Manure Processing Activities in Europe - Project reference: ENV.B.1 / ETU / 2010 / 0007

ASSESSMENT OF ECONOMIC FEASIBILITY AND ENVIRONMENTAL PERFORMANCE OF MANURE PROCESSING TECHNOLOGIES

28-10-2011

Technical Report No. IV to the European Commission, Directorate-General Environment

AGRO BUSINESS PARK

GIRO
gestió integral de residus orgànics
centre tecnològic

Title	**Assessment of economic feasibility and environmental performance of manure processing technologies** Technical Report No. IV to the European Commission, Directorate-General Environment, Manure Processing Activities in Europe - Project reference: ENV.B.1 / ETU / 2010 / 0007
Reference	Foged, Henning Lyngsø, Xavier Flotats, August Bonmati Blasi, Karl Martin Schelde, Jordi Palatsi, Albert Magri and Zivko Juznik. 2011. Assessment of economic feasibility and environmental performance of manure processing technologies. Technical Report No. IV to the European Commission, Directorate-General Environment. Unpublished draft. 130 pp.
Front page photos	Upper left: Decanter centrifuge for after-digestion separation of digestate. Upper right: Composting of separated solid fraction of slurry in roofed store. Lower left: Dried and pelletized separation fraction from biogas plant. Lower right: Reception facilities at biogas plant.
Disclaimer	This report was produced with financial support of the European Union. Its content is the sole responsibility of Agro Business Park in cooperation with GIRO Centre Tecnològic and is in no way reflecting the opinion of the European Union.

PREFACE

Manure processing is presently a subject that enjoys considerable attention in the EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for manure handling in agriculture.

Within this context, the objective of this technical report is to assess the economic feasibility and environmental performance of the most common techniques for both large and small scale installations for processing of livestock manure. The findings and conclusions are to a large degree based on seven case studies, i.e. commercially operating livestock manure processing plants, which were carefully selected so that they make a good representation of sizes, locations, ownership structures and technological configurations of current livestock manure processing plants in EU.

On basis of these seven case studies, this report suggests that there is a huge variation in economic and environmental performance of livestock manure processing plants, and that the individual farmer or the individual plant chooses the most feasible and cheap technology configuration for processing of livestock manure, depending on the surplus of nitrogen in the area, combined with regional framework conditions and other matters of importance for decision making.

This report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project "Manure Processing Activities in Europe", project reference: ENV.B.1 / ETU / 2010 / 0007. The Report includes deliverables related with Task 4 concerning "Assessment of economic feasibility and environmental performance of manure processing technologies".

We are thankful for the information and data that the seven livestock manure treatment plants kindly shared with us, and the time they spend for our visits and consultations.

Tjele, 28 October 2011

Henning Lyngsø Foged

Project Manager

Agro Business Park

TABLE OF CONTENT

EXECUTIVE SUMMARY

This report presents seven cases of livestock manure treatment plants, comprising 34 technologies with little overlap, and being located in four EU Member States, namely Spain, Netherlands, Slovenia and Denmark.

The plants have been described in details with respect to their mass balance, energy balance, environmental performance and economic performance, based on information and data provided by the plants themselves. A number of key indicators are gathered in summary tables, directly comparable between the plants.

There is a huge variation in the performance of the plants as it appears from the following assessment parameters:

- Capacities varies from 10,000 m^3 to 375,000 m^3 treated influent per year (at Randers / slurry acidification plant and Morsø Bioenergy / biogas plant with de-centralised pre-separation of slurry, respectively)
- The energy balance varies from +128 to ÷800 kWh per m^3 treated influent (at Aspergas / biogas + composting plant and Tracjusa / biogas + fertiliser pellets production plant, respectively)
- The saved nitrogen loss, i.e. the livestock treatment plant's ability to reduce loss of N to the environment in comparison to the reference situation, varies from 0.89 to ÷1.6 kg N_{total} per m^3 treated influent (at Calldetenes / nitrification-denitrification plant and Aspergas / biogas + composting plant, respectively)
- The reduced CO_{2e} emissions, i.e. the livestock treatment plant's ability to reduce loss of CO_{2e} to the environment in comparison to the reference situation, varies from 0 to 82.5 kg CO_{2e} per m^3 treated influent (at Randers / slurry acidification plant and Tracjusa / biogas + fertiliser pellets production plant, respectively). The CO_{2e} reduction effect takes into account both effects of replacing fossil fuel with renewable energy, as well as effects of storage and transport.
- The investment requirement varies from 6.6 to 163.6 € per m^3 treated influent (at Randers / slurry acidification plant and Tracjusa / biogas + fertiliser pellets production plant, respectively)
- The net cost of processing without subsidies varies from 0.66 to 8.07 € per m^3 treated influent (at Randers / slurry acidification plant and Kumac Mineralen / manure concentrates production plant, respectively)
- The net cost of processing without subsidies varies from 0.14 to 2.7 € per kg N_{total} in treated influent (at Randers / slurry acidification plant and Domžale / biogas + stripping / absorption, respectively)
- The number of technologies varies from 1 to 10 (at Randers / slurry acidification plant and Tracjusa / biogas + fertiliser pellets production plant, respectively), which is considered of importance in relation to the complexity and risks of managing the plants

There exist at least two major directions in livestock manure processing regarding nutrient management;

- removal of nutrients / elimination of the livestock manure, at least for the livestock farm that produced it;
- maximised recycling of plant nutrients.

Removal of nutrients is the objective only for one of the plants in the case studies. The general trend is to recover plant nutrients, due to the environmental impacts and overall costs of removing nutrients from livestock manure. Depending on the surplus of nitrogen in the area, combined with framework conditions and other factors, the individual farmer or the individual plant chooses the most feasible and cheap technology configuration for processing of livestock manure.

The cheapest processing plant is the acidification plant near Randers in Denmark, both considering net costs excluding subsidies per m^3 biomass treated (0.98 € / m^3) and per Kg N_{total} in the influent (0.21 € / kg N). One reason for this might be that there is only one livestock manure treatment technology involved, and this technology provides impressive impacts on emissions in stable, storage and during spreading of the livestock manure. The economic key figures do not consider the extra yield obtained in crop production thanks to the additional fertiliser effect of the slurry, neither the time the farmer saves during operations nor the saved investment in covering the slurry tanks. Consequently, acidification seems to be a win-win technology for farming and environment. The drawback might be that the acidified slurry loses its potential for being used in a biogas plant, due to the acid having inhibiting effect on the methanogenesis.

The most expensive plant is the Tracjusa plant in Spain with an estimated processing cost excluding subsidies of around 43 € / m^3, and therefore heavily dependent on a defined "feed-in" electrical tariff. The plant has invested in no less than 10 different manure processing technologies and has high costs for drying and pelletizing the separation solids; a practice that would not be sustainable if external benefits were not considered and envisaged, such as the use of waste heat from a CHP fed with natural gas, decentralised electricity generation, modernised electrical grids and natural gas supplies in rural areas, improvement of economical activities via local job creation and more stable energy supplies in rural areas, a significant decrease in CO_{2e} and ammonia emissions.

The investments vary from 6.6 to 163.6 € / m^3 influent, lowest for Calldetenes and highest for Tracjusa. The investment requirement is an important parameter for the willingness of the investor, and much associated with the relevance as a Best Available Technology. Private investors would typically prefer solutions with the smallest investment requirement in order to reduce the risks on investment plans that includes several uncertainties, as subsidies and market prices can easily change over time.

The investment size, as mentioned above, is an important parameter in risk assessment. The complexity of the plant is another risk factor, and this is to some extent related with the number of technologies the plant is configured with.

The society has an interest in promotion of manure processing technologies with positive environmental or climatic impacts, and to avoid those with negative impacts.

It is from analysing data from the seven case studies not possible to make any firm conclusions about economy of scale. The economy of the case study plants are more a result of the chosen technology configuration than of their size.

There is a tendency to a better economy in the private person owned plants. However, it is not possible to draw any conclusions as the comparison is based at only a few case study plants with widely different technological configurations.

1: BACKGROUND

Manure processing technologies have, despite their relative novelty, been described in the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF document) (European Union, 2003) and by Foged (2010), including environmental, climatic and economic impacts, according the Best Available Technique (BAT) methodology and other ways to describe such technologies.

However, in practice, technologies are used in widely diverse contexts; manure treatment plants typically consist of several successive manure treatment technologies. Other manure processing plant specificities include the chemical composition and type of the treated biomass, the legislation and framework conditions (subsidies), the farming structure, the ownership, and the capacity / size of the plant.

There exist at least two major directions in livestock manure processing;

- removal of nutrients / elimination of the livestock manure, at least for the livestock farm that produced it;
- maximised recycling of plant nutrients.

This report presents 7 cases of livestock manure treatment plants in four EU countries, namely Spain, Netherlands, Slovenia and Denmark. The processing capacity on the seven case farms varies from 10,000 ton to 375,000 ton treated biomass per year, and the plants represents in total 34 different livestock manure treatment technologies with little overlap. The seven cases are described in detail by their concrete economy, their environmental, social, climatic and other impacts. The economy is analysed with and without subsidies. The seven cases thus give a unique insight into the impacts of livestock manure processing in practice, where technologies are combined in processing plants.

2: METHODOLOGY AND ORGANISATION

This report has the objective to present

- comprehensive economic feasibility (taking into consideration both investment costs and operational costs and revenues) and environmental performance analysis of seven manure processing plants / installations, representing the main manure processing techniques;
- analysis of economy of scale for case study techniques; and
- description of the nature of investments in manure processing plants, which are public or private investments, or joint partnerships, public or private.

2.1: Selection of case studies

The use of practical livestock manure treatment plants as case studies ensures a higher degree of verification of more theoretically based desk studies about manure processing technologies (Xavier et al. 2011) and characteristics of end and by-products (Foged et al., 2011).

The seven case studies were selected so that their location was with a good geographical spreading in the EU. Case studies were also chosen so to represent a wide variety of manure processing technologies, based on both the principles of removal and recycling of plant nutrients. The case studies were also selected so that they represent both small-scale farm plants and large centralised plants, and having various types of ownership.

The representation of the seven chosen case studies is presented in the following table.

Table 2.1: Characteristics of case studies.

