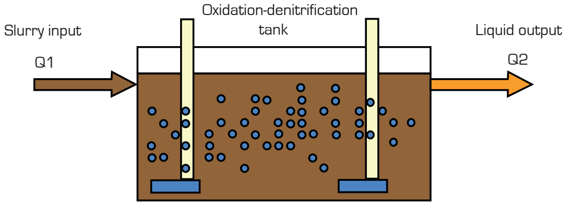

Figure 5.4.2. Scheme b: nitrification and denitrification in the same tank

TECHNICAL DESCRIPTION

The treatment for the combined removal of the organic substance and nitrogen is based on an oxidation phase in which the organic matter is degraded and organic nitrogen is mineralized. In this stage aerobic microorganisms also transform ammonia nitrogen in nitrate form. To ensure the concentration of the O_2 required, air is blown through aeration systems and diffusers.

The anoxic phase that allows the transformation of the nitrates into molecular nitrogen (N_2) is performed by heterotrophic microorganisms and requires the availability of organic carbon.

The result of this treatment is a reduction of the organic matter that is oxidized with the consequent reduction of odor and the removal of nitrogen, which can reach high efficiencies, releasing into the atmosphere even 90% of the nitrogen entering the process.

Bacterial growth produces a biomass that can be separated by sedimentation and partially recirculated to ensure adequate concentration of the biomass in the two phases of the treatment. The two phases, in simplified installations may be carried out with alternating anoxic and oxygenation in the same tank with cycles lasting 4-12h.

The separation before biological treatment should be performed to remove solids, reduce organic load, and thereby reduce the size of the system and the energy requirements.

The sludge produced by the process, may be used for the production of energy (biogas) or may be stored as such or after dehydration by separation with centrifuges or belt presses.

Energy consumption is high. The stage of nitrification-denitrification can have high removal yields that arrive at 95% of the total nitrogen that enters this stage, but the separated solid fractions and sludge that are produced contain a significant proportion of the nitrogen contained in the effluent plant initiated (25-40%) and all the phosphorus that is separated from the liquid fraction leaving the plant.

The solid fractions should be used in the fields. The liquid fraction might be further treated and discharged in surface waters, but as it seldom reaches the required limits, it is generally spread on the fields.

The nitrification process is represented by a set of reactions that take place in an aerobic environment that can be summarized as follows:

- $C_5H_7O_2N + 5O_2 \rightarrow 5CO_2 + 2H_2O + NH_3$ where the organic matter is degraded and organic nitrogen is transformed in ammonia.

- $NH_3 + 2O_2 \rightarrow NO^-_3 + H_2O + H+$ where ammonia is converted in nitrate.

The microrganisms taking part in the transformation of nitrogen are two specialized groups of nitrifying bacteria, autotrophic strictly aerobic type: bacteria group nitrosomonas operate the first step by oxidizing ammonia to nitrite and the second group nitrobacter oxidize nitrite to nitrate. Fundamental to the activity of these bacteria appears to be the concentration of dissolved oxygen (supplied with suitable blowers); in fact they have maximum speeds to the oxygen concentration of 3 mg/l of O_2, decreasing the concentration, the speed decays significantly, until essentially zero at concentrations less than 0.5 mg/l. The value that is normally adopted in the plants to ensure a good nitrification is a dissolved oxygen concentrations of 2 mg/l.

For a good result of the reactions of nitrification a very important parameter is the temperature, in fact, the variation of this parameter the growth rate of nitrosomonas is being very sensitive. The rate of growth of these microorganisms increases by about three times, passing from 10 to 20 ° C.

The requirement of oxygen for the aerobic phase is:

- 0.9 kg O_2 per kg of BOD removed.

- 4.6 kg O_2 per kg of ammonia oxidized.

Air diffusion systems of oxidation tanks may have different transfer rate in relation to the size of the bubbles that produce and of the movement within the mass. In general terms it can be considered unitary consumption for oxygen transfer medium equal to 1.6-1.8 kg of O_2/kWh, although the range of variation may be much higher depending on the systems used with minimum values of 1 kg of O_2/kWh and maximum of 2.5 kg O_2 / kWh.

After the nitrification phase the effluent is maintained in conditions of anoxia, here will occur the denitrification phase where nitrates coming from the preceding stage are transformed into molecular nitrogen and released into the atmosphere.

In anoxic environment, facultative anaerobic bacteria use nitrate as an electron acceptor, releasing into the atmosphere the molecular nitrogen as a waste product of the following reaction:

$$2NWO^{-}_{3} \rightarrow N_{2} + 3O_{2}$$

The denitrification process therefore consists in the reduction of nitrates to molecular nitrogen, operated by bacteria, which, in addition to oxygen deficiency, require, for the carrying out of the process of a source of organic carbon.

The supply of carbon in installations for the treatment of animal manure, characterized by a high content of organic substance, can derive by the slurry itself, adopting appropriate configuration of the plant.

The aerobic process for nitrogen removal is generally implemented according to two possible treatment schemes.

Aerobic process with aeration and anoxic phase in different tanks (NDN)

This solution consists of two separate tanks for the two phases and a thickener to remove the sludge contained in the output liquid (scheme a). This operational scheme is used when high removal performances are required and the output can be further treated to remove phosphorus and remaining solids before discharge in surface waters.

In order to maintain an adequate concentration of organic carbon in the denitrification phase, the denitrification tank is placed at the beginning of the process, thus the organic carbon contained in the input slurry can be available to the microorganisms. The mixed liquor is continuously recirculated to bring the nitrates obtained in the oxidation phase to the denitrification tank.

Figure 5.4.3. Aerobic process with aeration (left) and anoxic phase (right) in different tanks. In the foreground the sedimentation tank.

The mixed liquor is then sent to a thickener that concentrates solids (and microorganisms) in the bottom by sedimentation. The sludge is extracted by a pump and partly recirculated (to maintain the desired concentration of biomass in the process tanks), and partly remove

Aerobic process in Sequencing Batch Reactors (SBR)

SBR system involves the input of slurry in a tank which occurs the nitrification-denitrification process by air insufflation alternating periods of anoxia (Scheme b). The air insufflation is the only energy cost of the system and also provides for the mixing. Unlike the nitro-denitro system in SBR system the sedimentation phase is performed in the same tank, before discharge. Part of the sludge exit the tank with the liquid as there is not an external thickener.

It is useful to provide a separation upstream to reduce the organic load and reduce the consumption of oxygen.

Figure 5.4.4. Aerobic process with aeration (left) and anoxic phase (right) in different tanks. In the foreground the sedimentation tank.

MAIN OPERATIONAL PARAMETERS

The process in the two configurations is affected by several operational parameters, some of which are related to the bacteria activity (nitrification and denitrification rate, mixed liquor suspended solids).

The nitrogen removal efficiency is a design parameter as its value is used to size the plant and the equipment. The efficiency can vary in a range of values: from 60 to 90% for NDN and from 30 to 70% for SBR. One of the key parameter is temperature of the process, which is depending on the climatic conditions, i.e. on the location of the site. The type of blower is another operational parameter that does not influence the process but affect the energy consumption. The required oxygen concentration is set as default value to 2 mg/l.

There are two constraints. One is related to the total solids. When they are over 25 (NDN) or 30 (SBR) kg/l the process cannot run as expected. In this case, a solid liquid separation process is required. The second is related organic carbon availability for the denitrifying bacteria. In case there is not enough internal organic carbon source, the process will require an external source of organic carbon.

PERFORMANCES

The input characteristics and the nitrogen removal level required affect the performances of the process. An example of typical values is reported in table 5.4.1 for the two plant configurations. As can be noted, the NDN solution seems to remove volume and some elements like phosphorus but it has be considered that there is a production of sludge not accounted in these values.

Table 5.4.1. Typical values for NDN and SBR treatment technologies.

Removal Efficiencies (main parameters)	NDN	SBR
Flow rate (m^3/day)	11%	0%
Mass flow rate (t/day)	11%	0%
Total solids (kg/t)	55%	44%
VS (kg/t)	62%	48%
COD (kg/t)	91%	67%
TKN (kg/t)	77%	60%
TAN (kg/t)	73%	50%
TP (kg/t)	28%	0%
TK (kg/t)	0%	0%
EC (dS/m)	0%	0%
pH	-5%	-4%

Typical energy consumption is 2.5-3 kWh per kg of nitrogen removed.

Regarding pathogens reduction, the results can vary according the process temperature. Salmonellae, Escherichia coli and other Enterobacteriacae are sensitive to temperatures above 45°C. Under these conditions, aeration times of 48h are sufficient for inactivation. However, these conditions are not always reached and, in general, a reduction is obtained but not a complete inactivation (Burton and Turner, 2003).

CLIMATE CHANGE

The process is based on aeration that requires electric energy for the blower. Thus, considering a CO_2 emission of 0.181 kg kWh-1, the emissions are 0.45-0.54 kg CO_2 kg per kg of nitrogen removed.

During the nitrification-denitrification process, an amount of N_2O is produced. The emissions of this powerful GHG are mainly related to the correct management of the plant. A reference value could be 5% that is an average between the values of 0-10% found by Béline and Martinez (2002).

A further emission is related to ammonia volatilisation that may occur in some point of the process. Also in this case an average value has been used as default value (3% of initial ammoniacal N content of the slurry).

FUTURE TREND

The aerobic treatment for nitrogen removal has been for several years practically the only proposed treatment for nitrogen removal for existing farms with high nutrient surplus. The process is energy requiring and produce emissions of GHGs and ammonia. Moreover, the nitrogen is lost to the air.

In the last years some new technologies has been proposed to recover nitrogen from the slurry for further use in agriculture or other sectors. Therefore the aerobic treatment may become less attractive in the future. Furthermore, the revision of the BREF document for the definition of the BAT in application of the IED may modify the applicability of this technique to specific conditions.

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5.5. COMPOSTING

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OVERVIEW

Amongst the manure management strategies, composting is gaining interest due to the economic and environmental profits, since this process eliminates or reduces the risks associated with direct land application and leads to a final stabilised product which can be used to improve and maintain soil quality and fertility (Larney and Hao, 2007).

Composting is a spontaneous biological decomposition process of solid organic material in a predominantly aerobic environment, during which bacteria, fungi and other microorganisms, including microarthropods, break down organic materials into a stable, usable organic substrate called compost. Then, composting is a biooxidative process involving the mineralisation and partial humification of the organic matter (OM), leading to a stabilised final product, free of phytotoxicity and pathogens and with certain humic properties (Zucconi and de Bertoldi, 1987). Thus, composting helps to recycle elements of agronomic interest (macro- and micronutrients, OM), reduces waste volume and moisture content, degrades toxic organic substances and reduces the risk of pathogen transfers and weed seed viability through waste sanitisation, making the material easier to handle, pelletise and transport out of regions. Recently, composting has received renewed and widened interest as a means of addressing current waste management challenges, in particular for reducing the amount of wastes going to landfills and the associated CH_4 emissions from the degradation of organic materials.

The composting process occurs spontaneously (no external energy is required), during which the simple organic compounds are easily mineralised and metabolised by the microorganisms under the presence of oxygen, producing CO_2 and inorganic compounds, releasing heat (exothermic process), which increases the temperature of the material. Then the process is constituted by two phases (Figure 5.5.1), indicated by the development of the temperature profile: the bio-oxidative phase and the maturing phase, called the curing phase (Bernal *et al.*, 2009).

The bio-oxidative phase is developed in three steps (Keener *et al.*, 2000):

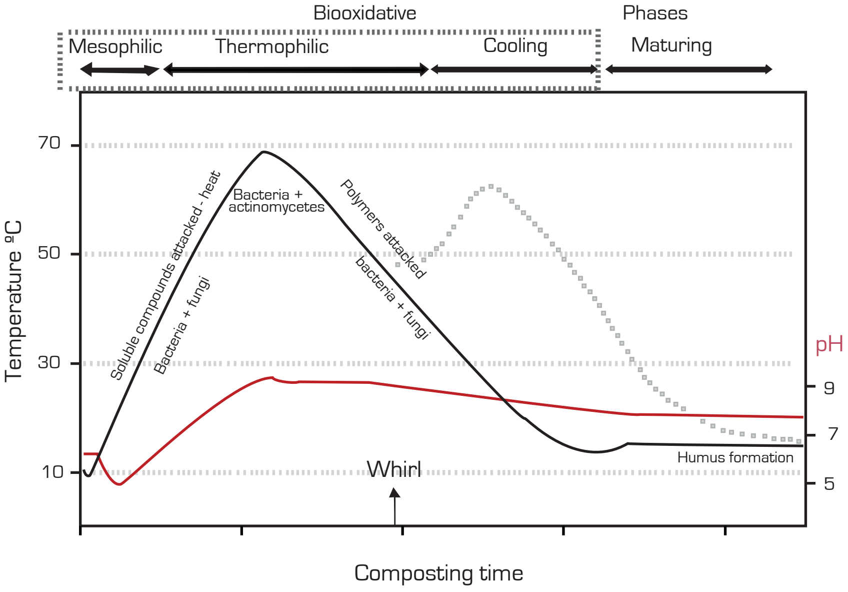

Figure 5.5.1. Temperature profile describing the different phases of the composting process (dotted line indicates the temperature after a mechanical turning).

1) an initial mesophilic phase lasting 1-3 days, where mesophilic bacteria and fungi degrade simple compounds (sugars, amino acids, proteins, etc.) increasing quickly the temperature;

2) thermophilic phase, where thermophilic microorganisms degrade fats, cellulose, hemicellulose and some lignin, during this phase the maximum degradation of the OM occurs together with the destruction of pathogens;

3) cooling phase, characterised by a decrease of the temperature due to the reduction of the microbial activity associated with the depletion of degradable organic substrates, the composting mass is re-colonised by mesophilic microorganisms which are able to degrade the remaining sugars, cellulose and hemicellulose.

In general, pig slurry usually shows several characteristics that strongly influence the design and development of the composting process (Moral *et al.*, 2005; Yagüe *et al.*, 2012):

- Neutral-basic pH values, which together with low C/N ratio and high ammonium concentration can lead to high nitrogen loses by ammonia volatilisation.
- High electrical conductivity values, which can reduce the quality of the final compost obtained.
- High moisture content, which makes difficult composting without bulking agent.
- Presence of contaminants, such as heavy metals (especially Zn and Cu in slurry from piglets).
- Presence of pathogens (bacteria, viruses and parasites).

Then, pig slurry shows excessive water content to be directly composted, so a pre-treatment based on a solid-liquid separation may be necessary. This process of phase separation allows the concentration of the total and volatile solids in the solid fraction, with adequate conditions for composting. Also, the addition of a bulking agent improves the composting of pig slurry optimising the substrate properties, such as air space, moisture content, C/N ratio, particle density, pH and mechanical structure, affecting positively the decomposition rate. In this sense, lignocellulosic agricultural and forestry by-products are commonly used as bulking agents in co-composting of animal manures (Bernal *et al.*, 2009), such as cereal straw, cotton gin waste, hay and wood by-products (pine shavings, chestnut burr and leaves and sawdust). All have low moisture and high organic-C contents and high C/N ratios (an average of 50 for cereal straw and > 80 for wood by-products), which can compensate for the low values of the animal manures and slurries.

SCHEME

The composting process for pig slurry can be represented as a material flow diagram (Figure 5.5.2): the pig slurry is collected and stored in a tank, then subject to a solid-liquid separation process, the liquid can be subject to further treatment or used in agricultural land. The solid fraction is composted by mixing with an adequate bulking agent, and during the biooxidative phase, aeration is provided to the composting mass. Finally, a maturation period is required for obtaining mature compost, during which aeration is not further needed.

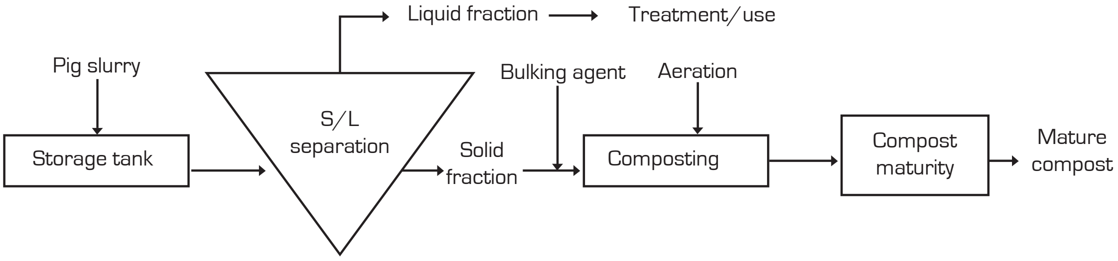

Figure 5.5.2. Scheme of the composting process of pig slurry.

Figure 5.5.3 and 5.5.4. Windrow composting: turning machinery.

TECHNICAL DESCRIPTION

Composting occurs naturally, but efficient composting requires the control of several factors which determine the optimal conditions for microbial development and organic matter (OM) degradation. Such factors can be divided into two groups: those depending on the formulation of the composting mix (nutrient balance, pH, particle size, porosity and moisture), and those dependent on the process handling (O_2 concentration, temperature and water content) (Bernal, 2008):

Nutritional balance: mainly defined by the C/N ratio. The adequate C/N ratio for composting is in the range 25-35, because it is considered that the microorganisms require 30 parts of C per unit of N; high C/N ratios make the process very slow as there is an excess of degradable substrate for the microorganisms; at low C/N ratio, there is an excess of N per degradable C and inorganic N is produced in excess and can be lost by ammonia volatilisation.

pH: A pH of 6.7-9.0 supports good microbial activity during composting. Optimum values are between 5.5 and 8.0 (de Bertoldi *et al.*, 1983; Miller, 1992). Usually pH is not a key factor for manure composting, however, it is very relevant for controlling N-losses by ammonia volatilisation, which can be particularly high at pH > 7.5.

Microorganisms: The microorganisms involved in composting develop according to the temperature profile (Ryckeboer *et al.*, 2003): Bacteria predominate early in composting (mesophilic phase); fungi are present during all the process but predominate at water levels below 35 % and are not active at temperatures > 60ºC; Actinomycetes predominate during stabilisation and curing, and together with fungi are able to degrade resistant polymers Above 60 ºC, pathogens and parasites are inhibited.

Particle size and distribution: these parameters are critical for balancing the surface area for growth of microorganisms and the maintenance of adequate porosity for aeration. The larger the particle size, the lower the surface area to mass ratio, so, large particles do not decompose adequately because their interior has difficult accessibility for the microorganisms. However, too small particles can compact the mass, reducing the porosity and aeration (Haug, 1993). For agitated systems and forced aeration 10 mm is considered the optimum particle size, but for large heaps and natural aeration 50 mm size may be adequate (Gajalakshimi and Abbasi, 2008).

Porosity: it affects the air distribution. Porosity greater than 50% causes the pile to remain at a low temperature because energy lost exceeds heat produced. Too little porosity leads to anaerobic conditions and odour generation. The percentage air-filled pore space of composting piles should be in the range of 35-50%.

Aeration: this is a key factor for composting. Proper aeration controls the temperature, removes excess moisture and CO_2 and provides O_2 for the biological processes. The optimum O_2 concentration is between 15 and 20% (Miller, 1992). Insufficient aeration can lead to anaerobic conditions, and the proliferation of anaerobic microorganisms and odours; excessive ventilation can cool down the mass, reducing the microbial metabolic activity (Kulcu and Yaldiz, 2004).

Moisture: The optimum water content for composting generally ranges 50-60% (Gajalakshmi and Abbasi, 2008). The moisture content should not saturate the pores, allowing the circulation of O_2 and the gases resulting from the OM degradation. When the moisture content exceeds 60%, O_2 movement is inhibited and the process tends to become anaerobic (Das and Keener, 1997).

Temperature: The temperature pattern shows the microbial activity and the occurrence of the composting process. The optimum temperature range is 40-65ºC (de Bertoldi *et al.*, 1983), and temperatures above 55ºC are required for sanitisation. At temperatures above 63ºC, microbial activity declines rapidly as the optimum for various thermophiles is surpassed. The range of 52-60ºC is the most favourable for decomposition (Miller, 1992).

Different technologies have been developed for composting based on the aeration system: by turning the pile, by forced aeration, or by passive aeration where air is allowed to passively flow through the pile (Imbeah, 1998). The technological difficulty increases in the order: Static pile with passive aeration; windrow with mechanical turning; static pile with forced aeration; in-vessel systems (composting reactors).

Passive aeration occurs through three mechanisms: molecular diffusion, wind and thermal convection; but aeration can be assisted by the use of perforated pipes traversing the pile. Although the system is very cheap, anaerobic conditions can develop if it is not carefully controlled. Windrow composting refers to a common system in which the solids are spread in a long heap and the aeration is supplied by mechanical turning at frequent intervals. A wide range of machinery can be employed for the mechanical agitation of the material, from simple loading shovels to specialised windrow-turning equipment. Aerated static piles are based on the construction of a well-blended pile, on top of a system of aeration pipes or on a porous floor with pipes underneath. There are two main systems: under positive pressure, the air is blown through by means of an air-blower (Rutgers system - temperature feedback control), whilst under negative pressure or suction (Beltsville system) the exhaust air may be passed through a biofilter for odour control. In-vessel systems are essentially closed reactors which can incorporate the gas treatment. They can be categorised as: containers, silos, agitated bays (bed), tunnels and enclosed halls.

Figure 5.5.5. Windrow composting: static pile system with forced aeration. View of the air forced system.

PERFORMANCE

The performance of the composting process is basically indicated by the evolution of the temperature and the OM degradation and stabilisation. Adequate composting process may pass through the three steps of the biooxidative phase and also through the maturation phase, during which degradation of the OM, and microbial stabilisation should take place together with the destructions of pathogenic microorganism, leading to stabilised and sanitised compost. The adequate performance of the process should lead to mature, stabilized compost with humic properties of the OM and free of phytotoxicity and pathogens. All these properties, together with the concentration of nutrients define compost quality and therefore its use.

Then compost quality criteria include: agronomic parameters (moisture, soluble salts, pH, OM macro- and micronutrients, C/N ratio and inorganic-N forms); microbial stability (microbial respiration measured as CO_2 production or O_2 consumption; shelf-heating test; and presence of degradable compounds such as volatile fatty acids or soluble organic-C); hygienic aspects (mainly *E. coli* and *Salmonella*); absence of phytotoxicity (by germination and plant growth tests); OM humification (humification indices, humic substances concentration and characterisation by elemental, molecular and spectroscopic analyses, functional groups and cation exchange capacity); physical properties (colour, odour, particle size); the presence of undesired components (germinating weed seeds, glass, metals, plastics, stones, etc.) and the concentration of heavy metals.

CLIMATE CHANGE

During composting, both greenhouse gases CH_4 and N_2O and the acidifying gas NH_3 may be produced and emitted from the heap. The emission of gases reflects transformation of the organic matter. Ammonia emission is affected by total ammoniacal nitrogen ($TAN=NH_3+NH_4+$), temperature and pH. Immediately after starting the composting, temperatures are high and pH increases due to the degradation of organic acids, which shift the equilibrium NH_4+ - NH_3 towards NH_3. The warm air is transported to the surface of the compost material creating a convection flow to transport the released NH_3 to the surface and to the atmosphere. In consequence, the potential for NH_3 emission is increased and NH_3 is emitted mainly during the thermophilic phase of composting; after few weeks the emission declines to low values due to depletion of NH_3 and NH_4+ being transformed to organic N or nitrified.

Large quantities of CO_2 and CH_4 are produced during the degradation of the organic matter. In the biooxidative phase, the heap may contain anaerobic pockets due to a higher O_2 consumption than O_2 replenishment which can enhance CH_4 production by methanogenic microorganisms (Hellmann *et al.*, 1997). Then, the production rate of CH_4 increases with temperature (Husted, 1994) until the limit temperature for the microorganism survival is surpassed and CH_4 production decline. Methane production may start at initiation of the composting process but the emission is often delayed, because the CH_4 produced in the centre of the heap is transformed to CO_2 during transport to the surface (Sommer and Møller 2000). The CH_4 production is exponential related to temperature and emission can therefore be high during the thermophilic phase and decline to low rates in the mesophilic phase due to lower temperatures and depletion easily decomposable organic matter.

In compost heaps, little N_2O is emitted during the thermophilic phase, because little or no nitrate is produced and NO_3- is the substrate for production of N_2O. At temperatures above 40-45 ºC nitrification is insignificant, and increasing TAN concentration by mineralization will inhibit the nitrificants due to excessive NH_3 concentration (Kim *et al*. 2006). When temperature decreases colder sites are emerging in the compost heap, where nitrification may be active and N_2O can be produced and emitted to the atmosphere. Then, the highest N_2O emission is measured after the temperature of the heaps has declined to mesophilic conditions. Even if temperature is high in the centre of the compost heap, N_2O may be produced in the surface with lower temperature and low N_2O emission can be measured during the thermophilic phase.

The use of bulking agents may reduce N_2O and CH_4 emission (Pardo *et al*. 2015) due to increased porosity, a higher air exchange and reduction in anaerobic regions in the heap (Sommer and Møller, 2000). However, these treatments may enhance NH_3 emission and the treatment can contribute to pollution swopping: Greater NH_3 losses from an actively turned heap of manure were measured than from a static heap, whereas N_2O emissions was higher from the static heap than the actively turned heap with enhanced air (Amon *et al*., 2001).

FUTURE TREND

There is a need to develop a market for compost which support or promotes manure composting. This greatly depends on the definition and adoption of quality standards. Quality criteria are set in different countries based on maturity degree, agronomic criteria (OM, nutrients, pH and EC), hygienic conditions and also on the presence of impurities (plastics, metals, glass or stones), and of weed seeds - which can affect crop production negatively. All countries have established concentration limits for heavy metals, according to the toxic character of each element and their consideration as plant micronutrients. However, the lack of harmonization at international level creates legal uncertainty for waste management decisions and for the promotion of quality assurance. In Europe, the proposed End-of-Waste criteria for biodegradable waste subject to biological treatment (Saveyn & Eder, 2014) could be the most-efficient way of setting standards for composts that enable their free circulation in the internal European market and allow their use without further monitoring and control of the soils to which they are applied. The identification of reliable parameters to assess compost quality may define the specific conditions and rules for the uses of compost. For soil applications, the diversity in soil properties, climate and land use practices throughout Europe and within each country need to be considered.

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5.6. CONCENTRATION BY VACUUM EVAPORATION

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OVERVIEW

Nutrient redistribution between areas with a structural livestock manures surplus, and those with a shortage, is limited by the high cost of transportation and spreading due to the high water content in slurry (more than 90%) and its relative low nutrient concentration. The aim of evaporation is to vaporize (applying heat) most of the water from a solution (in this case the slurry liquid fraction) and obtaining a concentrate that contains a desired product (in this case nutrients and organic matter). Apart from obtaining a concentrate with a lower water content and higher nutrient concentration than the original slurry, another objective should be to obtain a purified condensate (water) that could be reused (Bonmatí *et al.*, 2003)

In Europe, this technology is mainly implemented in the field of the treatment of residuals from industrial production, in some cases with the aim of recovering chemicals, like in the galvanic industry. Vacuum evaporation has been applied for years also to the treatment of landfill leachate. In the agro-industry sector, this technology has been tested on the dairy industry, for the recovery of proteins from serum, in the olive oil industry, for the treatment of wastewater from mills and of olive husks. Other tests have been performed on residues from the production of wood pulp and paper (Chiumenti *et al.*, 2013). Regarding livestock manures, evaporation has been applied for processing pig slurry and digestate from co-digestion biogas plants (Flotats *et al.*, 2009). In the case of Spain, there were 21 centralized pig slurry processing plants using this process. Nevertheless, for economical reasons these plants have been all closed.

SCHEME

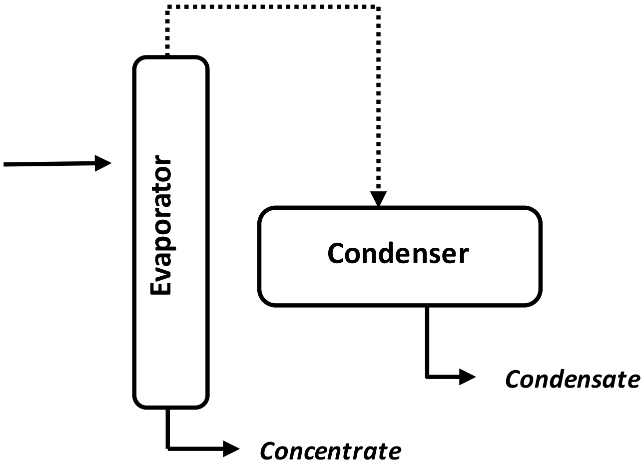

Figure 5.6.1. Schematic diagram of the vacuum evaporation process.

Figure 5.6.2. Vacuum evaporator. Tracjusa treatment plant (Catalonia, Spain)

TECHNICAL DESCRIPTION

Evaporation could be performed at atmospheric pressure or at vacuum conditions. Vacuum evaporation is more common as the lower process temperature of the process and the closed vessel used allow to a better emission control and less energy consumption could be expected. When the pressure inside the evaporator unit is reduced below the vapour pressure of the liquid, the liquid evaporates and consequent concentration of treated substrate occurs; evaporated water, then, is condensed by cooling and collected in the condensate tank (Figure 5.6.1) (Chiumenti *et al*., 2013).

By means of this process, a concentrated with a solid content of 25-30 % of total solids (TS) could be obtained, representing between 15-20% of the process flow rate (from the acidified fraction of a digested pig slurry with TS 2.5-3.5% in an industrial working facility). Moreover, up to 98% of nitrogen recovery (remaining in the concentrate) could be achieved, if pH is maintained <5.5.

In terms of energy consumption, 21 kWh/m^3slurry of electrical energy and between 107 and 353 kWh/m^3slurry of heat have been obtained in a pilot experience at farm scale unit treating 0.5 m^3/hour (Flotats *et al*., 2011). On the other hand, the increasing number of evaporation steps could decrease energy consumption significantly. For this reason a full scale evaporation system usually consists in at least two steps. The energy consumption for single-effect evaporators is very high and makes up most of the cost for an evaporation system. Each evaporation step added reduces the energy consumption by 33%; although investment cost increases.

Although with a clear different evaporator designs, the process could be attractive with slurries/manures of high dry matter content, especially over 30% (e.g. poultry) due to the smaller amounts of water to be removed and higher yields of dry product (Burton and Turner, 2003), but energy and economy issues should be analyze carefully.

PERFORMANCE

Slurry evaporation can lead to severe atmospheric pollution if it is not operated correctly. Slurry contains volatile compounds that are emitted when temperature is raised. In this sense, vacuum evaporation offers several advantages: as it occurs in a closed system, the exhaust gases can be easily treated, and the low treatment temperatures, resulting from the low treatment pressures, reduce the emission of volatile compounds.

To ensure the recovery of nitrogen in the concentrate flow stream, and guarantee its absence in the recovered condensates, ammonia (NH_3-N)-ammonium (NH_4+-N) equilibrium must be modified, by means of pH control (usually adding a strong acid) (Figure 5.6.3). If pH inside the evaporator is maintained under pH 5.5 it is guaranteed that ammonium will be recovered in the concentrate. Contrary at pH<5.5 other volatile organics as volatile fatty acids (VFA) are present in its un-ionized form (volatile) and can be easily transferred to condensate, with clearly implications (organic contamination) in condensates and post-treatment requirements. In the case of streams previously treated by anaerobic digestion this organic contamination could be lower.

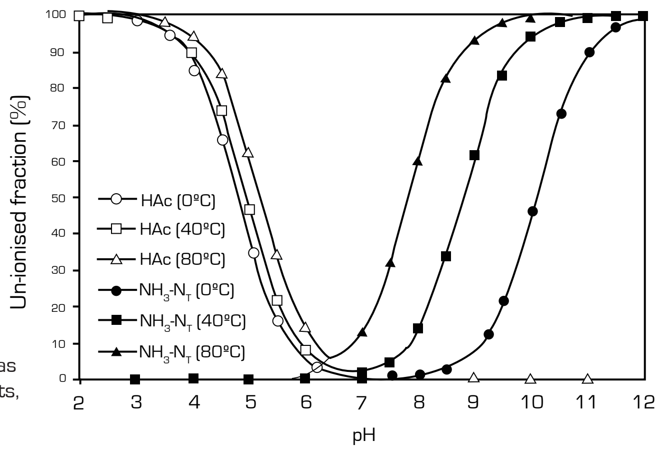

Figure 5.6.3. NH_3-N and un-ionized acetic acid (HAc) fraction as a function of pH at different temperatures (Bonmatí and Flotats, 2003).

For pH regulation, sulphuric acid or other strong acid should be added (Bonmatí and Flotats, 2003). The acid consumption will depend on the slurry/manure alkalinity. The reagents are not needed to be reagent grade. Consequently, in some applications it has been used H_2SO_4 sub-products of low purity.

As it has been mentioned, the processed stream (liquid manure/slurry) requires a previous acidification step to avoid ammonia emission. The use of a strong acid has different implications:

- The choice of constructive materials (resistance to high temperature and low pH). It requires high quality materials (e.g. stainless steel).
- Risk of accidents and requirement of training courses of risk and safety to workers.
- Introduction of S forms (if acidification is performed with H_2SO_4) that could appear (at low concentrations) in condensates.

Figure 5.6.4. Windrow composting: static pile system with forced aeration. View of the air forced system.

Although this process is applied usually at large scale, there are pilot experiences at farm scale.

From the point of view of the effects on air water and soils, the process theoretically does not show air emissions, since evaporated flow is recovered as a condensate. Thus, theoretical the process is "0 gas emissions" including odours. If heavy metals are present in the raw manure, they would be found in the concentrate stream, and depending of their concentration the use of concentrate as fertilizer could be limited.

CLIMATE CHANGE

The average energy consumption of the process consisting in one evaporation effect is around 21 kWh/m^3 slurry of electrical energy and between 107 and 353 kWh/m^3 slurry of thermal energy (with an average treatment flow of 0.5 m^3/h). Thus, considering a CO_2 emission of 0.181 kg kWh-1, the emissions related to electrical energy consumption are about 3.8 kg CO_2 kg per m^3 of treated slurry and 19.4-63.9 kg CO_2 kg per m^3 of treated slurry in terms of heat energy consumption. The latter could be reduced if part of the thermal energy is provided by a residual thermal stream (e.g. recovered thermal energy from a CHP engine fuelled with biogas). Other GHG emissions such as methane are negligible in this process.

FUTURE TRENDS

The future trends of this technology are conditional mainly on the thermal energy requirements. The existence of an inexpensive source of heat is the main limitation for the practical application of this process at farm scale.

In this sense, previous anaerobic digestion presented clear advantages: it provided a fraction of the required energy and it removed organic matter, preventing its volatilisation in the evaporation process and providing higher quality condensates. These advantages make the combined treatment strategy economically more feasible than the evaporation process alone.

It is important to perform a significant evaluation of the feasibility of the vacuum evaporation technology, in relation to the effective requirements for the management of the process (energy, acid consumption), and, hence, about its economic sustainability.

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5.7. THERMAL DRYING

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OVERVIEW

The technology processes the solid fraction of digestate or manure by thermal drying getting a dried end-product with very low water content (< 15%). It is economically sustainable only if a surplus of thermal energy produced by combined heat and power unit (CHP) is available. For this, the drying process is generally linked to the anaerobic digestion (AD) and linked to the presence of CHP that uses the biogas, deriving from AD process, to produce electricity usually sold to the grid.

The purposes of the drying process are:

- produce a commercial fertilizer, stable and easily to transport and land spreading;
- volume and weight reduction of the digestate or manure;
- nutrient (N, P and K) and organic matter concentration and recovery.

Typically for manure or digestate processing, a belt dryer technologies inside a closed chamber ventilated by a hot air flow (70-110°C) are used. This solution requires the capture and treatment by an acid scrubber of the exhaust air from the dryer before its emissions in atmosphere.

Manure or digestate thermal drying processing meets the need to reduce the loss of nutrients in the environment. The process achieves the objective of not dissipate nutrient and organic matter in the atmosphere, but it recovers them in a renewable fertilizer, exportable in non livestock intensive areas.

SCHEME

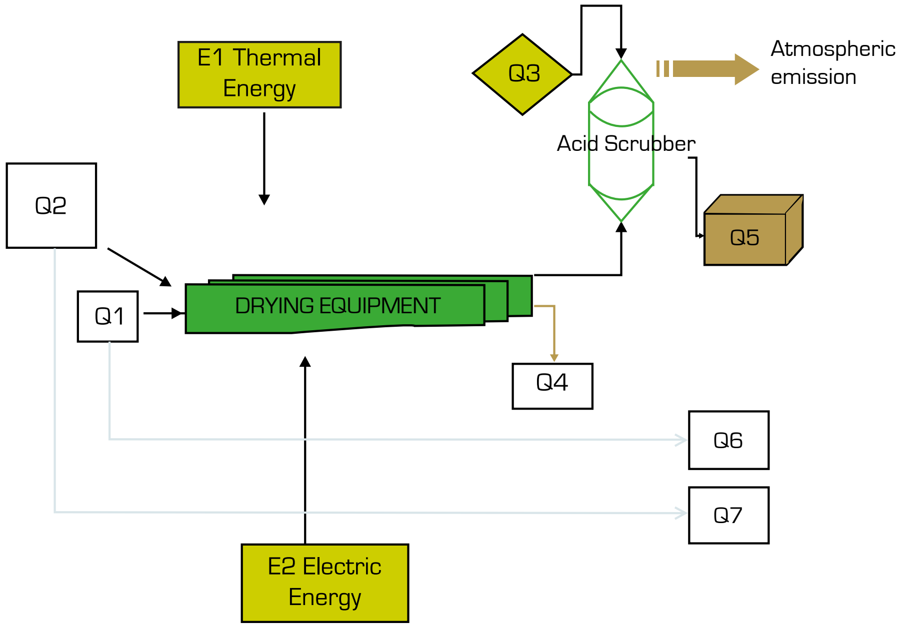

Figure 5.7.1. Treatment process scheme.