Case study	Main principle	Number of livestock manure processing technologies	Ton livestock manure treated per year	Investor type
Large scale centralised anaerobic digestion plant, including mobile decentralised centrifuge separation with flocculation, and separation after digestion, at Morsø Bioenenrgi in Denmark.	Recycling of nutrients	2	375,000	Cooperative, farmer owned
Farm scale installation for in-house acidification of slurry at a pig farm in Haslev near Randers, Denmark.	Recycling of nutrients	1	10,000	Private
Large scale plant for converting pig slurry to purified water and concentrates. Based on a series of separation and filter technologies. Kumac Mineralen, the Netherlands.	Recycling of nutrients	7	80,000	Private partnership, owned by two companies.

Case study	Main principle	Number of livestock manure processing technologies	Ton livestock manure treated per year	Investor type
Nitrification and de-nitrification (NDN) at Calldetenes (Osona, Spain).	Removal of nutrients	4	11,811	Private, farmer owned
Combination anaerobic digestion – evaporation and drying (Tracjusa, Garrigues, Spain). Pig slurry and some co-digestion.	Recycling of nutrients	10	110,000	Founded by private companies (farmers, engineering companies, banks, etc., but with an income warranted by government function of the electrical energy provided to the grid.
Combination of anaerobic co-digestion and stripping pig manure (Domžale, Slovenia).	Recycling of nutrients	7	127,750	Private, owned by a company
Installation, with a combination of anaerobic digestion and composting, treating cattle manure (Apergas, Girona –Spain).	Recycling of nutrients	3	21,800	Private, owned by the company Apergas

2.2: Description of case studies

The case studies are described in the following chapters, according to the following structure:

Table 2.2: Commented table of content for the presentation of case studies.

Section	Title	Comment
1	Introduction	▪ General framework (social, legal, problems to be solved at local, regional or country level, other) explaining the motivations for the kind of technology adopted.
2	General description of the plant	▪ Plant localization ▪ Characterization of the farm (or group of farms for centralized plants): number of animals, manure produced, characteristics of this manure; other co-substrates if co-treatment, other. ▪ Companies which has designed and constructed the plant (some description of its profile and kind of products offered). ▪ Plant operator (Individual, farmer, technical team, other). ▪ Year of start-up. ▪ Diagram of the plant (using the diagrams developed by Xavier et al. (2011) and description of every unit (volumes, hydraulic retention time, electrical power, etc.).

		▪ Descriptive pictures of the plant.
3	Technical data	▪ Mass balance step by step, referring the diagram, with the following information (units: g / m^3, kg / m^3, ton / m^3), when available: - Flow rates - TS (total solids) - VS (volatile solids) - COD (chemical oxygen demand) - N (N_{total} or Nitrogen Total Kjeldahl / NTK) - $N\text{-}NH_4$ - $N\text{-}NO_2$ - $N\text{-}NO_3$ - P - K - Heavy metals - Electrical conductivity - Efficiencies on removals or separations for the above variables - Biogas production ($CH_4 + CO_2$) ▪ Energy balance step by step, referring the diagram, with the following information - Installed electrical power (kW per unit) - Electrical consumption - Electrical production (for CHP units) - Heat consumption - Heat production (for CHP units) - General energy balance
4	Environmental data	▪ Estimated CH_4 emissions (kg / year) ▪ Estimated N_2O emissions (kg / year) ▪ Estimated NH_3 emissions (kg / year) ▪ Estimated equivalent CO_2 emissions of greenhouse gases: balance of electrical consumption (CO_2 equivalent based on national electrical mix as reference), CH_4 emissions, fossil fuel consumption (natural gas, transport, other), N_2O, etc. ▪ NOx emissions ▪ Odour emissions
5	Economical data	▪ General description of the financing aspects: subsidies, banks participation, payments by farmer. ▪ Investment (detailed for every unit if possible, and other initial costs such as connection to electrical grid, etc.). ▪ Financial costs (mortgage, bank loan, other) ▪ Operative costs: reagents, energy consumption, salaries ▪ Incomes: biogas or electrical or heat sales, by-products sales,

		subsidies, other ▪ General indexes: - Net cost per ton of manure treated - Net cost per N removed or per N recovered and sold
6	Social aspects	▪ Employment: direct and indirect jobs ▪ Acceptance of neighbours ▪ Odours (appreciation of farm owners or the neighbours) ▪ Opinion of farmers about the interest of the plant for the farming business and about the problem processing was designed to solve
7	Other	▪ Prizes obtained by the plant ▪ Controls by authorities ▪ General evaluation
8	Summary	Table with the more relevant data: Technical, environmental and economical.

Transport of pig slurry into the plant is considered only if this is organised by the livestock manure processing plant. Likewise, only activities carried out by the plant operator where considered in the study.

2.3: Data collection

Data, information, pictures, etc. for this report were mainly collected via visits to the plants, meetings with the owners and operators of the plants, and by analyzing technical reports related to the plant. In some cases, data were abundant but disperse, contradictory or not updated. In these cases, assumptions were made.

In each Annex related to each facility, assumptions made to estimate emissions are mainly based on IPCC (2006) guidelines or other references, which are explained in the text.

3: SYNTHESIS OF ASSESSMENT OF ECONOMIC FEASIBILITY AND ENVIRONMENTAL PERFORMANCE OF MANURE PROCESSING TECNOLOGIES

This chapter provides an assessment of the economic feasibility and the environmental performance of manure processing technologies, based on the seven case studies, which represents 34 livestock manure processing technologies with only little overlap.

In order to ease the overview of the environmental, climatic, energetic and economic performance of the different plants, the key indicators are gathered in Table 3.1 below.

On basis of these key indicators, the following issues will be discussed:

- Economic feasibility
    - Net cost of processing, € / m^3 and € / kg N_{total}
    - Investment requirements
    - Complexity and risks in management
    - Socio-economic-environmental aspects
- Economy of scale for case study techniques
- Nature of the investments in manure processing plants

Table 3.1: Compilation of key indicators for the seven case studies. Reference is made to the individual, annexed case studies for details and clarification of calculation methods.

Issue	Parameter value						
Plant / company name or location	Morsø Bioenergy	Randers	Kumac Mineralen	Calldetenes	Tracjusa	Domžale	Apergas
Country	Denmark	Denmark	Netherlands	Spain	Spain	Slovenia	Spain
TECHNICAL PERFORMANCE							
Major processing technologies	Anaerobic digestion and separation	Acidification of slurry	A series of separation and filtration technologies	Separation of solid / liquid fraction, exporting the solid fraction, and nitrogen removal by nitrification-denitrification	Combination of anaerobic digestion, and concentration by vacuum evaporation, drying and pelletizing	Anaerobic digestion and stripping / absorption	Anaerobic digestion and composting of solid fraction
Mass balance							
Influent, m^3 per year	375,000	10,045	80,000	11,811	110,000	60,833	21,800
▪ Influent 1	375,000 / pig slurry	10,000 / pig slurry	80,000 / pig slurry	10,245 / pig slurry	106,500 / pig slurry	18,250 / pig slurry	18,772 / cow slurry
▪ Influent 2		45 / sulphuric acid		1,556 / cattle slurry		42,583 / co-substrates	3,118 / co-substrates
End and by-products, ton per year							
▪ End and by-product 1	15,000 / separation solids	10,045 / acidified slurry	16,002 / separation solids	726 / separation solids	5,825 / manure pellets	No data / Solid fraction	21,191 / liquid fraction

Issue	Parameter value						
▪ End and by-product 2	105,000 / separation liquids		24,003 / concentrate from reverse osmosis	11,334 / liquid fraction denitrified		No data / Treated digested fraction	233 / manure compost
▪ End and by-product 3			40,005 / effluent water			No data / Ammonia solution	
Energy balance							
▪ Net consumption of energy per m^3 treated livestock manure and other products, kWh / m^3	14	1.8	1.5	16.2	851	-	-
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	49.3	-	-	-	-58.88	29.7	128.1
ENVIRONMENTAL PERFORMANCE							
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg / m^3 treated	- 0.169	- 0.75	0	- 0.89	-1.3	No data	1.6
▪ Net influence on production of greenhouse gases, kg CO_{2e} / m^3 treated	- 17.4	-	- 2.04	-4.58	-82.49	No data	- 28.9
ECONOMICAL PERFORMANCE							
▪ Net cost of processing, € / m^3	3.84	0,66	8.07	2.86	1.90	6.5	+3,15 (2010) -7.64 (2011)
▪ Net cost of processing, € / kg Ntotal treated	2.27	0,14	1.27	0.87	0.48	2.7	+0.98 (2010)

Issue	Parameter value						
							-2.39 (2011)
▪ Net cost of processing excluding subsidies, € / m^3	4.90	0.98	8.07	3.29	43.72	No data	No data
▪ Net cost of processing excluding subsidies, € / kg Ntotal treated	2.90	0.21	1.27	1.01	11.22	No data	No data

3.1: Economic feasibility

3.1.1: Net cost of processing, € / m3 and € / kg Ntotal treated

The cheapest processing plant is the acidification plant near Randers in Denmark, both considering net costs excluding subsidies per m^3 biomass treated (0.98 € / m^3) and per Kg N_{total} in the influent (0.21 € / kg N). One reason for this might be that there is only one livestock manure treatment technology involved, and this technology provides impressive impacts on emissions in stable, storage and during spreading of the livestock manure. The economic key figures do not consider the extra yield obtained in crop production thanks to the additional fertiliser effect of the slurry, neither the time the farmer saves during operations nor the saved investment in covering the slurry tanks. Consequently, acidification seems to be a win-win technology for farming and environment. The drawback might be that the acidified slurry loses its potential for being used in a biogas plant, due to the acid having inhibiting effect on the methanogenesis.

The most expensive plant is the Tracjusa plant in Spain with an estimated processing cost excluding subsidies of around 43 € / m^3, and therefore heavily dependent on a defined “feed-in” electrical tariff. The plant has invested in no less than 10 different manure processing technologies and has high costs for drying and pelletizing the separation solids; a practice that would not be sustainable if external benefits were not considered and envisaged, such as the use of waste heat from a CHP fed with natural gas, decentralised electricity generation, modernised electrical grids and natural gas supplies in rural areas, improvement of economical activities via local job creation and more stable energy supplies in rural areas, a significant decrease in CO_{2e} and ammonia emissions.

3.1.2: Investment requirements

The following table 3.2 provides an analysis of investments.

Table 3.2: Investments for the 7 case studies.

	Investment (without subsidies)		
Plant	Total, €	m^3 influent	€ / m^3 influent
Morsø Bioenergy	9,750,000	375,000	26.0
Randers	125,000	10,000	12.5
Kumac Mineralen	1,925,000	80,000	24.1
Calldetenes	77,638	11,811	6.6
Tracjusa	18,000,000	110,000	163.6
Domžale	4,000,000	127,750	31.3
Apergas	1,410,800	21,800	64.7

The investments vary from 6.6 to 163.6 € / m^3 influent, lowest for Calldetenes and highest for Tracjusa. The investment requirement is an important parameter for the willingness of the investor, and much associated with the relevance as a Best Available Technology. Private investors would typically prefer solutions with the smallest investment requirement in order to reduce the risks on investment plans that include several uncertainties, as subsidies and market prices can easily change over time.

3.1.3: Complexity and risks in management

The investment size, as mentioned above, is an important parameter in risk assessment.

The complexity of the plant is another risk factor, and this is to some extent related with the number of technologies the plant is configured with.

- The slurry acidification plant near Randers in Denmark is a very simple and robust technology, only comprising one processing technology, which requires a minimum of supervision and furthermore being equipped with sensors that stop the system in case of errors. The main risks are associated with accidental spill of sulphuric acid, having corrosive effects on metals and organic substances due to its strong acidity with a pH as low as around 1.0. Risks appear especially in connection with receipt of new supplies of sulphuric acid, which is handled by a professional transport company; anyway the plant owner should ensure the personnel is informed about the risks associated with handling of sulphuric acid, that there are first aid kit available, that there is established an emergency plan, and that the layout of the installation is organised in a way so that risks for vehicles'collision with storage tanks are minimized.
- Kumac Mineralen is probably an exception; despite it comprises seven technologies it only requires less than 1 hour per day for supervision, which has much to do with the fact that there are stable qualities and amounts of inputs and outputs from the plant, and all processed are automated.

An important advantage of the acidification plant near Randers is also that it is completely independent of incomes from sales of end and by-products; there are therefore no market risks.

3.1.4: Socio-economic-environmental aspects

The Calldetenes plant is losing some nitrogen during the processing, which includes nitrification and de-nitrification; about 15,000 kg N is removed in the process. This would otherwise have a market value if another manure processing technology was used, which would recycle the nitrogen via end and by-products that could be marketed. The economic value of the lost N is for a crop production farmer in general the same as nitrogen in mineral fertiliser, about 1.1 to 1.5 € per kg. For the society the nitrification-denitrification process means additional CO_{2e} emissions for production of more mineral fertilisers, and a higher production of greenhouse gases in form of nitrous oxide from livestock farming. 21

Likewise, while the reduction of CO_{2e} emissions of greenhouse gases is impossible to capitalise for the individual farmer or the individual plant without a CO_2 quota, it has a concrete economic value for the society due to the market value of CO_{2e} reductions. Here the biogas plants provide benefit for the society via their contribution to reduce the CO_{2e} emissions and in the same time produce renewable energy, which reduce dependence on imported energy.

The society has also a clear interest in the impacts on emissions of nitrogen due to its eutrophication effect of especially marine waters, but also on inland waters, and its adverse impacts on drinking water quality. Here the Tracjusa plant seems, with reference to Table 3.1, to be the best concept.

It is also important for the society that end and by-products are separated in different fractions, as this enables a more balanced fertilisation and especially avoids phosphorus over-fertilisation. The reasons for this are phosphorus' effect on eutrophication of especially inland waters, and society's dependency on import of more and more expensive phosphorus, which is a depleting resource. Five of the plants have separated fractions as end / by-products (this is not the case for the slurry acidification plant and for the Tracjusa plant).

3.2: Economy of scale for case study techniques

Figure 3.1, below, showing the economy of scale for the seven case studies expressed as treatment cost per m^3 of influent biomass to the plants, was elaborated on basis of information from Table 2.1.

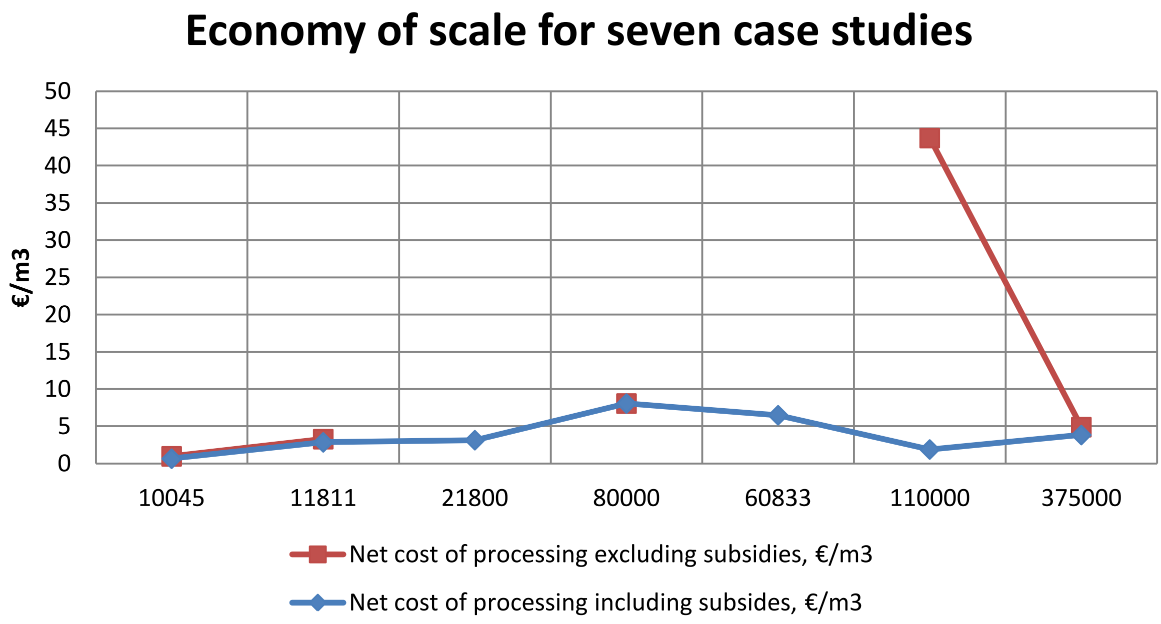


Figure 3.1: Economy of scale for the seven case study plants, expressed as treatment cost per m^3 influent biomass, with and without subsidies.

Theoretically, there is an advantage of larger livestock manure treatment plants, with respect to the investment costs. Flotats et al. (2011) indicates that for instance biogas plants become cheaper with increasing size, in terms of investment cost per m^3 treatment capacity. Other advantages of large plants are:

- Better productivity, for instance increased energy efficiency of the biogas based electricity generator with increased size;
- Better productivity, for instance increased energy efficiency of the biogas based electricity generator with increased size (for instance increase from 39% for small CHP units to 41% for large).
- A larger production volume of end and by-products gives large plants a better position for marketing their products.
- They have a better basis for cost efficient use of a more advanced technology configuration; this allow them to co-digest manure with various types of cheap, organic wastes, for instance slaughterhouse waste.
- They function as regional re-distribution centres for livestock manure.
- They avoid that the individual farmer binds more capital in his own production facility.

The drawback of larger livestock manure treatment plants are that transport of biomass to and from the plants become more expensive, and the operational management more complex. Here Morsø Bioenergy has maybe found a good solution in the decentralised separation of the slurry, so only the solid fraction is transported to the biogas plant. Large livestock manure treatment plans also need to comply with requirements for specific technology configuration, for instance reception facilities with air cleaning and facilities for disinfection of vehicles coming in and out of the plant with livestock manure and end and by-products. Additionally, large processing plants have due to their operations larger requirements for official registration and control, for instance in relation to waste regulations.

The ideal size of a livestock manure treatment plant must be evaluated in each case on basis of the decisive parameters, especially the investments and the transport costs, but also taking into consideration

- the requirements for official registration and control, for instance in relation to waste regulations, which favour larger plants;
- the requirements for specific technology configuration, for instance reception facilities with air cleaning and facilities for disinfection of vehicles coming in and out of the plant with livestock manure and end and by-products, which favour farm-scale plants;
- the ability to provide a stable supply of end and by-products, both with respect to quality and amounts, which favour large scale plants;
- the ability to make efficient use of certain technology-components, such as pelletizing, which favour large scale plants; and
- the efficiency of the electricity generation of biogas generators, which favour large scale biogas plants.

From the seven case studies it is with reference to Figure 3.1 not possible to make any firm conclusions about economy of scale. The economy of the case study plants are more a result of the chosen technology configuration than of their size.

However, the slurry acidification technology is only relevant for individual farms as a stand-alone technology; acidification can be part of the configuration of a larger livestock manure processing plant.

3.3: Nature of the investments in manure processing plants

With reference to Table 2.1, the ownership of the seven case plants is divided on 2 co-operatives, 3 private companies, and 2 private persons.

Table 3.3 is elaborated on basis of information in Table 3.1, and shows the treatment costs in relation to the ownership of the installations.

Table 3.3: Net cost of livestock manure processing in relation to the ownership of the installations.

Type of ownership	Number of plants	Average m^3 treated biomass	Net cost of processing, € / m3	
			Excluding subsidies	Including subsidies
Co-operatives	2	250,000	24.22	2.80
Private persons	3	10,906	2.14	1.76
Private companies	2	76,516	8.07	5.91

There is with reference to Table 3.3 a tendency to a better economy in the private person owned plants. However, it is not possible to draw any conclusions as the comparison is based at only a few case study plants with widely different technological configurations.