- Q1: Solid fraction from S/L separation.
- Q2: Liquid fraction from S/L separation (treatable if a surplus heat after treating all solid fraction is available).
- Q3: Sulfuric acid required in acid scrubber.
- Q4: Dried Digestated.
- Q5: Ammonium sulphate.
- Q6 – Q7: Surplus of solid fraction (Q1) and/or surplus of liquid fraction (Q2) not treatable due to not enough thermal energy.

TECHNICAL DESCRIPTION

In table 5.7.1, drying processes are classified according to the temperature of process, heat transfer modalities and handling of the substrate to be dried.

In low temperature thermal drying (<110°C), the heat exchange with substrate is convective and high volumes of air and long residence time on the bed/belt of drying are needed (from 20 minutes to over 1 hour). In the processes at high temperature (much higher than 120° C), usually, the heat exchange with substrate is both convective and conductive. The residence times is reduced (some minutes or less), and the temperature of drying of the product remains constant over time.

The process is applied commonly to solid fractions of digestate or manure with a dry matter content from 14 to 22%. The raw digestate or manure has to be previously subjected to solid-liquid separation. The solid fraction produced by the separator is loaded on a belt or tape and it enters in the drying closed chamber. If a thermal energy surplus is available, a portion of the dried solid that exits from the drying chamber could be mixed with an amount of the liquid fraction produced by the separator and so this mixture loaded as input to the drying chamber. A hot air flow is produced by heat exchanger using thermal energy from CHP. Air extractor fans keep the drying chamber in under pressure and the hot air runs through the ventilated tape loaded with manure. The tape can have more levels. The wet manure is loaded in upper level and at the end is discharged from the lowest level. The dried product can be pelletized for its easier management and more profitable marketing.

The circuit of the drying exhaust air stream can be opened with its discharging in the atmosphere (usually if temperature process is low < 110° and high volume of air are used), or closed with recirculation of the air prior to its condensation (usually at high process temperature to recover heat and where the volume of the air stream is low). In the first case devices are very often required (scrubber) for the capture of ammonia, volatile organic compounds (VOC) and dust. By closed circuit may be avoided gasses and odour emissions, since there are no emissions into the atmosphere by recirculating the air flow, but energy for vapour condensation is needed. The treatment of the exhaust air stream from the dryer, rich in ammonia and water vapour, through a washing scrubber unit (with sulfuric acid) recoveries ammonia in a ammonium sulfate solution ($(NH_4)_2SO_4$), which can be used as liquid fertilizer or recirculated in the process of drying in order to enrich in nitrogen content the final dried product.

Figure 5.7.2. Dryer plant with scrubber and CHP. Green Energy farm - Brescia, Italy (CRPA, 2015).

Table 5.7.1. Type and classification of thermal drying process.

Temperature of drying process	Heat transfer modalities	Holder/Handling of the substrate	Circuit of the drying airflow
(< 110°C)	Drying airflow heated by Heat exchanger with water or thermal oil (hot water and/or hot gases by CHP)	Belt, Bed, tape or rotating discs with forced ventilation	Open, atmospheric discharge after treated
	Hot gases used directly		
(> 120°C)	Drying airflow and substrate heated by Heat exchanger with thermal oil (hot gases by CHP)	Rotating cylinder	Open, atmospheric discharge after treated
			Closed with condensation and recirculation of airflow
		Internal high speed rotor	Open, atmospheric discharge after treated
			Closed with condensation and recirculation of airflow

PERFORMANCES

Main operational information:

- Total solids in dried product is greater than 80-85%,
- End product can be pelletizing;
- Sulfuric acid required in scrubber: 3,5 kg H_2SO_4 per kg N-NH_4 strippable;
- Recommended thermal energy available for technologies with open circuit and temperature process < 110°C: > 200 kWth ;
- Recommended thermal energy available for technologies with close airflow circuit and temperature process >> 120°C (for example internal high speed rotor): around 1 MWth;
- Expected plant life: 15 years;
- Level of complexity: medium-high;
- Scale: large farm scale or cluster farms scale;
- Technology reliability: discrete;
- Development level: good, with real farm scale applications on manure and digestate;

Nutrient balance and end-products:

- End product (with final TS 85%): 14-15% of the influent mass of manure/digestate;
- Evaporated water: 85-86% of influent mass of manure/digestate;
- Nitrogen (considering 100 as input and TAN 40-45% of TKN of influent raw solid fraction): 3.6% as N in ammonia emission, 59.6% N in end dried product and 36.8% N in ammonium sulfate solution from scrubber;
- Almost complete recovery in dried product of P, K and mineral content.

Energy:

- Thermal energy consumption: about 1.3 kWh kg-1 evaporated water in case of low efficiency belt/tape dryer, even less than 0.85 kWh kg-1 evaporated water for the more efficiently drying system, as horizontal static chamber with rotary blade system;
- Electric energy consumption: from 15 kW t-1 of product to be dried for belt/tape dryer at 1 MW scaling, to 30 kW t-1 for 300 kW scaling. Energy consumption can rise over in case of system with internal rotor at high temperature and condensation and recirculation of airflow.

Economy balance:

- Profitable commercialization of the dried product as fertilizer with high organic matter content: 40-100 €/t if not pelletized and 80-150 €/t if pelletized in relation to NPK content and nutrient and organic matter request framework;
- Profitable commercialization of the ammonium sulfate solution from scrubber: economic value could reach 30 €/t if N content is 6% and the solution is not so polluted by suspended solids;
- Reduction of the transport costs and easier delocalization of nutrients to high distances;
- Costs reduction due to less land needed for manure spreading, especially in nutrient surplus area with vulnerable zone.

Figure 5.7.3. (Left) Dried digestate end-product. Green Energy farm - Brescia, Italy (CRPA, 2015).

Pathogens:

- Significant reduction of the pathogens content (particularly Escherichia Coli and Salmonella) if the process temperature is greater than 90°C and the total solid content of end-product is greater than 80-85%.

Figure 5.7.4. Dryer plant: close chamber (blu) with inside the holding belt system, scrubber box (white) and big bag filled with dried digestate in front of flubox with ammonium sulphate solution. San Giuliano farm - Trento, Italy (CRPA, 2013).

Figure 5.7.5. TurboDryer with internal high speed rotor. VOMM – Milano, Italy (CRPA, 2013).

CLIMATE CHANGE

Thermal drying produces a stable material by physical-mechanical treatment reducing the GHG emissions of the dried product compared to GHG emissions from the storage, handling and land spreading of the untreated slurry or digestate. If thermal energy surplus produced by combined heat and power unit (CHP) is used, fossil fuels to produce thermal energy are not needed and the CO_2eq/kWhth is null. Moreover, thermal drying recovers N, P and K from manure to produce a valuable fertilizer (pellet and ammonium sulphate). 4.57 kg CO_2eq/kg N, 1.18 kg CO_2eq/kg P_2O_5 and 0.64 kg CO_2eq/kg K_2O (JRC Report EUR 27215 EN, 2015), deriving from the production of synthetic fertilizers and replaced by renewable fertilizers, are saved.

FUTURE TRENDS

EU policies on environmental and climate protection are going to rise manure and end-waste product processing technologies.

Thermal drying helps the nutrient recycling and the future trend could be positive. Production of mineral N and P fertilizers will become more expensive in the future, synthetic fertilizers production have impacts on greenhouse gas emissions and mineral P is a non renewable source and so the technologies that produce renewable fertilizers by manure processing could be favoured.

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5.8. AMMONIA STRIPPING AND ABSORPTION

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OVERVIEW

Ammonia air stripping is a physic-chemical process that aims to transfer volatile ammonia (strongly dependent on pH and temperature) from a liquid phase to a gas phase by means of a liquid-gas (air or steam) intimate contact (usually in countercurrent) and its subsequent recovery in an acidic solution as ammonium salt or by condensation. The process is usually performed in columns with packing material to favour the contact between liquid and gas (Frear *et al.*, 2011).

Ammonia stripping can be combined with anaerobic digestion process treating manure as there is a considerable concentration of ammonia in the effluent due to the biological conversion process, organic nitrogen is degraded to ammonia. Ammonia air stripping requires either addition of alkali to increase the pH and/or heat to increase the temperature to release the free ammonia (Bonmatí and Flotats, 2003). In that respect, when combining anaerobic digestion with a stripping/absorption process, the biogas produced during anaerobic digestion can partially or totally provide the heat needed for stripping at high temperature.

Ammonia stripping has already been successfully applied to anaerobic digestion (AD) supernatant from municipal wastewater treatment plants, landfill leachate, and industrial wastewater at commercial scale. It has also been successfully tested in the laboratory for swine manure wastewater as well as digested dairy manure supernatant, achieving more than 90% ammonia removal in the trials (Bonmatí and Flotats, 2003, Laureni *et al.*, 2013, Jiang *et al.*, 2014). However, on farm-based AD systems not many cases can be found. In Lombardy Region (Italy), there are some facilities that have been implemented as part of a treatment chain mainly as post-treatment of anaerobic digestion supernatant (Moscatelli, G. and Fabbri, C., 2008)

In the livestock sector, the process has been applied, both as pre- and post-treatment to anaerobic digestion, to pig slurries, cattle and fermented chicken manures, with a wide range of reported removal efficiencies. However, a clear relationship between the characteristics of livestock manures and removal efficiency has not yet been established, but the content of organic matter is likely to be the parameter more relevant (Laureni *et al.*, 2013).

SCHEME

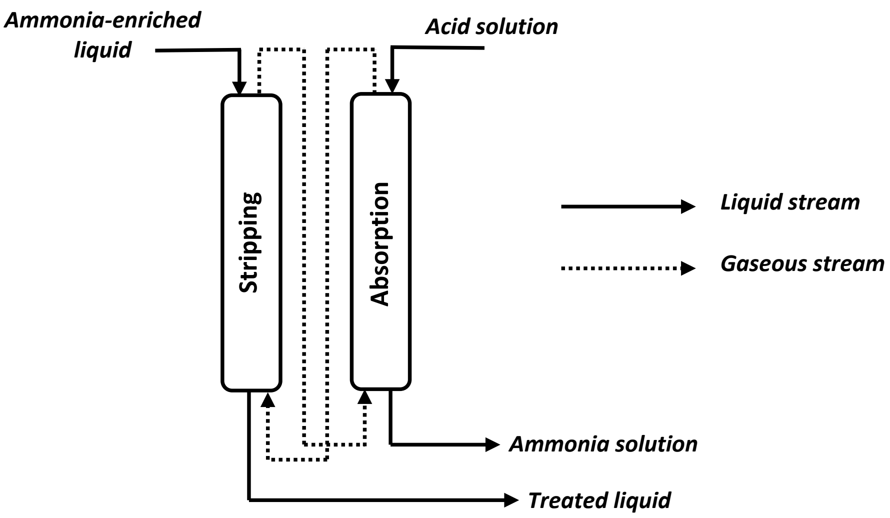

Figure 5.8.1. Schematic diagram of the stripping-absorption process.

TECHNICAL DESCRIPTION

Figure 5.8.1 shows a schematic diagram of the stripping-absorption technology. The process is usually performed in vertical columns where the liquid phase (ammonia riche stream) is introduced in the upper part while the gaseous phase enters in countercurrent from the bottom. To enhance the liquid/gas contact the columns are usually filled with packing material (specifically shaped pieces of inert material). Stripped ammonia is recovered either by absorption in a second column, with a countercurrent acid solution, or by vapour condensation, obtaining NH_4OH or ammonia salts. Both, liquid ammonia solutions and solid ammonia salts could be used directly as fertilizers or sold to other industrial applications (WWT of paper industry). Previous anaerobic digestion, with the objective to remove volatile organic matter, enhances the stripping process, avoiding volatile organic compounds (VOC) transfer to the absorbed solution (Bonmatí and Flotats, 2003; Laureni *et al.* 2013).

The amount of ammonia that can be stripped from a liquid waste or absorbed in the acidic solution is, to a great extent, dependent on two thermodynamic equilibria: ammonia dissociation equilibrium in the liquid and ammonia gas/liquid equilibrium (Henry's Law). Ammonia equilibrium in aqueous solution is pH and temperature dependent and free ammonia concentration is expressed with the following equation,

$$[NH_3]=\frac{[NH_3+NH_4^+]}{1+\frac{[H^+]}{k_a}}=\frac{[NH_3+NH_4^+]}{1+10^{pKa-pH}}$$

where $[NH_3]$ is the free-ammonia concentration, $[NH_3+NH_4+]$ is the total ammonia concentration, [H+] is the hydrogen ion concentration, and Ka is the acid ionisation constant for ammonia. pKa can be expressed as function of temperature T by the following equation obtained by polynomial regression of data from Lide (1993). The higher the pH and temperature, the higher the free ammonia fraction.

$$pKa = 4{\cdot}10^{-8} \times T^3 + 9{\cdot}10^{-5} \times T^2 - 0.0356 \times T + 10.072$$

PERFORMANCE

As stated before, the two fundamental control parameters of the process are temperature and pH as they establish the equilibrium between ammonia (NH_3) and ammonium (NH_4+). pH is usually set between 9 and 10 by means of base addition or previous CO_2 stripping. For air stripping typical working temperatures are set lower than 100°C while higher temperatures are characteristics of steam stripping. With respect to the reagents used, NaOH, $Ca(OH)_2$ or other bases are added to increase the pH (if CO_2 stripping is not enough), whereas H_2SO_4, HNO_3 or H_3PO_4 solutions are commonly used to absorb the NH_3 from the gas phase.

In terms of energy consumption, it is directly related with the process efficiency. Up to 95% of ammonia reduction can be achieved under optimal conditions and almost complete ammonia recovery by absorption in acid solutions is possible with only few acid stoichiometric excess (1.1:2 H_2SO_4:NH_3), but energy consumption and therefore the marginal cost for the Nremoval can increase unacceptably (138%) in comparison with a process at 86% efficiency (Sagberg *et al.*, 2006).

On the other hand, depending on the working temperature, thermal energy requirements may play a primary role in energy consumption but, as it was stated before, biogas use in cogeneration equipments could provide the required energy to heat the slurry up.

The investment cost could be set between 0.25 and 0.5 M€ for treating 10-15 m^3/h and the operational costs amount to 0.66€/m^3 for NaOH and 0.21 €/m^3 for H_2SO_4 as well as 2.5-4.5 €/kg of stripped nitrogen (only for the stripping column). At least an equivalent range of values should be considered for the absorption step (Flotats *et al.*, 2011)

Figure 5.8.2. Ammonia stripping plant located in an agricultural biogas plant in Brescia, Italy - CRPA, 2015

CLIMATE CHANGE

The average energy consumption of the process at 85% efficiency is around 6 kWh per kg of stripped nitrogen (Sagberg *et al*., 2006). Thus, considering a CO_2 emission of 0.181 kg kWh-1, the emissions related to the overall process come to 1.086 kg CO_2 kg per Kg of stripped nitrogen. Considering 2000 mg NH_4-N /L slurry, CO_2 emissions are about 2.2 Kg CO_2/m^3slurry. Other GHG emissions such as methane are negligible in this process.

FUTURE TRENDS

In the perspective of its industrial implementation with animal slurries, stripping/absorption technology has to tackle two major challenges: investment and running costs that should be in accordance with the economy of the agricultural sector, and the quality of the recovered product that should be of marketable quality – in terms of nutrients concentration and organic matter contamination – in order to cover part of the operational costs. However, so far, only limited information is available about the quality of the recovered product and, hence, about its potential usability (i.e. as raw material for the fertilizer industry). In this respect, it has been observed a higher level of contamination of the salts derived from fresh slurry, compared to the digested one (Bonmatí and Flotats, 2003), but works have deal about the quantification of the entrapped organics (Laureni *et al*. 2013). Moreover, new studies are necessaries in order to optimize the process in terms of energy and reagent consumption, making this technology attractive for the agro industrial sector.

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5.9. FILTRATION AND REVERSE OSMOSIS

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OVERVIEW

Filtration systems have long been used to provide clean drinking water but have in recent years been investigated for liquid manure treatment. Manure filtrations are a group of processes that can remove solids, organic matter, N, P and K from manure. The technologies are available in four types: microfiltration (MF), ultrafiltration (UF), nanofiltration (NF) and reverse osmosis (RO). These types fall into two groups, MF and UF are mainly for reducing solids whereas NF and RO can be used for removal of TAN and K.

MF and UF operate at low pressure due to the relatively large molecules and particles removed and this is reflected in the rate of flux across the filter membrane.

The process follows traditional separation (the liquid fraction follows the filtration pathway) and often pre-filtration of around 100μm is employed to remove smaller particles to prevent clogging or damage to the membrane.

NF and RO are systems that can be used for ammonia removal / recovery as part of the filtration. These methods usually require MF (and, as mentioned above, a separation procedure prior to that) as a pre-treatment. The ammonium molecules in manure (complexed with manure anions) are retained by NF whereas free ammonia passes through. Thus lowered pH, that favours the equilibrium towards ammonium rather than free ammonia, can be used to reduce the amount of TAN passing through the filter.

NF and RO are systems that require considerable pressure to operate and thus have greater technical complexity compared to MF and UF. The processes have a high pressure build up and this must be countered by high operating pressure.

Biological treatment of manure (such as anaerobic digestion) can increase the proportion of fine particles that can either pass or block MF membranes. Such systems need to be frequently back-washed to remove particles that are trapped in the pores and the cake that is likely to form on the surface, and it has been known for flow through MF membranes to be reduced to less than 20% after only 50 days of operation. Similarly, performance reported for a UF system operating with AD treated pig manure found the flow rate reduced to less than 10% in 60 days, although this reduced flow rate then remained stable. Flushing with acidic solutions at high temperature can remove many of the trapped particles although a significant amount will remain permanently trapped within the material matrix.

SCHEME

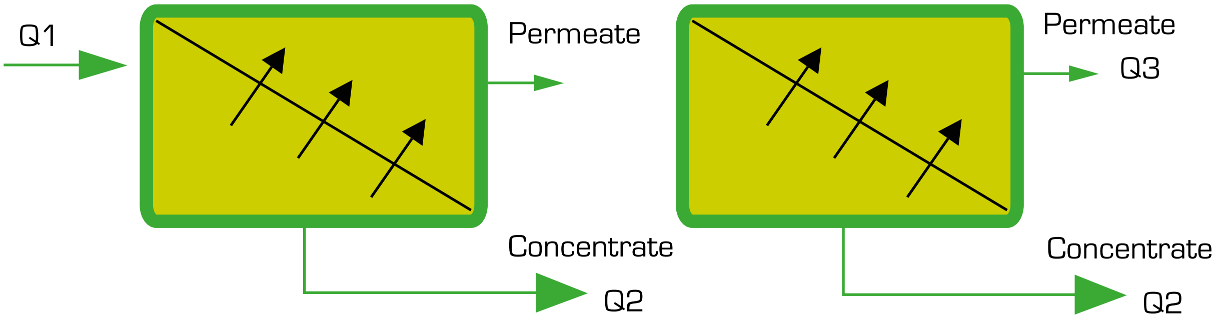

Figure 5.9.1. Scheme or the treatment process.

TECHNICAL DESCRIPTION

MF membranes are often ceramic or cellulose esters. Ceramic membranes are usually aluminium oxide or sintered titanium. Ceramic membranes offer greater flux (ca. 65 l/m^2/h compared to ca. 40 l/m^2/h of cellulose ester membranes) whereas cellulose esters produce a better permeate quality with lower solids and chemical oxygen demand. Ceramic membranes have many advantages over cellulose esters such as narrow pore size distribution, easy cleaning, longer lifetime and resistance to pH extremes but are considerably more expensive and as such are not favoured.

RO membranes are often made of polyamide or polysulphone.

The membranes are available in a variety of modules:

- Spiral wound modules are common in many industries and have the smallest footprint and are cheap but are prone to blocking due to colloid scale formation in manure treatment operations.

- Tubular membranes consist of membrane tubes packed together in parallel. They are suitable for high suspended solids systems but have a large footprint and internal volume making operation and cleaning costly.

- Fibre membranes can handle large flow rates in a small area, the design resembles the tubular type but the membrane tubes have a much smaller diameter (<2mm compared to 12-25mm for the tubular designs).

- Flat membranes are flat sheets of membrane material.

NF typically retains molecules from >200-400 Da to150 Da whereas RO can retain molecules/particles and dissolved salts over 100 Da.

The filtration processes follow a general trend of increased system pressure and lower flux as the pore size decreases, as shown in Table 5.9.1.

Table 5.9.1. Filtration processes

Type	Pore size (μm)	Pressure (bar)	Flux (litres per square metre per hour)
MF	0.03-10	0.1-2.0	>50
UF	0.002-0.1	1-5	10-50
NF	0.001-0.01	5-20	1.4-12
RO	0.0001	10-100	0.05-1.4

(information sourced from www.agro-technology-atlas.eu)

PERFORMANCES

The main operational parameters are the flow rate through the filter, the pH and trans - membrane pressure.

MF AND UF

MF can remove 75% suspended solids, 85% COD but <20% N. Almost 90% of P can be removed by UF as P tends to be associated with particles of 0.45-10μm.

NF AND RO

NF unit has been shown to remove 52% of TAN and 78% of K.

For RO, TAN retention has been found to be in the range of 93% to 99.8% producing concentrate with TAN between 6–10 gl−1. Retention of TS for RO systems has been found to be in the range of 83-100%.

TAN retention is greatly increased at lower pH, in RO membranes TAN retention can be close to 100% at pH 4.

NF produces a filtrate quality that is suitably clean for washing purposes in animal housing or irrigation. NF and RO also produce filtrates of a quality suitable for animal house washing, although consecutive treatment cycles or using zeolites or ion exchange columns can improve the quality to that suitable for release into water courses.

Particle retention in the order MF<UF<NF<RO means that performance is better at the expense of increased pressure (and energy consumption) and decreased flux.

ENERGY BALANCE

Typical energy consumption of the filtration systems are 0.2-1 kWh/m^3 for UF, 0.7-1.5 kWh/m^3 for NF and 1.5-10 kWh/m^3 for RO (www.agro-technology-atlas.eu).

Electrical consumption of MF/UF + RO for main European suppliers (OFEN, 2009):

- 12.8 kWh/t (KTBL)
- 28 kWh/m^3 (Lemmens)
- 30 kWh/t manure (WUR)
- 22 kWh/m^3 - 60.000 m^3/year (A3 Watersolutions)

Average electrical consumption: 27 kWh/m^3

ECONOMY BALANCE

For MF systems the expense of the ceramic filters does not outweigh the longer life and easier maintenance when compared to cellulose esters. The greater energy consumption of the systems with smaller particle retention size will greatly increase investment and operation costs.

Typical costs for a filtration system:

- Spiral wound element water 137 € per m^2
- Spiral wound element industrial 320 € per m^2
- Tubular 1,278€ per m^2
- Plate and frame > 1,540 € per m^2
- Fibre system > 1,540 € per m^2
- Ceramic > 2,720 € per m^2

PATHOGENS

Pathogens can be removed by the various filtration technologies, it has been shown that some viruses and bacteria are removed by MF and consequently the progressively smaller particle retention of UF, NF and RO can also remove these more completely.

CLIMATE CHANGE

Filtration of manure may not have a direct effect on greenhouse gas emissions but the removal of ammonia nitrogen could reduce N_2O emissions from the solid fractions. The solid fractions of manure also have a lower methane emission due to the more aerobic nature of the material, but there could be considerable emission of CH_4 and NH_3 from the liquid fraction, depending on storage and application techniques: increased N in the liquid fraction could be volatilised, deposited and converted to N_2O whereas the anaerobic nature of the liquid would produce CH_4 emissions. The liquid fraction has more reduced COD than the whole manure, but as the COD is in a soluble or minute particulate state, CH_4 production would be quite rapid once anaerobic conditions were met.

FUTURE TREND

Due to the high operational and maintenance costs, manure filtration is likely to remain feasible in very special situations only. Improvements in materials, both in terms of costs and longevity would make these technologies more widespread.

Figure 5.9.2. Ultra filtration unit.

Figure 5.9.3. Rotary-microfilter units.

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www.agro-technology-atlas.eu

5.10. PHYTODEPURATION

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OVERVIEW

Phytodepuration (constructed wetlands - CWs) is a wastewater treatment based on physical, chemical, and biological processes and mechanisms already existing in natural wetland environments, such as: sedimentation, filtration, plant uptake, microbial removal, chemical precipitation, hydrolysis, aerobic respiration, nitrification/denitrification.

There is no single pathway that describes the complete range of processes involved in the removal of a given substance. Due to this complexity, constructed wetlands have been considered "black box" systems since their introduction (García *et al*., 2010).

Constructed wetlands are able to remove or reduce nutrient load (especially nitrogen), organic matter and pollutants from wastewater, achieving good water quality.

Constructed wetlands have been used successfully in municipal and agro-industrial wastewater treatment.

Constructed wetland systems are mainly classified as:

- free-water surface (FWS), where the water flows over the substrate in contact with the atmosphere,
- sub-surface flow (SSF), where the water circulates through a filter media. Sub-surface systems are then distinguished according to the flow direction, horizontal (HF) or vertical (VF).

SCHEME

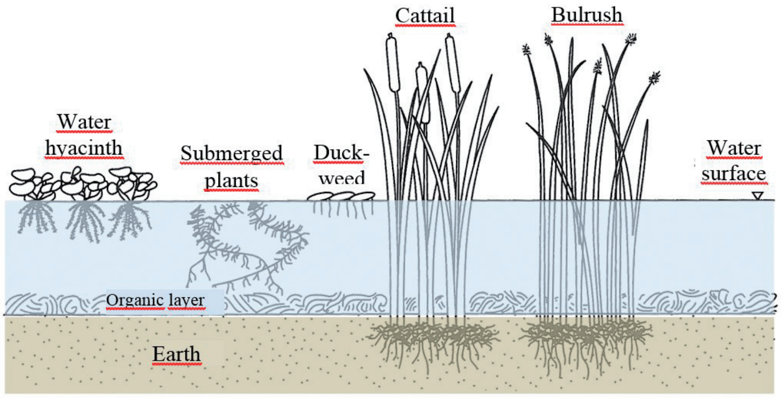

Figure 5.10.1. Scheme of a FWS constructed wetland (modified from Metcalf & Eddy, 2000).

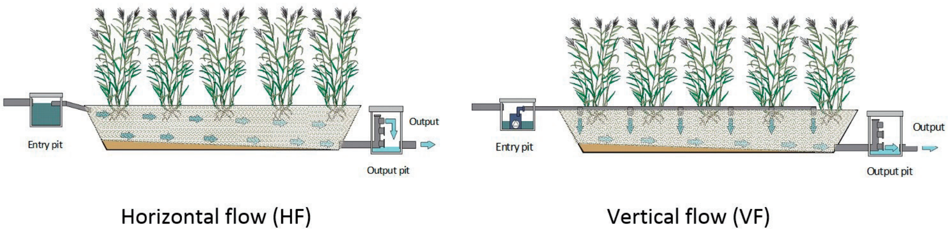

Figure 5.10.2. Scheme of a SSF constructed wetland with horizontal flow (left) and with vertical flow (right) (ARPAT, 2005).

TECHNICAL DESCRIPTION

The free-water surface (FWS) systems reproduce natural marshlands, in which the water is in direct contact with the atmosphere. Usually consist of channels with the bottom made of impermeable soil or an artificial impermeable barrier (made of PVC or HDPE, > 1 mm thickness), floating and/or emergent vegetation and shallow water levels (0.1 to 0.6 m).

The subsurface flow (SSF) systems are based on a filter media (crushed stone, gravel, sand) and the wastewater flow is through this. It provides a filtering effect, substrate for plant development and extended surface area for microorganisms. The depth of SSF systems is usually between 0.5 and 1.0 m. Recommended gravel diameter varies from 5 to 20 mm and greater gravel or crushed stone should be used where the wastewater get into and out of the wetland. Sand is used especially in vertical SFF.

In horizontal SSF wetlands, the medium is kept saturated under a continuous wastewater flow. Oxygen is then transferred from the atmosphere into the wetland through the emergent plants.

Vertical SSF operated as a batch process rather than in continuous flow mode. Wastewater is dosed at timed intervals so that the filter is allowed to drain. Consequently, the system is not always saturated by wastewater and oxygen is more easily transferred in it from the air through diffusion. Vertical systems have greater treatment capacity than horizontal (require less area to treat the same organic load). On the other hand, VF systems are more susceptible to clogging.

The recommended ratio between the width and length of the lagoons for SSF systems is 1:2 and the bottom slope should be around 1%. The time taken by the water to cross these lagoons is usually of the order of a few days in FWS and horizontal SSF and of some hours in vertical SSF.

There are hybrid systems that combine the different types of constructed wetlands, in order to achieve higher removal rates. Generally, vertical systems are combined with horizontal in order to produce successively nitrification and denitrification process increasing nitrogen removal.

The filling material, in addition to being the support of vegetation, plays an active action of mechanical filtration and constitutes, together with the root systems, the substrate for the adhesion of biofilm (bacteria, fungi, protozoa, small metazoans).

Plant species to be used in constructed wetland can be classified as:

- floating, suited to FWS, such as duckweed (Lemna spp.), water lily (Nymphea spp.), water water hyacinth (Eichhornia crassipes);

- subemergents, suited to FWS, such as pondweed (Potamogeton spp.), water weed (Elodea Canadensis), coontail (Ceratophyllum demersum);

- emergent, suited to both FWS and SSF, such as reed (Phragmites australis), cattail (Typha latifolia), bulrush (Scirpus spp.), rush (Juncus spp., Cyperus spp., others).

The most used plant in SSF systems is undoubtedly Phragmites australis. For this, the SSF are often called 'reed bed'.

Figure 5.10.3. Pipe network in a V-SSF constructed wetland before planting (CRPA, 2011).

Figure 5.10.4. Plant developments in a H-SSF constructed wetland (CRPA, 2006).

The removal efficiencies of the organic matter and nutrients are usually higher for SSF than for FWS but in SSF an excessive load of suspended solids can cause a rapid clogging.

Conversion of wastewater nitrogen to gaseous forms of N is the major mechanism for N removal by CWs, whilst plant uptake and accumulation in the CWs accounted for a limited fraction of the N load. Phosphorus can be oxidised and removed by settling/filtration or removed by plant and microbial adsorption. Predation and natural die-off of pathogens occurs in constructed wetlands.

A system of constructed wetlands for livestock slurry is able to provide adequate performance only if placed at the end of a treatment line that includes upstream other treatments with strong removal of the organic load, suspended solids, nitrogen and phosphorus.

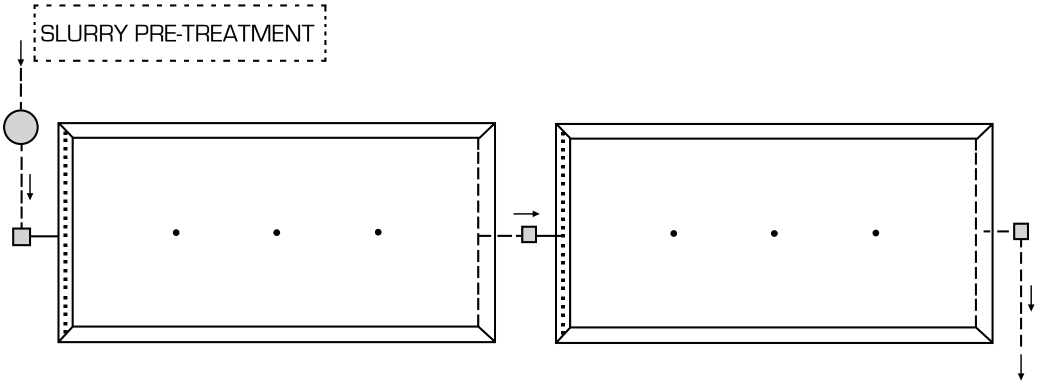

Figure 5.10.5. Typical layout of a phytodepuration plant, with a pre-treatment, two wetlands and control wells (CRPA, 2006).

PERFORMANCES

Main operational information:

- Phytodepuration is recommended only for the purification of pre-treated slurry or wastewater
- Treated effluent can be discharged both in public sewerage system or in surface watercourse, depending on the residual concentration of pollutants
- Treated effluent can be reused for fertigation of crops
- Removal rates may vary during the year due to seasonal weather patterns
- In some circumstances pollutants might even be released (e.g. extreme rainfalls events)
- Expected plant life is at least 10 years
- Technology reliability is good for municipal wastewater, not still sufficiently investigated for different kinds of livestock slurry;
- In the livestock sector good achievements are limited to the treatment of wastewater from the dairy parlor and pre-treated pig slurry
- Odor and insects can be a problem, especially in FWS systems
- The following loading rates are recommended (EPA, 2000):

• BOD_5 and TSS	< 70 kg/ha per day
• TKN or NH_3	< 3 kg/ha per day
• TP	< 0.2 kg/ha per day
• Hydraulic loading	< 500 m^3/ha per day
• Retention time	> 10 days

- The optimal hydraulic load is between 200 and 500 m^3/ha day. The risk of having less than 200 m^3/ha day when treating slurry is a real risk if the BOD, TSS TKN and TP recommended loading rates are met.

Nutrient balance and end-products:

- Nutrients removal is affected by the hydraulic retention time (HRT), temperature, physical and chemical properties of the medium, plant type

- Typical N removal rates in CWs varied between 40 and 70% or more when the N load is low

- Vertical SSF systems gave the best performances on N removal, especially if combined with horizontal SSF or FWS systems

- Removal of phosphorus in all types of constructed wetlands is low unless special substrates (SSF) with high sorption capacity are used

- Research has shown that over time wetland P removal sites become saturated in this element

Energy:

- Low energy demand, if any, since water can be transferred by gravity though the system

Economy balance:

- Relatively large land requirement compared to conventional wastewater treatment systems

- Easy construction, low level of complexity, minimal equipment needs, low running costs

- Biomass harvesting and management are the most complex/costly step, especially if does not exist a profitable end-product marketing.

Pathogens:

- In general, fecal coliform removal is excellent through the wetland system (especially SSF)

CLIMATE CHANGE

CWs offer a low energy solution compared to conventional wastewater treatment plant. Each kWh of electric energy saved, produces a GHG emissions reduction of 0.491 kg CO_2 if corresponding to the Spanish electricity mix (0.632 kg CO_2 if corresponding to the Italian electricity mix) and related to consumers and low voltage (Ecoinvent, 2014).

A risk of GHG (CH_4 and N_2O) emissions exists since the nitrification-denitrification process is difficult to be controlled in CWs. The emission factor (EF) for CH_4 is a function of the maximum CH_4 producing potential (Bo) and the methane correction factor (MCF): EF = BO • MCF. The 2006 IPCC Guidelines provide a default Bo value for domestic and industrial wastewater of 0.25 kg CH_4/kg COD and a MCF factor of 0.4 for FWS, 0.1 for Horizontal SSF and 0.01 for Vertical SSF CWs. The emission factors for N_2O emitted from domestic and industrial wastewater treated by CWs are 0.0013 kg N_2O-N/kg N for FWS, 0.0079 kgN_2O-N/kg N for Horizontal SSF and 0.00023 kgN_2O-N/kg N for Vertical SSF (IPCC, 2013. Supplement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories).

CLIMATE CHANGE

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FUTURE TRENDS

In the livestock sector good achievements are limited to the treatment of wastewater from the dairy parlor and pre-treated pig slurry. The constructed wetlands application in the livestock sector is fairly recent but with good prospects as a finishing treatment whilst the use of the phytodepuration on slurry as a stand-alone treatment system is not recommended. CWs are a good option to treat dairy or agroindustrial wastewater where the public sewage is far and land surface is available for the CWs building.

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5.11. LAND SPREADING

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OVERVIEW

Land spreading has been the traditional method for recycling animal manures. It has historically been considered a valuable resource to restore soil nutrients and improve crop production (Wadman *et al*., 1987).

Land application is not exactly a treatment technology but, when possible, it is the simplest and most recommended management not only for raw manure but for other organic end-products coming from different treatment systems to be used as organic fertilizer.

Both raw and processed manure are an excellent source of major plant nutrients such as nitrogen, phosphorus and potassium (NPK) and also provide many of the secondary nutrients that plants require.

A good spreading plan, through the application of the organic fertiliser at the moment when the crops require the nutrient and adjusting the rates to their necessities, greatly improves the crop yields, reduces fertilizing costs, minimizes nutrient losses to the environment, enhances the levels of soil organic matter and also helps compliance with regulations (Defra, 2011).

Animal manure is by far the largest by-product resulting from animal production. Livestock activities in Europe generate 1,400 million tonnes of manure (Foged *et al*., 2011).