4: REFERENCES AND FURTHER READING

- Bernet N; Delgenes N; Moletta R (1996). Denitrifcation by anaerobic sludge in piggery wastewater. Environmental Technology, 1996, 17: 293-300.
- Birkmose, T. B. 2010. Økonomisk gevinst i marken ved forsuring af kvæg- og svinegylle, Notat, Dansk Landbrugsrådgivning, Landscentret.
- Bonmatí, A. (2001). Thermal energy uses for the improvement of pig slurry anaerobic digestion and recovery of useful products. PhD Thesis. University of Lleida (UdL). Lleida, July 2001.
- Bonmatí, A., Flotats, X., Mateu. L., Campos, E. (2001). Study of thermal hydrolysis as a pre-treatment to mesophilic anaerobic digestion of pig slurry. *Water Science and Technology*, 44(4): 109-116.
- Bonmatí, A., Flotats, X. (2003). Pig slurry concentration by vacuum evaporation: influence of previous mesophilic anaerobic digestion process. J. Air Waste Manage. 53: 21–31.
- Bonmatí, A., Campos, E., Flotats, X. (2003). Concentration of pig slurry by evaporation: anaerobic digestion as the key process. *Water Science and Technology*, 48(4): 189-194.
- Burton, C.H., Turner, C. (2003). Manure Management: Treatment Strategies for Sustainable Agriculture, second ed. Silsoe Research Institute, Wrest Park, Silsoe,Bedford, UK.
- ECOFYS (2004). Evaluación de las tecnologías de tratamiento y valorización de purines representadas en la ADAP en relación con la emisión de gases de efecto invernadero. Final report, September 2004. ECOFYS, Barcelona, Spain.
- EMEP-CORINAIR (2007). Emission Inventory Guidebook; technical report 16 / 2007. Chapter B111. http: / / www.eea.europa.eu / publications / EMEPCORINAIR5European Commission. 2003. Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs. Integrated Pollution Prevention and Control (IPPC). The European IPPC Bureau. 383 pp.
- Flotats, Xavier, Henning Lyngsø Foged, August Bonmati Blasi, Jordi Palatsi, Albert Magri and Karl Martin Schelde. 2011. Manure Processing technologies. Technical Report No. II concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 132 pp.
- Flotats, X. (2001). Informe sobre àrea de localització idònia de les plantes de tractament de residus ramaders a la zona nord de la comarca de les Garrigues [Report about the optimal localization of the pig manure treatment plants at the North area of Les Garrigues county]. January 15th 2001.
- Flotats, X., Campos, E., Palatsi, J. (2004). Concentración de deyecciones ganaderas mediante procesos térmicos. In *Actas del II Encuentro Internacional gestión residuos orgánicos*. Pamplona (Navarra), 28-29 October 2004
- Flotats, X. Bonmatí, A., Fernández, B., Magrí, A. (2009). Manure treatment technologies: On-farm versus centralized strategies. NE Spain as case study. Bioresource Technology 100: 5519–5526
- Foged, Henning Lyngsø, Xavier Flotats, August Bonmati Blasi, Jordi Palatsi and Albert Magri. 2011. Inventory of manure processing activities in Europe. Technical Report No. III concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 78 pp.
- Foged, Henning Lyngsø, Xavier Flotats, August Bonmati Blasi, Jordi Palatsi, Albert Magri and Karl Martin Schelde. 2011. Inventory of manure processing activities in Europe. Technical Report No. I concerning "Manure Processing Activities in Europe" to the European Commission, Directorate-General Environment. 132 pp.

- Foged, Henning Lyngsø. 2010. Best Available Technologies for Manure Treatment – for Intensive Rearing of Pigs in Baltic Sea Region EU Member States. Published by Baltic Sea 2020, Stockholm. 102 pp.
- Foged, Henning Lyngsø. 2009. Report from visit to Holland. Unpublished.
- Forster, P., Ramaswamy, V., Artaxo, P., Berntsen, T., Betts, R., Fahey, D.W., Haywood, J., Lean, J., Lowe, D.C., Myhre, G., Nganga, J., Prinn, R., Raga, G., M., S., Van Dorland, R. (2007). Changes in Atmospheric Constituents and in Radiative Forcing. In: S. Solomon et al. (Editors), Climate Change 2007: The Physical Science Basis. Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press, Cambridge, U.K.
- Frandsen, Thorkild Qvist and Karl Martin Schelde. 2007. FarmTest: Gylleforsuring Infarm A / S, Bygninger nr. 41, Dansk Landbrugsrådgivning, Landscentret.
- GESFER (2011). Seguiment de tractaments; tractaments individuals. SAT Caseta d'en Grau. Lleida, 2 de febrer de 2011.
- Gonzalo, C. (2004). El sistema de tratamiento de purines ABT-CARBOFIL, un sistema de tratamiento de purines homologado, sencillo eficaz y económico. *Retema* 99, 32-36.
- Gurri, A. (2003). Planteamiento global del tratamiento de purines en granja. *PORCpress* 14, 36-38.
- Hjorth-Gregersen, Kurt. 2002. Status for økonomien i biogasfællesanlæg. Abstract from Report No. 136, Institute of Food and Resource Economics, Faculty of Life Sciences, University of Copenhagen, Denmark.
- IC (2003). Estudio comparative de emisiones de efecto invernadero y de amoníaco asociadas a la gestión de purines. Final report, April 2003. Institut Cerdà, Barcelona, Spain.
- IPCC (2006). IPCC Guidelines for National Greenhouse Gas Inventories. Volume 4: Agriculture, Forestry and Other Land Use; Chapter 10, Emissions from Livestock and Manure Management. Intergovernamental Panel on Climate Change (IPCC).
- Jørgensen, Peter Jacob. 2009. Biogas – green energy, PlanEnergi and Researcher for a Day – Faculty of Agricultural Sciences, Aarhus University, 2nd edition.
- Kai, P., Pedersen, P., Jensen, J.E., Hansen, M.N., and Sommer, S.G. 2008. A whole-farm assessment of the efficacy of slurry acidification in reducing ammonia emissions. Eur. J. Agron. 28:148-154.
- LEA-ABT (2004). Informe d'avaluació del sistema ABT-Carbofil per al tractament de la fracció líquida de purins implementat a Calldetenes (Osona). Lleida-Cerdanyola, 16 de setembre de 2004.
- Loyon L.; Guiziou F.; Beline F.; Peu P. (2007). Gaseous emissions (NH_3, N_2O, CH_4 and CO_2) from the aerobic treatment of piggery slurry - Comparison with a conventional storage system. *Biosystems Engineering* 97: 472-480.
- Magrí, A.; Palatsi, J.; Fernández, B.; Flotats, X. (2007). Pig slurry treatment strategies - dealing with nitrogen management. *In:* Bosch, A.D.; Teira, M.R.; Villar, J.M. (ed.). *Towards a Better Efficiency in N Use.* Ed. Milenio. Lleida, Spain. pp. 457-459.
- OCCC (2011). Guía práctica para el cálculo de emisiones de gases de efecto invernadero (GEI) [Practical guide to estimate greenhouse gases emisión (GGE)], version March 2010. *Oficina Catalana del Canvi Climàtic*, Generalitat de Catalunya, Barcelona, Spain.

- Olesen, J.E. 2008. In 'Landbrug og Klima – analyse af landbrugets virkemidler til reduktion af drivhusgasser og de økonomiske konsekvenser', chapter 6, p. 34. Ministry of Food, Agriculture and Fisheries, Denmark.
- Palatsi, J., Campos-Pozuelo, E., Torres, M., Porras, S., Flotats, X. (2005a). Full-scale combination of anaerobic digestion and concentration by evaporation in Garrigues (Lleida, Spain): evaluation after 2 years of operation. In: Bernal, M.P., Moral, R., Clemente, R., Paredes, C. (Eds.), Sustainable Organic Waste Management for Environmental Protection and Food Safety, vol. II. Murcia, Spain, pp. 155–158.
- Palatsi, J., E.Campos, M. Torres, M. Jiménez, S. Porras, X. Flotats (2005b). Manure management, anaerobic digestion and acidification: key processes for a pig slurry thermo-concentration treatment. Full-scale evaluation. In *Conference Proceedings of the 4th Internacional Symposium. Anaerobic Digestión od Solid Waste.* Copenhagen (Dinamarca), 31 agosto – 2 septiembre 2005. Volume 2, pp 189-194.
- Pedersen, P. 2004. Svovlsyrebehandling af gylle i slagtesvinestald med drænet gulv. Meddelelse nr. 683, Landsudvalget for Svin, pp. 12.
- Personal information. 2011. Mr. Josep Vicens. Apergas CO, Vilademuls (Catalonia, Spain).
- Personal information. 2011. Mr. Kurt Christensen (KC), Næssundvej 234, DK – 7970 Redsted Mors.
- Personal information. 2011. Mr. Mogens Sommer Jensen, Amstrupgårdsvej 40, DK 8940 Randers SV.
- Rajagopal R.; Béline F. (2011). Nitrogen removal via nitrite pathway and the related nitrous oxide emission during piggery wastewater treatment. *Bioresource Technology* 102: 4042-4046.
- Rodriguez, J. (2001). TRACJUSA: Animal litter treatment plant producing biogas with an associated 16.3 MW cogeneration plant in Juneda (Lleida). InfoPower Plant report. Infopower, 34: 19:45.
- Technology Sheet: Acidification of slurry. 2011. Environmental protection Agency, Danish Ministry of the Environment)
- Teira, M.R., Flotats, X. (2003). A method for livestock waste management planning in NE Spain. *Waste Management*. 23(10): 917-932.
- Vanotti, M.B.; Szogi, A.A.; Vives, C.A. (2008). Greenhouse gas emission reduction and environmental quality improvement from implementation of aerobic waste treatment systems in swine farms. *Waste Management* 28: 759-766.

5: ABBREVIATIONS AND ACRONYMS

ABP	Agro Business Park A / S
AU	Animal Unit. Danish coefficient that expresses the nutrient load of livestock. 1 AU = 100 kg N in livestock manure ex. storage = app. 36 produced slaughter pigs from 32 to 107 kg.
BAT	Best Available Technique, as defined in Directive 2008 / 1 / EEC
BREF	Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs
Ca	Calcium - the conversion factor from CaO to Ca is 0.7146.
CO_2	Carbon dioxide
CO_{2e}	Carbon dioxide equivalent. A unit of measurement that allows the effect of different greenhouse gases and other factors to be compared using carbon dioxide as a standard unit for reference. The term is defined and used in slightly different ways in the context of emissions and atmospheric concentrations of greenhouse gases. Methane (CH_4) is 25 times, and nitroux oxide (N_2O) 298 times more powerful greenhouses gases than CO_2.
CPH	Combined Heat and Power
DG ENV	European Commission, Directorate-General Environment
DM	Dry matter
EU	European Union
FAO	Food and Agriculture Organisation of the United Nations.
GHG	Green House Gases - CO_2, CH_4, N_2O and NO_x
GIRO	GIRO Centre Tecnològic
IED	Industrial Emissions Directive 2010 / 75 / EEC
IPPC	Integrated Pollution Prevention and Control, as defined in Directive 2008 / 1 / EEC, now replaced by the Industrial Emissions Directive 2010 / 75 / EEC
IRPP	Intensive Rearing Pigs and Poultry
IRR	Internal Rate of Return
K	Potassium - the conversion factor from K_2O to K is 0.8301.
KC	Manager at Morsø BioEnergy.
Laughing gas	Nitrous oxide, N_2O – a greenhouse gas with a climate impact that is around 300 times that of CO_2
LSU	The livestock unit, abbreviated as LSU (or sometimes as LU), is a reference unit which facilitates the aggregation of livestock from various species and age as per convention, via the use of specific coefficients established initially on the basis of the nutritional or feed requirement of each type of animal (see table below for an overview of the most commonly used coefficients). The reference unit used for the calculation of livestock units (=1 LSU) is the grazing equivalent of one adult dairy cow producing 3 000 kg of milk annually, without additional concentrated foodstuffs. See also http://epp.eurostat.ec.europa.eu/statistics_explained/index.php/Glossary:Livestock_unit_(LSU.
MBE	Morsø BioEnergy
MSJ	Slurry acidification plant near Randers, Denmark.

Mg	Magnesium - the conversion factor from MgO to Mg is 0.6031.
MS	Member State of the European Union
N	Nitrogen
Na	Sodium - the conversion factor from Na_2O to Na is 0.741839763.
NVZ	Nitrate Vulnerable Zone, as defined in Directive 676 / 91 / EEC
OU	Odour Units
P	Phosphorus – the conversion factor from P_2O_5 to P is 0.436681223.
VS	Volatile solids

ANNEX A: MORSØ BIOENERGI / BIOGAS PRODUCTION ON BASIS OF DECENTRALISED SLURRY SEPARATION

A.1: Introduction

Biogas production is a well known technology, having the advantages that

- it recovers renewable energy from wet biomass;
- it increases the bio-availability of the nitrogen in the livestock manure and other organic biomass, whereby more nitrogen is recycled in the agricultural production and less is lost to the environment provided spreading happen when the crops need the nutrients (as principally required by the Nitrates Directive to be introduced in the Member States via Mandatory Measures or Good Agricultural Practices);
- it reduces the CO_{2e} emissions;
- it sanitises the livestock manure; and
- it reduces the smell from storing and spreading of livestock manure.

Most biogas plants based on livestock manure usually receive also inputs from industrial waste or bio energy crops, so to secure the overall economy of the plant.

On the Danish island Mors, the situation is slightly different. The density of livestock production is very high at Mors and, according to Danish legislation farmers must have availability to a certain amount of land related to the size of their livestock production. Consequently, arable land is very expensive to buy or rent. The direct alternative would be to export some slurry (nutrients) out of the island, to other areas with less density of livestock production – but slurry is too expensive to be transported at long distances.

Several farmers found that a biogas plant supplemented with a separation unit could be the best long term solution – even though farmers have to pay a quite expensive membership to join the plant, this solution is economically more attractive than an alternative investment in expensive arable land to secure the livestock production.

A.2: General description of the plant

A.2.1: Plant localization

The Morsø BioEnergy (MBE) plant is located in Denmark (DK) on the small island of Mors in the Liim Fjord at the north-west of Jutland, approximately 100 km west of the city of Aalborg. Mors has an extension of 364 km^2 and a population of 22,000 inhabitants. The main business activities on the island are related to agriculture and farming, and there is a great concentration of especially pig production.

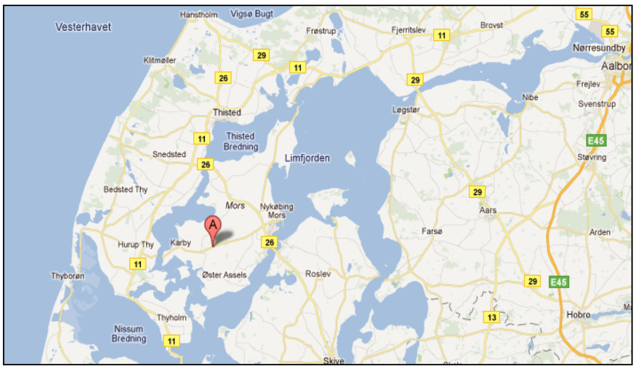
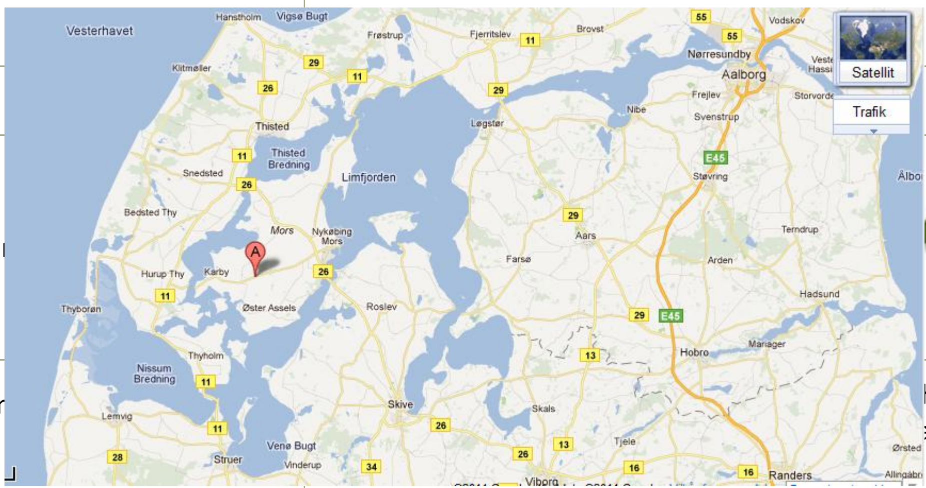


Figure A.1: Location of the MBE plant.

Some further details about Morsø BioEnergy:

Table A.1: Details about Morsø BioEnergy.

Issue	Description
Name and address	Morsø BioEnergy (MBE) Næssundvej 234 DK-7970 Redsted Mors
Tel.	+45 2331 0215
E-mail	
Web	
Design and co	ADAN
Daily manager	hristensen. aff,
Year of start up	2009



A.2.2: Illustrations from the plant

Picture A.1: MBE plant (air view).



Picture A.2: Anaerobic digester (reactor, 7,000 m³).

Picture A.3: Gas storage.

Picture A.4: Storage facility for solid fraction.

Picture A.5: CPH unit.

Picture A.6: Valve pit.

Picture A.7: Central for slurry inflow.

The MBE plant is a centralized plant and, at the moment, is owned jointly by 70 farmers. The farmers are primarily pig producers, but also dairy and mink producers are represented.

A.2.3: The process

MBE is a mesophile biogas plant (homogenised liquid biomass of a constant temperature of 30-45°C) and the input biomass is 100% based on livestock manure from local farmers on the island Mors.

The MBE plant is basically not interested in the possibility to co-digest with industrial waste to boost the gas production, because one of the main reasons to built the plant was the farmers' possibility to export nutrients (N and P) away from the island.

The slurry is separated after digestion; the solid fraction has high concentrations of N and P and can be exported from the isle. Co-digestion with industrial waste would thus just increase the amount of nutrients to export.

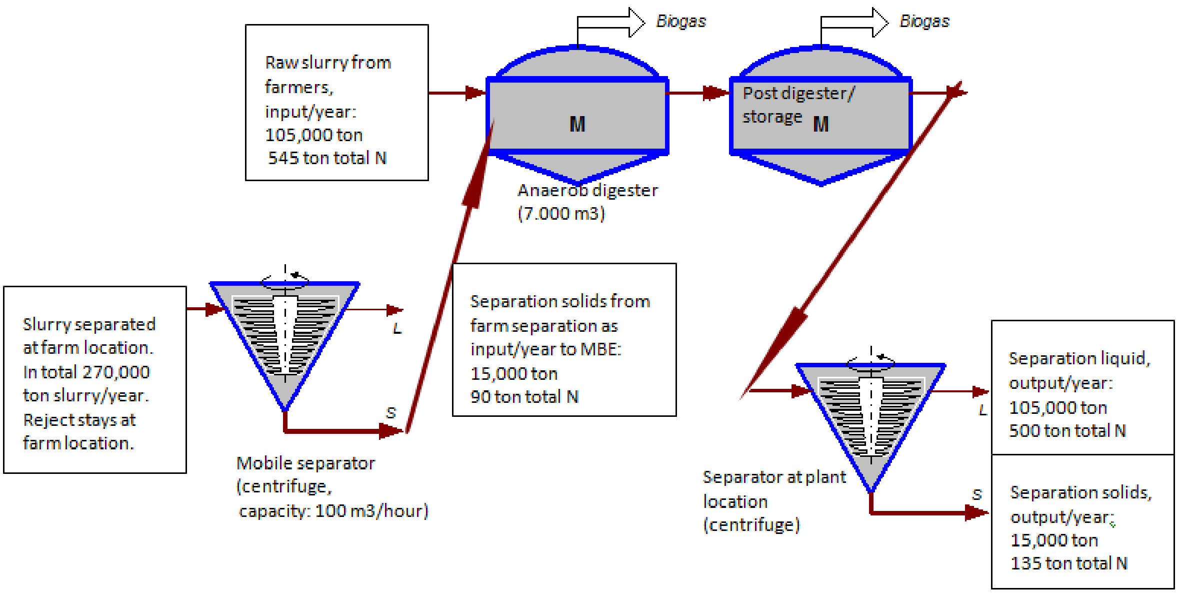


Figure A.2: MBE process diagram.

A.3: Technical data

On year basis the MBE plant treats 375,000 ton of slurry. Slurry is preliminary processed in the farm and separated into a liquid a solid fraction. This means that only the solid fraction has to be transported to the plant. The liquid fraction with very low DM and thereby low gas potential is kept at the farm for fertilizing.

In this way the amount of biomass / slurry to be transported and handled at the plant can be reduced to approximately 120,000 ton of biomass per year (see table A.2).

Table A.2: Capacity and energy production.

	Capacity of MBE
Separated pig slurry for production of influent separation solids	270,000 ton / year
Digested biomass, raw slurry plus separation solids	120,000 ton / year
Biogas production	4,300,000 m3 / year
Power production	10,000 MWh / year
Heat production	8,500 MWh / year

Despite the application limit of 170 kg/ha nitrogen from livestock manure leaving storage per ha as prescribed by the Nitrates Directive, Denmark has in its legislation introduced a limit of only 140 kg N per ha for pig farms, and it should also be mentioned that the entire Denmark is designated as Nitrate Vulnerable Zone according the Nitrates Directive. On this basis, the amount of nitrogen in the solid fraction, which is the end product from the MBE plant, represents an area of 2,500 ha for spreading livestock manure. The MBE plant therefore and in terms of livestock density has the same value for the pig producers at the Morsø isle, as if they could buy additionally 2,500 ha.

A.3.1: Energy balance

The MBE plant has two trucks which in total drives 220,000 km annually, and the consumption of diesel for transport is approximately 90,000 litres per year.