A wide range of equipment and techniques are used to spread slurry and solid manure to land. Much of the manure was used to be applied to land using machinery which spreads slurry or solid manure over the whole soil surface ('broadcast') by throwing it into the air. In some countries (e.g. the Netherlands, Denmark and Belgium-Flanders), the use of band spreaders and injectors for slurry is required to reduce emissions. In many other countries, these techniques are also becoming increasingly popular. Solid manure is broadcasted after being chopped or shredded into smaller pieces. Manure should be incorporated into the soil, being this a legal requirement in some Member States. Contractors are often used for manure spreading and manure is not always spread on the producer's own land (BREF, 2015).

SCHEME

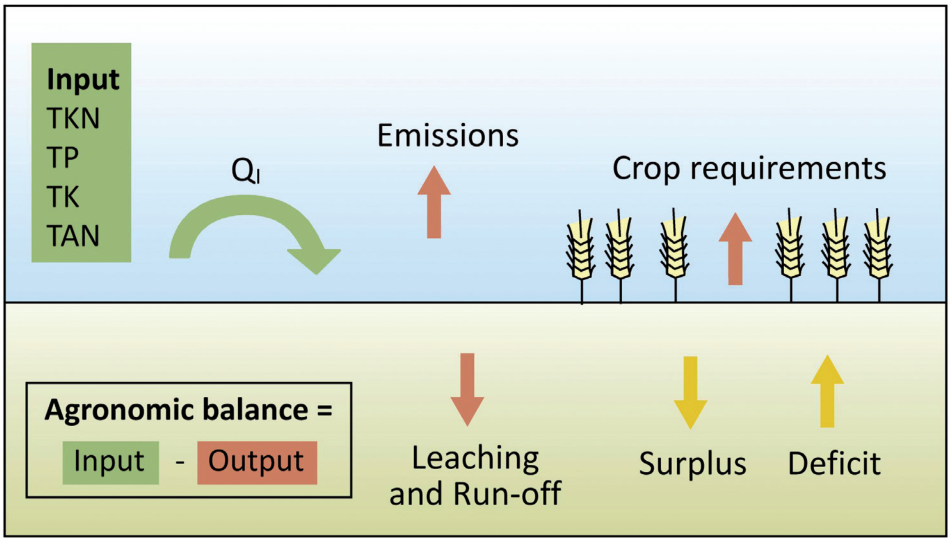

Figure 5.11.1. Scheme of manure land spreading.

TECHNICAL DESCRIPTION

The type, amount and composition of the organic products applied, as well as the crop requirements, should be known, so the nutrients can be effectively managed in dose and time. The organic products that can be used in this case as organic fertilizer are raw manure, a mixture of different manures, digestate or other end-products of the treatment systems.

The application equipment (Table 5.11.1) varies depending on the type of manure or input (liquid or solid), application techniques, land use and structure of the soil.

Table 5.11.1. Common land application equipments for different inputs.

INPUT TYPE	APPLICATION EQUIPMENT
LIQUID	Splash plate or broadcast
	Band spreading/Surface application
	Injection
SOLID	Solid spreading

The spreading and transport of manure can be regulated according to the time of year, temperature/climate, field slope, buffer zones, etc. The operator should be aware of these regulations (BREF, 2015).

These techniques do not require the use of large infrastructure for their implementation and operating costs are not high.

Many factors influence the volatilisation of ammonia after the application of the manure, such as climate conditions, manure type crop growth stage and application equipment. The effective means to reduce ammonia emissions are acidification of manure, surface application systems or injection or the immediate incorporation of manure into the soil.

The incorporation of technological tools that help planning and controlling the flow of nutrients locally reduces environmental risks (Petersen *et al*., 2007).

Figures 5.11.2-5.11.5. Different types of application systems.

PERFORMANCE

There are four groups of parameters that should be considered (Table 5.11.2) in the land spreading that affect nutrient balance, emissions and energy and economy balance.

Table 5.11.2. Aspects and parameters that affect land spreading.

INPUT TYPE	APPLICATION EQUIPMENT
GENERAL	Country (climate, legal aspects, economy) Legal requirements (N, P, K, metals, pathogens, others)
MANURE/ DIGESTATE	Type of raw manure or others (Nutrient availability factor (NA, PA, KA)) Composition Quantity
CROP	Type of crop (crop uptake, yield) Surface (ha) Vulnerable/Non-vulnerable zone Limiting nutrient (NPK)
APPLICATION PROCEDURE	Type of spreading system Type of vehicle used for the spreading Spreading season (warm or cold)

NUTRIENT BALANCE AND LOSSES

The basis of land spreading is the agronomic balance (Figure 5.11.1), where the amount and composition of the manure, the crop's nutritional requirements (NPK) and the expected yield, as well as the legislation applicable to the area, are taken into account.

A good plan regarding agronomic aspects, doses and time are a prerequisite to an optimised use of manure as fertilisers in a balanced scenario. The plan should ensure that the necessary quantities of essential nutrients are supplied in time when crops demand them. If the crop requires more nutrients than the available in the area by means of organic products, it can be supplied with mineral fertiliser. On the other hand, a surplus scenario is found when not all manure nutrients are taken up by plants and the reduction of nutrients, whether by exportation to other areas or applying treating technologies, is required.

Even when the best practices are used, there are always losses during and after the land spreading:

Nutrient losses due to leaching and run-off affect the nitrogen, phosphorus and potassium. They are related to the quantity and type of product, the type of crop, the season of application and the soil quality.

Nutrient losses due to air emissions affect the nitrogen balance. They are related to the quantity and type of product, the spreading system, the incorporation or not to the soil and the temperature.

The nutrient available in the organic products for crops in the season of application is estimated subtracting the nutrient losses to the input nutrients.

Plants can only use nutrients that are in an inorganic form. Manures N and P are present in organic forms and are not considered 100% available to the plants. The availability of K in manure is considered similar to the commercial fertiliser. The nutrient availability factor is the proportion of every nutrient available for crops; it depends on the type of manure.

Nevertheless, crop requirements cannot always be satisfied entirely with organic fertiliser when these are higher than the maximum application dose allowed by law. Therefore, the nutrient balance should be carried out based on the most restrictive condition: the nutrient available to cover crop requirements or the maximum dose allowed by law.

EMISSIONS

Emissions of ammonia are usually lower when the air temperature, wind speed, solar radiation and slurry dry matter content decreases. In addition, emissions of ammonia as a percentage of TAN applied usually decrease with increasing TAN concentration and application rate. Emissions from different manure types will also vary. Emissions are also dependent on soil conditions that affect infiltration rates. For example, well-draining, coarse textured, dry soils, which allow faster infiltration, will give rise to lower emissions than wet and compact soils with reduced infiltration rate (BREF, 2015).

A slurry with a high viscosity will increase NH_3 emissions, by reducing the infiltration of liquid with dissolved TAN into the soil during application. It has been observed for example that digested slurry penetrates the soil more easily and rapidly, not sticking to the surface as much as raw manure (BREF, 2015).

GHG emissions in land spreading are mainly due to N_2O emissions.

ENERGY

Land spreading requires energy for transport and application activities. The fuel consumption of the vehicles depends on the distance travelled, the equipment used and the condition of the plot.

ECONOMIC BALANCE

In the economic balance, expenses will be determined by the equipment, diesel consumption and manpower. The approach to this cost is different if the farmer is the owner of the machinery or, on the contrary, uses contractors.

The costs for manure application calculated at individual farm level, taking into account the machine costs and operating time for manure application per year may vary from 1.6 to 13 €/m^3 manure applied (Huijsmans *et al.*, 2003).

One of the key factors that affect the cost of the land application is the transport distance, which will determine the diesel consumption and the manpower.

Manure application costs by trailing hose, trailing foot, shallow injector and land injector are on average ca. 2€/m^3 higher than for surface spreading (Huijsmans *et al.*, 2003). Manure application by a contractor may be less expensive because a contractor may be able to use the machinery more efficiently (more working hours per year), particularly on the smaller farms.

Incomes could exist as the organic fertiliser has a monetary value estimated according to its content in N, P and K and the average price of the fertilising units in the European mineral fertiliser market. The value of the slurry applied on the field is around 5.1 €/t based on the content of N, P, and K and a utilisation of N of 75%, of which 65% is the first year effect (Jacobsen, 2011). Nevertheless, the real price will depend on the market demand of the area.

CLIMATE CHANGE

Practices used to spread manure or digestate in the field or meadow land have a high influence on GHG emissions. Ideally, organic fertilisers should be spread in a liquid form to penetrate rapidly into the soil, or if solid, should be rapidly incorporated. Farmers can share expensive implements that target an optimised use of manure and digestate reducing thus N_2O and NH_3 emissions (CEU, 2015).

N_2O emissions are produced on soil by nitrification-denitrification reactions after land application of slurry, and in the surface layer of storage systems; CH_4 is produced by the anaerobic decomposition of organic matter contained in the slurry (Chadwick *et al.*, 2011).

Overall, lowering the concentration of N in manure, preventing anaerobic conditions or reducing the concentration of degradable manure C are successful strategies for reducing GHG emissions from manure applied to soil. Separation of manure solids and anaerobic degradation pre-treatments can mitigate CH_4 emission from subsurface-applied manure, which may otherwise be higher than from surface-applied manure. The timing of the manure application (e.g. avoiding application before the rain) and maintaining soil pH above 6.5 may decrease N_2O emissions (Hristov *et al.* 2013).

The use of manure as an alternative or complement to mineral fertiliser reduces the emissions produced in the manufacture and transport of inorganic fertilisers. Per m^3 of manure as organic fertiliser properly managed, the emission is reduced by 16.6 kg of CO_2 eq (Ceotto, 2005). It also reduces N_2O emissions from the use of inorganic nitrogen fertilisers.

FUTURE TREND

Animal manure is an alternative to energy intensive and high-cost synthetic fertiliser and can be a very effective fertiliser source when the available nutrient content and mineralisation rate are synchronised with crop nutrient uptake (Montes *et al.* 2014).

The EU nitrogen management strategies have to be reconsidered in light of the promotion of organic fertilisation at the expense of chemical fertilisers (that are extremely energy demanding for their synthesis and contribute to 12% of the emissions), and the scientifically proven fact that most crops prefer the N-ammonium form present in manure and biogas digestate instead of the N-nitrate form which is highly prone to be leached to the water table (CEU, 2015).

Europe is highly dependent on imports of phosphorous and potassium fertilizers (finite resources) and of natural gas used for the synthesis of nitrogen fertilizers (CEU, 2015). The recovery of these nutrients from manures would be desirable.

An important issue for the management of manure in Europe is that it contains 7 million tN which can be used as organic fertiliser to substitute a considerable part of the 11 million tN contained in mineral fertilisers applied to crops (Leip 2011, Iguacel 2006). If all this manure is used for crop fertilisation, the use of mineral fertiliser could possibly decrease by half, curbing the entry of nitrogen into soils. The consequence would be a considerable reduction of the emission of nitrous oxide to the atmosphere, and also the reduction of nitrogen loads to water bodies. At present, the total nitrogen loads to European rivers are 4 million tN (Seitzinger *et al.* 2009), and the environmental damages from this pollution is above 5,200 million Euros (Martínez y Albiac 2006). Also, using less mineral fertiliser would reduce the GHG emissions from its industrial production.

One alternative is to get the collaboration of stakeholders in order to achieve the collective action of pollution abatement. This requires the cooperation among individual farmers, professional associations, transformation and distribution industries, environment organizations, and local, regional and national authorities responsible for agricultural, environmental and water policies. The challenge is not easy and requires a great organizational effort for the use of manure as substitute of mineral fertilisation.

In most of the European countries, nitrogen is the limiting factor in land application due to its environmental impact. However, in some other countries (e.g. Ireland, Sweden, Estonia, Finland, Germany, Belgium-Flanders, Denmark, Lithuania, Latvia and Poland), the phosphorus load is used as a limiting factor as well, either as a legal constraint or as a recommendation only (BREF, 2015).

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6. CASE STUDIES ACROSS EUROPE

6. INTRODUCTION - COMBINATION OF PROCESSES

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INTRODUCTION – COMBINATION OF PROCESSES

The aim of the project has been also to monitor and evaluate treatment plants and manure management schemes in order to obtain useful information for the development and validation of the software tool.

The following chapters contain the a brief description of the case studies evaluated in the project with a summary of the main results obtained.

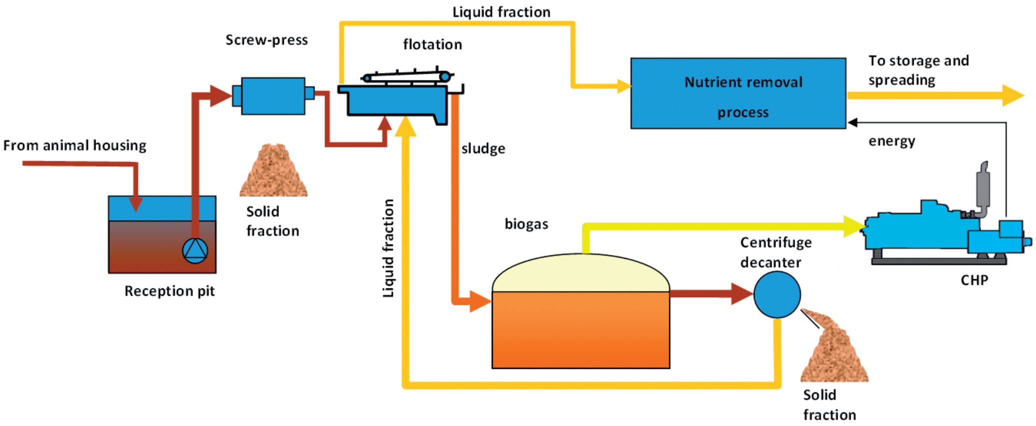
It has to be emphasised that the project did not focus on the single technology but on the practical management systems. In this context, one of the more interesting aspects regards the combination of specific processes to set-up management schemes.

In fact, even if the monitoring activity has collected information from each unit of the treatments plants, the overall performance of the system has been the final aim of the assessment.

The combination of processes is a frequent solution for different reason. Some technologies alone are not directly usable for manure management. For example, a farm that produces liquid manure and aim to produce compost needs to have a phase separation in order to produce a solid fraction suitable for composting.

The aerobic treatments benefits of a previous separation and almost all practical installations have introduced this pre-treatment.

When a farm have a nutrient surplus and cannot manage it transporting manure in the surrounding area, some treatment to remove nutrients should be implemented. In this case, the solution selected is often to combine anaerobic digestion with the process to remove nutrients. The biogas produced and the consequent possibility to sell energy can sustain the cost of the treatment for nutrient removal. In this configuration, the treatment plants can be complex and include different technologies. As an example, in figure 6.1 is reported a scheme of a plant where the manure is initially separated with a screw-



Figures 6.1. An example of the combination of different processes to reduce emissions from manure management.

press and a flotation. This pre-treatment produces a liquid fraction that is then sent to a nutrient removal process (stripping, reverse osmosis, aerobic treatment). The sludge is treated in an anaerobic digester to produce biogas and afterwards separated with a centrifuge decanter. The liquid fraction is recirculated to the flotation. The biogas is used in a co-generator and the energy partly used for the nutrient removal requirements.

The treatment scheme described in this example can improve the environmental sustainability of the manure management but require investment and controlling skills that are not usually available in a livestock farms. Thus when this type of solution is implemented it is often supported by a group of associated farmers. The collective treatment plants can be more convenient due to the size and the possibilities to hire dedicate personnel for the plant.

The drawback of collective solutions is the need to transport manure from the farms to the centralised treatment plant and then to transport back the processed manure to the associated farms.

The varieties of processes and treatment plants monitored during the project produced a good knowledge useful for the definition of every process and their combination. Moreover, the several datasets obtained have been used to validate the software tool with practical case studies.

6.1. CASE STUDY 1: MANAGEMENT OF DAIRY SLURRY IN THE ANAEROBIC DIGESTION TREATMENT PLANT OF HTN BIOGAS, S.L IN CAPARROSO (NAVARRA, SPAIN)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

Sarga has monitored and evaluated the treatment plant managed by HTN Biogas, S.L. (Figure 6.1.1), and located in Caparroso (Navarra, Spain). It manages the slurry generated in a dairy farm with 3,000 heads, 2 km away from the facilities. The anaerobic digestion process treats 380 m^3/day of slurry representing, in terms of mass, 65% of the feedstock that enters into the processing line. The other 35% are co-substrates such as other manures, agrofood industry waste, slaughterhouse by-products, sludges, etc.

Dairy slurry is transported through a pipeline and collected in a reception tank where it is mixed with co-substrates and homogenised before its feeding into the digestion unit. All the feedstock is sanitised in a pasteurisation unit at the beginning of the treatment. Then, a mesophilic digestion, in the absence of oxygen, is carried out in two processing lines working in parallel. Two combined heat and power units (CHP units), of 2 MWe each one, use the biogas obtained to produce enough energy to cover the necessities of the plant and sell the surplus to the public grid.

The digestate is separated in a centrifuge into two phases: liquid and solid. The company manages approximately 6,900 has of land fields in the nearby area, in which both fractions are used as valuable organic fertiliser.

Figure 6.1.1. General view of the anaerobic digestion treatment plant in Caparroso (Navarra, Spain).

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

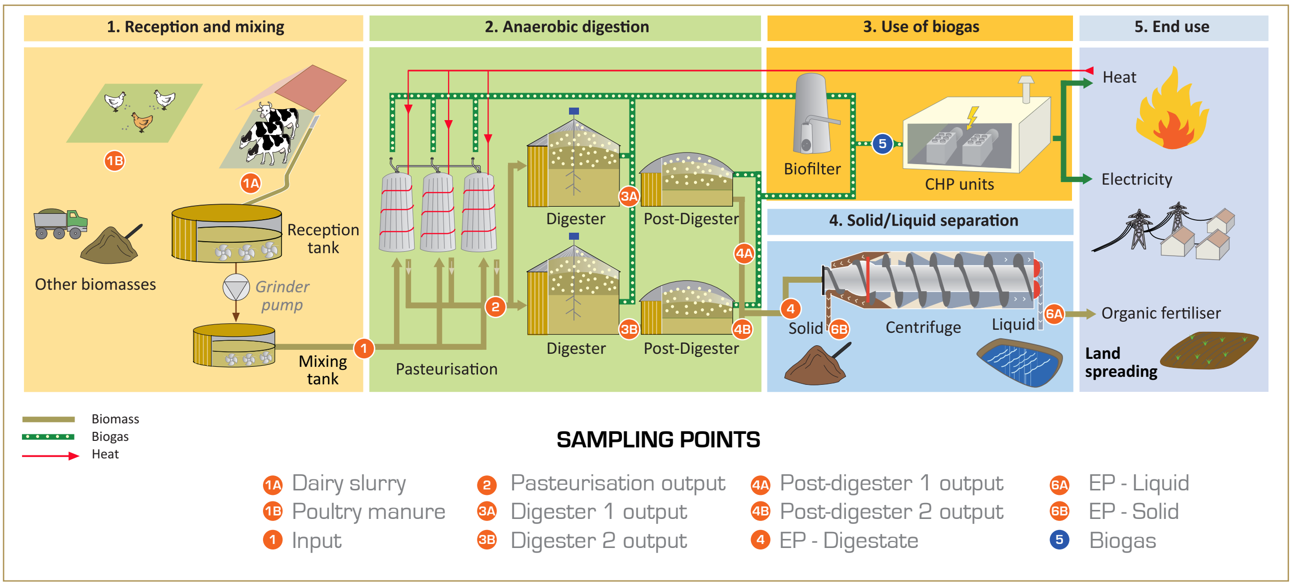

Figure 6.1.1. Scheme of the management system in Caparroso (Navarra, Spain).

Table 6.1.1. Main data of the treatment plant.

Input:	
- Dairy slurry (t/year)	144,419
- Poultry manure (t/year)	9,550
- Agrofood industry wastes (t/year)	61,807
Hydraulic retention time (digester + postdigester) (days)	63
Temperature of anaerobic digestion (ºC)	41
CHP unit power (kWe)1	2,900
End-products:	
- Digestate (t/year)	182,467
- Biogas (m3/year)	8,837,893
- Heat (MWh/year)	17,226
- Electricity (MWh/year)	17,027

[1] In the facilities, there are two CHP units of 2,000 kWe each one. Nevertheless, during the monitoring period, the plant worked using only a power of 2,900 kWe.

The processing line (Figure 6.1.2 and Table 6.1.1) of the treatment plant is made up of the following steps:

1. Reception and mixing. A 2-km-long pipeline transports the slurry from the dairy farm to the plant using gravity as impelling force. The manure is mixed in the reception tank of 800 m^3 with the co-substrates, which are transported by lorry. A first roughing takes place inside this tank with a grinder pump. Then, the feedstock is pumped into a mixing tank of 550 m^3 where it is stored and homogenised.

2. Anaerobic digestion. Prior to the anaerobic digestion, a pasteurisation unit removes all the bacteria and seeds from the feedstock operating at 70 ºC for 1 hour. The temperature of the input flow is previously raised in two heat exchangers working in line in order to soften the temperature gradient. The first one uses the temperature of the pasteurised product, which is over 70 ºC. The second one uses the surplus heat produced in the CHP engines.

The biogas is produced and collected in two anaerobic digestion lines working in parallel. Each one is made up of a digester of 8,000 m^3 and a post-digester of 3,000 m^3, both of them thermally isolated. The mesophilic process, in the absence of oxygen, remains at 41 ºC and the hydraulic retention times are *ca.* 63 days. The vertical stirrers homogenise the liquid in the digesters and make the release of the biogas easier.

3. Use of biogas. The biogas, stored in the digesters and post-digesters, is fed into two CHP units of 2 MWe. These produced enough electricity and heat to cover the necessities of the facility and the surplus was sold to the general grid. A security torch burns the exceeding biogas when necessary.

4. Solid/Liquid separation. The digestate is separated in a centrifuge-decanter adding cationic polyelectrolyte in order to improve its performance. The end-products obtained: a liquid and solid fraction of the digestate that are stored in a closed tank and a covered warehouse respectively.

5. End use. Both fractions obtained in the separation step, as well as the digestate without any subsequent treatment occasionally, are used as valuable organic fertiliser on the land fields of the surrounding area. A specific fertilising plan is followed. It adjusts the application doses to the necessities of the crops, bearing in mind the legal restrictions. During the periods of time that fertilisation is not required; the liquid fraction is stored in two open lagoons until the appropriate time arrives. The spreading of end products covers distances up to 20 kilometres prioritising short distances for the liquid and longer distances for the solid. The vehicles used in the application of the liquid fraction have integrated a surface application system that prevents the emissions generated in this activity.

3. RESULTS OF THE ASSESSMENT

Table 6.1,2. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	17 sampling campaigns		Sampling frequency
			Average	S.D.	
TKN	kg/t	1. INPUT	3.76	1.45	1 sample/month
		4. EP - Digestate	3.94	0.88	1 sample/month
		6A. EP – Liquid	3.90	0.87	1 sample/month
		6B. EP - Solid	11.42	11.34	1 sample/month
Increase (+)/Decrease (-)[1] (%)			+4.9%		
TAN	kg/t	1. INPUT	2.50	0.79	1 sample/month
		4. EP - Digestate	3.06	0.86	1 sample/month
		6A. EP – Liquid	3.18	0.65	1 sample/month
		6B. EP - Solid	2.93	1.36	1 sample/month
Increase (+)/Decrease (-)[1] (%)			+22.4%		
DM	kg/t	1. INPUT	83.71	10.55	1 sample/month
		4. EP - Digestate	46.49	10.43	1 sample/month
		6A. EP – Liquid	32.32	3.68	1 sample/month
		6B. EP - Solid	315.88	42.61	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-44.5%		
VS	kg/t	1. INPUT	64.30	9.72	1 sample/month
		4. EP - Digestate	28.27	7.73	1 sample/month
		6A. EP – Liquid	18.14	5.29	1 sample/month
		6B. EP - Solid	207.30	45.95	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-56.0%		
COD	kg/t	1. INPUT	70.27	19.13	1 sample/month
		4. EP - Digestate	38.59	15.33	1 sample/month
		6A. EP – Liquid	33.56	7.07	1 sample/month
		6B. EP - Solid	71.12	49.08	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-45.1%		
P	kg/t	1. INPUT	0.82	0.76	1 sample/month
		4. EP - Digestate	0.64	0.61	1 sample/month
		6A. EP – Liquid	0.60	0.86	1 sample/month
		6B. EP - Solid	6.58	10.71	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-21.7%		

Parameter	Units	Sampling point	17 sampling campaigns		Sampling frequency
			Average	S.D.	
K	kg/t	1. INPUT	1.84	0.35	1 sample/month
		4. EP - Digestate	1.82	0.50	1 sample/month
		6A. EP – Liquid	1.87	0.39	1 sample/month
		6B. EP - Solid	2.70	1.55	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-1.1%		
Cu	kg/t	1. INPUT	0.006	0.001	1 sample/month
		4. EP - Digestate	0.006	0.002	1 sample/month
		6A. EP – Liquid	0.005	0.008	1 sample/month
		6B. EP - Solid	0.012	0.005	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-4.8%		
Zn	kg/t	1. INPUT	0.024	0.006	1 sample/month
		4. EP - Digestate	0.024	0.009	1 sample/month
		6A. EP – Liquid	0.020	0.005	1 sample/month
		6B. EP - Solid	0.069	0.019	1 sample/month
Increase (+)/Decrease (-)[1] (%)			-1.2%		
EC	mS/cm	1. INPUT	18.4	2.5	1 sample/month
		4. EP - Digestate	22.4	3.8	1 sample/month
		6A. EP – Liquid	24.1	2.1	1 sample/month
		6B. EP - Solid	6.1	5.3	1 sample/month
Increase (+)/Decrease (-)[1] (%)			+22.0%		
pH	pH u.	1. INPUT	6.7	0.5	1 sample/month
		4. EP - Digestate	7.9	0.2	1 sample/month
		6A. EP – Liquid	8.1	0.3	1 sample/month
		6B. EP - Solid	8.5	0.5	1 sample/month
Increase (+)/Decrease (-)[1] (%)			+18.5%		

[1] The increase/decrease percentages have been calculated bearing in mind the quantity and composition of the feedstock that enters the pasteurisation unit (1. INPUT) and the quantity and composition of digestate obtained after the anaerobic digestion unit and prior to its solid/liquid separation (4. EP-Digestate).

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol (CEMP) developed in the LIFE+ MANEV project (Chapter 3). The monitoring lasted 17 months of steady operation of the facilities. The information and data required for the evaluation were collected from:

- Daily records: manual and/or automatic records of the main parameters of the processing line: daily flows, temperatures, electricity consumption, biogas production, etc.
- Monthly sampling campaigns: representative samples of some specific points along the processing line (Figure 6.1.2) were taken periodically and subsequently analysed in a qualified external laboratory.

Table 6.1.2 shows the **mass balance** of the end-product digestate (4. EP-Digestate) compared with the mixture of raw dairy slurry and co-substrates (1. INPUT), as well as the main chemical characteristics (average and standard deviation (S.D.)).

The main evaluation results for the treatment system assessed in the plant of HTN Biogas, S.L. are shown in Table 6.1.3. The data obtained are compared to an agricultural scenario in which all the slurry would be directly applied on the land fields as organic fertiliser.

Table 6.1.3. Summary of the monitoring and evaluation results

			Without treatment system		**HTN Biogas**	
Environment	Global Warming Potential	kg $CO_{2\,eq.}$/t	58.30 (only slurry) 84.85 (slurry + cosubstrates)[1]		30.67	
	Acidification Potential	kg $SO_{2\,eq.}$/t	1.98 (only slurry) 2.75 (slurry + cosubstrates)[1]		2.92	
Energy[2]	Electrical energy balance	kWh/t	-		60.1	
	Thermal energy balance	kWh/t	-		Surplus	
	Fuel	kWh/t	-		0	
Economy	Incomes	€/t	-		-	
	Expenses	€/t	-		-	
Agronomy	Nitrogen balance[3]	kg N/ha[4]	Maize 343.1 (30.9)	Barley 57.5 (5.2)	Maize 402.7 (90.5)	Barley 67.5 (15.2)
	Phosphorus balance[3]	kg P/ha	Maize 102.1 (-20.1)	Barley 17.1 (-6.9)	Maize 65.3 (-57.3)	Barley 10.9 (-13.0)
	Potassium balance[3]	kg K/ha	Maize 230.2 (-26.2)	Barley 38.6 (-7.2)	Maize 186.1 (-70.4)	Barley 31.2 (-14.6)
Social impact	Job demand – Operator[5]	h/y	-		17,000[6]	
	Job demand – Specialised technician[5]	h/y	-		5,100[7]	
	Odour	1-4	-		2	
	Noise	Yes/No	-		Yes	
Biosecurity	Pathogens reduction	Yes/No	-		Yes	

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[1] Global Warming Potential of a management system in which the same mixture of slurry + co-substrates was directly applied in the land fields of the area as organic fertiliser. It has been used the same quantity and composition of the INPUT for the evaluation.

[2] Values are referred to the steps 2, 3 and 4 of the processing line.

[3] kg/ha applied (Balance: Nutrients applied - Nutrient requirements of the crop (kg/ha); Nutrients applied = EP-digestate concentration x application dose (kg/ha)).

Balance based on readily available nitrogen of the digestate (ammoniacal nitrogen).

In the case of the scenario "without treatment system" the balance was carried out with the composition of the raw slurry, not with the input.

[4] The nutrient demand of maize cannot be supplied at 100% with digestate due to legal restrictions in application doses. Nevertheless, the nutrient balance has been simulated considering the use of digestate uniquely for the fertilisation, in order to verify the NPK balance in digestate composition vs. crop requirements.

[5] It has been considered 1700 hours / year • job post (average values from the database of the Organisation for Economic Co-operation and Development (OECD) Stat. Data taken on November 26, 2014, 12:08 UTC (GMT)).

[6] 10 operators

[7] 3 plant managers and specialised technicians/coordinators.

I. ENVIRONMENT

Emissions. The emissions of the whole management system have been evaluated following the guidelines established in the CEMP and based on Tier 2 methodology of IPCC, taking into account as starting point the slurry transport from the farm to the plant, including emissions related to the road transport of cosubstrates, digestate storage, digestate transport and land spreading of the end products as organic fertiliser. The storage time at the farm is negligible because the collection is daily managed in order to use the slurry as fresh as possible in the anaerobic digestion. The liquid fraction of digestate is firstly stored in a covered tank and if necessary, out of the fertilising season, in two lagoons.

The total estimated annual emissions of greenhouse gases (GHG) are *ca*. 6,618 t CO_2 eq./year. Land spreading would be responsible for approximately 50% of the total GHG emissions linked to this management system and to a minor extent, digestate storage which would be responsible for *ca*. 42% of the total emissions. The other 8% was generated in the centralised transport system (Figures 6.1.3 and 6.1.4).

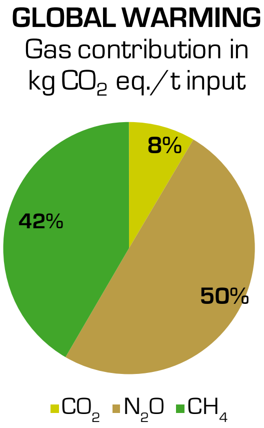

Figure 6.1.3. Gas contribution of the management system to the global warming potential.

Additionally, the plant recovers approximately 5,268,823 m^3 of methane per year, which is equivalent to a global warming potential of 86,409 t CO_2 eq./year. This methane is used to produce renewable energy in the CHP units that is exported out of the system and contributes to cut down the energy consumption coming from fossil fuels.

In summer 2014, a field trial in a maize field was carried out in order to evaluate the ammonia emission rate when diluted digestate (1:10-1:30) is applied using a sprinkle irrigation system. The estimations were based on a mass balance, sampling and monitoring volumes and composition of diluted digestate before and after spreading (LIFE+ MANEV technical report, 2015). The trial was replicated four times. It took place during summer under climate conditions that were supposed to enhance emission generation (average temperatures around 30 ºC and wind speed of 2 m/s). The results obtained concluded that, under trial conditions, the ammonia nitrogen losses were approximately 20% of the total ammonia nitrogen injected into the irrigation system (Figure 6.1.5). This value is lower than the emission factor provided by the EMEP/EEA in its emission inventory guidebook (EMEP/EEA, 2010), which is, in the case of the land spreading of dairy cow slurry, 55% of the total ammoniacal nitrogen applied onto the field.

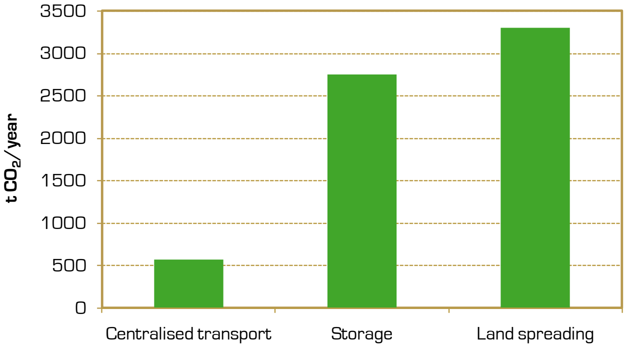

Figure 6.1.4. Gas emission in the different steps of the management system.

The acidification impact of NH_3 and NOx emissions, estimated following the CEMP and the EMEP/EEA guidelines, was approximately 629 t SO_2 eq./year. The digestate storage was responsible for 37% of these emissions and land spreading for 63%. Centralised transport emissions were negligible (Figures 6.1.6 and 6.1.7).

Water and soil. The digestate contains a higher proportion of mineral nitrogen, which improves its availability for the plants in the short term. Thus, well managed and applied at the proper time, digestate can be more efficient covering crop requirements and preventing run-off or soil accumulation.

II. ENERGY

The biogas generated in the process is collected from the pasteurisation tanks, digesters and post-digesters. The average daily biogas production is 24,213 m^3/day (CH_4 content of 59.6%) and the two CHP units have an electrical efficiency of 42.7% and a thermal efficiency of 43.2% (Table 6.1.4).

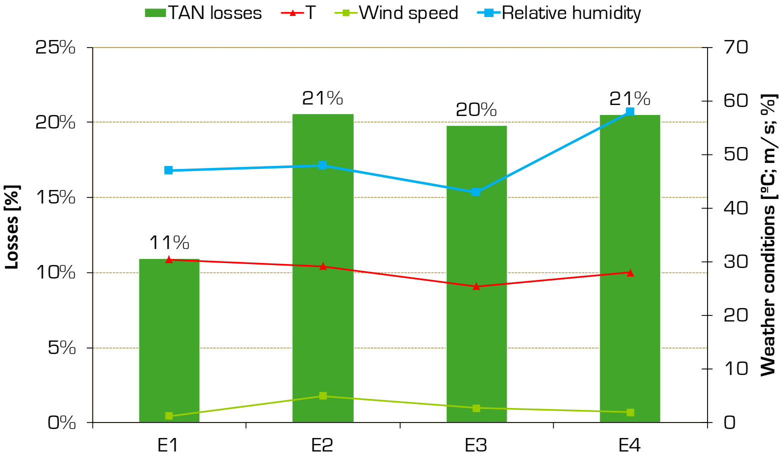

Figure 6.1.5. Ammonia nitrogen losses in the emission field trials.

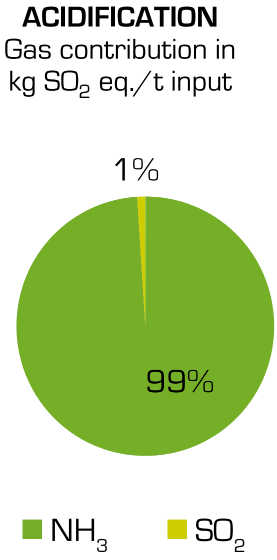

Figure 6.1.6.. Gas contribution of the management system to the acidification.

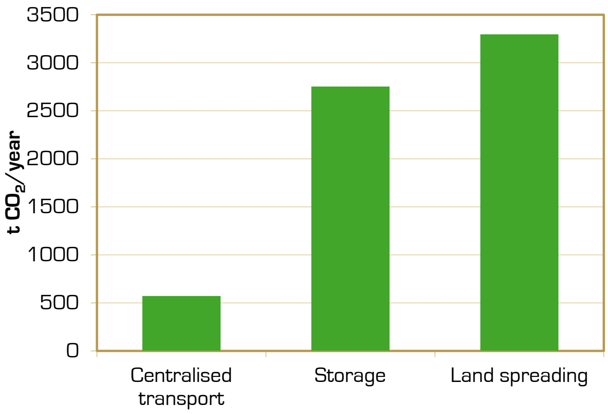

Figure 6.1.7. Gas emission in the different steps of the management system contributing to the acidification.

The addition of organic co-substrates to the process increases the organic load up to 2.6 kg of organic matter/ m^3 digester/day and the biogas productions up to 37.2 m^3 biogas/t input, in comparison to biogas productivity data reviewed in scientific bibliography for slurry that vary among 10 – 22 m^3 biogas/t slurry (Flotats, 2011; MARMA 2010).

The average annual production of energy in the plant, during the monitoring period, was 17,027 MWh of electricity and 17,226 MWh of heat, while the electrical consumption in the facilities was 16% of the electricity generated.

Electricity consumption was distributed as follows in the plant: 20% cogeneration system, 2 to 9% general services such as illumination and 70 to 80% the equipment installed in the biomass line, being the stirring systems responsible for 50% of this energy consumption.

Table 6.1,4. Main energy data of the treatment plant.

Average biogas production (m^3 biogas/t input)	37.2
Average biogas production (m^3/year)	8,837,893
Average biogas composition (% CH_4)	59.6
Electrical energy average production (kWh/ m^3 biogas)	1.93
Electrical energy average production (kWh/t input)	71.59
Thermal energy average production (kWh/m^3 biogas)	1.95
Thermal energy average production (kWh/t input)	72.43
Average electrical energy consumption in the facilities (kWh/t input)	11.5

III. ECONOMY

The investment of the plant was over €14.2 million (2011). The operating costs of the facility are significantly affected by the feed-in-tariff and national subsidies policies defined by the government, which makes the economic viability of these facilities, in some occasions, vulnerable to the changes in the national energetic policies.

The annual recovery of 5,268,823 m^3 of methane had a market value of €741,387 according to the market price of the emission allowances in November 2015: 8,58 €/t CO_2 eq. (European Emission Allowances 30/11/2015).

The monetary value of the organic fertiliser produced would be around 7 €/t, according to its NPK content and the average price of the most frequently used mineral fertilisers in Europe (Eurostat, 2015). Considering an average annual production of digestate of 182,467 t/year, this would generate an annual income of 1,277,268 €/year. Nevertheless, local agricultural practices rule the demand and market price of these products. In addition, it has to be taken into account other factors such as the added value of the organic matter content in digestate, the loss of value due to the unbalanced nutrient content of digestate (according to crop requirements), the handling difficulties or the ratio of organic/inorganic forms of nitrogen in the product, although inorganic content is higher in the digestate than in raw manure due to the mineralisation process that takes place during anaerobic digestion.

IV. AGRONOMY

The digestate, as well as the two fractions obtained after the separation centrifuge, are applied on the land fields of the area: a solid fraction with a high content of phosphorus and a liquid fraction with a high content of nitrogen and potassium (Table 6.1.5 and Figure 6.1.8). Three of them are used as valuable organic fertiliser, being transported longer distances in the case of solid and managed in the nearer areas in the case of liquid and digestate.

Table 6.1.5. Separation efficiency of the centrifuge.

	Separation efficiency (%)	Min	Max
DM	41 ± 9	28	53
TKN	12 ± 6	2	21
P	44 ± 9	28	56
K	7 ± 4	1	11

*Separation efficiency (in terms of mass)=[[Digestate – Liquid fraction]/Digestate] x 100.

Values of P, K and metals are not affected by the digestion process, although solid fraction concentrates 6% of the digestate mass, 44% of total phosphorus and 41% of the dry matter, while liquid fraction contains 94% of the total digestate mass, 88% of total nitrogen and up to 93% of potassium.

The anaerobic process increased TAN by 22%, raising the TAN/TKN ratio by 17% in the process.

More than 6,900 has are included in the fertilising plan in which the growth of rainfed barley (52% of total land surface) and irrigated maize (41% of the total land surface) prevails with an average yield in Navarra of 2.18 and 11.15 t/ha respectively (Estadísticas agrícolas, Producción agrícola, Gobierno de Navarra, 2014).

The average nutrient requirements of these crops are estimated at 24 kg of N /t of crop, 11 kg of P_2O_5 /t crop and 21 kg of K_2O/t crop in the case of barley and 28 kg of N /t crop, 11 kg of P_2O_5/t crop and 23 kg of K_2O/t crop in the case of maize (Dominguez, 1997). Thus, when comparing nutrient requirements with the NPK content of the end-products (Figure 6.1.9 and 6.1.10) it can be concluded that digestate represents a well balanced fertiliser, bearing in mind the nitrogen fraction readily available for plants, which is approximately 78% of the total nitrogen content (ratio TAN/TKN). Solid fraction is a valuable source of phosphorus which is appropriate at the sowing time in the case of maize and cheaper to transport longer distances. The liquid fraction has a major fraction of nitrogen in its ready available form for the crops and at the major part of potassium as well.

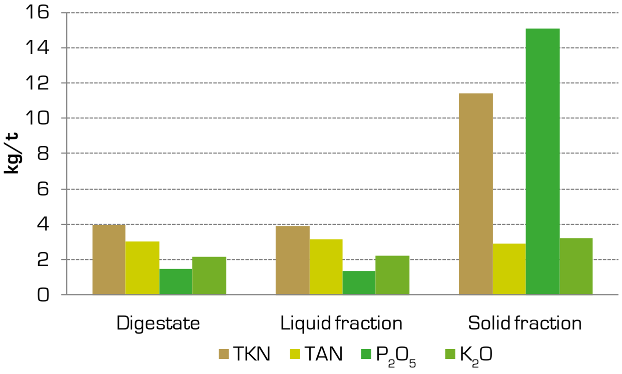

Figure 6.1.8. End-products composition.

In the case of maize, if application doses are calculated in terms of nitrogen crop demand, 7.1 t digestate/t crop should be applied in order to cover all the necessities. Meanwhile, phosphorus contribution would also be fully covered and two-thirds of the potassium. If the balance

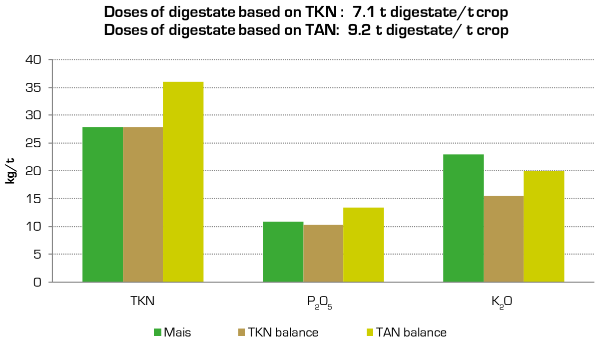

Figure 6.1.9. Maize nutrient demand and digestate composition.

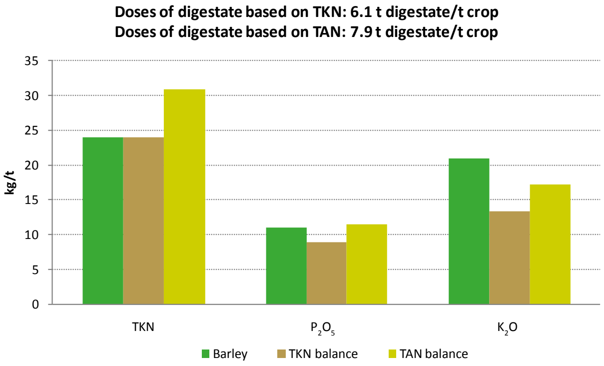

Figure 6.1.10. Barley nutrient demand and digestate contribution.

is carried out bearing in mind ammoniacal nitrogen, which is the readily available form of the nitrogen, potassium necessities will be almost covered yet phosphorus might be overdosed. In the case of barley, phosphorus necessities would be easily covered yet potassium requirements might be not sufficient. Nevertheless, other factors such as soil characteristics and composition or other nutrient sources should be assessed in every case in order to determine whether additional mineral fertilising is required or not.

V. SOCIAL IMPACT

The facility is located far from the nearest village and 2 km away from the farm. The slurry is transported by pipeline using gravity as the impelling force, which prevents the generation of road traffic and no noise, odour or relevant cost are linked to it.

The building where all the organic products are received is carefully kept closed whenever there are no loading/unloading activities. An extraction system collects the air from inside and treats it in a biological filter so as to remove odours. The warehouse where the solid fraction is stored is also maintained closed and the liquid fraction is collected in a covered tank.

All the digesters are covered with green metal sheets which minimise the visual impact of the buildings.

The large dimension of the facility required the creation of 13 new jobs directly involved in the operation of the plant and 10 additional indirect jobs.

VI. BIOSECURITY

E. coli and *Salmonella* values were completely removed after the pasteurisation step, and no further trace of them was found since in the processing line.

4. CONCLUSIONS

The anaerobic digestion system evaluated enable achieving, among others, two environmental benefits related to gas emissions, it is a source of renewable energy recovering 8,837,893 m^3 of biogas/year, which is equivalent to 86,409 t CO$_2$ eq./year and it prevents greenhouse gas emissions generated in the manure management, mainly due to the reduction of CH$_4$ emissions in the storage.

The use of closed buildings with biofilter systems and storage tanks, prevent the emission of odours and other gases such us NH$_3$ that take place mainly in digestate storage and land spreading.

The macronutrients concentration remains constant throughout the processing line. The almost 7,000 has of land fields included in the fertilising plan enable properly managing the digestate as organic fertiliser. The decanter-centrifuge let separate 6% of the digestate in the solid fraction, in terms of mass, concentrating approx. 41% of dry matter and 44% of phosphorus.

The efficiency of the process is optimised with the addition of cosubstrates. Nevertheless, the economic viability of the plant still remains vulnerable to the changes in the energy regulations and subsidies.

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6.2. CASE STUDY 2: CENTRALISED MANAGEMENT OF PIG SLURRY IN THE ANAEROBIC DIGESTION TREATMENT PLANT OF PURINES ALMAZÁN, S.L IN ALMAZÁN (CASTILLA Y LEÓN, SPAIN)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

Sarga has monitored and evaluated the treatment plant managed by Purines Almazán, S.L. (Figure 6.2.1) and located in Almazán (Castilla y León, Spain). It carries out a centralised management of the slurry generated in 32 pig farms of the area. The facilities treat between 100 - 140 m^3/day of pig manure in an anaerobic digestion process.

The raw slurry is transported by lorry from the farms to the plant. Pig slurry is collected in a reception tank where it is mixed and homogenised prior to its feeding into the digestion unit. The mesophilic anaerobic process consists of one digester followed by a post-digester, working in line. A combined heat and power unit (CHP unit), with an electric power of 250 kWe, produces energy that is used in the plant. The surplus of electricity is sold to the public grid.

The treatment plant incorporated, in mid 2015, an additional unit at the beginning of the processing line in order to feed sterilised carcasses of pigs directly into the primary digester.

The digestate is stored in a tank and two auxiliary lagoons, one covered and one uncovered, before being spread as a valuable organic fertiliser onto the crop fields of the surrounding area.

Figure 6.2.1. General view of the anaerobic digestion treatment plant in Almazán (Castilla y León, Spain).

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

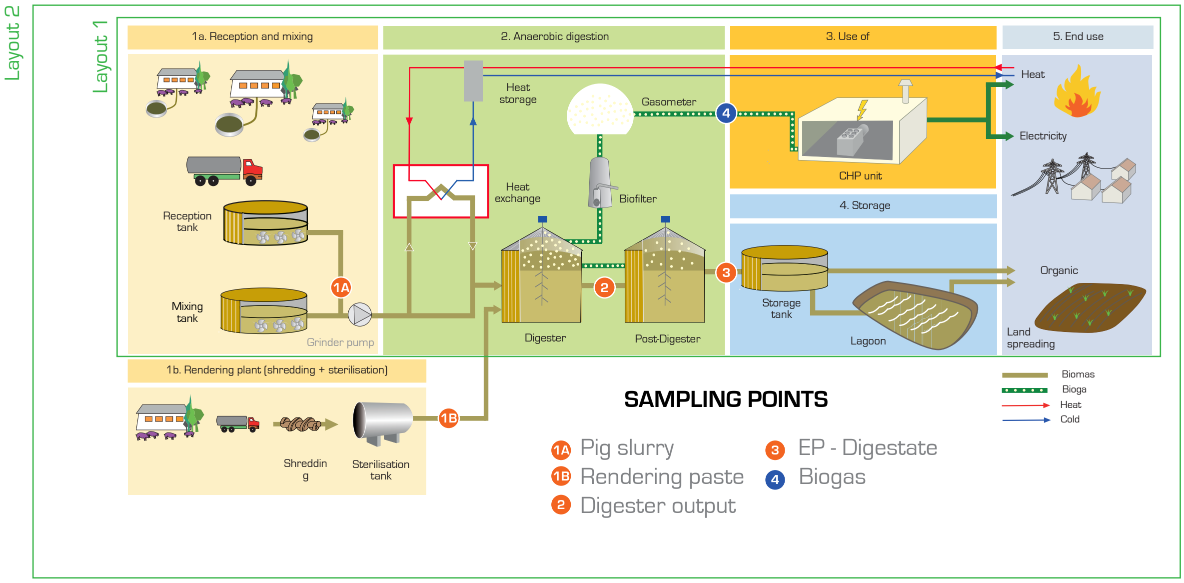

Figure 6.2.2. Scheme of the management system in Almazán (Castilla y León, Spain).

Table 6.2.1. Main data of the treatment plant in 2014 and 2015.

	Layout 1	Layout 2
Inputs:		
- Pig slurry (t/year)	38,254	38,430
- Pig carcasses (t/year)	-	2,120
Hydraulic retention time of anaerobic digestion (days)	37	33
Digester (days)	29	26
Post-digester (days)	8	7
Temperature of anaerobic digestion (ºC)	38.3	38.8
CHP unit power (kWe)	250	250
End- products:		
- Digestate (t/year)	37,366	36,467
- Biogas (m^3/year)	586,056	944,256
- Electricity (MWh/year)	1,491	1,727
- Heat (MWh/year)	1,699	1,973

The processing line (Figure 6.2.2 and Table 6.2.1) of the treatment plant is made up of the following steps:

1.a. Reception and mixing. A 35 m^3 capacity lorry transports the slurry from the pig farms to the treatment plant and discharges it into a reception tank of 520 m^3, where a first roughing takes place with a metal grid. Then, the slurry is pumped into a mixing tank of 550 m^3 where it is stored and homogenised before entering the anaerobic digestion unit.

1.b. Rendering plant. In May 2015, an additional rendering processing unit was incorporated into the treatment line aimed at feeding pig carcasses to the digester, previously sterilised at 133 ºC and 3 bars for 20 minutes. The whole process lasts approximately 2.5-3 hours.

Properly disinfected facilities guarantee the necessary sanitary conditions and prevent the dissemination and transference of pathogens due to the transport.

1. Anaerobic digestion. The feedstock is preheated in a heat exchanger using the exceeding heat produced in the (CHP unit). The biogas is generated, in the absence of oxygen, in a digester of 3,000 m^3 and a post-digester of 800 m^3 in line, thermally isolated at 38 ºC with an average hydraulic retention time of 37 days (29 and 8 days respectively). Average values are slightly lower after the addition of the rendering process to the processing line, 33 days (26 and 7 days respectively).

2. Use of biogas. The biogas, cleaned in a biofilter and stored in an external gasometer, is used in a 250 kWe CHP unit to produce electricity and heat. This energy covers the necessities of the facilities, and the surplus electricity is sold to the general grid. The heat generated in the exhaust gases of the engine is used to raise the temperature of the feeding before entering in the digester. There is a security torch for the burning of the biogas surplus when necessary.

3. Storage. Digestate is stored in one uncovered tank and two lagoons of 2,500 m^3, one covered and one uncovered.

4. End use. The production of electricity and heat in the facilities is partially used to cover the process necessities. The surplus electricity is sold to the grid. The digestate is spread as valuable organic fertiliser onto the land fields of the surrounding area.

3. RESULTS OF THE ASSESSMENT

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol (CEMP) developed in the LIFE+ MANEV project (Chapter 3). In the case of layout 1 the monitoring lasted 17 months of steady operation of the facilities. The start-up of the rendering plant took place in May 2015, and this new configuration (layout 2) was monitored for 6 months in order to assess its performance in comparison with the prior. The information and data required for the evaluation were collected from:

- Daily records: manual and/or automatic records of the main parameters of the processing line: daily flows, temperatures, electric consumption, biogas production, etc.

- Monthly sampling campaigns: representative samples of some specific points along the processing line (Figure 6.2.2) were taken and subsequently analysed in a qualified external laboratory.

Table 6.2.2 shows the mass balance of the end-product digestate (3. EP-Digestate) compared with the input: pig slurry in layout 1 (1a. Pig slurry) and the mixture of pig slurry and pig carcasses in layout 2, as well as the main chemical characteristics (average and standard deviation (S.D.)).

Table 6.2.2. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	Layout 1 17 sampling campaigns		Layout 2[1] 6 sampling campaigns		Sampling frequency
			Average	S. D.	Average	S. D.	
TKN	kg/t	1a. Pig slurry	3.41	0.98	2.60	0.95	1 sample/month
		1b. Pig carcasses			17.42	4.87	1 sample/month
					3.38[2]		
		3. EP - Digestate	3.51	0.69	3.60	0.68	1 sample/month
Increase (+)/Decrease (-) (%)			**+ 3.0 %**		**+ 6.6 %**		
TAN	kg/t	1a. Pig slurry	2.82	0.91	2.09	0.87	1 sample/month
		1b. Pig carcasses			7.97	2.53	1 sample/month
					2.39[2]		
		3. EP - Digestate	2.97	0.70	2.91	0.79	1 sample/month
Increase (+)/Decrease (-) (%)			**+ 5.3%**		+ 21.6%		
DM	kg/t	1a. Pig slurry	30.06	18.20	30.83	15.47	1 sample/month
		1b. Pig carcasses			341.67	72.13	1 sample/month
					47.08[2]		
		3. EP - Digestate	21.00	9.65	24.50	7.97	1 sample/month
Increase (+)/Decrease (-) (%)			**- 30.1%**		**+ 48.0%**		

Parameter	Units	Sampling point	Layout 1 17 sampling campaigns		Layout 2[1] 6 sampling campaigns		Sampling frequency
			Average	S. D.	Average	S. D.	
VS	kg/t	1a. Pig slurry	20.84	14.55	21.22	11.85	1 sample/month
		1b. Pig carcasses			300.17	60.13	1 sample/month
					35.81[2]		
		3. EP - Digestate	12.64	7.55	15.45	6.25	1 sample/month
Increase (+)/Decrease (-) (%)			**- 39.3%**		**- 56.9%**		
COD	kg/t	1a. Pig slurry	33.75	20.64	27.83	15.82	1 sample/month
		1b. Pig carcasses			523.12	180.32	1 sample/month
					53.72[2]		
		3. EP - Digestate	19.34	7.76	22.14	3.51	1 sample/month
Increase (+)/Decrease (-) (%)			**- 42.7%**		**- 58.8%**		
P	kg/t	1a. Pig slurry	0.32	0.20	0.32	0.28	1 sample/month
		1b. Pig carcasses			3.46	1.91	1 sample/month
					0.48[2]		
		3. EP - Digestate	0.29	0.25	0.25	0.16	1 sample/month
Increase (+)/Decrease (-) (%)			**-11.7%**		**-47.5%**		
K	kg/t	1a. Pig slurry	1.71	0.53	1.36	0.46	1 sample/month
		1b. Pig carcasses			2.11	0.42	1 sample/month
					1.40[2]		
		3. EP - Digestate	1.68	0.34	1.36	0.26	1 sample/month
Increase (+)/Decrease (-) (%)			**-1.6%**		**-3.4%**		
Cu	kg/t	1a. Pig slurry	0.009	0.004	0.007	0.006	1 sample/month
		1b. Pig carcasses			0.005	0.003	1 sample/month
					0.007[2]		
		3. EP - Digestate	0.008	0.003	0.006	0.005	1 sample/month
Increase (+)/Decrease (-) (%)			**- 10.8%**		**- 13.2%**		
Zn	kg/t	1a. Pig slurry	0.071	0.046	0.051	0.039	1 sample/month
		1b. Pig carcasses			0.060	0.016	1 sample/month
					0.052[2]		
		3. EP - Digestate	0.062	0.031	0.049	0.038	1 sample/month
Increase (+)/Decrease (-) (%)			**- 11.9%**		**-5.1%**		
EC	mS/cm	1a. Pig slurry	18.8	3.8	18.9	4.3	1 sample/month
		1b. Pig carcasses			11.1	11.0	1 sample/month
					18.5[2]		
		3. EP - Digestate	20.7	1.7	24.3	2.4	1 sample/month
Increase (+)/Decrease (-) (%)			**+ 9.8%**		**+31.5%**		
pH	pH u.	1a. Pig slurry	7.3	0.4	7.2	0.3	1 sample/month
		1b. Pig carcasses			6.5	0.4	1 sample/month
					7.1[2]		
		3. EP - Digestate	7.9	0.2	7.8	0.1	1 sample/month
Increase (+)/Decrease (-) (%)			**+ 7.8 %**		**+9.0%**		

[1] In the case of layout 2, the increase/decrease percentages have been calculated bearing in mind the quantity and composition of the input mixture (pig slurry + pig carcasses)[2] and digestate.

[2] Calculated parameter: weighted average composition of the mixture of pig slurry and pig carcasses fed into the digester. This mixture, in terms of mass, was 5.2% of pig carcasses and 94.8% of pig slurry during the monitoring period.

The main evaluation results for the treatment system assessed in the plant of Purines Almazán, S.L. are shown in Table 6.2.3. The data obtained are compared to the initial scenario prior to the start-up of the treatment plant where the raw pig slurry was applied directly in the land fields without any treatment.

Table 6.2.3. Summary of the monitoring and evaluation results.

			Without treatment system	**LAYOUT 1**	**LAYOUT 2**
Environment	Global Warming Potential	kg $CO_{2\ eq.}$/t	36.37 (only slurry) 52.67 (slurry + carcasses)	29.10	34.00
	Acidification Potential	kg $SO_{2\ eq.}$/t	2.32 (only slurry) 1.98 (slurry + carcasses)	2.39	2.16
Energy[1]	Electrical energy balance	kWh/t	-	34.6	48.0
	Thermal energy balance	kWh/t	-	Surplus	Surplus
	Fuel	kWh/t	-	0	0
Economy	Income	€/t	-	2.8	5.5
	Expenses	€/t	-	6	7
Agronomy	Nitrogen balance[2]	kg N/ha	67.7 (11.7)	66.2 (10.2)	69.2 (13.2)
	Phosphorus balance[2]	kg P/ha	6.4 (-4.9)	5.4 (-5.9)	4.8 (-6.5)
	Potassium balance[2]	kg K/ha	34.0 (0.7)	31.8 (-1.6)	26.1 (-7.3)
Social impact	Job demand – Operator [3]	h/y	-	5,100[4]	5,100[4]
	Job demand – Specialised technician[3]	h/y	-	3,400[5]	3,400[5]
	Odour	1-4	-	2	3
	Noise	Yes/No	-	Yes	Yes
Biosecurity	Pathogens reduction	YES/NO	NO	YES	YES

[1] Values are referred to the steps 1.b, 2 and 3 of the processing line.

[2] kg/ha applied (Balance: Nutrients applied – Nutrient requirements of the crop (kg/ha); Nutrients applied = EP-Digestate concentration x application dose (kg/ha)).

Balance based on readily available nitrogen (ammoniacal nitrogen).

[3] It has been considered 1700 hours / year • job post (Average values from the database of the Organisation for Economic Co-operation and Development (OECD) Stat. Data taken on November 26, 2014 12:08 UTC (GMT)).

[4] 3 operators

[5] 1 plant manager full-time and 2 coordinators part-time.

I. ENVIRONMENT

Emissions. The emissions of the whole management system have been evaluated following the guidelines established in the CEMP and based on Tier 2 methodology of IPCC, taking into account as starting point the slurry transport from the farms to the plant and as final destination the land spreading of the digestate as organic fertiliser. The storage time at farms is negligible because the collection is managed to use the slurry as fresh as possible in the anaerobic digestion.

The total estimated annual greenhouse gas (GHG) emissions are *ca.* 1,113 t CO_2 eq./year and 1,379 t CO_2 eq./year in layout 1 and 2 respectively. Land spreading would be responsible for more than 55% of the total GHG emissions linked to this management system and to a minor extent, digestate storage which would be responsible for approximately 40% of the total emissions (Figures 6.2.3 and 6.2.4). The Global Warming Potential reduction obtained is mainly due to the lower methane emissions during the storage.

Additionally, the plant recovers approximately 380,655 m^3 of methane per year in layout 1 and 593,207 m^3 of methane per year in layout 2, which is equivalent to a global warming potential of 6,243 tons of CO_2 eq./year and 9,729 tons of CO_2 eq./year respectively. This methane is used to produce renewable energy in the CHP unit that is exported of the system, contributing to reduce the energy consumption coming from fossil fuels.

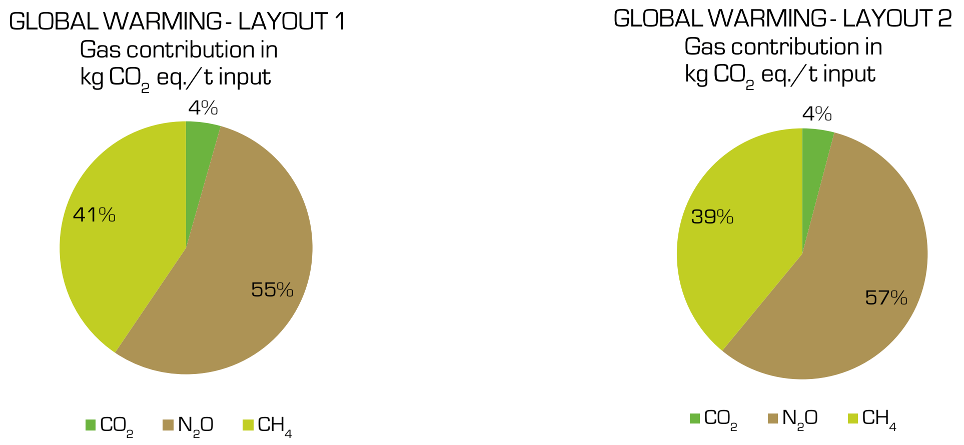

Figure 6.2.3. Gas contribution of the management system to the global warming potential.

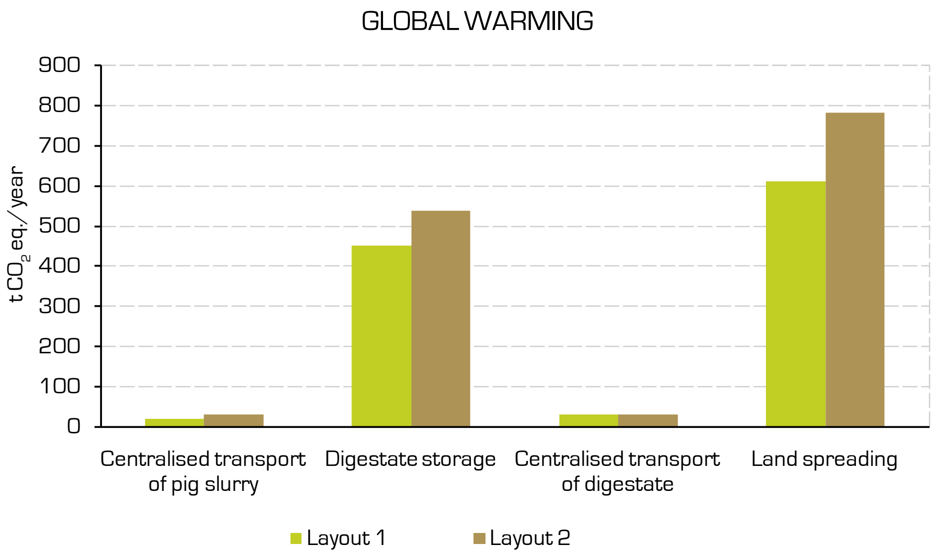

Figure 6.2.4. Gas emission in the different steps of the management system contributing to the global warming potential.

The total emissions of NH_3 and NOx were estimated following the CEMP guidelines based on EMEP/EEA emission inventory guidebook 2010. The acidification impact of these emissions was approximately 90 t SO_2 eq./year in both layouts. Digestate storage was responsible for 33% of these emissions and land spreading for 66%. Centralised transport emissions were negligible (Figures 6.2.5 and 6.2.6).

In summer 2015, before starting up the rendering plant, the emissions generated in final digestate storage lagoons were measured with an adapted methodology based on the use of dynamic chambers for the sampling and a photoacoustic device for the measurements (LIFE+ MANEV technical report, 2015 (Arriaga *et al.*, 2015); Peu *et al.*, 1999). The two storage lagoons of the facility, one covered and one uncovered, were monitored (Figures 6.2.7 and 6.2.8). The trial took place under conditions that may enhance the emission generation (30 ºC and 3.1 m/s wind speed (average values during the trial)) and the results obtained concluded that the emissions generated were mainly due to NH_3 and CH_4, while no N_2O emissions were detected. The reduction of NH_3 and CH_4 emissions achieved were nearly 100% using the covered system. The use of a covered lagoon prevents the generation of emissions during the final storage of digestate before its land spreading.

If the experimental data collected during the trial are used in the gas emission estimations, figures and emis-

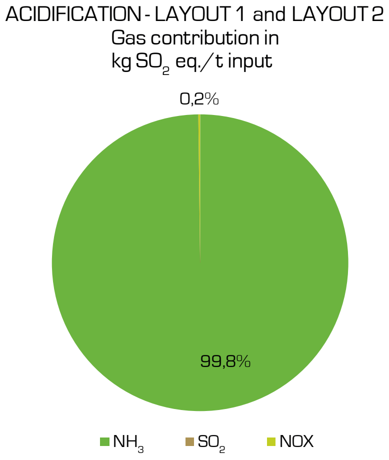

Figure 6.2.5. Gas contribution of the management system to the acidification.

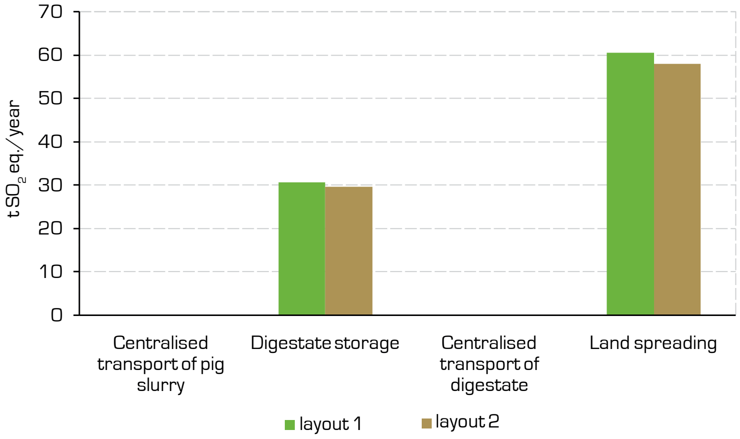

Figure 6.2.6. Gas emission in the different steps of the management system contributing to the acidification.

sion distribution would be different along the management system. Digestate storage emissions would rise to 1,184 t CO_2 eq./year, 2.5 times higher than the ones estimated with the CEMP methodology based on IPCC emission factors. It is important to remark that the conditions in which the trial took place where the most disadvantageous for that system combining high temperatures and wind. Thus, the average emission rate could be overestimated if the appraisal is based on the values measured in the essay. Further research would be necessary to have a wider view about the evolution of these emissions in different seasons, covering all weather conditions, and validating the methodology used in the measurements.

The average emission rates of NH_3 measured in the experimental trial (0.33-0.50 mg $NH_3/m^2/min$) were lower regarding the information usually found in the scientific bibliography and the calculations carried out based on EMEP/EEA methodology. The acidification potential is reduced one-third using experimental data instead of official methodologies in this case.

Water and soil. Digestate is applied on the surrounding land fields as a valuable organic fertiliser. The anaerobic digestion process does not change the overall TKN/P ratio, and it only has an effect on the nitrogen availability (DG Environment, 2011). The digestate contains a higher proportion of mineral nitrogen, which improves its availability for the plants in the short term. Thus, well managed and applied at the proper time, digestate can be more efficient covering crop requirements and preventing runoff or soil accumulation.

Figures 6.2.7 and 6.2.8. Emission measurements in the uncovered and covered lagoons in the treatment plant of Purines Almazan, SL (Castilla y León, Spain).

Table 6.2.4. Main energy data of the treatment plant.

	Layout 1	Layout 2
Average biogas production (m^3 biogas/t input)	15.76	23.29
Average biogas production (m^3 biogas/year)	586,056	944,256
Average biogas composition (% CH_4)	65.0	62.8
Electrical energy average production (kWh/m^3 biogas)	2.6	2.4
Electrical energy average production (kWh/t input)	40.7	56.3
Thermal energy average production (kWh/m^3 biogas)	2.9	2.8
Thermal energy average production (kWh/t input)	46.4	64.4
Average electrical energy consumption in the facilities (kWh/t input)	6.1	8.3

II. ENERGY

The biogas produced is 1,600 m^3 /day (CH_4 content of 65.0%) in layout 1 and 2,587 m^3 /day (CH_4 content of 62.8%) in layout 2 (Table 6.2.4).

The addition of sterilised pig carcasses to the process has increased the organic load fed to the anaerobic digestion process from 0.64 to 0.73 kg of organic matter/m^3 digester/day and the production of biogas is almost doubled, while average methane content in biogas has barely decreased by 3.3% from 65.0 % to 62.8%.

Thus, when pig carcasses are added to the process in a ratio 1:18 (layout 2), the electrical and thermal energy production per cubic metre of biogas is slightly lower, but the overall production per ton of input increased *ca.* 47.8%.

The average annual production of energy in the plant, during the monitoring period, was 1,491 MWh of electricity and 1,699 MWh of heat in layout 1, while the electrical consumption in the facilities is 15% of the electricity generated. Meanwhile, in layout 2 the average annual production of energy was approximately 1,717 MWh of electricity and 1,973 MWh of heat, while the proportion of electrical consumption in the facilities remained the same, 15% of the electricity generated (Figure 6.2.9).

The annual recovery of 380,656 m^3 of methane when the plant was treating only raw manure had a market value of €54,000 according to the market price of the European Emission Allowances in November 2015: 8.58 €/t CO_2 eq. (European Emission Allowances 30/11/2015). The annual recovery of methane after the set up of the rendering process, 593,207 m^3 of methane, would provide an income of €84,152 if this sector would be included in the carbon credits market.

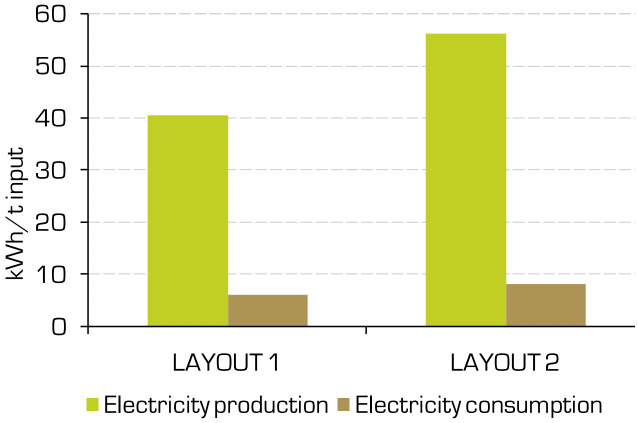

Figure 6.2.9. Energy balance in the management system of the treatment plant of Purines Almazan S.L.

III. ECONOMY

The investment of the plant was over 3.6 million Euros (2011).

The economic balance of anaerobic digestion facilities is significantly affected by the feed-in-tariff and subsidy policies established by the national government for biogas-based electricity production, which makes its economic viability vulnerable to modifications in the regulation of this sector that has changed considerably in the last years in Spain.

The monetary value of the organic fertiliser produced would be around 6 €/t, according to its content in N, P and K and the average price of the fertilising units in the European mineral fertiliser market (Eurostat, 2015). Considering an average annual production of digestate of around 37,000 t/year, this would generate an annual income of €222,000. Nevertheless, local agricultural practices rule the demand and market price of these products. In addition, other factor have to be taken into account such as the added value of the organic matter content in digestate, the loss of value due to its unbalanced nutrient composition (according to crop requirements) or its handling difficulties. The loss of efficiency due to the lack of readiness of organic forms of nitrogen is diminished because of the mineralisation that takes place during anaerobic digestion.

IV. AGRONOMY

In Castilla y León, where the treatment plant is located, the growth of rainfed winter crops prevails such as wheat or barley with an average yield of 2,0 t/ha (Anuario de estadística agraria, 2014). The average nutrient requirements of this kind of crops are estimated at 28 kg of N/t of crop, 13 kg of P_2O_5/t crop and 20 kg of K_2O/t crop (Dominguez, 1997). Thus, when comparing nutrient requirements with the NPK digestate content, 3.5:0.7:2.0 in layout 1 and 3.6:0.6:1.6 in layout 2, it can be concluded that it represents a well-balanced fertiliser, bearing in mind that the nitrogen fraction readily available for plants is approximately 81 and 85% of the total nitrogen content (ratio TAN/TKN) respectively (Figure 6.2.10). If doses are calculated in terms of nitrogen crop demand, 9.5 t digestate/t crop should be applied, and potassium necessities would be fully covered. Only P contribution may be below crop requirements. Nevertheless, other factors such as soil characteristics should be assessed in every case in order to determine whether additional mineral fertilising is required or not. The annual digestate generated in this facility enables covering the fertilising requirements of around 2,000 has.