The separation at farm location is processed by MBE itself, by using a special developed mobile separation unit – a big centrifuge separator placed at a truck.

The centrifuge is a GEA Westfalia GEAP 100, and the capacity is 100 m^3 per hour. The mobile separator drives among the MBE-farmers with the longest distance to the plant and separates their slurry, and the solid is then transported to MBE.

Table A.3: Energy balance.

	MWh / year	kWh / m^3 treated pig slurry (375,000 ton / year)
Energy consumption (power)	- 4,200	- 11.2
Diesel consumption (90,000 l diesel, 1 litres = 11.6 kWh)	- 1,044	- 2.8
Energy production (heat and power)	18,500	49.3

	MWh / year	kWh / m^3 treated pig slurry (375,000 ton / year)
Energy balance (net energy production)	**13,256**	**35.3**

The farmer suppliers located closest to the MBE plant delivers the slurry un-separated.

Picture A.8: Illustration of the MBE mobile separator.

As most of the inflow to the plant is received as solid fraction, the plant has an ideal opportunity to optimize the dry matter content in the reactor tank, and thereby optimizes the utility of the plant.

In table 4 the content of nutrients and dry matter in the MBE biomass fractions is shown, and the dry matter percent is higher for the digested slurry than normal raw slurry (approximately 5 - 10 % higher than raw slurry. The dry matter content of the biomass pumped into the digestion tank is higher than normal, i.e. up to 15%, whereas the normal is 8%.

Table A.4: Content of nutrients in MBE biomass fractions (period average).

	Total N, kg / ton	Ammonium-N, kg / ton	Phosphorus, kg / ton	Potassium, kg / ton	Dry matter, %
Digested slurry	7.8	4.1	2.0	3.1	8.0
Solid fraction	10.4	3.9	9.2	3.0	27.8
Liquid fraction	6.8	4.3	0.4	3.1	3.6

A.3.2: Mass balance

The capacity, flow rates and energy balance for MBE is shown in figure A.2.

A.4: Environmental data

There have not been registered or measured airborne emissions from the MBE plant.

The relevant nutrients in the fractions can be seen in table A.4.

There are no data available for TS, VS, COD, NTK and heavy metals. Though, heavy metals are checked by the public control once a year and the levels have been below the limits for compost[1] according to Danish legislation.

The biogas process contributes positively to the reduction of greenhouse gas emissions in comparison to the reference situation: spreading of the slurry without treatment. According to Danish calculations, digestion of pig slurry contributes with 29.9 kg CO_{2e} per m^3 slurry, see table A.5.

Table A.5: Reduction of green house gases by biogas production from pig slurry (from Olesen et al., 2008).

Source	Kg CO_2-eqv. per m^3 slurry
Methane (storage)	24.2
Nitrous oxide (storage)	8.0
Nitrous oxide (in connection to field application)	2.5
Methane from biogas plant (loss)	- 4.8
Total	29,9

Table A.6: Reduction of green house gases, total for MBE.

(Data per m^3 slurry from table A.5 (pig slurry))	Reduction of GHG Ton CO_{2e}	
Source	120,000 ton	270,000 ton[2]
Methane (storage)	2,904	5,227
Nitrous oxide (storage)	960	756
Nitrous oxide (in connection to field application	300	236
Methane from biogas plant (loss)	- 576	- 1,037
Total	3,588	5,182[3]
Total reduction for MBE plant	**8,770**	
Transport (220,000 km / year)[4]	- 149	
Power consumption (4,200 MWh / year)[5]	- 2,100	

[1] A part of the separation solids from the plant is sold as compost, although no controlled composting process happen on the MBE plant.

[2] The amount of farm separated slurry, where the solid fraction is transported to the MBE plant.

[3] Due to separation efficiency of 80% for dry matter and 35% for nitrogen, the CO_2 effect is reduced to 80 % for methane, and 35% for nitrous oxide (Olesen et al., 2008).

[4] The CO_2 impact of truck transport is 675.27 g CO_2 / km (OCCC, 2011).

GHG balance for MBE plant	**6,521**
GHG balance for MBE plant, kg CO_{2e} / m^3 influent	**17.4**

It is considered, that the bioavailability of the nitrogen in the digested slurry is increased with 10%, which in this case (the total amount of treated nitrogen is 635 ton – see Figure A.2) is equal to 63,500 kg N or 0,169 kg N per m^3 influent, which additionally is re-circulated in the crop production, rather than being lost to the nature.

A.4.1: Odour

Odour from livestock manure is complex and based on a large number of chemical compounds, of which the most important comprise ammonia (NH_3), hydrogen sulphide (H_2S), trimethyleamine ($N(CH_3)_3$), and methanethiol (CH_4S). Odour is measured in odour units (OU).

A number of odour compounds in the slurry are broken down in the biogas process, but others are formed in their place. The number of odour units (OU) is therefore often just as high above digested slurry as it is above untreated slurry. There is, nevertheless, a marked difference when the slurry is applied. The odour is not as strong and pungent from digested slurry as from raw slurry, and it also disappears faster from a fertilised field, partly because the digested slurry percolates faster into the soil due to its lower DM content.

MBE plant has not had any serious trouble with odour at the plant location.

A.5: Economical data

A.5.1: Investment

The MBE plant was built in 2008-2009; investments are listed in table A.7.
The financing of the investment is mainly based on loans at two local banks (80 % of investment). 10 % is capital from the farmers and the rest is a subsidy from the Danish Energy Agency.

Table A.7: Investment categories of the MBE plant.

	Without subsidies	With investment subsidy
	1,000 Euro	
Biogas plant and locality	5,600	5,600
Heat and power unit	1,500	1,500
Transport and separation unit	1,200	1,200
Financing and start up	500	500
Counsel and advice	700	700
Various investment costs	250	250

[5] The CO_2 impact of 1 kWh electrical power is 0.5 kg CO_{2e} in Denmark - http: / / www.goenergi.dk / forbruger / alt-om-energiforbrug / miljoe / elforbrug / fakta-om-co2-og-el

	Without subsidies	With investment subsidy
	1,000 Euro	
Investment subsidy from Danish Energy Agency	-	800
Total investment	**9,750**	**8,950**
Depreciation, 6,75%, 15 years	658	604
Real interest rate payment, 3.25%	317	291
Maintenance, 2.5%	244	224
Annual capacity costs, total	**1,219**	**1,119**
Annual capacity cost per m^3 treated biomass	**10.16**	**9.32**

A.5.2: Description of model for farmer membership

To be able to deliver slurry to the MBE plant, farmers must pay a membership fee to MBE according to the following model:

- 1 fixed fee of 2,400 Euro annually
- 147 Euro per delivered Animal Unit (AU)[6]

Beyond the membership the farmer must pay for treatment of the delivered slurry. The MBE plant has several options depending of the farmers need:

Table A.8: Options for treatment of slurry.

Options from MBE	Average treatment cost, Euro / ton slurry
Raw slurry collected at the farm, and post-digestion separation liquids returned to the farm	2.0
Raw slurry collected at the farm, and nothing returns	6.4
Raw slurry separated at the farm by MBE, and MBE receives the separation solids	3.1
The farmer separates the slurry, and the solid fraction is delivered to MBE	4.7 (pr. ton solids)

A.5.2: Income and operational costs

The MBE plant has income from its production of heat and power.

[6] An Animal Unit (AU) is a Danish coefficient for the nutrient load of livestock. 1 AU = 100 kg N from storage per year.

The produced power is sold to the electrical net, and the heat is in wintertime sold to the local community CPH station (Sdr. Herred). In the summertime there is a surplus of heat.

Electricity produced at a biogas plant is in Denmark paid with a 10 years guaranteed, and price index regulated price, presently app. 0.10 € per kWh. This is, dependent on the current market price, around twice the market price of electricity.

Table A.9 shows the allocation of the income.

Table A.9: Income categories.

	With subsidies	Without subsidies
	1,000 Euro / year	
Power sale	1,000	500
Heat sale	400	400
Total income	**1,400**	**900**

The following Table A.10 lists the operational costs of the plant.

Table A.10: Operational costs categories.

	1,000 Euro / year
Energy consumption	400
Transport (incl. diesel)	760
Payroll costs	380
Material consumption	80
Total operational costs	**1,620**

Table A.11 provides an overview of the total economy of the MBE plant.

Table A.11: Net costs.

	With subsidies	Without subsidies
Net cost / unit	Euro	
Capacity costs	1,219,000	1,119,000
Operational costs	1,620,000	1,620,000
Income	1,400,000	900,000
Net costs, total per year	1,439,000	1,839,000
Net cost at 375,000 ton treated slurry and separation solids per year, Euro / m^3	3.84	4.90
Net cost at 635,000 kg N-total treated per year, Euro / kg N-	2.27	2.90

total		

A.6: Social aspects

MBE plant has experienced a few complaints from neighbours, due to smell, but there is a good dialog, and the MBE does not expect serious problems.

The effect on the local job situation at the island can in best case scenario be positive, because the MBE plant gives farmers with an intensive livestock production a possibility to keep on going, and it is well known that farmers create jobs in the downstream industry - such as slaughterhouses, dairies, machine industry, service trade etc.

A.7: Other

Calculations for Danish biogas plants show an average production of 22 m^3 biogas per ton of slurry (containing in average 6% dry matter).

The anaerobic digestion process converts the main part of the organic bound nitrogen into ammonium, and thereby the concentration of ammonium in digested slurry is increased op to 20 % compared to undigested slurry. This affects the bio-availability (also called field effect) of the nitrogen: Field trials performed by the Danish Agricultural Advisory Service have proven 17-30% higher field effect of N in digested slurry, compared to non-digested slurry – however, the increase of the field effect is higher for cattle slurry than for pig slurry, wherefore we in this report assume 10% increase of the bio-availability. The digestate is more homogenous, e.g. less lumpy, nutrients more evenly spread out, making the digestate easier to seep evenly into the crop root area which enable better nutrient uptake from crops.

A.8: Summary

The Morsø BioEnergy (MBE) biogas plant at the island of Mors is a new built plant from 2009. The plant is using new and well proven technology and is the only plant in Denmark producing biogas based on livestock manure alone.

MBE plant treats 120,000 ton of livestock manure per year, but by using a concept where a mobile separator separates some of the farmers' slurry on the farm location and only transports the solids fraction to the plant, MBE treats dry matter from in total 375,000 ton slurry / year.

The biogas production from MBE (4,300,000 m^3 / year) is utilized as heat (8,500 MWh / year) and power (10,000 MWh / year). The heat is sold to local community CPH station (primarily wintertime).