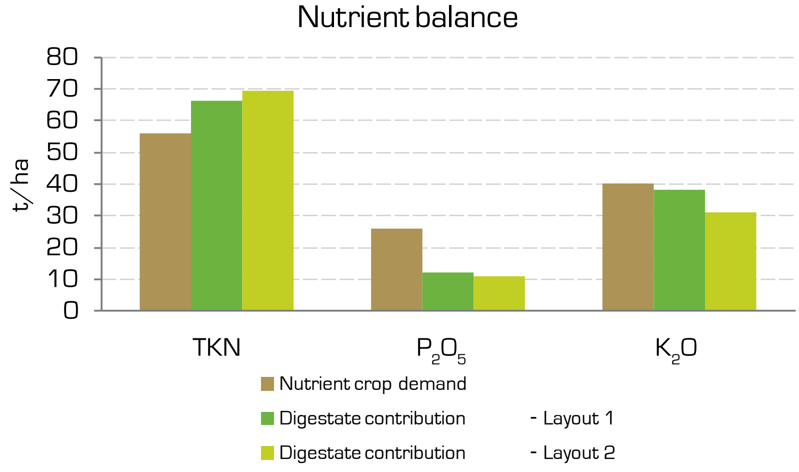

Figure 6.2.10. Nutrient balance based on the readily available nitrogen form of the digestate (ammoniacal nitrogen (TAN)) and the nutrient demand of the crops fertilised in the system.

The process increased TAN by 5.3% in the case of layout 1 and 21.6% in layout 2. Values of P, K and metals are not affected by the digestion process.

V. SOCIAL IMPACT

The facility is located far from the nearest town and at least 1 km from the nearest major road. Therefore, there is no odour nuisance in urban areas.

All the digesters are covered with green metal sheets which minimise the visual impact of the buildings.

In the plant, one plant manager and three assistants work at full time. Additionally, two coordinators work part-time.

VI. BIOSECURITY

E. coli values were significantly reduced after the digestion process, and no *salmonella* was detected in any case in the digestate.

4. CONCLUSIONS

The anaerobic digestion system evaluated let achieve, among others, two environmental benefits related to gas emissions, it is a source of renewable energy recovering 586,056 of biogas/year when 38,254 t of pig slurry were managed in a centralised system, and 944,256 m^3 of biogas/year when pig slurry and pig carcasses were mixed and fed together into anaerobic digestion. This is equivalent to 6,243 and 9,729 t CO_2 eq./year respectively. In addition, it saves the greenhouse gas emissions generated in the manure management, mainly due to the reduction of CH_4 emissions in the storage.

The use of covered lagoons, prevent almost completely the emissions during the digestate storage, although its further effect in the land spreading step should be evaluated. NH_3 emissions, that take place in digestate storage and land spreading, are responsible for the acidification caused in the management system.

When pig carcasses are added to the process, in a ratio 1:18 in terms of mass, the biogas production increased from 15.76 to 23.29 m^3 biogas/t feedstock while the quality of the biogas generated in the process barely decreased.

The efficiency of the process was improved when the rendering plant was started up, although it could be further optimised increasing the installed power of the CHP unit. Nevertheless, the economic viability of the plant is highly vulnerable to changes in energy regulation and subsidises of feed-in-tariff.

The macronutrients concentration remained constant throughout the processing line. Therefore, the farmland required was the same as initially in both configurations so as to manage the digestate properly as organic fertiliser.

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6.3. CASE STUDY 3: MANAGEMENT OF SLURRY IN THE FOULUM BIOGAS PLANT OF THE AARHUS UNIVERSITY IN TJELE (JUTLAND, DENMARK)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

The treatment plant is situated at Aarhus University Foulum, Tjele (Jutland, Denmark). The site is for agricultural research and produces daily approximately 65 tons of liquid manure (Figures 6.3.1 and 6.3.2). The manure source is approximately equal (in terms of mass and volume) from pigs and dairy cattle. There are both breeding and fattening pigs on site although due to the experimental nature of the facility the numbers can vary over time. There is also a manure input from chickens and mink although the quantity is extremely small in comparison to the pigs and cattle.

Upon opening the biogas plant operated on an input of *ca.* 65 tons of liquid manure each day that was supplemented with *ca.* 10 tons of maize and/or grass silage and 1-2 tons of glycerol from the German biodiesel industry and oily fish waste from Norway. However, the non-manure inputs were not providing good economy so at the start of the MANEV monitoring period they were substituted for deep litter manures, grasses, vegetable wastes and straws.

Prior to 2007, the manure management system consisted of three covered storage containers of 2,500 m^3 operating in series then to final storage in open lagoons with natural crust covers and application of this manure as required to the associated fields. The field's total *ca.* 500 ha of which around 200 ha are used for crop or hay production. The manure storage facility is located 1-2 km from the animal buildings.

In 2007 a biogas plant was constructed adjacent to the manure storage facility. This was done partly for treatment of the university manure in a way that was sensitive towards emissions of greenhouse gasses (GHGs) and providing energy in the form of biogas, and partly because the plant is a testing facility for new equipment, methods and feedstocks. The site has around 700 staff and considerable laboratory and animal facilities, which mean large quantities of heat are required in winter and hot water required all year round.


Figure 6.3.1. The AU Foulum facility. The central red buildings are offices whereas most of the surrounding grey buildings are for animals or equipment storage.


Figure 6.3.2. The main reactor with the new solids loading belt/screw system.

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

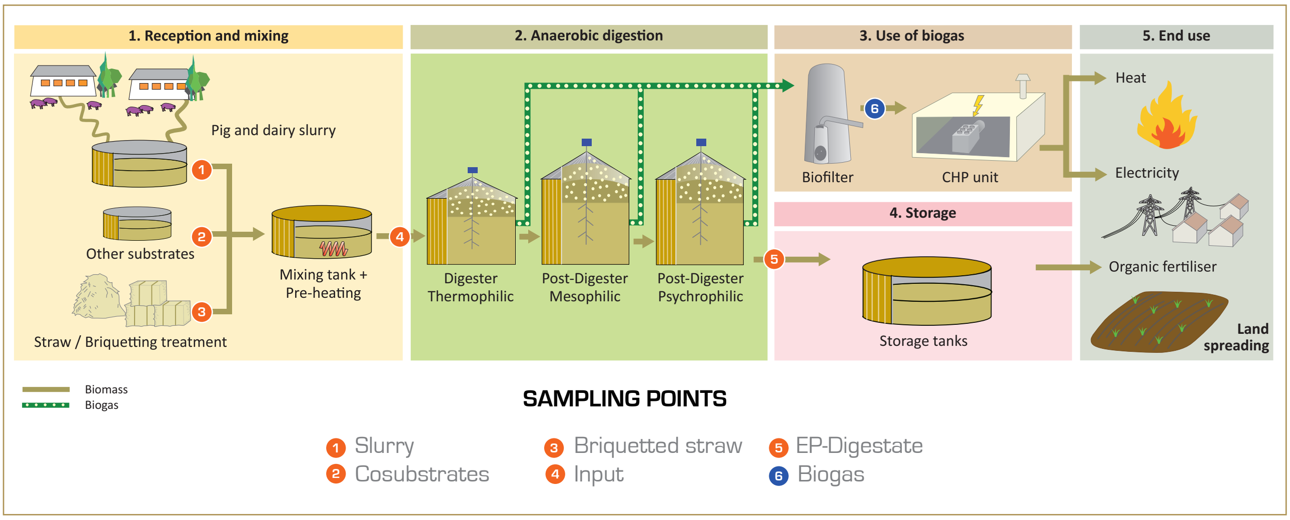

Figure 6.3.3. Scheme of the management system in Foulum (Tjele, Denmark).

Table 6.3.1. Main data of the treatment plant.

Input:	
- Dairy cattle slurry (t/year)	10,972
- Fattening pig slurry (t/year)	10,972
- Briquetted straw (t/year)	489
- Maize silage (t/year)	1,493
- Deep litter, grass, vegetable wastes (t/year)	4,645
Hydraulic retention time (days):	
- Digester (days)	14
- Post-digester 1 (days)	28
- Post-digester 2 (days)	28
Temperature of anaerobic digestion (ºC)	52
CHP unit power (kWe)	650
End products:	
- Digestate (t/year)	24,000
- Electricity (MWh/year)	2,774
- Heat (MWh/year)	4,882

The processing line (Figure 6.3.3 and Table 6.3.1) of the treatment plant is made up of the following steps:

1. Reception and mixing. The main tank stores manure with a volume of 600 m^3 and there are two smaller ones for other liquid substrates. There is a mixing tank that is weighed to ensure the correct masses of liquid inputs and silage (through a screw loading system) are added to the tank. When the correct mixture has been achieved it is heated and then pumped into the reactor, although a corresponding mass of digestate is pumped from the reactor to the post digesters prior to each feeding event. The usual feeding cycle operates nine times per day.

2. Anaerobic digestion. The primary reactor is of cylindrical steel construction with a working volume of 1,100 m^3, operating at 52°C with a typical hydraulic retention time of 14 days. After the main reactor the digestate is pumped to two post digesters operating in series, of 2,500 m^3 volume each constructed of concrete panels with a flexible roof. These post digesters have three functions: first they work as digesters to extract residual biogas not produced in the main reactor, second they are for gas storage for the biogas produced in the entire process, and lastly they allow the digestate to cool to ambient temperature to reduce emissions in the final storage lagoons.

3. Use of biogas. The biogas produced is utilised in a 650kWe combined heat and power unit (CHP unit), following biological H_2S removal.

4. Storage. In summer 2014 the final storage lagoons were replaced with concrete storage tanks with flexible covers, similar to the post digesters although there is no gas connection from these to the rest of the system.

5. End use. The digestate is applied as required to the associated fields for crop or hay production.

3. RESULTS OF THE ASSESSMENT

Table 6.3.2. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	29 sampling campaigns		Sampling frequency
			Average	S.D.	
TKN	kg/t	1. Fattening pig slurry	2.55	1.44	1 / month
		1. Dairy cattle manure	2.55	1.44	1 / month
		2. Maize silage	3.79	0.34	2 months
		2. Deep litter/grass...	7.02	0.82	1/ month
		3. Briquetted straw			
		5. EP-Digestate	2.57	0.49	1/month
Increase (+)/Decrease (-)[1] (%)			-23.0%		
TAN	kg/t	1. Fattening pig slurry	1.24	0.11	1 / month
		1. Dairy cattle manure	1.24	0.11	1 / month
		2. Maize silage	0.71	0.14	2 months
		2. Deep litter/grass...	0.60	0.22	2 months
		3. Briquetted straw			
		5. EP-Digestate	1.92	0.24	1 / month
Increase (+)/Decrease (-)[1] (%)			+59.0%		
DM	kg/t	1. Fattening pig slurry	38.48	12.10	1 / week
		1. Dairy cattle manure	38.48	12.10	1 / week
		2. Maize silage	304.81	28.40	1 / month
		2. Deep litter/grass...	451.48	55.36	1 / month
		3. Briquetted straw	880.90	15.80	2 months
		5. EP-Digestate	54.73	10.33	4 / month
Increase (+)/Decrease (-)[1] (%)			-45.8%		
VS	kg/t	1. Fattening pig slurry	30.97	10.2	1 / week
		1. Dairy cattle manure	30.97	10.2	1 / week
		2. Maize silage	282.23	15.56	1 / month
		2. Deep litter/grass...	409.23	58.06	1 / month
		3. Briquetted straw	841.6		2 months
		5. EP-Digestate	50.16	8.44	
Increase (+)/Decrease (-)[1] (%)			-52.7%		
COD	kg/t	1. Fattening pig slurry	22.00	10.42	2 months
		1. Dairy cattle manure	22.00	10.42	2 months
		2. Maize silage			
		2. Deep litter/grass...	580.00	24.00	2 months
		3. Briquetted straw			
		5. EP-Digestate	42.50	20.00	2 months
Increase (+)/Decrease (-)[1] (%)			-51.6%		

Parameter	Units	Sampling point	29 sampling campaigns		Sampling frequency
			Average	S.D.	
P	kg/t	1. Fattening pig slurry	0.34	0.16	2 / year
		1. Dairy cattle manure	0.34	0.16	2 / year
		2. Maize silage	0.71	0.17	2 / year
		2. Deep litter/grass...	1.17	0.14	2 / year
		3. Briquetted straw			
		5. EP-Digestate	0.62	0.10	2 / year
Increase (+)/Decrease (-)[1] (%)			+6.3%		
Cu	kg/t	1. Fattening pig slurry	0.003	0.001	2 / year
		1. Dairy cattle manure	0.003	0.001	2 / year
		2. Maize silage			
		2. Deep litter/grass...	0.003	0.001	2 / year
		3. Briquetted straw			2 / year
		5. EP-Digestate	0.003	0.001	2 / year
Increase (+)/Decrease (-)[1] (%)			+11.4%		
Zn	kg/t	1. Fattening pig slurry	0.014	0.004	2 / year
		1. Dairy cattle manure	0.014	0.004	2 / year
		2. Maize silage			
		2. Deep litter/grass...	0.003	0.001	2 / year
		3. Briquetted straw			
		5. EP-Digestate	0.015	0.002	2 / year
Increase (+)/Decrease (-)[1] (%)			+24.1		
EC	mS/cm	1. Fattening pig slurry	12.58	1.45	1 / week
		1. Dairy cattle manure	12.58	1.45	1 / week
		2. Maize silage			
		2. Deep litter/grass...	16.06	10.51	1 / week
		3. Briquetted straw			
		5. EP-Digestate	17.95	1.59	1 / week
Increase (+)/Decrease (-)[1] (%)			+9.4%		
pH	pH u.	1. Fattening pig slurry	7.14	0.23	1 / week
		1. Dairy cattle manure	7.14	0.23	1 / week
		2. Maize silage			
		2. Deep litter/grass...	5.70	0.74	1 / week
		3. Briquetted straw			
		5. EP-Digestate	7.60	0.10	1 / week
Increase (+)/Decrease (-)[1] (%)			+10.6%		

[1] The increase/decrease percentages have been calculated bearing in mind the quantity and composition of the input mixture that enters de plant (4. Input) and the quantity and composition of the digestate obtained after the anaerobic digestion unit (5. EP-Digestate).

The main evaluation results for the treatment system assessed in the plant are shown in Table 6.3.3.

Table 6.3,3. Summary of the monitoring and evaluation results.

			Foulum biogas plant
Environment	Global Warming Potential	kg CO$_{2\ eq}$/t	N/A
	Acidification Potential	kg SO$_{2\ eq}$/t	N/A
Energy	Electrical energy balance	kWh/t	80.92
	Thermal energy balance	kWh/t	139.17
	Fuel	kWh/t	N/A
Economy	Income	€/t	22.49
	Expenses[1]	€/t	1.64
Agronomy[2]	Nitrogen balance	kg N/ha	-55.0
	Phosphorus balance	kg P/ha	-37.7
	Potassium balance	kg K/ha	N/A
Social impact	Job demand – Operator[3]	h/y	200
	Job demand – Specialised technician[4]	h/y	1,900
	Odor	1-4	1
	Noise	Yes/No	Yes
Biosecurity	Pathogens reduction	Yes/No	Yes

[1] Expenses due to electrical consumption only.

[2] The agronomic balance is based on the crop requirements and the organic fertiliser applied. The figures have been obtained taking into account the digestate production of the biogas plant (quantity and composition), an application restriction of 140 kg N/ha and a land field surface of 440 ha of wheat and maize.

[3] 2 assistants full time

[4] 1 manager

I. ENVIRONMENT

The plant produces approximately 700,000 m^3 of methane per year, which has a global warming potential of 11,480 tons CO$_2$ equivalents per year. Other emissions such as ammonia or GHGs to the air or nitrate to the water are very limited due to the (now) enclosed design of the entire system from on-site storage of substrates through to products.

II. ENERGY

A change of inputs at the start of the MANEV monitoring period made a considerable difference to the plant performance; the glycerol and fish waste previously used were both easily digestible substrates with a high methane yield, whereas the new substrates, grasses, straws and deep litters were much slower to degrade with a lower yield. Thus, the plant biogas production fell from *ca.* 5,500 m^3 per day to 4,000-5,000 m^3 per day (Table 6.3.4), with a reduction in CH$_4$ concentration from around 60% to 52% due to substrate differences. However, the new substrates were much cheaper (in some cases free apart from handling) so the economy of the plant was better.

The plant has a gross annual energy value of 7,600 MWh based on the gas production (and therefore the value that is used for calculation of economy). The recorded annual energy production of the plant as it stands with CHP is 2,500 MWh of electricity and 4,000 MWh of heat, a total energy efficiency of around 92%. The annual electrical and heat requirements of the plant are *ca.* 825 MWh and 1,000 MWh, respectively, although this includes consumption of both energy forms in the research buildings.

Table 6.3.4 Main energy data of the treatment plant.

Average biogas production (m^3/day)	4,124
Average biogas production (m^3 biogas/t input)	53.78
Average biogas composition (% CH$_4$)	52
Electrical energy average production (kWh/m^3 biogas)	1.83
Electrical energy average production (kWh/t input)	99
Thermal energy average production (kWh/m^3 biogas)	3.25
Thermal energy average production (kWh/t input)	174
Average electrical energy consumption in the facilities (kWh/t input)	27.41
Thermal energy average consumption in the facilities (kWh/t input)	35.29

III. ECONOMY

The plant annual production of 700,000 m^3 of methane has a Danish market value of €421,344 at the current rate of €15.4/Gj. There is no set monetary value of the fertiliser produced, although it can be estimated that the digestate is equivalent to approximately 50,000 kg N and 5,500 kg P per year.

IV. AGRONOMY

The process increased TAN by 6% on average during the monitoring period, thus improving the fertiliser value of the digestate. The input value for TKN and TAN includes the addition of co-substrates. Of course, a portion of the carbon is lost to biogas although it is argued that this should not change soil carbon levels as this carbon would have been mineralised in the soil quite rapidly if the material had been spread on the land without digestion beforehand. Values of total P, K and metals are not affected by the digestion process.

V. SOCIAL IMPACT

The biogas plant is visually obvious in the landscape but is not particularly close to many dwellings and is at least 1.5 km from the major road from which it is visible. Odour measurements were made following recommended procedures but no odour was detected at the plant boundaries and noise is not excessive.

The plant has a minor job creation role, although exact numbers are not possible to give due to the fact that the plant is also a research facility and therefore the full time plant manager and one full time assistant plus several other assistants (as required) are perhaps not representative.

VI.BIOSECURITY

The biogas plant had measured values of *E. coli* in the final product that were only 2% of that found in the input, with no *Salmonella* detected.

4. CONCLUSIONS

The biogas plant at AU Foulum is a successful method of producing income from manure, even though the Danish incentives for biogas are not particularly high. Despite this, there is a drive towards increased AD systems for manure treatment in the country. The plant shows that it is possible to make biogas economically (when incentives are applied) using only agricultural wastes such as manures and straws and without purposely grown energy crops. The plant saves 11,480 tons of CO_2 equivalents in terms of the methane produced, compared to a situation where the methane would form in storage and be lost to the environment.

The ability of the site to utilise a great deal of the heat produced by CHP helps the energy and economic balance and in many areas of Denmark district heat systems exist that could be used with biogas plants. However, the incentive of €15.4 / Gj of gross energy is leading the industry towards natural gas grid injection. Grid injection has storage possibilities, which is useful in Denmark where there is considerable wind energy, often to the point of over production in the winter months.

6.4. CASE STUDY 4: COLLECTIVE TREATMENT PLANT MANAGED BY AGROENERGIE BERGAMASCHE S.C.A. IN LOMBARDY (ITALY)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

The studied management system is a collective treatment plant with an anaerobic digestion phase for energy production and a nitrogen removal phase (Figure 6.4.1). It is located in Bergamo province (Martinengo, Lombardy, Italy) in an intensive livestock area where there is a high surplus of nitrogen and has been designated as vulnerable zone.

Originally, the collective treatment plant (site 1) involved 12 livestock units belonging to 10 farms (pigs, cows and poultry), located 0.5 to 6 km far away from the plant, for a total daily production of around 240 m^3 of manure. Starting from the autumn of 2013, the treatment plant has been expanded with a new second treatment plant (site 2). The two sites in full operation are processing almost 685 m^3 of manure per day (295 and 390 m^3, in site 1 and site 2, respectively). Most of the incoming product consists in slurries, although some co-substrates are also used, while the liquid effluent treated is the relevant product transported back to the associated farms. The two sites at the moment are collecting manure from 24 livestock units (Table 6.4.1). The raw manure is transported by trucks and slurry tankers with the exception of the nearby farm, connected by mean of a pipeline.

At first, manure is processed in an anaerobic digestion reactor for the production of energy. The digested effluent is then separated, in order to reduce load and to separate most of the phosphorus. The solid fraction is stored, while the liquid fraction is treated for biological nitrogen removal. This process is carried out in two Sequencing Batch Reactors (SBRs) on both sites. The liquid effluent is finally stored in storage tanks. Then, it is transported to the farms by trucks slurry tankers or pipelines for storage before being spread as valuable organic fertilizer at farm-level.

Figure 6.4.1. Aerial view of the collective treatment plant in Martinengo (Lombardy, Italy). Site 1 on the left and site 2 on the right.

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

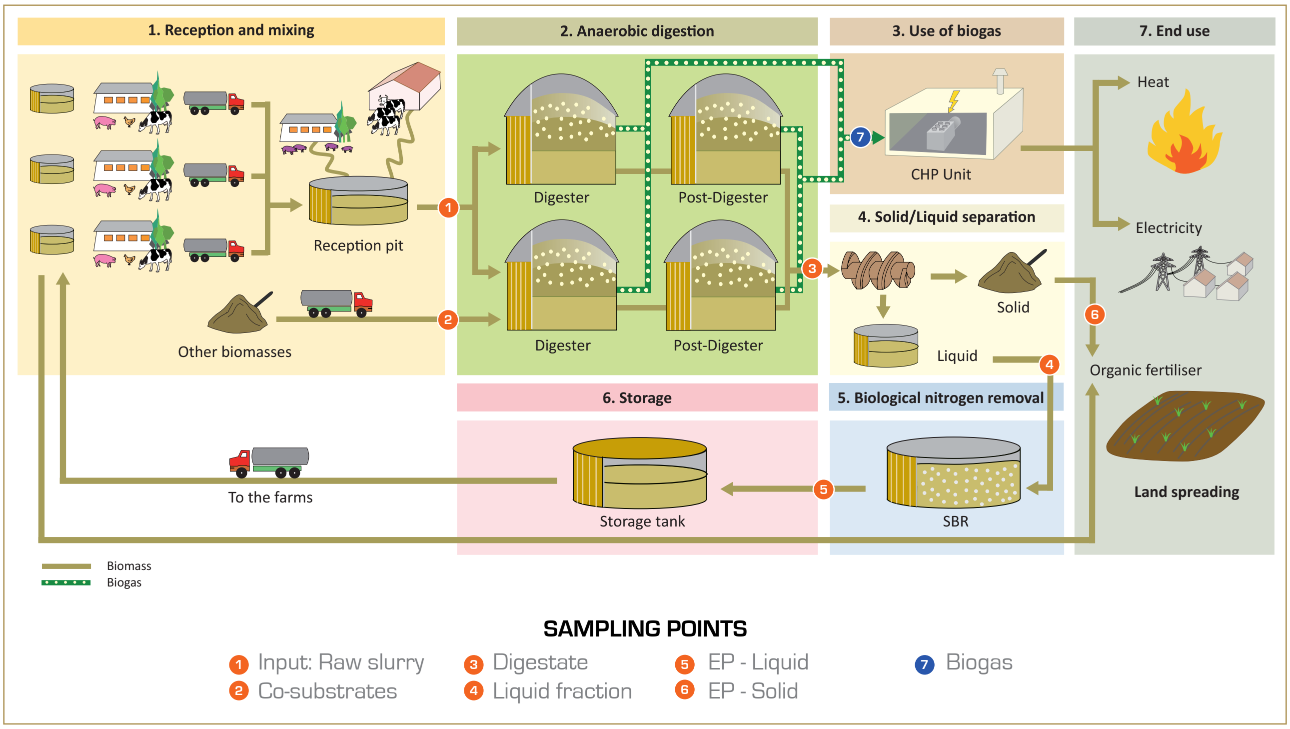


Figure 6.4.2. Scheme of the management system in Martinengo (Lombardy, Italy). The same scheme applies to both sites.

Table 6.4.1. Main data of the collective treatment plant.

Raw Manure	Cattle slurry (93.5%), pig slurry (4.4%) and laying hen manure (2.1%)	
Co-substrates	Corn silage, flour cereals and derivatives and molasses	
	SITE 1	**SITE 1 + SITE 2**
Livestock units	12	24
Raw manure treated (m^3/day)	295	685
CHP unit power (kWe)	999	1,998
Electricity production (MWh/year)	7,400	13,990
Land surface (ha)	452	927
End products	Liquid and solid fraction	

The processing line (Figure 6.4.2) of the collective treatment plant is made up of the following steps:

1. Reception and mixing. The manure produced by the different farms is collected in a 2 continuously mixed pre storage tanks of 885 and 570 m^3. The raw slurry is mixed with the co-substrates and solid and poultry manure before the anaerobic digestion unit (site 2) or in the digester (site 1).

2. Anaerobic digestion. The collected manure is firstly processed in an anaerobic digestion phase for the production of energy. This step is carried out under mesophilic conditions (38-40 °C) in two digesters and two post-digester in line on both sites. The total volume of the reactors (digesters) is 10,930 m^3, while the post-digesters have a capacity of 12,740 m^3. The anaerobically digested slurry produced in two digesters is then conveyed to the two post-digester on both sites.

3. Use of biogas. The biogas produced in each reactor is collected, treated for sulphur (S) removal and then conveyed to the two combined heat and power (CHP) units for energy production. A CHP engines of 999 kW of electric power each, produces electricity that supplies the necessities of the plant and the exceeding is sold to the general network. The heat is used to raise the temperature of the feeding to the digester and post-digester.

4. Solid/Liquid separation. The digested slurry out coming from post-digester is then separated with two decanter centrifuges for the production of a liquid and solid fraction. The solid fraction is stored and partly sold to horticultural farms placed nearby the treatment plant, while the liquid fraction is further treated.

5. Biological nitrogen removal. The liquid fraction is treated through a nitrification-denitrification step for nitrogen removal. This treatment is carried out into 2 Sequencing Batch Reactors (SBR) for each site working in parallel. In each SBR, four phases occur: Fill and draw phase (liquid fraction are pumped into the reactor and treated slurry are conveyed to storages); Mixing phase (denitrification); Aerobic phase (nitrification); Sedimentation phase.

6. Storage. The treated effluent is then pumped to the final storage, consisting of 3 covered storage tanks of 12,620 m^3 of total capacity.

7. End use. Here, the trucks and slurry tankers collect the effluent and return it to farms, where it is stored before being spread as valuable organic fertilizer at farm-level.

3. RESULTS OF THE ASSESSMENT

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol (CEMP) developed in the LIFE+ MANEV project (Chapter 3) and covering five years of steady operation of the treatment plant. The information and data were collected in three ways:

- Daily records: manual and automatic registration of the main parameters of the processing line and of each processing units at key points: daily flows raw slurry, biomasses and solid manure incoming, and end-product outcoming), temperatures, pH, dissolved oxygen, electric production and consumption, biogas quality and production.

- Monthly sampling of manure: representative monthly samples of manure (6 different points) of each processing units were taken. Analysis (TKN, TAN, P, K, DM, VS, COD, pH, and EC), has been performed by internal and external labs and by field equipment.

- Periodically monitoring data: data of the farms connected to the treatment plant with the relevant livestock and field data, other analysis pathogen agents (*E. coli* and Salmonella) and heavy metals (Cu and Zn).

Table 6.4.2 shows the average removal efficiencies mass balance of the liquid fraction at the exit of the step 5 (biological nitrogen removal) compared with input (raw slurry, solid and poultry manure and cosubstrate), during the monitoring period, as well as the chemical characteristics (average and S.D.) of raw manure (1. INPUT), treated effluent (5. EP-Liquid) and solid fraction (6. EP-solid).

Table 6.4.2. Main analytical data and performance of the treatment system (Originally - site 1 and Expanded site 1+2) from 2011 to 2015.

			604 samples				
Parameter	**Units**	**Sampling point**	**Originally (SITE 1)**		**Expanded (SITE 1+2)**		**Sampling frequency**
			Average	**S. D.**	**Average**	**S. D.**	
TKN	kg/t	1. INPUT	3.73	0.69	3.77	0.74	1 sample/month
		5. EP-Liquid	2.29	0.60	2.49	0.68	1 sample/month
		6. EP-Solid	6.58	0.43	6.73	0.45	1 sample/month
Removal efficiency (%)			**46.6%**		**42.2%**		
TAN	kg/t	1. INPUT	1.92	0.54	1.86	0.47	1 sample/month
		5. EP-Liquid	1.17	0.65	1.31	0.62	1 sample/month
		6. EP-Solid	2.03	0.53	2.02	0.51	1 sample/month
Removal efficiency (%)			**47.0%**		**39.0%**		

Parameter	Units	Sampling point	604 samples				Sampling frequency
			Originally (SITE 1)		Expanded (SITE 1+2)		
			Average	S. D.	Average	S. D.	
DM	kg/t	1. INPUT	76.1	17.2	80.3	18.9	1 sample/month
		5. EP-Liquid	27.8	5.5	26.4	4.6	1 sample/month
		6. EP-Solid	222.9	17.3	223.2	15.1	1 sample/month
Removal efficiency (%)			**68.2%**		**71.4%**		
VS	kg/t	1. INPUT	62.4	13.2	65.0	15.0	1 sample/month
		5. EP-Liquid	17.8	6.4	15.9	5.2	1 sample/month
		6. EP-Solid	183.4	23.3	180.3	20.4	1 sample/month
Removal efficiency (%)			**75.3%**		**78.8%**		
COD	kg/t	1. INPUT	65.3	38.2	76.3	39.0	every 3 months
		5. EP-Liquid	21.8	8.9	20.9	10.0	every 3 months
		6. EP-Solid	217.0	24.0	226.0	23.0	every 3 months
Removal efficiency (%)			**71.0%**		**76.1%**		
TP	kg/t	1. INPUT	1.02	0.45	1.03	0.25	1 sample/month
		5. EP-Liquid	0.45	0.19	0.39	0.04	1 sample/month
		6. EP-Solid	2.90	0.31	3.05	0.42	1 sample/month
Removal efficiency (%)			**62.0%**		**66.9%**		
TK	kg/t	1. INPUT	2.47	0.73	2.58	0.65	1 sample/month
		5. EP-Liquid	2.20	0.13	2.25	0.22	1 sample/month
		6. EP-Solid	2.85	0.63	2.51	0.19	1 sample/month
Removal efficiency (%)			**22.4%**		**24.1%**		
Cu	kg/t	1. INPUT	0.005	0.003	0.006	0.001	every 3 months
		5. EP-Liquid	0.004	0.000	0.004	0.001	every 3 months
		6. EP-Solid	0.010	0.001	0.013	0.005	every 3 months
Removal efficiency (%)			**34.4%**		**42.6%**		
Zn	kg/t	1. INPUT	0.023	0.012	0.023	0.002	every 3 months
		5. EP-Liquid	0.013	0.001	0.012	0.002	every 3 months
		6. EP-Solid	0.038	0.005	0.040	0.005	every 3 months
Removal efficiency (%)			**51.9%**		**52.9%**		
EC	mS/cm	1. INPUT	13.6	1.9	13.5	1.6	1 sample/month
		5. EP-Liquid	19.5	1.3	19.3	1.5	1 sample/month
		6. EP-Solid	0.69	1.14	1.02	1.27	1 sample/month
Removal efficiency (%)			**-43.8%**		**-42.9%**		
pH	pH u.	1. INPUT	7.2	0.2	7.0	0.3	1 sample/month
		5. EP-Liquid	8.4	0.2	8.5	0.2	1 sample/month
		6. EP-Solid	8.9	0.3	8.9	0.3	1 sample/month
Removal efficiency (%)			**-16.6%**		**-20.8%**		

The average nitrogen concentration (raw slurry, solid and poultry manure and cosubstrate) on the treatment system during monitoring period was 3.73 and 3.77 kg N/t per day (Table 6.4.2) for originally (site 1) and expanded (site 1+2), respectively. The dry matter (DM) content decreased from 8.0% to 2.6% on the liquid fraction, due to anaerobic digestion phase and solid-liquid separation by centrifuge. Considering the original treatment plant (site 1), the total nitrogen (TKN) and total ammoniacal nitrogen (TAN) average removal efficiency of the monitoring period, were 46.6% and 47%, respectively. In the expanded treatment plant comparing to the originally, the TKN and TAN average removal efficiencies decrease to 42.2% and 39.0%, respectively.

Table 6.4.3. Summary of the monitoring and evaluation results of the treatment system (Originally - site 1 and Expanded site 1+2).

			Originally (SITE1)	Expanded (SITE 1+2)	Without treatment system
Environment[1]	Global Warming Potential	kg CO$_2$ eq. /t	20.79	20.86	74.30
	Acidification Potential	kg SO$_2$ eq./t	0.90	0.96	1.83
Energy[2]	Electrical energy balance	kWh/t	-	53.73	0
	Thermal energy balance	kWh/t	-	Surplus	0
	Fuel	kWh/t	-	-0.99	0
€ Economy[3]	Income	€/t	-	15.78	0
	Expenses	€/t	-	14.40	0
Agronomy	Nitrogen balance	kg N/ha	189	242	355
	Phosphorus balance	kg P/ha	24	32	102
	Potassium balance	kg K/ha	192	190	221
Social impact[2]	Job demand – Operator [3]	h/y	6,800	11,900	0
	Job demand – Specialised technician	h/y	425	850	0
	Odour	(1-4)	1	1	-
	Noise	Yes/No	NO	NO	-
	Pathogens reduction	E. coli	99.6%	99.8%	0%
Biosecurity	Pathogens reduction	Salmonella	Absence/Presence	Absence/Presence	Presence

[1] Values are referred to the whole management system from farm storage to land application.

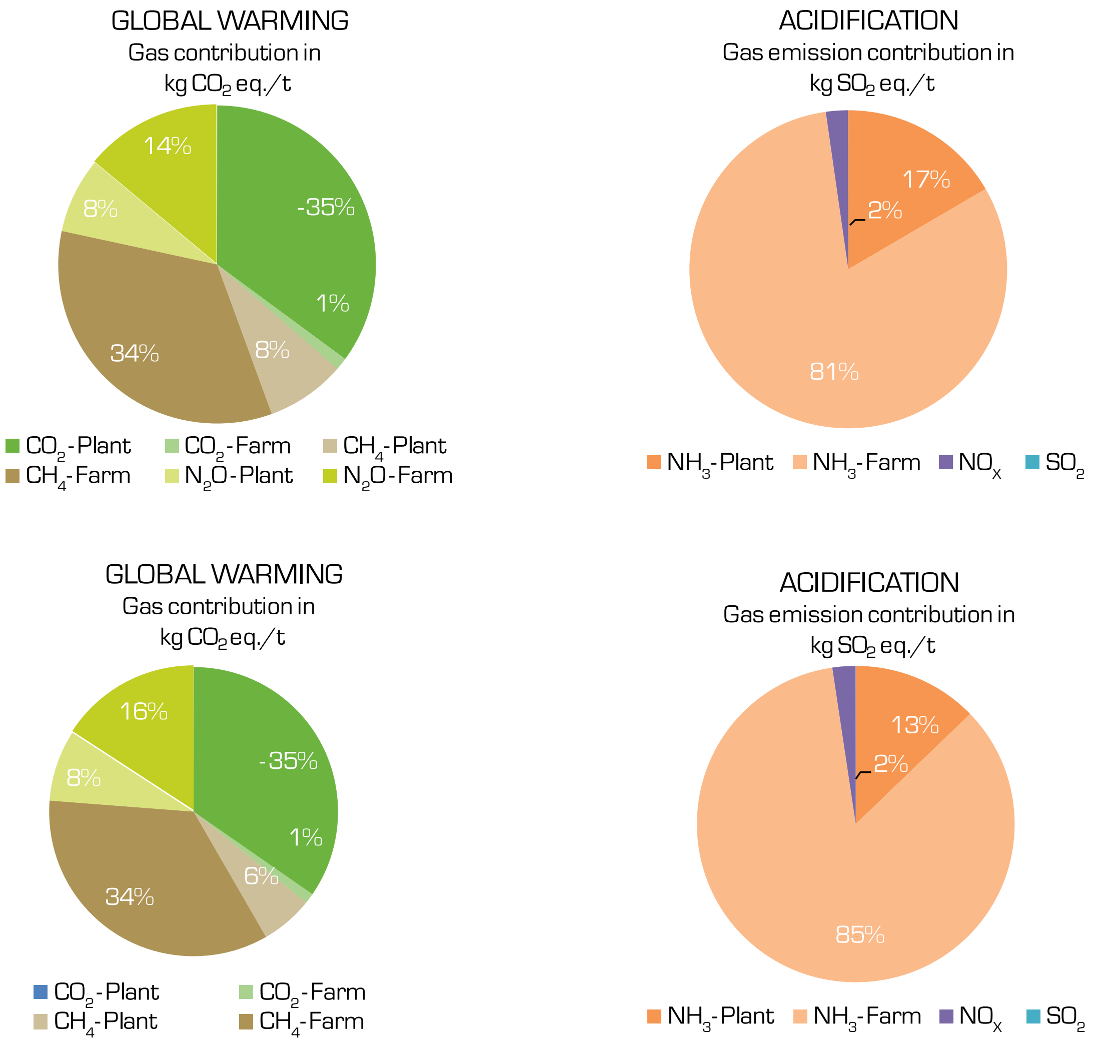
[2] Values are referred to steps 2, 3, 4 and 5.

[3] Values are referred to the processing line of the treatment plant including plant storage and transport farm/plant.

I. ENVIRONMENT

Emissions. Contribution of the treatment plant emissions to the Global Warming Potential (GWP) and to the Acidification Potential (AP) was calculated according to the CEMP and is reported in Table 6.4.3 and Figure 6.4.3. Total emissions with the treatment plant were 20.79 and 20.86 kg CO$_2$ eq. per tons of treated manure for originally (site 1) and expanded (site 1+2), respectively. The AP of the treatment system resulted lower than GWP, with values between 0.90 and 0.96 kg SO$_2$ eq. per tons of treated manure. Moreover, the GWP average reduction between the management systems with treatment plant and without treatment plant resulted of 70%, whereas the AP reduction resulted almost of 50%.

The GWP reduction obtained by treatment system is greatly due to the renewable energy production (-35%) by anaerobic digestion and also due to the lower methane emissions (6% from treatment plant and 34% from farm storage) and low N content of treated effluent in the final storage and land application compared to management system without treatment plant. Instead the AP reduction was mainly due to the ammonia emissions (Figure 6.4.3) from treatment plant (13%) and during final storage and land application (85%).


GLOBAL WARMING
Gas contribution in kg CO_2 eq./t

ACIDIFICATION
Gas emission contribution in kg SO_2 eq./t

GLOBAL WARMING
Gas contribution in kg CO_2 eq./t

ACIDIFICATION
Gas emission contribution in kg SO_2 eq./t

Figure 6.4.3. Gas contribution of the treatment system emissions to the Global Warming Potential and to the Acidification Potential. Originally treatment system (site 1) on the left and Expanded on the right (site 1+2).

Water. According to agronomy balance, there is a nitrogen and phosphorus surplus. The calculations are referred to nitrogen content of the liquid and solid end-product during farm storage. Consequently, considering field efficiency about 50% of the nitrogen content to the field (during farm storage and land application) the surplus is negligible compared to crop demands.

Soil. Case study is located in a non-potentially salt affected area according to “Saline and Sodic Soils in European Union” map.

II. ENERGY

The average electricity produced by anaerobic digestion (AD) processing unit was 67.45 kWh/t treated (Table 6.4.3). Instead, the average consumption by treatment plant was 13.72 kWh/t treated (AD process unit 7.4kWh/t, phase separation 0.7 kWh/t and SBR N/DN 5.6 kWh/t). The energy balance was 52.74 kWh/t treated.

III. ECONOMY

The Incomes and Expenses are referred to the treatment plant (AD, separation, SBR N/DN and storage processing unit) including plant storage and transport costs (farm-plant). The running incomes (99% energy production and 1% solid end-product sold, Figure 6.4.4) are close to 15.8€/t treated effluent and the cost are 14.4€/t treated effluent, generating an economic profit of 1.4€/t. The expenses of the treatment system are mainly due to cosubstrates (27%), depreciation (19%), maintenance costs (18%) and transport costs (17%).

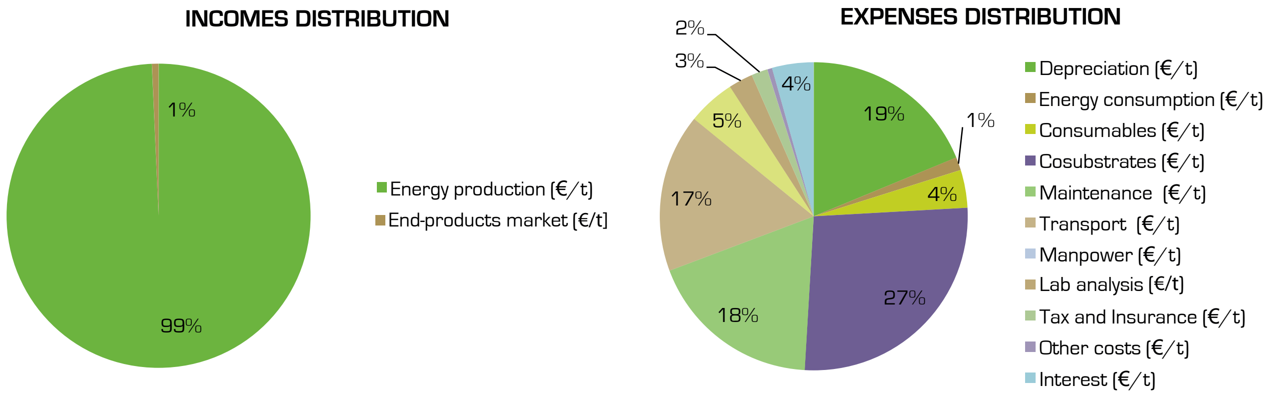


Figure 6.4.4. Incomes and expenses distribution of the expanded treatment system.

IV. AGRONOMY

The treatment system produces two end-products: the treated liquid fraction and the solid fraction. According to agronomy balance there is a nitrogen surplus equivalent to 189 and 242 kg N/ha for originally (site 1) and expanded (site 1+2), respectively (Table 6.4.3 and Figure 6.4.5). Anyway, as explained for water pollution, the nitrogen content in end-product is referred to pre-storage in the farms. During the storage phase and land application there are significant nitrogen losses. Thus, considering an efficiency of 50%, the nitrogen surplus is reduced almost to zero. There is a limited phosphorous surplus (24 and 32 kg P/ha originally and expanded treatment system, respectively), whereas a significant potassium surplus (192 and 190 kg K/ha).

V. SOCIAL IMPACT

The treatment plant has 7 operators (full time) and a part time specialised technician. The odour emissions are extreme tolerable compared to ambient air quality standards. Odour measurements highlighted very low odorous emissivity of SBRs also during aerobic phase (1, Table 6.4.3). The acoustic impact is conformed to limits specified by local regulations. The visual impact measured according to the CEMP has been categorised as low.

VI. BIOSECURITY

With the treatment plant has been obtained a 99% reduction of the pathogen agents (*E. coli*). Despite the process reduces the presence of pathogens in both end products; *Salmonella Spp.* is still often present, especially in the solid fraction (Table 6.4.3), in some case due to cross contamination.

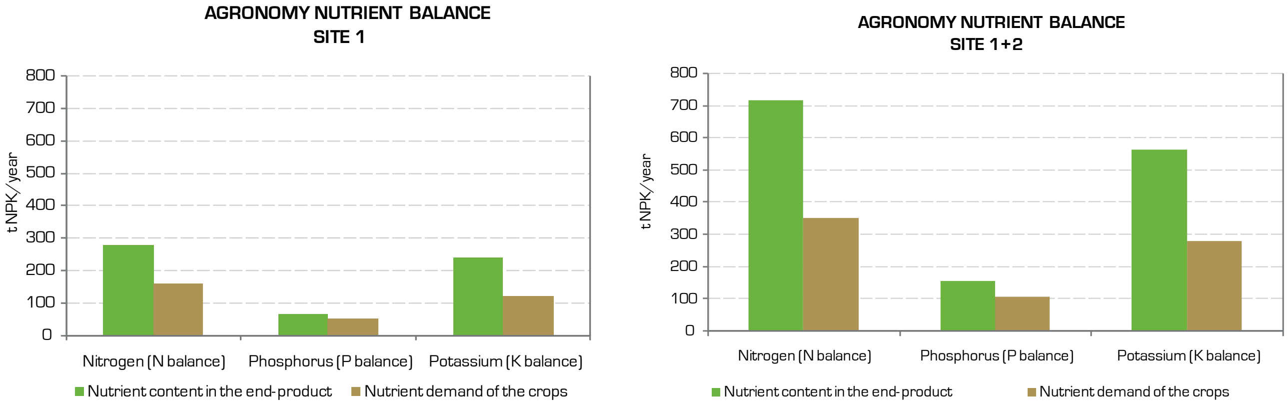


Figure 6.4.5. Nutrient balance of the Originally treatment system on the left (SITE 1) and Expanded on the right (SITE 1+2).

4. CONCLUSIONS

The economic profit, arising from the sale of electricity produced by CHP powered with biogas from anaerobic digestion, can compensate the cost of the SBR biological nitrogen removal treatment, making this solution sustainable from the environmental and economical point of view to reduce nitrogen surplus in intensive livestock area where there is a high surplus of nitrogen and has been designated as vulnerable zone. The case study used has highlighted how a collective treatment system might be effective in the reduction of emissions to air and potential nitrogen pollution of surface and ground waters, confirming the benefit in terms of acidification effect and eutrophication potential. Moreover the GWP reduction obtained demonstrates how these collective management systems might be sustainable despite the higher emissions due to transportation.

The nitrogen removal efficiency obtained during monitoring period seems quite good (average value 40%). In any case the total nitrogen removed is less than the foreseen values in the plant design. Higher nitrogen removal efficiencies (up to 60%) have been obtained for short periods. Furthermore the monitoring activity carried out during the project has supported the identification of the necessary interventions to improve the efficiency of the treatment.

Further benefits derive from the reduction of odors and the production of a stabilised effluent that can be used as fertiliser more efficiently.

6.5. CASE STUDY 5: CAMPO BÒ ANAEROBIC DIGESTION TREATMENT PLANT IN PARMA (EMILIA ROMAGNA, ITALY)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

Campo Bò is a closed cycle pig farm for the production of heavy pigs for Parma ham, with about 975 sows and 950 t of live weight. The main breeding is located in Basilicagoiano (Parma, Emilia Romagna region, Italy), where the sows and a part of the fattening pigs are placed for a total live weight of about 500 tons. The remaining fattening pigs are bred in other two sites. In the main breeding in Basilicagoiano, the daily average production of pig slurry is 86 m^3. The slurry treatment line (Figures 6.5.1 and 6.5.2) consists of an anaerobic digestion (AD) followed by an innovative aerobic biological treatment: SHARON – Single reactor High rate Ammonium Removal Over Nitrite - (Hellinga *et al.*, 1998).

The anaerobic digestion of raw pig slurry is carried in a mesophilic completely stirred reactor (CSTR). The biogas is used by a combined heat and power (CHP) unit -with an electric power of 85 kWe.

A NDN SHARON process (with nitrification stopped over nitrite) was carried in a SBR (Sequential Batch Reactor) pilot plant with part of the digestate. The pilot was designed in collaboration by CRPA and Veolia Water Technologies Italia – Services. The innovative SHARON process was tested because: the pig slurry digestate has low COD readily available content and the nitrification stopped over nitrite requires 40% COD less than the conventional N/DN, it saves electricity to supply oxygen and makes a lower production of sludge.

Digestate is stored in lagoons before being spread as valuable organic fertilizer in the surrounding area.

Figure 6.5.1. Anaerobic digestion, CSTR reactor and gasometer in Campo Bò (Emilia Romagna, Italy).

Figure 6.5.2. SHARON-SBR reactor in Campo Bò (Emilia Romagna, Italy).

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

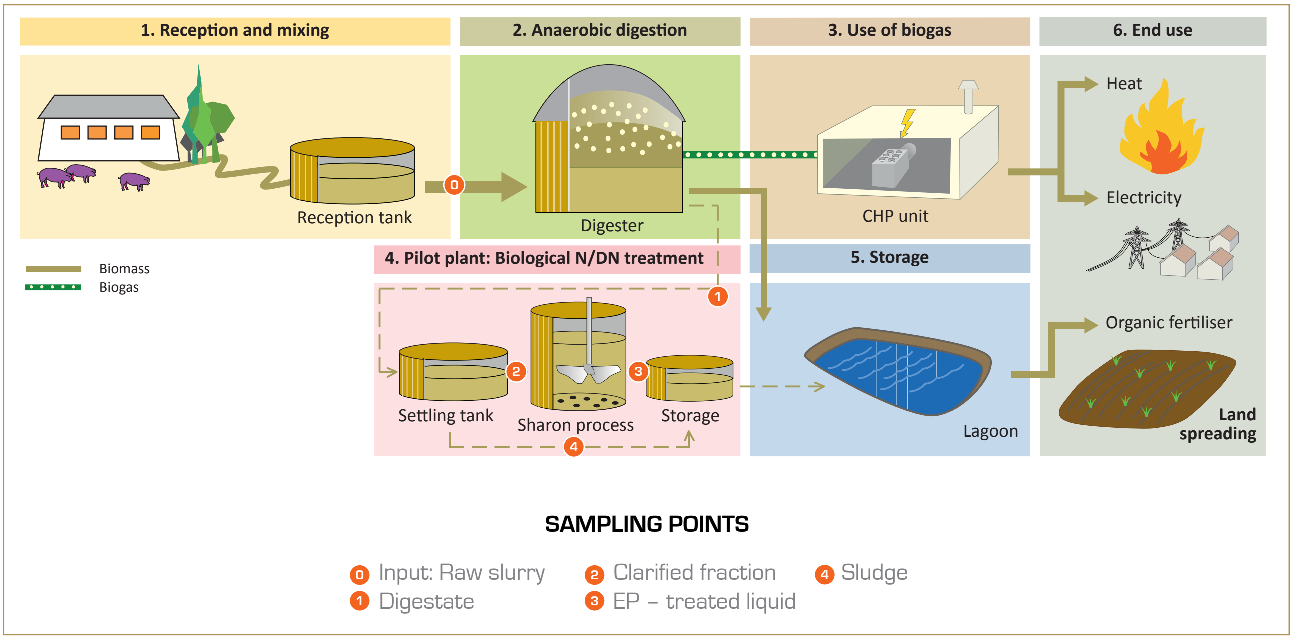

Figure 6.5.3. Scheme of the management system in Campo Bò (Emilia Romagna, Italy).

Table 6.5.1. Main data of the treatment plant.

Pig slurry (t/year)	31,400
Hydraulic retention time (AD) (days)	21
Temperature of anaerobic digestion (ºC)	40
CHP unit power (kWe)	85
End-products:	
- Digestate (t/year)	31,170
- Biogas (m^3/year)	211,700
- Heat (MWh/year)	690
- Electricity (MWh/year)	407

The processing line of the treatment (Figure 6.5.3 and Table 6.5.1) plant is made up of the following steps:

1. Reception and mixing. Pig slurry is daily discharged from the pits of the pig livestock sector and it is collected in an underground reception tank. In this tank the slurry is mixed and pumped to the anaerobic digestion unit.

2. Anaerobic digestion. The biogas is generated in a mesophilic completely stirred reactor (CSTR) with a volume of 1,780 m^3 and a hydraulic retention time (HRT) of 21 days.

3. Use of biogas. A CHP engine with an electric power of 85 kWe, powered by biogas, produces electricity that is sold to the grid. The thermal energy from CHP is used to heat the digester. There is a security torch for the burning of the biogas not used by CHP.

4. Pilot plant: Biological N/DN treatment. Part of the pig slurry digested enters in a pre-settling tank (with radius of 0.75 m and high 2.05 m), where the coarse and inert solid fraction are removed by natural gravity.

The biological treatment of digestate is performed by SHARON process in a sequential batch reactor (SBR).

The reactor is fully insulated and it has a process volume of about 3 m^3 and is able to handle 1,000 dm^3 digestate daily (only 1 m^3/day of the 86 m^3/day of pig slurry digestate is treated by SBR). The SBR is a cylindrical tank with a radius of 0.66 m with a useful hydraulic head of 2.23 m. All treatment steps are performed in the same reactor sequentially. The steps of the biological treatment are: loading of fresh digestate before each denitrification phase (with only mixing), nitrification phase (with aeration and mixing), sedimentation, sludge and effluent output. Denitrification and nitrification take place 4 times per cycle. Each anoxic denitrification phase lasts 35 minutes and the aerobic nitrification phase lasts 42 minutes. In one day, the system provided a succession of 4 cycles, lasting approximately 6 hours each.

5. Storage. The digestate is stored in tanks and lagoons. The total storage capacity is 17,807 m^3.

6. End use. The end-product of the treatment plant is spread on the arable land surrounding the farm as a valuable organic fertiliser.

3. RESULTS OF THE ASSESSMENT

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol developed in the LIFE+ MANEV project (Chapter 3) and covering at least one natural year of the facilities. The information and data required for the evaluation were collected from:

- Manual registration of slurry and digestate flows, AD temperatures, electric consumption and energy production.
- Automatic data logging of the main parameters of the biological treatment in the SBR N/DN, as temperatures, pH, O_2 concentration.
- Sampling sessions, along the processing line, of the raw pig slurry, raw digestate and treated digestate and their chemical analysis in CRPA laboratory.

Table 6.5.2 shows the mass balance and average removal efficiency, considering treated effluent from AD+SBR N/DN (sampling point 3) vs. raw pig slurry (sampling point 0), during the whole monitoring activity, as well as the chemical characteristics (average and S.D.) of raw pig slurry (0), digestate (1) and treated effluent (3).

Table 6.5.2. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	(0) 17 samples; (1) 24 samples; (3) 42 samples		Sampling frequency
			Average	S. D.	
TKN	kg/t	0. Pig slurry	2.99	0.35	1 sample/month
		1. EP - Digestate	2.50	0.27	2 sample/month
		3. EP – treated liquid	0.44	0.32	1 sample/week
AD Removal efficiency (0-1)			**16.2 %**		
SBR N/DN Removal efficiency (1-3)			**82.3 %**		
Total Removal efficiency (0-3)			**85.2 %**		
TAN	kg/t	0. Pig slurry	2.07	0.31	1 sample/month
		1. EP - Digestate	1.99	0.21	2 sample/month
		3. EP – treated liquid	0.35	0.29	1 sample/week
AD Removal efficiency (0-1)			**4.0 %**		
SBR N/DN Removal efficiency (1-3)			**82.5 %**		
Total Removal efficiency (0-3)			**83.2 %**		

Parameter	Units	Sampling point	(0) 17 samples; (1) 24 samples; (3) 42 samples		Sampling frequency
			Average	S. D.	
DM	kg/t	0. Pig slurry	24.1	6.5	1 sample/month
		1. EP - Digestate	14.7	2.1	2 sample/month
		3. EP – treated liquid	7.3	1.4	1 sample/week
AD Removal efficiency (0-1)			**39.0 %**		
SBR N/DN Removal efficiency (1-3)			**50.1 %**		
Total Removal efficiency (0-3)			**69.6 %**		
VS	kg/t	0. Pig slurry	15.20	4.1	1 sample/month
		1. EP - Digestate	6.90	1.2	2 sample/month
		3. EP – treated liquid	1.45	1.1	1 sample/week
AD Removal efficiency (0-1)			**54.8 %**		
SBR N/DN Removal efficiency (1-3)			**78.9 %**		
Total Removal efficiency (0-3)			**90.4 %**		
COD	kg/t	0. Pig slurry	41.20	9.6	1 sample/month
		1. EP - Digestate	12.40	2.0	2 sample/month
		3. EP – treated liquid	2.90	1.3	1 sample/week
AD Removal efficiency (between 0-1)			**69.8 %**		
SBR N/DN Removal efficiency (between 1-3)			**76.6 %**		
Total Removal efficiency (between 0-3)			**92.9 %**		
TP	kg/t	0. Pig slurry	0.44	0.04	1 sample/month
		1. EP - Digestate	0.45	0.10	1 sample/month
		3. EP – treated liquid	0.06	0.02	1 sample/month
AD Removal efficiency (0-1)			**- 3.0 %**		
SBR N/DN Removal efficiency (1-3)			**86.7 %**		
Total Removal efficiency (0-3)			**86.3 %**		
TK	kg/t	0. Pig slurry	1.86	0.06	1 sample/month
		1. EP - Digestate	1.61	0.26	1 sample/month
		3. EP – treated liquid	1.18	0.12	1 sample/month
AD Removal efficiency (0-1)			**13.4 %**		
SBR N/DN Removal efficiency (1-3)			**26.5 %**		
Total Removal efficiency (0-3)			**36.3 %**		
EC	mS/cm	0. Pig slurry	16.7	2.0	1 sample/month
		1. EP - Digestate	17.4	0.9	1 sample/month
		3. EP – treated liquid	9.2	1.3	1 sample/month
AD Removal efficiency (0-1)			**- 4.3 %**		
SBR N/DN Removal efficiency (1-3)			**47.3 %**		
Total Removal efficiency (0-3)			**44.9 %**		
pH	pH u.	0. Pig slurry	7.0	0.3	1 sample/month
		1. EP - Digestate	7.7	0.1	2 sample/month
		3. EP – treated liquid	7.5	0.4	1 sample/week

To get the nitrosation stopped to nitrite and denitrification of nitrite to N_2 gas, the growth of AOB bacteria (ammonium oxidizers,) should be encouraged at the expense of NOB bacteria (nitrite oxidizers). This was possible when the AOB growth rate was greater than that of NOB, exploiting the different sensitivities of these two bacterial groups.

The process parameters of the SBR that allowed the maximum removal efficiency during the monitoring activity were: temperature 35-36°C (the thermal surplus resulting from the hot water produced by the CHP can be used to heat the SBR); pH 7.5 – 8.3; dissolved oxygen 1.2 mg/L; HRT 2.6 day; solid retention time (SRT) 25-30 days and volatile suspended solid (VSS) concentration inside reactor 12-13 g L-1 with a VSS/TSS (total suspended solid) ratio of 0.70-0.75.

The average nitrogen load rate (NLR) during activity was 0.84 kg N/m^3 reactor per day, with a standard deviation (S.D.) of 0.11. The average COD/N ratio in digestate in input to SBR was 4.3 with a S.D. of 1.5.

Considering NO_2^- - N nitrite (500.6 mg kg-1) and NO_3^- - N nitrate (2.5 mg kg-^{1}) average content in the treated effluent from SBR (these two nitrogen forms are not included in the TKN analysis content (Table 6.5.2), the average total nitrogen (TKN) removal efficiency of the whole monitoring period versus the raw pig slurry N content, was 68%. In 25 days of the monitoring period, milk whey (2% of the daily volume loaded into the SBR) was added to the digestate, as a readily available carbon source, to make the process more stable. Milk whey was present in the farm as a surplus by-product from pig feeding. During this time the total nitrogen removal efficiency increased and was stable between 79 and 91%.

The main evaluation results for the treatment system assessed in the plant of Campo Bo, S.L. are shown in Table 6.5.3.

Table 6.5.3. Summary of the monitoring and evaluation results

			Campo Bò treatment plant
Environment	Global Warming Potential	kg $CO_{2\ eq.}$/t	16.1
	Acidification Potential	kg $SO_{2\ eq.}$/t	0.18
Energy[1]	Electrical energy balance	kWh/t	8.75
	Thermal energy balance	kWh/t	0
	Fuel	kWh/t	0
Economy	Income	€/t	2.45
	Expenses	€/t	1.61
Agronomy	Nitrogen balance	kg N/ha	35
	Phosphorus balance	kg P/ha	-3
	Potassium balance	kg K/ha	-30
Social impact	Job demand – Operator [3]	h/y	430
	Job demand – Specialised technician [3]	h/y	60
	Odour[1]	1-4	1
	Noise[2]	Yes/No	Yes
Biosecurity	Pathogens reduction[3]	Yes/No	Yes

[1] In AD process methane and hydrogen sulphide leaks are possible. There are odour emissions during air insufflations phase from SBR N/DN surface reactor.

[2] Noise can be reduced a lot if the CHP unit and the airblower are well soundproof.

[3] Anaerobic digestion reduces *Salmonella* and *E. coli*.

I. ENVIRONMENT

Emissions. Total emissions reduction, in tons of CO_2 eq. per year with the pig slurry treatment plant scenario compared to baseline scenario (without AD+SHARON), is 62%. The greenhouse gas (GHG) emissions reduction is greatly due to the recovery of the biogas to produce renewable energy (heat and electricity) and also due to the very low methane emissions and low N content of treated effluent in the final storage (vs. raw slurry storage).

The GHG emissions reduction is limited by the N_2O emission from the SBR aerobic treatment.

Water. According to the agronomy balance, there is only a slight nitrogen surplus (12%). The calculations are referred on the nitrogen content of the end-product before storage. Consequently, the nitrogen content to the field (in the spreading phase) is smaller and the surplus is reduced.

Soil. The scenario is located in a non-potentially salt affected area according to the “Saline and Sodic Soil” map.

II. ENERGY

The average biogas produced by AD treatment plant was 580 m^3/day with an average CH_4 content of 67%. The daily average gross electric production is, during the monitoring time, 1,117 kWh with an average of 15 operating hours per day. The average monitored yield in biogas was of 460 m^3 per ton VS loaded to AD reactor (308 m^3 of methane per ton VS). Table 6.5.4 shows the main data production of the anaerobic digestion plant.

Table 6.5,4. Main data of the anaerobic digestion treatment plant.

Average biogas production (m^3/day)	580
Average biogas yield (m^3 biogas/m^3 slurry)	6,744
Methane content in biogas (% CH_4)	67
Average electric production (kWh/m^3 biogas)	1,926
Average electric production (kWh/m^3 slurry)	12.99

The energy balance (Figure 6.5.4) is referred to AD processing unit without SBR N/DN pilot plant.

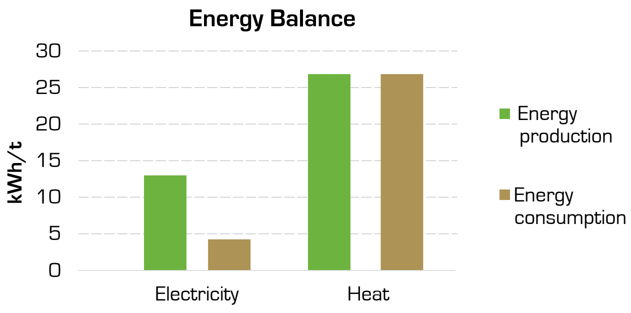

Figure 6.5.4. Energy balance in the management system of the treatment plant of Campo Bò.

The thermal energy is used for AD reactor heating without surplus. The surplus electrical energy is sold to the grid at 0.28 €/kWh in feed-in tariff.

III. ECONOMY

The Incomes and Expenses are referred to AD process unit without SBR N/DN pilot plant (Figure 6.5.5). The treatment line doesn’t aim, as priority, to generate an economic benefit. AD unit is able to produce an economic positive balance that can make post manure treatment more sustainable.

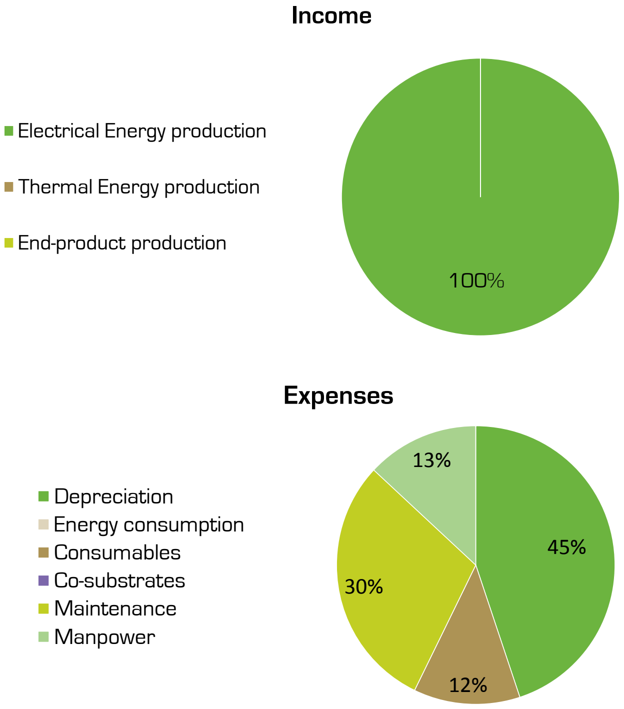

Figure 6.5.5. Energy balance in the management system of the treatment plant of Campo Bò.

IV. AGRONOMY

Nitrogen content in end-product is referred to pre-storage. During the storage phase there are significant nitrogen losses (Figure 6.5.6).

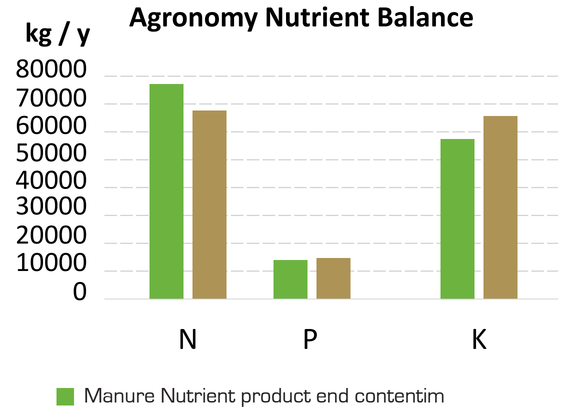

Figure 6.5.6. Agronomy nutrient balance in the management system of the treatment plant of Campo Bò.

Phosphorus and potassium balance are referred on the P and K mass, not on P_2O_5 and K_2O mass. Agronomy balance data in Table 6.5.3 are NPK average nutrient surplus per hectare related to the farming crop demand.

V. SOCIAL IMPACT

The AD treatment is a plant of small size and the creation of new jobs, even if present, is modest. AD treatment removes biodegradable organic compounds from manure and produces a more stabilised manure, reducing odour and gas emission during the storage and spreading phase.

4. CONCLUSIONS

The economic input arising from the sale of electric energy produced by CHP powered with biogas from anaerobic digestion supports the following SHARON N/DN biological treatment to reduce nitrogen surplus in areas with a high density of livestock.

The ratio between readily available carbon and nitrogen is a limiting factor when the pig slurry digestate is treated with biological N/DN. SHARON process, requiring less carbon than a conventional N/DN process, allows a good nitrogen removal efficiency (68%).

5. BIBLIOGRAPHY

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6.6. CASE STUDY 6: ANAEROBIC DIGESTION TREATMENT PLANT MANAGED BY APERGAS IN VILADEMULS (CATALONIA, SPAIN)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

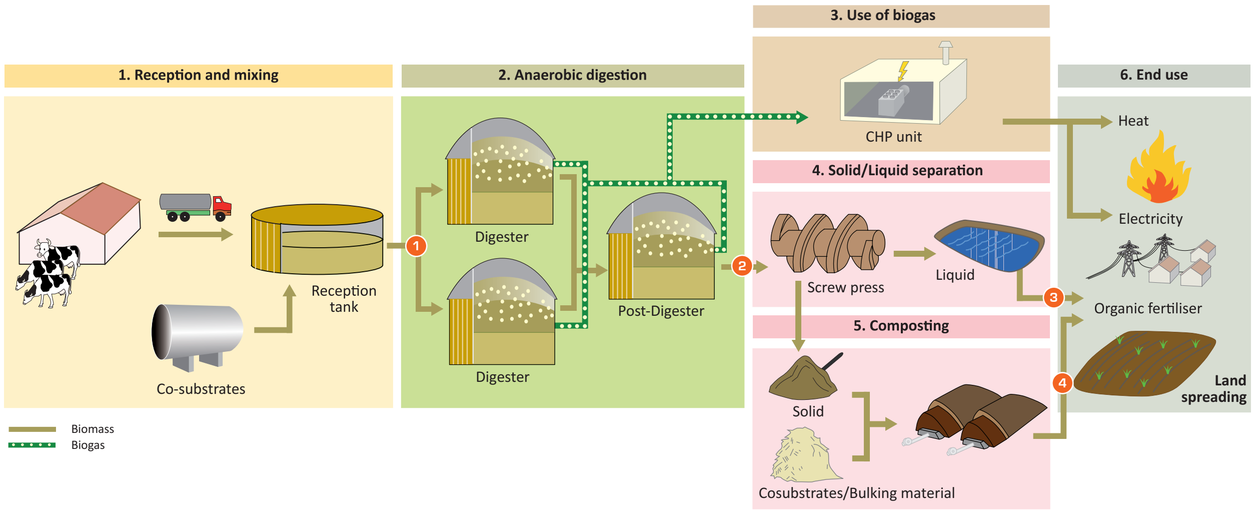
The treatment plant managed by Apergas is located in Sant Esteve de Guialbes, belonging to the municipality of Vilademuls (Girona, Catalonia, Spain) (Figure 6.6.1). The facility processes the manure produced in the nearby dairy cow farm (SAT Sant Mer) together with co-substrates with a total capacity of 36,000 t/year.

The treatment plant is the result of the synergy of three companies, SAT Sant Mer, EnErGi and Apergas which is the current operator of the plant. The design of the plant was done in 2007, the construction during 2008 and the start-up in 2009. In 2012, the plant was modified and a third anaerobic digester was included in the processing line.

The aim of the plant is to maximise the production of biogas and sell to the grid the electricity produced with the combined heat and power (CHP) engine (500 kWe) fuelled with biogas. The liquid phase of the digested is used as fertiliser in the nearby cropland, and the solid fraction is composted and sold as organic fertiliser.

Figure 6.6.1. General view of Apergas treatment plant in Vilademuls (Catalonia, Spain).

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM



SAMPLING POINTS

① INPUT: cow slurry+co-substrates
② EP - Digestate
③ EP – Liquid
④ EP – Compost

Figure 6.6.2. Processing line of Apergas treatment plant

Table 6.6.1. Main data of the processing line.

Input (Cow slurry + agro food waste) (t/year)	36,000
AD reactors	3
AD Hydraulic retention time (days)	35-40
AD process temperature (ºC)	37
CHP unit power (kWe)	500
Volume anaerobic reactors (m^3)	5,500
Mechanical separator (screw press)	Bauer S885
Effluent pond capacity(m^3)	10,000
Composting area (m^2)	786
End-products:	
- Digestate – Liquid fraction (t/year)	33,884
- Compost (t/year)	363
- Biogas (m^3/year)	324,903
- Heat (MWh/year)	Surplus[1]
- Electricity (MWh/year)	3,093,689

[1] The excess thermal energy produced is dissipated to the atmosphere.

The processing line (Figure 6.6.2) of the treatment plant is made up of the following steps:

1. Reception and mixing. The plant has two reception tanks. A closed co-substrate tank with a capacity of 60 m^3 and a slurry reception tank mechanically stirred with a capacity of 130 m^3 where the co-substrate and manure is mixed and pumped to the anaerobic reactors

2. Mesophilic anaerobic digestion. The biogas is generated in two primary reactors of 2,078 m^3 each and a secondary reactor of 1,450 m^3 in serial, thermally isolated at 37 ºC where the slurry is kept without oxygen during 35-40 days. The biogas is stored in the head space of two of the three reactors, with a total capacity of 1,000 (600 Nm^3 and 400 Nm^3).

3. Use of biogas: biogas purification and energy production. An activated carbon filter is used to remove H_2S from biogas and then electricity is produced in a CHP engine of 500 kWe. The electricity produced supplies the necessities of the facilities and the excess is sold to the grid. The heat is used to maintain the temperature of the digester. There is a security torch for burning the excess of biogas.

4. Solid/Liquid separation. The digestate coming from the secondary anaerobic reactor is mechanically separated in a screw press obtaining a liquid and a solid fraction.

5. Composting. The solid fraction is composted in 4 composting trench with forced aeration and cured in a concrete platform.

6. End use. Compost is sold as fertiliser or used as bed material in the dairy cow farm. The liquid fraction is then stored in a pond with a capacity of 10,000 m^3 before its use as fertiliser.

3. RESULTS OF THE ASSESSMENT

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol developed in the LIFE+ MANEV project (Chapter 3) and covering four years of steady operation of the facility. The information and data was collected by sampling campaigns. Solid and liquid samples at eight different locations were sampled monthly. Emissions sampling was performed every second month at three different points (initial and final storage, and composting piles).

Table 6.6.2 shows the mass balance and average removal efficiency during the monitoring period, as well as the chemical characteristics of the sampling points (average and standard deviation (S.D.).

Table 6.6.2. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	36 sampling campaigns		Samples
			Average	S. D.	
TKN	kg/t	1. INPUT	3.5	0.8	35
		3. EP-Liquid	3.5	0.5	31
		4. EP-Compost	8.4	3.0	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**1.4%**		
TAN	kg/t	1. INPUT	1.7	0.3	35
		3. EP-Liquid	2.2	0.4	31
		4. EP-Compost	1.4	1.0	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**-29.5%**		
DM	kg/t	1. INPUT	81.8	26.4	35
		3. EP-Liquid	35.6	6.2	31
		4. EP-Compost	292.8	63.8	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**56.4%**		
VS	kg/t	1. INPUT	70.0	24.3	35
		3. EP-Liquid	24.4	4.7	31
		4. EP-Compost	243.8	49.1	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**65.2%**		
COD	kg/t	1. INPUT	140.0	50.8	35
		3. EP-Liquid	47.5	9.2	36
		4. EP-Compost	-	-	-
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**66.0%**		

Parameter	Units	Sampling point	36 sampling campaigns		Samples
			Average	S. D.	
TP	kg/t	1. INPUT	0.6	0.2	35
		3. EP-Liquid	0.6	0.2	31
		4. EP-Compost	3.0	1.2	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**11.0%**		
Zn	kg/t	1. INPUT	0.054	0.078	12
		3. EP-Liquid	0.052	0.110	11
		4. EP-Compost	0.230	0.100	16
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**2.8%**		
Cu	kg/t	1. INPUT	0.015	0.012	13
		3. EP-Liquid	0.020	0.018	11
		4. EP-Compost	0.076	0.140	16
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**-35.1%**		
EC	mS/cm	1. INPUT	9.2	3.3	35
		3. EP-Liquid	12.5	4.5	31
		4. EP-Compost	2.7	2.7	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**-35.4%**		
pH	pH u.	1. INPUT	6.5	0.5	35
		3. EP-Liquid	8.0	0.2	31
		4. EP-Compost	8.0	0.6	25
Removal efficiency $_{\text{OUTPUT1-LF}}$ (%)			**-**		

Table 6.6.3 summarizes the main evaluation results regarding environment, agronomy, economy, energy, animal and human health issues and social impact.