Table A.13: Technical, economical and environmental key performance of the Morsø BioEnergy biogas plant.

Issue	Parameter value
Technical performance	
Major processing technologies	Anaerobic digestion and separation
Mass balance	
Influent, m^3 per year	375,000
▪ Pig slurry	375,000
End and by-products, ton per year	

Issue	Parameter value
▪ Separation solids	15,000
▪ Separation liquids	105,000
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	14
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	49,3
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg / m^3 treated	- 0.169
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	- 17.4
Economical performance	
▪ Net cost of processing, € / m^3	3.84
▪ Net cost of processing, € / kg N_{total}	2.27
▪ Net cost of processing excluding subsidies, € / m^3	4.90
▪ Net cost of processing excluding subsidies, € / kg N_{total}	2.90

ANNEX B: SLURRY ACIDIFICATION, NEAR RANDERS

B.1: Introduction

In recent years there has been increasing focus on reducing the impacts of livestock production near sensitive natural habitats such as heaths, raised bogs and grassland.

Environmental schemes, tightened in Denmark from 1 January 2007, establish general requirements for reduction of ammonia emission from expanding livestock productions, demanding farmers to use certain Best Available Techniques (BAT's), as cover of slurry tanks, which cannot be built closer than 300 metres to particularly sensitive habitats. Slurry tanks containing slurry which has been acidified or where other measures have been taken to reduce ammonia emissions are excluded.

Against this background, Mogens Sommer Jensens decided to invest in slurry acidification in order to obtain an environmental approval of his pig production unit.

B.2: General description of the plant

B.2.1: Plant localization

Infarm A/S has developed a facility that acidifies the slurry by adding concentrated sulphuric acid under controlled conditions. When the slurry pH is lowered to approx. 5.5 the nitrogen is mainly bound in the slurry rather than evaporated.

The reduced ammonia volatilization means that any nitrogen sensitive natural areas around livestock production suffer less N precipitation.. At the same time the acidified slurry contains more nitrogen and thus has a higher fertilizer value beneficial to the plant production.

The slurry acidification unit is installed at Mr. Mogens Sommer Jensens (MSJ) farm, located near the city of Randers (eastern Jutland, DK), and he has invested in an acidification plant from the Danish company Infarm A / S.

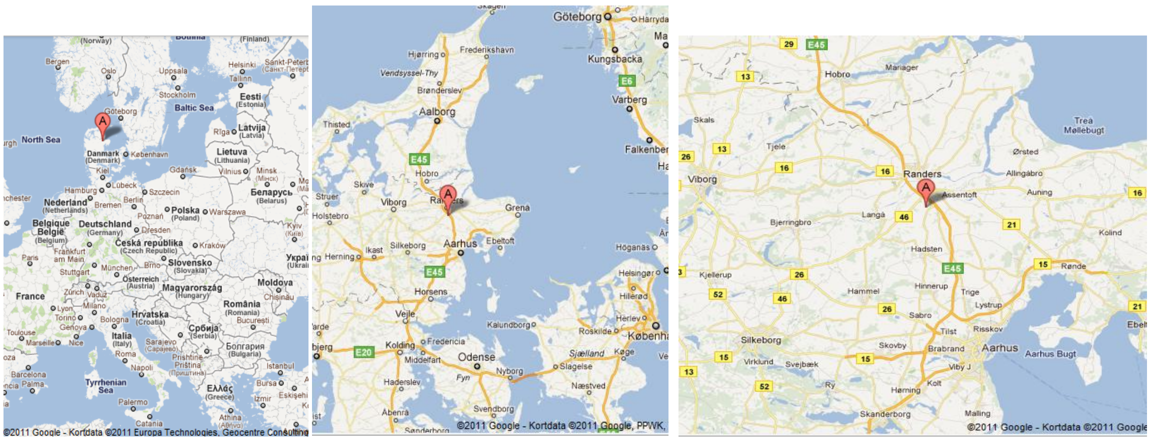


Figure B.1: Location of Mogens Sommer Jensens (MSJ) farm.

Some further details about the slurry acidification unit follows in Table B.1:

Table B.1: Details about the slurry acidification unit.

Issue	Description
Name and address	Mr. Mogens Sommer Jensen Amstrupgårdsvej 40 DK 8940 Randers SV
Tel.	+45 8644 7159
E-mail	engelsholm@post.tele.dk
Web	-
Design and construction	Infarm A / S Systemvej 6 DK – 9200 Aalborg SV www.infarm.dk
Daily management of the plant	The acidification plant is operated by the owner, Mr. Mogens Sommer Jensen (MSJ). The farm of MSJ consists of pig production (500 sows with piglets and 14,000 fattening pigs) and 540 hectares of arable land. The plant is treating slurry from 380 AU (Animal Units), equal to around 10,000 m^3 of slurry.
Year of start up	2006

B.2.2: Illustrations from the plant

Picture B.1: Acid tank

Picture B.2: Valve pit

Picture B.3: From left: Acid tank, process tank and a look in the valve pit.

Central parts of the acidification unit consist of:

- Acid tank, where sulphuric acid is stored and where it is dosed into the slurry.
- Process tank where slurry and acid are mixed and where aeration takes place.
- Technical well, which is the hub of slurry pipes between stables, process tank and storage tanks and where the compressor is located.

- Unit control system where the actual pH in the process tank can be read. Typically, the control system is located in an office or smaller room in connection to the stable. On new installations, there is a PC-based management system with improved opportunities for monitoring and ongoing storage of various operating data.

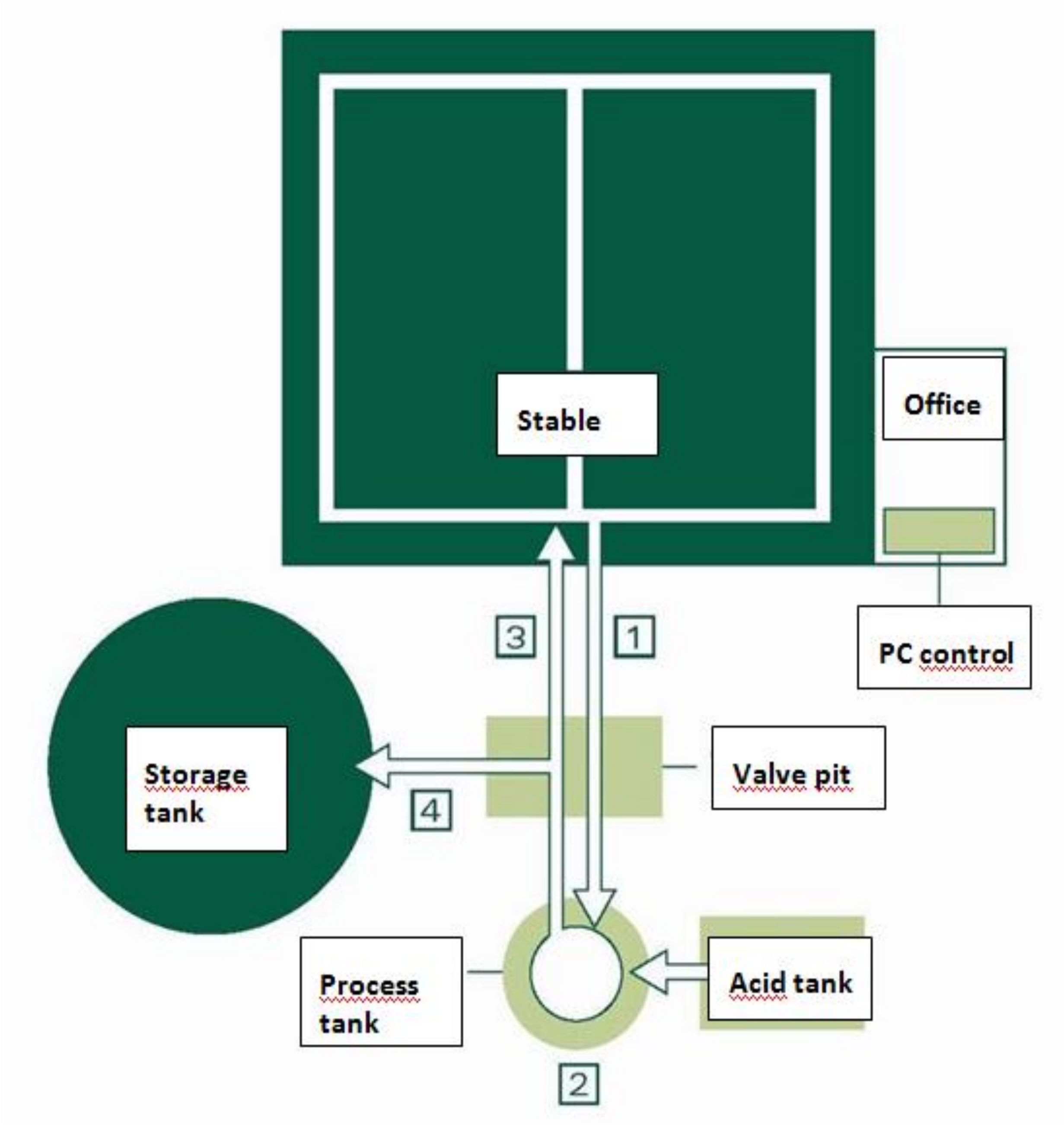


Figure B.1: Organisation of the slurry acidification plant.

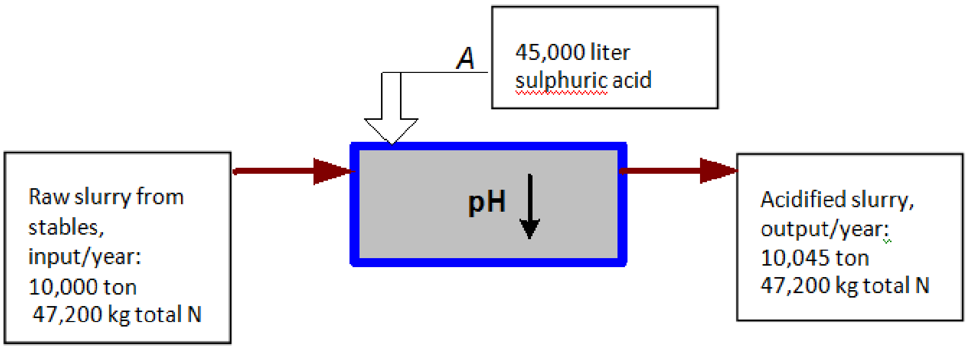


Figure B.2: Slurry acidification plant diagram.