Table 6.6.3. Summary of the monitoring and evaluation results.

			Reference situation (Storage)	Current situation (treatment plant
Environment	Global Warming Potential	kg CO_2 eq./t	92.1	21.4 (Without electricity benefits) -7.63 (With electricity benefits)
	Acidification Potential	kg SO_2 eq./ t	2.49	1.57
Economy	Incomes[1]	€/t	-	11.5
	Expenses	€/t	-	10.9
Energy	Electricity	kWh/t	-	85.9
	Heat[2]	kWh/t	-	Surplus
	Fuel[3]	kWh/t	-	0
Agronomy	Nitrogen balance[4]	kg N/ha	-	+29.4
	Phosphorus Balance[4]	kg P_2O_5/ha	-	+66.9
	Potassium Balance[4]	kg K_2O/ha	-	+65.1
Social impact	Job demand – Operator[5]	h/y	-	1,650
	Job demand – Specialised technician[6]	h/y	-	550
	Odor[7]	1-4	-	2
	Noise[8]	Yes/No	-	No
Biosecurity	Pathogens reduction[9]	Yes/No	-	Yes/No

[1] Data from 2014 (2013: 13.3 €/t). This significant decrease of incomes is due to the reduction of subsidy

[2] The excess thermal energy produced is dissipated to the atmosphere

[3] No fuel is used in the plant

[4] Balance carried out considering crops requirements

[5] Full time operator is required to run the plant.

[6] One third of the time of a specialised technician is required to run the plant.

[7] No odour distinct from the nearby farm is detected.

[8] The CHP is located in a soundproof ship container.

[9] A clear reduction o *E.Coli* is observed, but *Salmonella* is still present in some of the samples of the digestate.

On the other hand, compost is free of pathogens and could be sold without any health threatens.

I. ENVIRONMENT

Emissions. Data related to this case study (named Current situation) were compared with the situation previous to the biogas plant construction (named Reference situation) (Figures 6.6.3, 6.6.4 and 6.6.5).

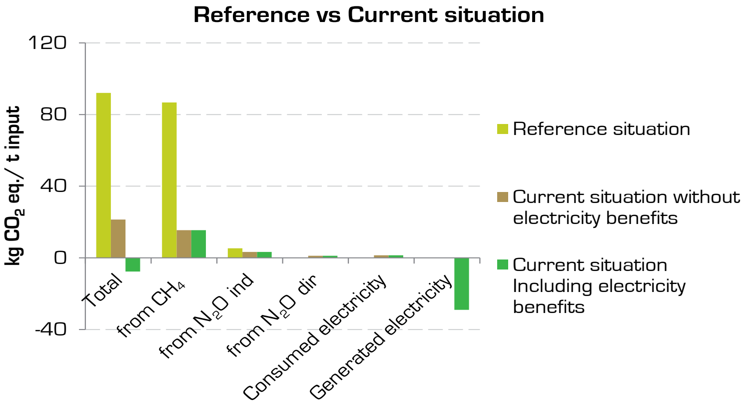


Figure 6.6.3. Comparison between reference situation (storage) and current situation (treatment plant).

Emissions at Reference situation and at Current situation were estimated following Tier 1, Tier 2 and Tier 3 models; and field emissions at Current situation were sampled for a four-year period. Emission values were compared for each sampling point.

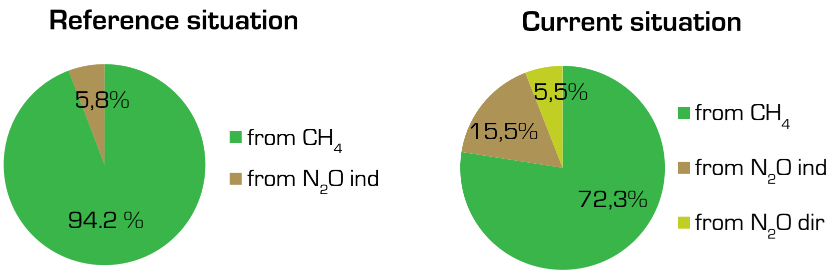


Figure 6.6.4. Global Warming Potential of gas emissions in reference situation (storage) and current situation (treatment plant).

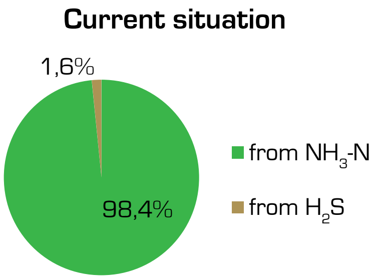


Figure 6.6.5. Acidification of gas emission in current situation (treatment plant).

As it can be seen in Figure 6.6.6, measured emissions and the different Tier models used to estimate emissions are different but in the same order of magnitude.

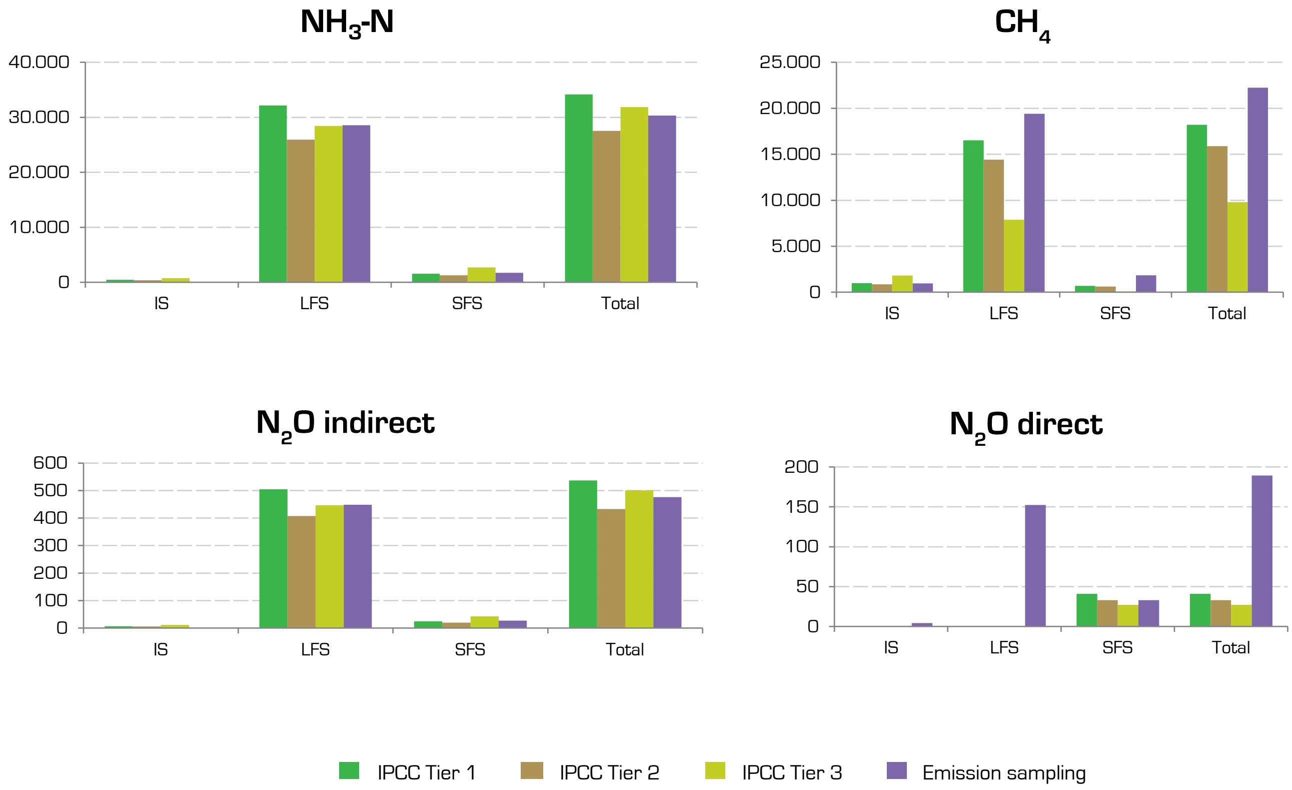


Figure 6.6.6. NH_3-N, CH_4, N_2Oindirect and N_2Odirect emission values by IPCC models and field measurements at influent storage (IS), liquid fraction storage (LFS) and solid fraction storage (SFS) of digestate at the biogas plant.

Contribution of plant emissions to the Global Warming Potential (GWP) and to the Acidification Potential (AP) was calculated according to IPCC conversion factors. Apergas treatment plant reduces 80% the GWP and 57% AP (Table 6.6.3) as compared with the references situation. The generated electricity from biogas was discharged to the electrical grid and the potential environmental benefits due to the avoided mix electricity generation were also estimated, resulting in a 110% GWP reduction.

Soil. Digestate liquid fraction is used as fertiliser in the nearby cropland owned by the dairy farm. Different plots have been sampled and analysed, showing that most of the soils are of good quality and no significant concentration of nutrients (P and NO_3^-) nor heavy metals are presents (Table 6.6.4 and Table 6.6.5).

Table 6.6.4. Main characteristics of soils fertilised with digestate liquid fraction from Apergas treatment plant.

Range	pH	CE µS/cm	P mg/kg	N_{org} mg/kg	NO_3^- mg/kg	K^+ mg/kg	Mg^{2+} mg/kg	IC mg C/g	TOC mg C/g	C/N
Max	8,5	425	35	2456	375	68	15	55	26	24
Min	7,9	46	6	793	16	3	2	2	9	6
Average	8,2	139	18	1688	107	11	6	34	18	11

Table 6.6.5. Heavy metals content of soils fertilised with digestate liquid fraction from Apergas treatment plant.

Range	Cd	Cu	Ni	Pb	Zn	Hg	Cr
Max	<0,5	82,0	24,0	18,0	77,0	1,0	41,0
Min	<0,5	<20	15,4	<5	41,8	<0,4	17,0
Average	<0,5	30,4	20,1	11,3	59,3	0,8	29,8

Regarding nutrient mass balance (Table 6.6.3), nitrogen is almost balanced, but 28.2 t/y and 27.4 t/y of P and K is accumulated each year in the fields fertilised with the digestate.

II. ENERGY

As mention before, the main objective of this plant is to produce energy and sold it to the grid. Table 6.6.6 summarizes the biogas production of the plant and the energy sold to the grid.

Table 6.6.6. Energy production in Apergas treatment plant.

Biogas production (m^3/day)	1,395
Biogas production (m^3biogas/t input)	14.1
Biogas composition (% CH_4)	65
Electricity production (kWh/year)	3,093,689
Electricity production (kWh/m^3 biogas)	6.0
Electricity production (kWh/t input)	85.9

III.ECONOMY

The investment cost of the plant was 1,410,800 € (2009), the running cost are 230,106 €/y and the incomes are close to 375,550 €/y. Nevertheless, the economic viability of the plant is heavily dependent on the subsidy to the production of renewable electricity.

IV. AGRONOMY

The treatment plant produces two end-products: the liquid fraction of the digestate and the compost of the solid fraction. The two end-products can be considered organic fertilisers as they have high nutrient concentration (N and P) (Table 6.6.2). In this respect, the compost has a higher dry matter and nutrient concentration than the liquid fraction and could be sold as a high quality organic fertilizer.

V. SOCIAL IMPACT

The plant has an operator (full time) and a part time (1/2 day) technician.

Apart from that, the plant have ensure the viability of the nearby daily cow farm, as manure is now managed in a proper manner.

VI. BIOSECURITY

Despite the treatment plant reduces the presence of pathogens in the digestate liquid fraction; there is still presence of *Salmonella* and *E. Coli* in this stream. Cross contamination coming from the farm during storage could explain the presence of pathogens in the digestate. On the other hand, compost is free of pathogens and could be sold without any health threatens.

4. CONCLUSIONS

Main conclusions of the survey of the biogas plant is that the sampling protocol developed for solid/liquid samples, as well as for air emissions is a good tool to evaluate the performance of a livestock manure processing plant. The emissions factors of this kind of processing plants have been established, showing that anaerobic process is a good strategy to diminish air emissions, preventing global warming and acidification. Theoretical air emissions calculations with the IPCC model it is also a good approach, but it should be adapted for each situation as many emissions factors are missing.

6.7. CASE STUDY 7: ON-FARM TREATMENT PLANT BASED ON SOLID-LIQUID SEPARATION AND NITRIFICATION-DENITRIFICATION OF THE LIQUID FRACTION FOR NITROGEN REMOVAL IN CUELLAR (CASTILLA Y LEÓN, SPAIN)

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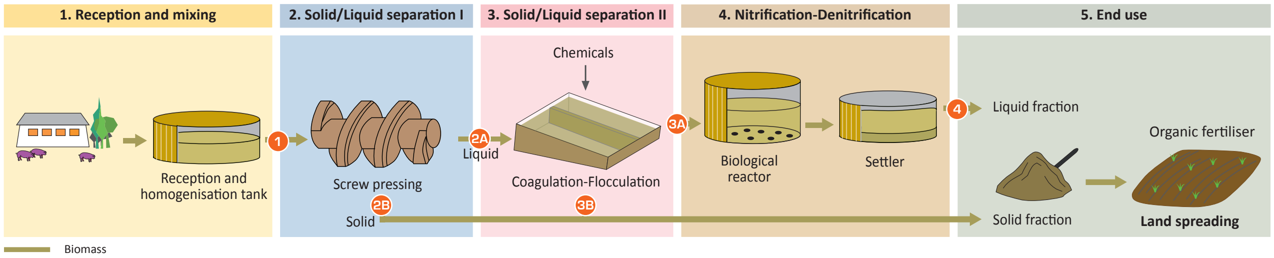
1. SCENARIO AND MANURE MANAGEMENT SYSTEM

This facility treated swine manure generated in a farrow to finish farm with approximately 300 sows (40 m^3/day) located in Cuellar (Segovia, Spain). The main objective of the treatment plant (Figures 6.7.1 and 6.7.2) was to remove surplus nitrogen in order to prevent water, soil and air pollution due to the over-application (N and P mainly) of manure in agriculture. The monitored system (Recudens, S.A., Santander, Spain) consisted of three processing units in series: screw pressing, coagulation-flocculation, and a nitrification-denitrification (NDN) unit (Riaño and García-González, 2014a). Nitrification is the aerobic oxidation of ammonium to nitrite and nitrate and denitrification is the reduction of nitrate to nitrite and nitrogen gas (N_2). This process is generally regarded as the most efficient and relatively cost-efficient means of removing ammonium from wastewater (Tchobanoglous and Burton, 1991). The correct separation of solids from liquids prior biological process has been reported as crucial to the success of this technology, making the biological treatment of the liquid fraction more economical and feasible (Martínez-Almeda and Barrera, 2005; Vanotti and Hunt, 2001).

Figure 6.7.1. Coagulation/Flocculation unit of the treatment plant in Cuellar (Castilla y León, Spain).

Figure 6.7.2. Aerobic biological treatment + settling of the treatment plant in Cuellar (Castilla y León, Spain).

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM



SAMPLING POINTS

① INPUT: raw manure
(2A) Liquid fraction of the screw pressing
(2B) Solid fraction of the screw pressing
(3A) Liquid fraction of the coagulation-flocculation
(3B) Solid fraction of the coagulation-flocculation
④ EP – Liquid: effluent after biological treatment

Figure 6.7.3. Scheme of the management system in Cuellar (Castilla y León, Spain).

The processing line of the treatment plant (Figure 6.7.3) is made up of the following steps:

1. Reception and mixing. homogenisation tank. The swine manure generated in the farm was stored in the homogenisation tank with a volume of 48 m^3, from where well raw mixed manure was pumped to the screw pressing unit.

2. Phase separation I. Screw pressing. This separator worked discontinuously for approximately 8 hours per day. By means of an endless screw, raw manure entered a cylindrical screen which had 0.5 mm openings. The separated solid fraction passed through a screw compactor and was stored for land application whereas the liquid fraction was stored in a tank with a volume of 160 m^3 previously to be pumped to the coagulation-flocculation unit.

3. Phase separation II. Coagulation-flocculation. This unit consisted of a coagulant and flocculant mixing section where polymers were activated with water, an in-line coagulant-flocculant injector where reagents were mixed with wastewater, and two parallel tanks (20 m long, 6 m wide) used to flocculate the suspended solids that remained in the liquid fraction. These tanks had a 9% slope and a maximum depth of 1.8 m. One side of each tank was at ground level, thus allowing the solid fraction to be easily withdrawn using a payloader. The separated solid fraction was stored for further land application, whereas the liquid fraction was stored in two tanks with a total volume of 48 m^3 from where it was continuously fed into the nitrification-denitrification unit.

4. Nitrification-denitrification. The liquid fraction was transferred to the NDN reactor with a volume of 350 m^3 using a peristaltic pump at an average flow rate of 1,500 L/h. Hydraulic retention time (HRT) in the biological reactor was approximately 9.7 days. The oxygen was provided to the system using submerged aerators that worked at intermittent intervals (80 min with aeration followed by 40 min without aeration), optimised in previous studies (Acitores *et al*., 2009). The NDN reactor presented a concentration of approximately 3.3 g/L mixed suspended solids (MLSS). The average daily loading rate of the system during the monitoring period was 43 kg N/day. NDN was followed by a settler with a volume of 20 m^3. Sludge issuing from the bottom of the settler was re-circulated to the NDN reactor. Biologically treated liquid fraction was stored in two ponds (1,300 m^2).

5. End use. The solid fraction generated in both separation units (screw press and coagulation-flocculation) was stored prior to its land application as organic fertiliser.

3. RESULTS OF THE ASSESSMENT

The monitoring of the treatment plant was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol developed in the LIFE+ MANEV project (Chapter 3) and covering four years of steady operation of the facility. The information and data was collected by sampling campaigns. Solid and liquid samples at eight different locations were sampled monthly. Emissions sampling was performed every second month at

Table 6.7.1. Main monitoring results of the processing line sampling.

Parameter	Units	Sampling point	48 samples		Sampling frequency
			Average	S. D.	
TKN	kg/t	1. INPUT	1.83	0.58	1 sample/week
		4. EP-Liquid	0.24	0.36	1 sample/week
Removal efficiency (%)			**89.6%**		
TAN	kg/t	1. INPUT	1.31	0.42	1 sample/week
		4. EP-Liquid	0.21	0.34	1 sample/week
Removal efficiency (%)			**87.2%**		
DM	kg/t	1. INPUT	22.85	11.71	1 sample/week
		4. EP-Liquid	4.54	0.69	1 sample/week
Removal efficiency (%)			**76.1%**		
VS	kg/t	1. INPUT	17.26	9.65	1 sample/week
		4. EP-Liquid	1.43	0.34	1 sample/week
Removal efficiency (%)			**89.6%**		
COD	kg/t	1. INPUT	21.98	11.30	1 sample/week
		4. EP-Liquid	0.80	0.73	1 sample/week
Removal efficiency (%)			**95.1%**		

Parameter	Units	Sampling point	48 samples		Sampling frequency
			Average	S. D.	
TP	kg/t	1. INPUT	0.53	0.35	1 sample/week
		4. EP-Liquid	0.05	0.02	1 sample/week
Removal efficiency (%)			**88.9%**		
Cu	kg/t	1. INPUT	0.008	0.006	1 sample/month
		4. EP-Liquid	<0.001	-	1 sample/month
Removal efficiency (%)			**>95%**		
Zn	kg/t	1. INPUT	0.036	0.026	1 sample/month
		4. EP-Liquid	<0.001	-	1 sample/month
Removal efficiency (%)			**>95%**		
EC	mS/cm	1. INPUT	11.69	2.56	1 sample/week
		4. EP-Liquid	5.95	2.28	1 sample/week
Removal efficiency (%)			**48.5%**		
pH	pH u.	1. INPUT	7.25	0.20	1 sample/week
		4. EP-Liquid	7.81	0.31	1 sample/week
Removal efficiency (%)			**-**		

The main evaluation results for the treatment system assessed in the plant are shown in Table 6.7.2.

Table 6.7.2. Summary of the monitoring and evaluation results.

			On-fam treatment plant
Environment	Global Warming Potential	kg CO_2 eq. /t	37.38
	Acidification Potential	kg SO_2 eq./t	0.76
Energy	Electrical energy balance	kWh/t	8.70
	Thermal energy balance	kWh/t	0
	Fuel	kWh/t	0.45
Economy	Income	€/t	1.20
	Expenses	€/t	5.89
Agronomy	Nitrogen balance	kg N/ha	N/A
	Phosphorus balance	kg P/ha	N/A
	Potassium balance	kg K/ha	N/A
Social impact	Job demand – Operator	h/y	1,460
	Job demand – Specialised technician	h/y	0
	Odour	1-4	4
	Noise	Yes/No	Yes
Biosecurity	Pathogens reduction	Yes/No	Yes

I. ENVIRONMENT

Emissions. In this swine manure treatment plant, greenhouse gas (GHG) emissions were estimated to be 37.4Kg CO_2-equiv per t of manure treated. Most of these emissions (up to 66%) were due to the anaerobic process that occurred in the homogenization tank prior to screw pressing. Methane emissions also occurred during storage of solid fractions prior land spreading and the final biologically treated effluent. Some strategies can be adopted in order to reduce methane emissions during manure storage, such as a wooden lid or a solid cover placed on the slurry tank (Riaño and García-González, 2014b). Other minor emissions occurred in the storage stages were indirect N_2O emissions were produced. The NDN unit was also responsible of the all direct N_2O emissions in the treatment plant, accounting for 6% of the total GHG emissions. CO_2 emissions derived from the electric use and fuel consumption representing less than 5%, most of them attributed to the intensive aeration in the NDN unit. Ammonia was estimated to be 0.8 kg SO_2 eq./t, 50% occurring in the homogenisation tank (Figure 6.7.4).

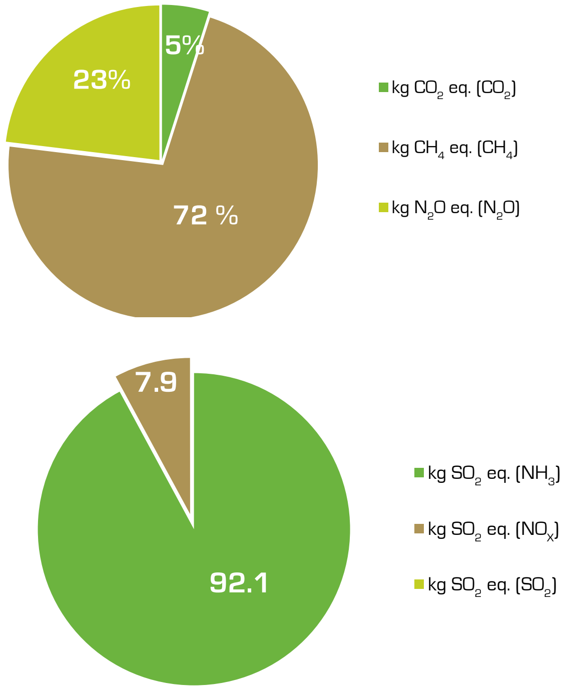


Figure 6.7.4. Gas contribution of the management system to the Global Warming Potential and Acidification Potential.

II. ENERGY

An average of 8.7 kWh/t of treated manure was needed to run the whole treatment plant on the farm, most of them (92%) consumed in the NDN unit due to the intensive aeration required for ammonium oxidation. The transportation of solid fractions to intermediate storage by tractor (a distance of 1 km from pig farm) and removal from the surplus area by truck also consumed energy (0.45 kW/t). In this type of technology, there is not energy production.

III. ECONOMY

Initial investment in the treatment plant amounted to approximately 350,000 € (year 2006). This does not include the cost of the screw press (estimated in 30,000€), construction of the homogenization tank and sewer connection from the pig farm to the treatment plant, since these were already installed in the pig farm prior to construction of the whole treatment plant. Capital investment has been identified as the most important challenge facing the implementation of cleaner treatment technologies, since they are very expensive compared to conventional manure management practices (Vanotti *et al.*, 2008). Without considering the depreciation, the screw pressing unit was the lowest contributor (0.4 €/t) to the total running cost of the treatment plant, whereas the coagulation-flocculation unit and the nitrification-denitrification process evidenced a similar running cost (1.5 €/t each unit). The main running costs were electricity and chemical products. The total cost (running cost and depreciation) was estimated to be 5.9 €/t (Figure 6.7.5). The profit that could be obtained from the sale of end-products (solid fractions) may to some extent compensate the higher costs involved in implementing cleaner technologies. In addition to which carbon trading is expected to grow in importance in near future.

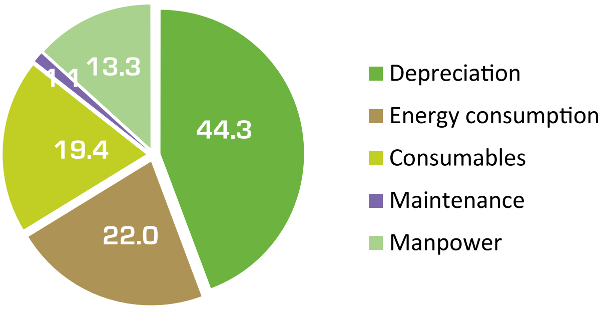


Figure 6.7.5. Incomes and expenses distribution of the treatment plant.

IV. AGRONOMY

Early separation of solids in swine manure treatment plant allows most of the organic carbon and nutrient compounds contained in the manure to be recovered, and therefore, value added products to be obtained. Specifically, solid fraction from screw pressing presented a concentration of 15.3 kg/t of nitrogen, 0.8 kg/t of phosphorous and 4.1 kg/t of potassium (on dry matter basis). The nutrient content of the solid fraction from coagulation-flocculation unit was even higher (46.3 kg/t of nitrogen, 2.8 kg/t of phosphorous and 15.2 kg/t of potassium).

V. SOCIAL IMPACT

One advantage of the treatment plant compared to other technologies is that its operation was assumed by the farmer itself as a regular task due to its simplicity at the steady stage.

VI. BIOSECURITY

This manure treatment system, initially designed for nitrogen removal, made possible to reduce microorganism concentration. Thus, microbial analysis performed on the different liquid fractions showed a consistent trend in *E. coli* and *Salmonella* reduction as a result of each stage of the treatment. The largest pathogen reduction occurred in the NDN reactor, which could be mainly attributed to environmental factors (such as temperature or sunlight) as well as predation in the biological reactor (Burton and Turner, 2003).

4. CONCLUSIONS

The monitored treatment plant, based on solid-liquid separation using screw pressing followed by coagulation-flocculation and nitrification-denitrification of the liquid fraction, achieved good reduction levels of solids, organic matter, nutrients, metals and pathogens from the raw manure, obtaining simultaneously rich organic and nutrient solid fractions. Treatment cost was estimated to be 5.9 €/t, system operation being assumed by the farmer as a regular task.

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6.8. CASE STUDY 8: COMPOSTING IN MURCIA (SPAIN)

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1. SCENARIO AND MANURE MANAGEMENT SYSTEM

The selected scenario for testing composting technology was a sow and piglet farm equipped with a solid-liquid slurry separation system, located in Guazamara (Almería) (Figure 6.8.1). The farm has capacity for 500 sows and piglets to 20 kg live weight, with a total estimated production of pig slurry of 3,060 t/y, and all pig slurry is collected and managed together. The infrastructure for slurry treatment includes a pig slurry storage tank, a mechanical solid-liquid separation system based on a screw-press (without flocculants), a tank with a bottom aeration system for treatment of the liquid fraction, a lagoon for storage of the treated liquid, and a solid-surface area next to the separator for storage of the solid fraction and for composting, with the adequate inclination for collecting any leaching in the pig slurry storage tank. The solid fraction was stored and sold to other farmers as solid manure for agricultural use, and the liquid fraction was used for fertirrigation of citrus at the farm. The management system monitored consisted of the composting of the solid fraction of pig slurry for adding value to the product with respect to the stored solid fraction.

Figure 6.8.1. Separation system and composting pile of the pig farm in the tested scenario.

2. SCHEME OF THE MANURE MANAGEMENT SYSTEM

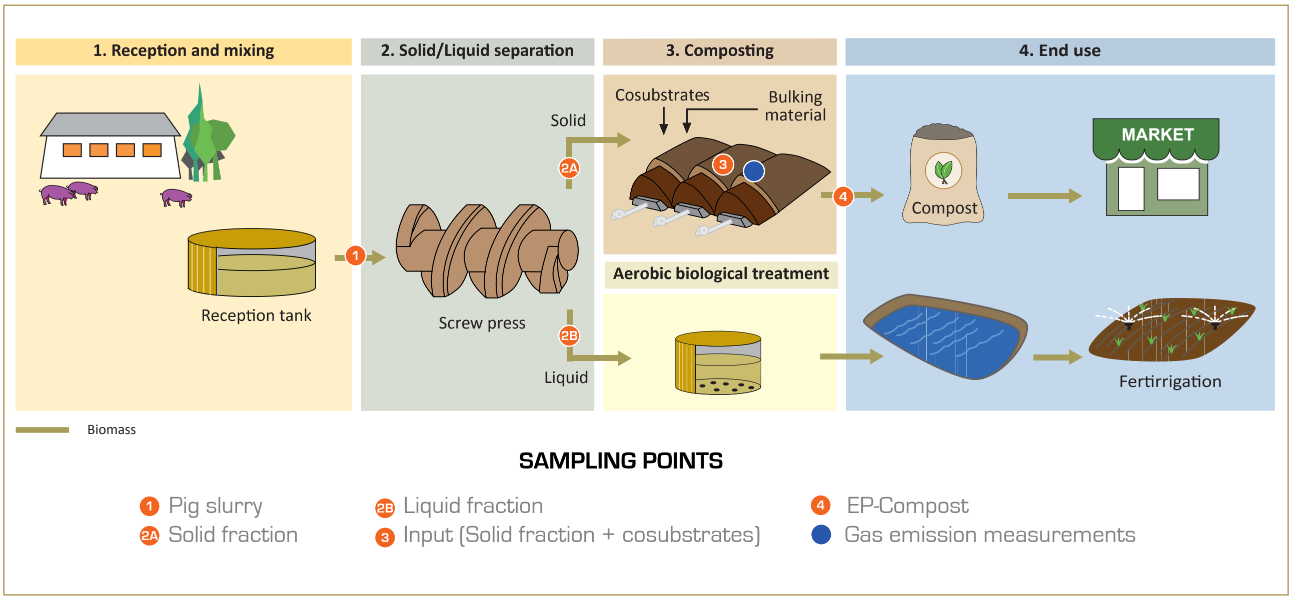

Figure 6.8.2. Scheme of the management system.

Table 6.8.1. Main data of the processing line.

	Strategy 1	Strategy 2
Pig slurry (t/year)	3,060	3,060
Cosubstrates (bulking material)	Cereal straw	Cotton gin waste
Amount (t/year)	453	283
Composting system	Semi-passive windrow	Semi-passive windrow
End-products:		
- Compost (t/year)	369	330
- Liquid fraction (t/year)	1,928	1,928

The manure treatment system evaluated at the farm (Figure 6.8.2 and Table 6.8.1) was divided in 4 steps:

1. Reception and mixing. Slurry storage.

2. Solid/Liquid separation. The solid-liquid slurry separation system of the farm was based on a screw press without flocculants. However, after the composting monitoring period (in September 2014), the solid-liquid separation system was updated to improve efficiency. The changes in the installation consisted of a two-phase separation system, introducing an inclined static screen with a sieve (500 µm) and a rotary brush system for self-cleaning connected to the screw-press (for removal of the coarse particles); the liquid phase obtained from this was later separated on a second solid-liquid separation system by a rotary mesh (200 µm) already in the installation. Both solid fractions were mixed and managed together. The liquid phase obtained was aerobically treated as before.

3. Composting. During the monitoring period of the composting technology, the solid fraction was obtained from the screw press. Two composting strategies were monitored based on the solid-liquid separation system: daily mechanical separation for 3-4 h and storage of the solid fraction for up to a month before composting; storage of the pig slurry with continuous separation of the solid for 3 days before composting. The solid fraction from the first strategy was mixed with cereal straw as the bulking agent (proportion 2:1, v:v), and cotton gin waste was used for the solid fraction in the second strategy (proportion 3:1, v:v).

The composting process was developed in trapezoidal piles using passive windrow with minimum mechanical turning (3 and 5 times in the first and second strategies, respectively), using the tractor available on the farm, and the moisture of the piles was adjusted to 60% at the time of sampling and/or turning. The bio-oxidative phase of composting was considered finished when the temperature of the pile was close to the ambient and re-heating did not occur after turning; then, the compost was left to mature for between 1.5 and 2 months. The total composting time was between 170 and 187 days for each strategy.

4. End use. Compost application.

3. RESULTS OF THE ASSESSMENT

The monitoring of the composting technology was carried out following the guidelines defined in the Common Evaluation and Monitoring Protocol developed in the LIFE+ MANEV project (Chapter 3). Strategy 1 started on January 2012 and continued until July 2012 and strategy 2 ran from May 2013 to November 2013. Also, the pig slurry and solid fraction produced were monitored from September 2011 to June 2012 in the first separation system, and from September 2014 to January 2015 for the improved separation system.

The sampling points used for materials and gaseous emissions are indicated in Figure 6.8.2: the original non-treated pig slurry (1); the solid (2A) and liquid (2B) fraction obtained after the separation system; the composting material (3) and the mature compost (4). Gaseous emissions were monitored in the slurry storage tank and during the composting. The efficiency of the new, improved solid-liquid separation system installed at the farm was monitored for each separation step, by calculating the recovery of organic matter (OM) and nutrients in the solid fraction. The efficiency of composting as a recovery operation for OM and nutrients has been evaluated by mass balance in the system.

The information and data were collected in three ways:

- Daily records: manual and automatic registration of the main parameters of the composting process: external and internal temperatures of the composting mass.
- Monthly sampling: representative monthly samples of the slurry, solid fraction and composting material corresponding to each processing unit were taken. Analysis (TKN, TAN, P, K, DM, VS, COD, pH, and EC) was performed using internal laboratory installations at CEBAS-CSIC.
- Periodical monitoring of data: data of the compost produced. After each composting trial, the mature compost was analysed for other parameters, such as pathogenic microorganisms (*E. coli* and Salmonella) by an external laboratory and heavy metals (Cu and Zn) using internal laboratory installations at CEBAS-CSIC.

Table 6.4.2 shows the average removal/recovery efficiencies mass balance of the mature compost at the exit of the step of composting (4. Compost) compared with pig slurry (1) and the solid fraction after the solid/liquid separation treatment, during the monitoring period. The main chemical characteristics (average and S.D.) are also shown in this table.

Table 6.8.2. Main analytical data and performance of the treatment system.

Parameter	Units	Sampling point	2 Sampling campaigns 14 Samples		Sampling frequency
			Average	S. D.	
TKN	kg/t	1. Pig slurry	3.90	1.00	1 sample/month
		2A. Solid fraction	4.00	0.50	1 sample/month
		3. INPUT (2A+cosubstrates)	5.40	0.50	1 sample/bulking
		4. Compost	16.20	4.22	1 sample/month
Separation efficiency (%) (2A-1)			**37.9%**		
Composting concentration (%) (4-3)			**67.8%**		
TAN	kg/t	1. Pig slurry	2.10	0.30	1 sample/month
		2A. Solid fraction	2.40	0.38	1 sample/month
		3. INPUT (2A+cosubstrates)	2.00	0.30	1 sample/ bulking
		4. Compost	0.68	0.92	1 sample/month
Separation efficiency (%) (2A-1)			**42.3%**		
Composting concentration (%) (4-3)			**7.0%**		

Parameter	Units	Sampling point	2 Sampling campaigns 14 Samples		Sampling frequency
			Average	**S. D.**	
DM	kg/t	1. Pig slurry	106.00	4.90	1 sample/month
		2A. Solid fraction	142.00	27.00	1 sample/month
		3. INPUT (2A+cosubstrates)	241.00	4.70	1 sample/ bulking
		4. Compost	590.00	130.00	1 sample/month
Separation efficiency (%) (2A-1)			**49.6%**		
Composting concentration (%) (4-3)			**55.7%**		
VS	kg/t	1. Pig slurry	73.00	5.40	1 sample/month
		2A. Solid fraction	126.00	11.50	1 sample/month
		3. INPUT (2A+cosubstrates)	183.00	38.00	1 sample/ bulking
		4. Compost	339.00	96.30	1 sample/month
Separation efficiency (%) (2A-1)			**63.9%**		
Composting concentration (%) (4-3)			**41.8%**		
COD	kg/t	1. Pig slurry	22.10	3.40	1 sample/month
		2A. Solid fraction	63.00	14.50	1 sample/month
		3. INPUT (2A+cosubstrates)	89.00	23.00	1 sample/ bulking
		4. Compost	160.50	50.90	1 sample/month
Separation efficiency (%) (2A-1)			**74.0%**		
Composting concentration (%) (4-3)			**40.7%**		
TP	kg/t	1. Pig slurry	2.10	0.40	1 sample/month
		2A. Solid fraction	1.50	0.30	1 sample/month
		3. INPUT (2A+cosubstrates)	4.40	1.30	1 sample/ bulking
		4. Compost	16.70	3.10	1 sample/month
Separation efficiency (%) (2A-1)			**26.4%**		
Composting concentration (%) (4-3)			**94.1%**		
TK	kg/t	1. Pig slurry	1.80	0.13	1 sample/month
		2A. Solid fraction	1.80	0.30	1 sample/month
		3. INPUT (2A+cosubstrates)	3,17	1,03	1 sample/ bulking
		4. Compost	9.48	6.65	1 sample/month
Separation efficiency (%) (2A-1)			**37.0%**		
Composting concentration (%) (4-3)			**59.5%**		
Cu	kg/t	1. Pig slurry	0.058	0.010	1 sample/month
		2A. Solid fraction	0.039	0.002	1 sample/month
		3. INPUT (2A+cosubstrates)	0.056	0.008	1 sample/ bulking
		4. Compost	0.240	0.050	1 sample/month
Separation efficiency (%) (2A-1)			**24.9%**		
Composting concentration (%) (4-3)			**100.0%**		

Parameter	Units	Sampling point	2 Sampling campaigns 14 Samples		Sampling frequency
			Average	S. D.	
Zn	kg/t	1. Pig slurry	0.058	0.010	1 sample/month
		2A. Solid fraction	0.039	0.002	1 sample/month
		3. INPUT (2A+cosubstrates)	0.056	0.008	1 sample/ bulking
		4. Compost	0.240	0.050	1 sample/month
Separation efficiency (%) (2A-1)			**24.9%**		
Composting concentration (%) (4-3)			**100.0%**		
EC	mS/cm	1. Pig slurry	17.50	1.40	1 sample/month
		2A. Solid fraction	3.02	1.60	1 sample/month
		3. INPUT (2A+cosubstrates)	2.78	1.07	1 sample/ bulking
		4. Compost	4.65	0.19	1 sample/month
pH	pH u.	1. Pig slurry	7.50	0.20	1 sample/month
		2A. Solid fraction	7.80	0.39	1 sample/month
		3. INPUT (2A+cosubstrates)	7.89	0.40	1 sample/ bulking
		4. Compost	6.90	0.57	1 sample/month

The evolution of the temperature in the composting system using cotton gin waste and the freshly collected solid fraction of pig slurry showed a fast development of the process, reaching thermophilic temperatures (> 40°C) in the first week, and up to 66 ºC during the thermophilic phase, which lasted for 70 days. However, for the system based on the stored solid fraction mixed with cereal straw, the temperature development was slow, reaching lower thermophilic values for a short time. Thus, the cotton gin waste provides better physical properties than cereal straw, improving aeration and promoting the rapid development of the microbial activity in the composting mass. Also, the freshly collected solid fraction has a higher content of water soluble carbon (50.4 g/kg) than the stored solid fraction (30.3 g/kg) used in first composting system, which implies that the actual composting mass had a higher proportion of easily degradable OM than the former material. The high temperatures reached during the process ensured the destruction of pathogens, according to the European guidelines on compost sanitation (Saveyn & Eder, 2014).

In both strategies the OM concentration decreased throughout the composting process (Figure 6.8.3), indicating its microbial degradation, which was detected also in the decrease of the TOC concentrations during composting, while a general increase in TN occurred as a concentration effect caused by the mass loss of the pile (Figure 6.8.3). The OM degradation was calculated as the OM losses, by a mass balance. After maturation, mineralisation of the OM accounted for 65-55 %; so, 35-45 % of the OM remained in the composts as stabilised OM. The results are within the range found by Szanto *et al.* (2007) during composting of pig manure with straw in turned piles (OM losses = 57%), and by Santos *et al.* (2016) using the solid fraction of pig slurry and two proportions of cotton gin waste in a pilot plant in a static Rutgers system (56.4–57.4%). According to this, strategy 2 was able to conserve about 45% of the OM in the final mature compost as stabilised OM, which could be returned to the soil when used in agriculture. The mineralisation of the OM led to increases in the electrical conductivity (EC) due to the release of mineral salts during the microbial decomposition,

In both strategies, the initial values of pH were slightly alkaline (7.6-8.2) and increased during the thermophilic phase of composting (up to 8.8), when the temperature was at its maximum. After this, when the temperature started to decrease below 40 ºC, the pH values decreased progressively in both systems, reaching values close to neutrality. The pH changes are closely related to the N-evolution pattern; initially, intense microbial activity mineralises the organic-N to NH_4^+-N, with a subsequent increase in pH (Nolan *et al.*, 2011); the later reduction could be related to the nitrification process - that can take place predominantly at mesophilic temperatures (20-35 ºC) (Sánchez-Monedero *et al.*, 2001), when the OM degradation slows down, allowing the nitrifying bacteria to develop under aerobic conditions.

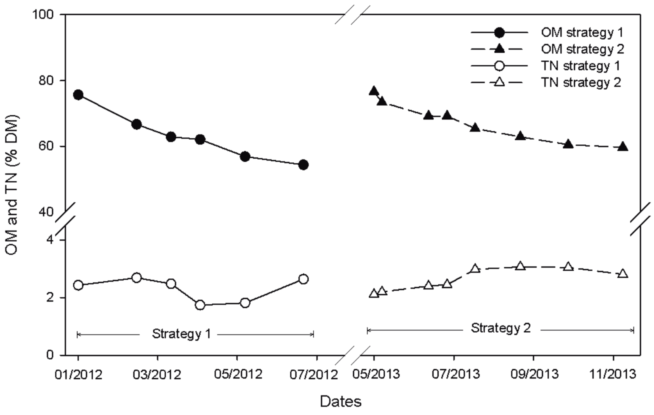

Figure 6.8.3. Evolution of OM and NT concentrations in both tested composting strategies.

The main evaluation results for the treatment system assessed in the plant are shown in Table 6.8.3.

Table 6.8.3. Summary of the monitoring and evaluation results of the composting unit.

Environment	Global warming potential	kg $CO_{2\ eq.}$/t	39.08
	Acidification potential	kg $SO_{2\ eq}$/t	3.47
Energy	Electrical energy balance	kWh/t	0
	Thermal energy balance	kWh/t	0
	Fuel	kWh/t	23.82
€ Economy	Income	€/t	1.71
	Expenses	€/t	17.88
Agronomy	Nitrogen balance	kg N/ha	6.31
	Phosphorus balance	kg P/ha	3.75
	Potassium balance	kg K/ha	4.08
Social impact	Job demand – Operator	h/y	150
	Job demand – Specialised technician	h/y	0
	Odour	1-4	Yes (2)
	Noise	Yes/No	No
Biosecurity	Pathogens reduction	Yes/No	Yes

I. ENVIRONMENT

Emissions. The impact of the composting technology concerning air pollution (acidification by NH_3) was evaluated according to the following equation (Ekinci *et al.*, 2000):

$$\text{N-loss (g/kg TN)} = -7.09 \times C/N + 82.5 \times pH - 203$$

Then, the average N losses by NH_3 volatilisation accounted for 331 g/kg TN, equivalent to 1.78 g/kg of composting mixture treated (2.17 kg NH_3/t). Therefore, taking into account the proportion of solid fraction of pig slurry in the composting mixture, and the annual production of pig slurry, the losses through ammonia volatilisation during composting can account 3,256 kg N/y.

Concerning climate change, the monitoring results showed a great difference between the emission fluxes of CH_4 and CO_2 from the storage tank without and with natural crust. Without crust the emissions accounted for 24.3 g C-CO_2/m²/day and 35.2 g C-CH_4/m²/day. The natural crust reduced the emissions to 9.5 g C-CO_2/m²/day and 5.1 g C-CH_4/m²/day (61 and 86 % reduction for CO_2 and CH_4, respectively). The solid crust formed at the surface acts as a physical cover of the tank (Petersen *et al.*, 2005). However, detectable N_2O fluxes from the storage tank were not found in any case (Sommer *et al.*, 2000), due to the negligible nitrate concentration in the pig slurry, as the bacteria responsible for the nitrification and denitrification process can be inhibited by high ammonia concentration in the pig slurry.

The gaseous emissions were monitored during the composting process in strategy 2. The CO_2 emission rate at the beginning of the process averaged 88 g $C\text{-}CO_2/m^2$/day, but the maximum emission was found at day 21 (310 g $C\text{-}CO_2/m^2$/day), when the degradation of the OM was high and the temperature reached its maximum. With respect to CH_4, the initial emission averaged 7.6 g $C\text{-}CH_4/m^2$/day, with the maximum at day 7 (37.9 g $C\text{-}CH_4/m^2$/day). This result can be due to the high initial moisture content of the pile (72.5 %), the high degradation rate of the OM and the height of the pile; all these could have limited the oxygen concentration inside the pile, indicating that frequent turning is needed to improve the aerobic conditions.

The dynamic of N_2O emission was different to the previously-mentioned gases. The greatest N_2O emissions occurred during the last steps of the process, the cooling and maturation phases - since nitrification mainly occurs when the temperature is below thermophilic values (<40-45°C). Average values ranged from 3.8 g $N\text{-}N_2O/m^2$/day to 0.22 mg $N\text{-}N_2O/m^2$/day, during the cooling and maturation phases, respectively. So, adequate aeration of the pile during such periods is also important for reducing N_2O emissions.

For the studied farm, the manure management scenario of composting has been evaluated according to the IPCC using Tier 2, which uses country-specific data (IPCC, 2006). The CH_4 emissions were estimated as 0.55 kg/t treated, and N_2O emissions accounted for 0.08 kg/t treated. Considering the CO_2 eq. for each GHG, the total emissions were estimated in 39.08 kg CO_2 eq/t. Taking into account the slurry production of the farm, the annual GHG emissions can be estimated as 58.62 t CO_2 eq for the composting technology.

II. ENERGY

The energy requirements have been evaluated according to the fuel consumption of the equipment used for preparation of the pile and the turnings and the time required. On the farm the equipment was a JOHN DEERE 3040 SDT tractor with a power of 90 hp and a charge capacity of 700 l. The estimated time for pile preparation was 2 minutes per tonne; each turning was about 1 minute per tonne of composting mixture, requiring 5 turnings per composting time (semi passive windrow). Then, the energy required per tonne of treated material was 23.8 kWh/t, which corresponded to 2.18 l/t of fuel. Taking into account the amount of fuel required per tonne and the annual slurry production, about 3,230 l/y of fuel was necessary per year for the composting process.

III. ECONOMY

The cost was estimated taking into account the amount of bulking agent required for composting, the energy cost and the personnel cost, as new investment was not required in the farm (Table 6.8.4). The personnel cost was estimated according to the time spent on pile preparation and turnings. Two estimations have been performed considering the separation efficiency of the initial system available at the farm, and the new improved system. The premises for calculation were:

- Total slurry produced in the farm: 3,060 m^3/y;
- Efficiency of separation system: initial system 37 % volume as solid fraction (1,132 m^3/y of solid fraction produced);
- Proportion of bulking agent: 3/1;
- Efficiency of the composting process: moisture reduction from 70 % up to 40 % in the mature compost; and OM degradation 55 % (45 % recovered in the mature compost);
- Composting process: preparation 2 minutes/t; turnings 4; time 1 minute/t; total time required 6 minutes per tonne of material;
- Energy cost: the fuel consumption according to the time required for the tractor;
- Personnel cost: the time that the farmer has to expend for compost preparation and turnings (6 min/t; equivalent to 150 h/y);
- Installation: cost associated with the maintenance of the installation and depreciation cost, considering 15 y of expected plant life.

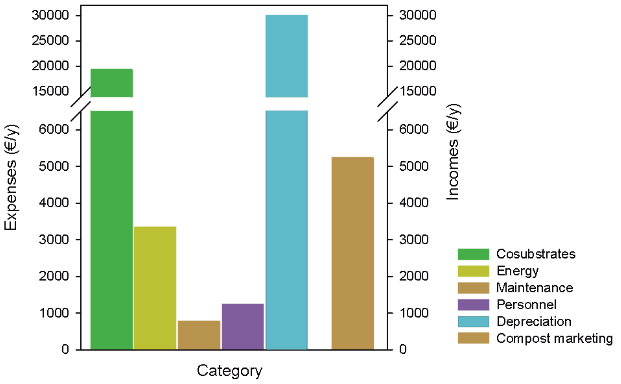

Figure 6.8.4. Economic estimation of the composting technology at the farm and the implication in the slurry treatment.

The economic evaluation was calculated according to the estimated production cost and the income from selling the compost produced. The quality of the compost is low due to the concentration of Zn and Cu, so the selling price was estimated as 15€/t (Ministerio de Medio Ambiente, 2015).

Therefore, most of the cost is associated with the depreciation of the installation. Considering only the running cost, the acquisition of the cosubstrates is the most costly, followed by the energy. Then, the economic impact of the composting technology implies 17.88€/t managed. Income from selling the compost can be estimated as 5,239 €/y, implying an annual cost of 49,500€, equivalent to 16.17€/t of slurry produced.

In the case of the monitored farm, the depreciation cost should not be taken into account because the composting system was run with the equipment already existing at the farm. Then, in the monitored installation the cost of the composting treatment system is calculated as 8.08 €/t of slurry produced. Therefore, the annual cost is €19,500, equivalent to 6.37 €/t of slurry produced.

Therefore, in order to obtain benefit from the process, or at least exceed the composting costs, the quality of the compost needs to be improved, for which the intake of Zn and Cu in the farm should be greatly reduced. Under those circumstances the compost could be sell at 50€/t, covering most of the running cost of the composting system.

IV. AGRONOMY

The composting system produced composts with high content of OM (60-55 % DM), which can improve the soil fertility, so that these materials can be used as sources of soil amendment and OM in agricultural land. The OM of the composts reached a good degree of stabilisation (according to the low water soluble-C) and of humification, as the C_{FA} values in both composts were below the maximum limit (<1.25%; Bernal *et al.*, 2009) for mature compost, with greater C_{HA} values giving the polymerisation index (C_{HA}/C_{FA}) above the limit (>1) proposed for mature compost (Bernal *et al.*, 2009) and thus confirming good development of the humification process.

The stability and maturity indices indicated that both strategies were able to produce well matured compost. However, strategy 2 may require a longer maturity period to complete nitrification, which may be restricted due to the low moisture content (30 %). Both composts are rich in TN content (2.81-2.65 % DM), and the inorganic-N is mainly as nitrate, which is directly available for crops. Also, the concentrations of P and K nutrients were high (P: 2.8 – 2.9 % DM; K: 0.95 – 2.08 % DM).

The EC values of the mature composts averaged 4.66 dS/m, higher than the upper limit (4 dS m^{-1}) for growing media, considered tolerable by plants of medium sensitivity. However, the use of those composts as soil fertilisers should not imply any risk for soil salinity.

In general, the heavy metal concentrations were lower than the limits established for compost by the Spanish and European guidelines (BOE, 2013; Saveyn and Eder, 2014), except for Zn and Cu, due to the high concentrations of these metals found in the pig slurry, mainly from piglets, as zinc oxide is introduced in the diets of piglets to avoid some digestive diseases and improve growth. The concentration of Zn and Cu limits the compost quality and use. However, such concentrations in the mature composts did not cause phytotoxic effects, according to the germination index (> 80 %).

The growth tests indicated that both composts can be applied to soil at very high proportions (up to 42 and 66%, respectively), without any phytotoxic effects to Z. mays. For salinity sensitive species (*L. sativa*), compost application of 7% to the soil can reduce plant growth by 50% (EC_{50}=7 %), but it is necessary to apply at least 21% compost to reduce emergence by 50% (LC_{50}=21 %). All these results indicate that the presence of Zn and Cu at high concentrations in the compost does not affect the plant germination and growth when composts are used at agronomical rates for soil fertilisation. However, salt-sensitive species can be affected when a high amount of compost is used in soil, but due to the concentration of soluble salts instead of those of Zn and Cu.

The value of the compost can be estimated in terms of the concentration of nutrients, mainly N, P and K. The agronomical evaluation of the farm was carried out considering the agricultural land associated with the farm. The crops consisted of citrus trees (lemons, grapefruits, oranges and clementines) in a total area of 1.57 ha. The end-products of the farm were: compost and liquid fraction from pig slurry, with annual production of about 350 and 2,000 t, respectively. Their agronomic value in terms of nutrient concentration was (N-P-K): 16.2-16.7-9.48 kg/t for the compost, and 2.4-0.058-1.7 kg/t for the liquid. The advantage of the liquid fraction is due to its water content, which can be used as enriched irrigation water for the trees. The nutrient requirement of citrus under drip irrigation is: 240 kg N/ha; 80 kg P_2O_5/ha; and 140 kg K_2O/ha (Ministerio de Medio Ambiente y Medio Rural y Marino, 2010). Then, a nutrient balance was calculated according to the nutrients produced and those required by the trees. The excess of nutrients in the farm was estimated as: 6.31 kg N/ha, 3.75 kg P/ha and 4.08 kg K/ha. Such an excess should be exported from the system in the compost.

Figure 6.8.5 shows the nutrient balance of the slurry treatment system of the monitored farm. A great excess of nutrients is produced in the farm through the compost and the liquid fraction, in comparison with the requirements of the citrus trees. Compost was responsible for 55 % of N (kg/y), 98 % of the P and 50 % of the K; so, this fraction can be exported from the system through compost marketing. However, a high excess of nutrients still occurs with the liquid fraction, mainly for N and K. Then, the reduction of such elements may require the application of depuration technologies to the liquid fraction, such as an efficient nitrification-denitrification system. However, high K may still remain in the liquid. An agronomic alternative based on the use of intercrops (high demand for N and K, such as lettuce, spinach or tomatoes), which could be established between the citrus trees, may be useful for improving the use of the nutrients within the system.

V. SOCIAL IMPACT

The farm monitored was of medium-small size, run by a family. Then, the social impact in terms of new employment is scarce as the time required for running the composting technology (150 h/y) can be easily achieved by the farmers and the current employees.

VI. BIOSECURITY

The implication of the technology in terms of animal and human health was established in terms of the persistence of pathogenic microorganisms in the compost. The presence of *E. coli* was not detected in any mature compost, and *Salmonella* was absent in 25 g DM, indicating adequate sanitisation of the compost. One of the main advantages of composting is the total elimination of pathogenic microorganisms and odours, which make the material easy to transport to other agricultural areas, exporting the excess of nutrients without health risks.

4. CONCLUSIONS

Composting is a technology that is affordable, technologically and economically, for the management of the pig slurry at the farm level. The procedure requires pretreatment of the pig slurry by a solid-liquid separation and the addition of a bulking agent for reducing moisture, to obtain adequate aeration and porosity of the solid fraction of pig slurry. These factors imply that composting should be seen as one step of a full process line for slurry management.

The process concentrates the nutrients in a solid material – compost - with added-value properties derived from the humified and stabilised organic matter, absence of pathogenic microorganisms and odours, allowing the safe exportation of the nutrients to other agricultural areas. The compost is a valuable organic fertiliser for soil application at agronomical rates, to provide the maximum benefit to soil and plants. This technology will allow the exportation from the farm of about 55 % of the N (kg/y), 98 % of the P and 50 % of the K of the end products (compost and liquid fraction).

The composting management practices in the farm can be used as a valuable tool to mitigate GHG emissions during pig slurry management. The aeration control is the key factor for CH_4 and N_2O emission.

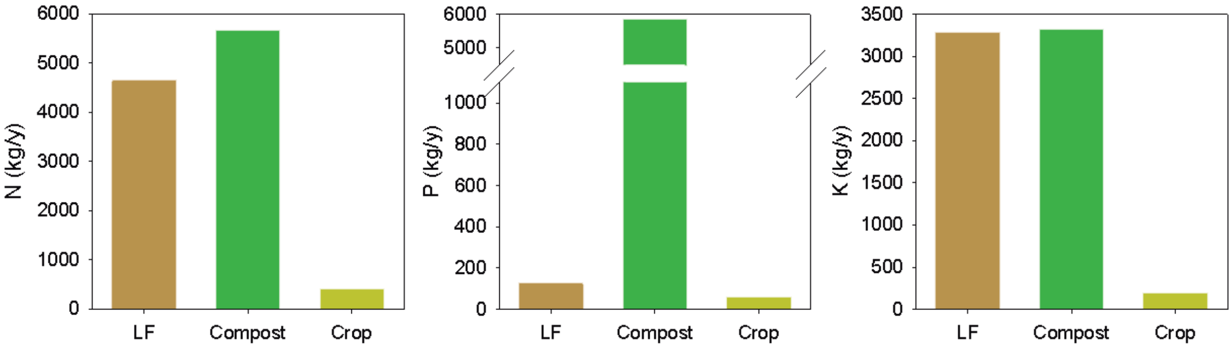

Figure 6.8.5. Agronomic evaluation of the treatment system at the farm: Nutrients in the liquid fraction, if the compost and required by the crop (citrus trees).

The technology is simple and does not require highly specialised personnel or highly sophisticated technology; so, it can be run by the farmer with the basic equipment of the farm.

The economic benefit from the technology is limited by the compost quality in terms of the Cu and Zn concentrations from piglet slurry, so its introduction into the treatment system of the farm should be restricted. Reduction of the economic cost implies:

- Increasing compost quality to obtain a high market price. This implies a separated collection and treatment of the slurry from piglets;

- Reducing the amount of bulking agent (cosubstrate). Solid-liquid separation may increase the efficiency, yielding a solid fraction with low moisture content. This action was taken by the farmer during the monitoring period;

- Optimise the turning frequency according to the thermal profile (mainly during the thermophilic phase, when maximum microbial degradation occurs).

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6.9. CASE STUDY 9: MANURE MANAGEMENT IN THE POLISH VOIVODESHIP OF WARMIŃSKO-MAZURSKIE (POLAND)

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1. CURRENT SITUATION OF MANURE MANAGEMENT IN POLAND

The basic method of manure management in Polish agriculture is the direct fertilisation of fields. Autumn is the best time for fertilising with manure, slurry and liquid manure, which are primarily a source of nitrogen for crops.

According to estimates of the Institute of Plant Cultivation, Fertilisation and Soil Science, the total annual production of solid manure in Poland amounts to approx. 80 million tons while the slurry production amounts approx. 21.5 million m^3. The most commonly used liquid manure is cattle slurry. It is also often poured mixed liquid manure: from the cowshed and piggery, especially on small farms.

The use and storage of natural fertilisers (solid manure and slurry) are regulated by the Act on fertilisers and fertilisation of 10 July 2007 and article 47 of the Water Law of 18 July 2001 as amended. The maximum permissible dose levels of natural fertilisers are specified by the rules of the Nitrates Directive. According to the guidelines, the amount of nitrogen used in natural fertilisers may not exceed 170 kg per year per hectare, so in the case of slurry maximum dose must not be greater than 45 m^3 per hectare, 35 tonnes of manure per hectare. Natural fertilisers can be used only in the period from 1 March to 30 November.

The most commonly used slurry spreading system in our agriculture is pouring slurry on the surface, usually using simple scoops spreading fertiliser in the form of liquid fan. However, this method results in significant losses of nitrogen contained in the manure, so manufacturers have marketed slurry tanks attachments, enabling the dispensing of liquid manure directly into soil. In this method of liquid manure spreading, nitrogen losses are only 3-5%. There are also important environmental benefits.

One of the processing manure technologies employed is composting, which is conducting to oxygen decomposition at high temperatures. Within few weeks the process delivers a smooth, organic fertiliser free of odours, pathogens, and a small amount of ammonia nitrogen.

The need to reduce ammonia emissions to the environment comes not only from toxicological and ecological reasons, but also legal, because there are a number of legal acts both in Poland and the European Union concerning the permissible concentrations of NH_3 in the natural environment. Problems with management of manure, the need for compliance with environmental standards and targets of the renewable energy sources development contributed to the development of investments in agricultural biogas plants in Poland. In recent years many such installations has been built. According to the register of manufacturers of agricultural biogas (03.07.2015) in Poland currently operates 61 biogas plants with a total installed electrical capacity of 68.5 MWe and an annual capacity of nearly 265 million m^3 of biogas.

2. MANURE MANAGEMENT SYSTEMS INVOLVED IN THE PROJECT

In the LIFE+ MANEV project four farms, described in Table 6.9.1, have been involved in the tasks carried out in Poland.

Table 6.9.1. Farms involved in the project.

Farm Upalty I (Figure 6.9.1)	
Area (ha)	1,600
Breeding	Pigs farming in closed cycle: primary flock of 730 sows Yearly sale: 19,000 porkers of 110 kg average.
Cultivation	Arable land: 1,550 ha Crops: Winter wheat, Spring barley, Winter oilseed rape, Corn and Triticale

Manure management system	Manure is stored in tanks and used as a natural fertiliser for corn and winter crops with the amount of 16-20 m^3 per ha. The large area of the farm allows using manure in a sustainable way.
	In 2014 a biogas plant was opened (Figure 6.9.1), the processing line consists of two sets of two primary digesters and one post-digester of 860 m^3 with a total volume 5,160 m^3. The pig slurry and pig manure from the farm is used as a substrate for the plant and digestate is used as a fertiliser.
	• Input:
	  • Pig slurry (t/year): 13,055
	  • Pig manure (t/year): 1,026
	  • Maize silage (t/year): 20,000
	• Organic load (t dry organic matter/day): 20.33
	• Organic load (kg dry organic matter/m^3 * day): 3.94
	• Biogas production (m^3/kg dry organic matter): 0.65
	• Biogas production (m^3/year): 4,798,720
	• Cogeneration system: Hours Energia model HE-KEC-999/1042-MTG999-B
	• CHP unit power: 999 kWe

Farm Upalty II	
Area (ha)	72
Breeding	N/A. It stores and manages manure transported from Upalty I
Cultivation	Main crops: Winter wheat, Winter oilseed rape
Manure management system	Manure is stored in tanks and used as a natural fertiliser

Farm Pierkunowo (Figure 6.9.2)	
Area (ha)	600
Breeding	Pigs farming in closed cycle: primary flock of 140 sows Yearly sale: 2,500 porkers Milk cow farming: 90 cows
Cultivation	Arable land: 430 ha Crops are mainly destined for a fodder for pigs, on a part of the land grass and clover is cultivated for the cows (65 ha of meadows and 31 ha of pasture).
Manure management system	Animal production waste consists of 3,500 m^3/year of pig slurry and 1,300 t/year of cattle manure Pig slurry is stored in tanks and spread in the fields as a natural fertiliser. Cattle manure is spread in the fields and ploughed.

Farm tawki	
Area (ha)	825
Breeding	Pigs farming in closed cycle: primary flock of 500 sows and 1,900 porkers.
Cultivation	Arable land: ca. 720 ha. Main crops: oilseed rape, winter wheat, brewery barley; also: corn, triticale and oat.
Manure management system	Manure is stored in tanks (overground and underground) of total volume of 6,000 m^3. It is used as a natural fertiliser for corn and winter oilseed rape. It is not used on grasslands.

Figure 6.9.1. Biogas plant Upalty.

Figure 6.9.2. Spreading of manure on the field in the farm Pierkunowo.

3. ACTIONS CARRIED OUT IN THE PROJECT

I.ENVIRONMENTAL MONITORING: SOIL, WATER AND AIR

In close cooperation with the abovementioned 4 manure producers, environmental monitoring of the influence of manure management on soil, water and air was done. Within this cooperation 32 field visits took place to gather detailed data on production, storage and use of farm excrement, including technology data, technical and financial information.

In order to make detailed studies of the impact of manure on the environment, a number of samples of soil, ground water and surface water were collected for the determination of nitrogen, phosphorus, potassium and organic matter. In addition, air analyses were carried out for determining the emissions of greenhouse gases and ammonia.

Figure 6.9.3. Air sampling in the pigsty in the farm Upalty I.

Based on the examination of atmospheric air, soil, groundwater and surface water in the farms Upalty I, Upalty II, Pierkunowo and tawki made for the project MANEV following conclusions were formulated:

1. Air.

The emission measurements included methane, carbon dioxide, hydrogen sulphide and ammonia. The sampling was carried out from 2011 to 2014 at intervals of six months at the livestock rooms (Figure 6.9.3), in the field before the pouring of liquid manure and during the pouring of liquid manure (Figure 6.9.4).

Figure 6.9.4. Air sampling on the field.

The results from the measurements of air pollution in the area of 4 farms showed that:

- In the livestock rooms practically during all measurements ammonia concentration was recorded at a level exceeding the reference value laid down in the Regulation of the Minister of Environment of 26 January 2010 concerning reference values for some substances in air (In the case of ammonia the limits are 400 µg/m^3 for one hour and 50 µg/m^3 during the whole year).

- Measured concentrations of methane and carbon dioxide in the pigsties of every farm were similar to each other and their level did not exceed 1%.

- The increase of the concentration of ammonia is noticeable practically in all measurement periods at the field during the pouring of liquid manure at a level exceeding the reference value laid down to the Regulation of the Minister of Environment of 26 January 2010. In the vast majority of the measurements made on the farms there were no concentrations of pollutants in the air at the field before pouring of liquid manure.

- For other indicators, i.e., methane, carbon dioxide and hydrogen sulphide at the field during the pouring of liquid manure no concentrations were detected (values below the limit of quantification of the method of measurement).

2. Soils

Based on the examinations of soils (Figure 6.9.5) in the farms the following conclusions were formulated:

Figure 6.9.5. Gathering soil samples.

- No influence of liquid manure was detected on soil pH. Analysis also showed no effect of manure on acidifying the arable layer of soils. In the examined farms, in the measurement periods occurring before and after fertilising, pH of the soil recorded were close to neutral and alkaline, which creates favourable conditions for high biological activity of the soil and along with meeting the other criteria gives good conditions for the development of the root system of plants.

- Fertilising with liquid manure showed a slight increase in electrical conductivity in farms Upalty I, Upalty II and Pierkunowo in measuring periods preceded by fertilising. In the farm tawki in the corresponding periods in the last three quarters of 2014 a drop in electrical conductivity was noticed. A slight increase of electrical conductivity is related to the increase in the content of dissolved salts in the soil solution. The values obtained on the basis of research differ only slightly when comparing the periods before and after fertilisation, indicating a lack or only insignificant impact of fertilising with a liquid manure on increased salinity of the soil and thus an enhanced ability to electrical conductivity.

- The studies have shown small efficiency in relation to the enrichment of topsoil with potassium in the analysed farms. In the farms Upalty I and Upalty II in the periods after fertilising with liquid manure slight loss of this element from the soil was observed, which may be associated with the granulometric composition of the soil and the rainfall. On light soils with low sorption capacity the loss of potassium is larger. In the farms Pierkunowo and tawki there were no significant differences in potassium content in the soil in the periods before and after fertilising.

- Manure is a source of micronutrients such as zinc and copper, whose growth should be noticeable in the case of regular use. In the analysed farms no effect of enriching the arable layer of soils in zinc and only slightly positive impact on the copper content was observed. Conducted procedures did not lead to soil pollution with heavy elements mentioned under the Regulation of the Minister of the Environment of 9 September 2002 on soil quality standards and earth quality standards in relation to class B arable land.

- The amount of phosphorus in measurement periods before fertilising and after pouring of liquid manure contained within the range typical for arable layer of soils (0.01-0.20%). There has also been a slight upward trend of the content of phosphorus in the soil before applying fertiliser treatments in all the farms. This is connected with the fact that the liquid manure is a good source of phosphorus, especially for topsoil.

- As in the case of phosphorus, the liquid manure can be a potential source of nitrogen. The obtained results show a downward trend in the case of nitrogen in the soil after the fertilising (farms: Upalty I, Upalty II, tawki). Only in the case of the farm Pierkunowo upward trend in the measurement series preceded by fertilising in relation to the measurement series occurring before pouring of liquid manure on the field. The nitrogen content in the soil and its durability is dependent on the origin of the soil, cultivating process and the type of crops, as well as the susceptibility to erosion of the soil.

- The studies also showed that in all farms nitrogen content in the soil in measuring periods before pouring of liquid manure and after the application of fertiliser contained in a range appropriate for mineral soils (0.02-0.35%), so no significant deficiency of this element in the arable layer of the soil was examined.

- The results illustrate a significant increase in organic matter in arable soil layer in the cases of farms: Upalty I, Upalty II, Pierkunowo. In the farm tawki appeared a slight downward trend in terms of organic matter in the soil after pouring of liquid manure, compared to soil samples taken before the fertilising. A potential increase in organic matter in the soil is caused by fertilisation with liquid manure is associated with the chemical composition and origin of the soil, age and physiology of pigs, as well as the type of feed used.

3. Groundwater

Based on the research of the groundwater (Figure 6.9.6) during the pouring of liquid manure on the fields in terms of indicators characterising the acidity (pH), indexes for salinity (electrical conductivity), indicators characterising the biogenic indicators (ammonia nitrogen, nitrite nitrogen, nitrate nitrogen, total phosphorus) and comparing them to the limits contained in the Regulation of the Minister of Environment on the criteria and method of assessing groundwater the following conclusions were formulated:

Figure 6.9.6. Gathering groundwater samples in the farm Pierkunowo.

- No influence of fertilising with liquid manure on the change of pH and electrical conductivity was observed. Water samples analysed can be classified in terms of these indicators to I-III class of water quality and good chemical state of groundwater.

- Examined indicators of ammonium and nitrite in the water in all measurement series, ranged in I-III water quality class which means good state, except for the transgression in the farm tawki.

- The nitrates results obtained from 2011 to 2014 during all measurement series illustrated the upward trend of this biogenic indicator. The highest values were examined in the second quarter of 2014 (89.5 mg/l) in the farm Upalty I which, as compared to the limiting values, classify water to poor chemical state. Transgressions were observed in all farms.

- Phosphate results obtained from 2011 to 2014 during 7 series of measurements in the considered farms illustrated the growth trends of this parameter on all farms and in particular in the farm Upalty I and tawki where the highest values were measured.

4. Surface waters

The surface water in farms was monitored (Figure 6.9.7) during the pouring of liquid manure and compared to the values contained in the Regulation of the Minister of the Environment of 22 October 2014 on the classification of the state of surface waters and environmental quality standards for priority substances, from all measurement periods run from 2011 to 2014. The following conclusions were formulated:

Figure 6.9.7. Gathering surface water samples in the farm Pierkunowo.

- The pH and electric conductivity in all the examined samples fit in the range classifying water to the I-II class of surface water quality, which means good state.

- The results of ammonia nitrogen in most samples fit in the range of I-II quality class.

- The measured values of nitrate nitrogen in the majority of water samples taken exceeded 5 mg/l, indicating that the water from these points included into waters not meeting the requirements of II quality class. That means the state of the water is below good, while it should be noted that elevated nitrogen nitrate was already observed in the blank sample.

- The results of total phosphorus in all measurement series during fertilising took differing levels, the highest values were observed in the samples taken at the farm Pierkunowo (8.6 mg/l).

- Analysing the results of phosphorus in the period of years 2011-2014 during 6 measurement series the declining trends of this parameter in relations to the blank sample and first taken samples were observed.

- It should be emphasised that the elevated level of nitrate nitrogen and phosphorus was already observed in the blank sample.

- In the fourth quarter of 2014 in the farm Pierkunowo due to drought found no flow of surface water.

Summarising research on water it can be certainly said that the presence of nitrogen and phosphorus compounds in groundwater and surface water can come (among other things) from fields fertilised with liquid manure. It is a negative phenomenon because phosphates are one of the basic biogenic factors causing massive algae growth and establishing their presence forces to track the composition of the water and combat blooms. The eutrophication of natural waters caused by an excessive concentration of phosphorus and nitrogen compounds is a highly detrimental phenomenon.

II. STUDY VISITS WITH THE AIM OF GETTING TO KNOW THE ACHIEVEMENTS OF OTHER COUNTRIES

Representatives of the project partner and the farmers from the four farms cooperating within the MANEV project took part in three study visits during which they had an opportunity to gain experience in the area of manure management based on the achievements of other countries.

First study visit took place on 27-30 June 2011 and its goal was to get acquainted with the Spanish model of processing manure from livestock production. Participants visited several places in Aragon: a pig farm in Tauste (Figure 6.9.8), a cutting plant in Valderrobres and a sewage treatment plant designed for manure and a biogas plant in Peñarroya de Tastavins.

Figure 6.9.8. Study visit in Spain.

Second study visit took place on 21-24 May 2012 in Italy (region Reggio Emilia and the surroundings of Milan). During the trip the participants visited agricultural biogas plants in Via Cella all'Oldo and in Correggio as well as an experimental farm in Landriano, which is monitored by the University of Milan, and also a livestock farm in Pieve Fissiraga (Figure 6.9.9).

On 2-5 June 2013 in Denmark third study visit took place (Figure 6.9.10). The delegation visited agricultural biogas plants in Over Løjstrup and in Thorsø as well as a biogas plant with other facilities in Foulum run by the Aarhus University.

Figure 6.9.9. Study visit in Italy.

As result of the entire demonstrative, disseminating and monitoring work carried out in the project, two agricultural biogas plants were built by 2 out of four farms cooperating within the MANEV project.

Figure 6.9.10. Study visit in Denmark..

4. CONCLUSIONS : FUTURE TRENDS OF MANURE MANAGEMENT IN POLAND

The rapid development of investments in agricultural biogas plants lasting several years has been heavily hampered due to the low purchase price of electricity and a significant reduction in prices of energy certificates, which are an important element of return on investment.

In 2015 a new law on renewable energy sources has been adopted. One of its key points is the introduction of a new model of support system for renewable energy development. Since 2016 in place of "green certificates" auction system will be introduced, under which a contract for the supply of electricity from renewable energy sources will receive those entrepreneurs who offer the lowest price. Such a solution raises many doubts among energy producers and thus until the new system is tested in practice, it is difficult to predict the further development of technology using manure to produce biogas in Poland.

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