B.3: Technical data

B.3.1: Process description

Addition of acid to the slurry causes a decrease of the slurry pH, whereby the slurry content of ammonia nitrogen is increasingly transformed into ammonium (NH_4^+) which does not evaporate. The addition of 5-7 kg concentrated sulphuric acid (H_2SO_4) per 1,000 kg livestock slurry decreases the slurry pH from approximately 7.0 to between pH 5.5 and 6.0.

For not having to acidify all the slurry at the same time, the total housing facilities are divided into several sections. Acidification of a section starts by pumping manure from the section to the process tank. The pump starts automatically, triggered by the slurry level and the pH.

In the process tank sulphuric acid is added to lower the pH. Adding of acid is done during stirring combined with aeration, i.e. air is pumped into the slurry. The pH is continuously measured as a control function to secure the pH is correct.

After acid addition the main part of the slurry is pumped back to the respective stable section, while the rest is pumped into the storage tank.

Typically slurry from a section is treated from 1 to 3 times a day.

In the process tank and at various locations in the housing sections electronic level sensors are placed to ensure the right level of slurry in the sections. Level sensors are placed at the storage tank as well. In general the plant is equipped with various alarm functions, enabling the plant to stop if an error occurs.

The acid tank is secured with an integrated capture unit with sight glass, which makes a possible leakage observable. The tank is equipped with an electro-mechanical volume meter, ensuring that the content of sulphuric acid can be read. Furthermore the tank is equipped with a built-in air dryer, and a valve secures that no condensation of water occurs. The acid addition is controlled and pH meters continuously cleaned with dried air, so the system works regardless of outdoor temperature.

B.3.2: Mass balance

The mass balance of an acidification plant is quite simple – the plant doesn't change the amount of slurry of the farm, but lowers pH by adding acid.

Table B.2: Input and output flow.

Fractions	Input	Output
Raw slurry (ton / year)	10,000	10,000
Raw slurry (kg N / year)	47,200[7]	47,200
Sulphuric acid consumption, kg / year	45,000[8]	45,000

Due to no lack of relevance, there has not been registered or measured TS, VS, COD, NTK, P, K or heavy metals from the slurry acidification plant.

Effect of the reduction of ammonia emission is based on scientific experimental data from this exact type of Infarm acidification plant.

pH is measured continuously (automatically) to secure the pH is lowered in a correct way.

B.3.3: Energy balance

The slurry acidification plant is not producing any energy

The acidification plant uses electricity for pumping slurry between stable sections[9] and the process tank, and for stirring in the process tank. Electricity is also consumed for the compressor, metering pump, pH meter, control unit, etc. The electricity consumption is of course dependent on the amount of slurry to be pumped, the length of slurry pipes, and the way the stable sections are organised.

MSJ has estimated the electricity consumption at approximately 1,500 kWh per month.

Table B.3: Energy balance.

Energy balance	kWh / year
Energy consumption (power)	18,000
Energy consumption per m^3 of slurry	1.8

B.4: Economical data

B.4.1: Investment

In this case the investment was 80,000 Euro for the acidification unit (year 2005), and additional investments for the extra process tank, pipes, electrical connection, etc. amounted approximately 45,000 Euro. A subsidy from a national state program for environmental technology covered 40% of the investment for the acidification unit, equivalent to 32,000 Euro.

[7] Content of total nitrogen in pig slurry, based on Danish excretion figures

[8] Based on adding 4.5 kg sulphuric acid per ton slurry

[9] I.e. different pig stables or parts of pig stables, which has a closed slurry cleaning system.

Table B.4: Investment costs of the slurry acidification plant.

	Without subsidies	With subsidies
	Euro	
Total investment	**125,000**	**93,000**
Depreciation, 6,75%, 15 years	8,438	6,278
Real interest rate payment, 3.25%	4,063	3,023
Maintenance, covered by service contract – see table B.5.	-	-
Annual capacity costs[10], total	**12,500**	**9,300**
Annual capacity cost per m^3 treated biomass	**1.25**	**0.93**

B.4.2: Acid consumption and costs

MSJ has registered a fairly stable use of sulphuric acid per ton of slurry. The consumption is between 4 and 5 kg per ton slurry.

MSJ informs that his cost for sulphuric acid at the moment is 0.16 Euro per kg acid, though in the last 6 years the price has varied between 0.10 and 0.24 Euro per kg.

Summarized, MSJ has costs for sulphuric acid at approximately 0.72 Euro per tonnes of slurry.

Table B.5: Operational costs categories.

	Euro / year
Energy consumption	1,680
Acid consumption	7,200
Maintenance and service contract	2,870
Total costs	11,750
Total costs / m^3 treated slurry	1.18

B.4.3: Operation time

Acidification will in most cases result in saving working hours due to the automated pumping of slurry. MSJ estimates that there is a net saving working time at approximately 15 minutes a week at his farm.

B.4.4: Acidified slurry: Content of nutrients and field application

A Danish scientific experiment has shown that frequently reduction of pH to below 6.0 in slurry, reduced ammonia emission by 70 % (Pedersen, 2004).

[10] I.e. sum of the above – see also a definition of capacity costs here - http: / / www.investopedia.com / terms / c / capacity-cost.asp#axzz1byEQnHG0

This reduced loss of ammonia will result in higher content of nitrogen in acidified slurry compared to untreated slurry – and thereby a potential higher nitrogen supply for field crops.

MSJ says the higher nitrogen content in the slurry gives an increased yield of 0.2 – 0.3 ton grain per ha due to the acidification of the slurry.

Moreover, the adding of sulphuric acid increases the content of sulphur as a nutrient in the treated slurry, and thereby the MSJ can save on purchase of sulphuric fertilizer.

MSJ informs that he spreads untreated slurry during days with most optimized weather conditions (humid, not windy, no sun etc.), in order to minimize volatilization of ammonia, and then the acidified slurry is spread on days with less optimal weather conditions.

Table B.6: Income categories.

	Theoretical income, Euro / year
Value of higher yields / ha, due to higher N application according to the acidification of slurry (estimation, based on scientific literature and experiments[11], Euro / ton slurry):	1.45
Treated amount of slurry, ton / year	10,000
Total income, Euro / year	14,500

Table B.7: Net costs

Net cost / unit	Without subsidies (Euro)	With subsidies (Euro)
Capacity costs	12,500	9,300
Operational costs	11,750	11,750
Income	14,500	14,500
Net costs, total per year	9,750	6,550
Net cost at 10,000 ton treated slurry per year, Euro / m^3	0.98	0.66
Net cost at 47,200 kg N-total treated per year, Euro / kg N-total	0.21	0.14

The result shows that the acidification technology has low costs, and moreover can contribute with higher income from field crops.

B.5: Environmental data

There has not been registered or measured emissions of CH_4, N_2O and NH_3 from the slurry acidification plant on the farm location of Mr. MSJ. However, scientific experiments verify a clear reduction of ammonia emission from slurry with reduced pH obtained with this type of acidification plant:

[11] Estimation based on Kai et al. 2008, and Birkmose, T. B. 2010. The estimation of 1.45 Euro is a combination of 0.30 Euro / ton in value of extra sulphur fertilizer, and 1.15 Euro value of extra crop yield.

- One experiment has shown that frequent reduction of pH to below 6.0 in slurry, reduced ammonia emission by 70 % from stable sections (Pedersen, 2004).
- Acidified slurry also reduces loss of ammonia during storage. Kai et al. (2008) showed 80% reduction of ammonia emission compared to untreated, uncovered slurry. The reduction was 50% compared to untreated, but covered slurry with a natural established crust.

Finally, acidified slurry contributes to a reduction of the ammonia emission during field application. The accumulated loss of ammonia measured 7 days after application of slurry with trail hoses, showed a reduction of 67% for acidified slurry in comparison to untreated slurry (Kai et al, 2008).

Table B.8: Reduction of NH_3-emissions.

Reduction of NH_3 emissions	Acidified slurry	Reference
Pig slurry	Reduction of emission of NH_3 per m^3 slurry, compared to raw slurry	
Stable	70%	Pedersen, 2004
Storage	50%	Kai et al., 2008
Application	67%	Kai et al., 2008
Estimated total saved NH_3 emission from stable, storage and application, (Kg N / m^3 slurry)[12]	0.75	Kai et al., 2008

As the experiments shows, acidifying of slurry is a suitable technology to reduce ammonia losses and consequently negative environmental impacts near the farm location due to lower loads of N precipitation.

MSJ also mentions that there is a clear effect on an improved working environment inside the stables due to lower content of ammonia in the air.

Concerning odour there is no statistic effect on reduced odour from acidified slurry. In general there are examples of increased odour levels from especially the process tank at the plant (Farm Test, 2007).

MSJ has also observed increased odour levels, but according to him these are occurring during application on the fields.

B.6: Social aspects

Motivation for investment

In this case MSJ made the decision of investing in acidification of slurry on his farm because of environmental legislation in connection with an expansion of his pig production. By investing in acidification technology he could prove a reduction of the potential loss of ammonia from his production to the authorities.

[12] In connection to this, it is assumed that the saved NH_3-N is available as higher N-content in the acidified slurry, corresponding to 7-13% higher N-content than raw slurry (Kai et al., 2008).

Between other types of manure processing technologies, MSJ chose acidification due to his expectation to potential higher nitrogen levels for his field crops.

B.7: Summary

The slurry acidification plant, located in Denmark at a farm belonging to Mr. Mogens Sommer Jensen (MSJ), was established in year 2006.

The acidification plant treats approximately 10,000 ton slurry / year, and prevents emission of estimated 7,500 kg NH_3-N / year, by keeping pH of the slurry below 5.5 to 6.0.

Table B.9: Technical, economical and environmental key performance of the slurry acidification plant.

Issue	Parameter value
Technical performance	
Major processing technologies	Acidification of slurry
Mass balance	
Influent, m^3 per year	10,045
▪ Pig slurry	10,000
▪ Sulphuric acid	45
End and by-products, ton per year	
▪ Acidified slurry	10,045
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	1.8
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	-
Environmental performance	
▪ Net influence on emissions of nitrogen (reduced NH3-N emission), kg N / m^3 treated	0.75
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	-
Economical performance	
▪ Net cost of processing, € / m^3	0.66
▪ Net cost of processing, € / kg N_{total}	0.14
▪ Net cost of processing excluding subsidies, € / m^3	0.98

Issue	Parameter value
▪ Net cost of processing excluding subsidies, € / kg N_{total}	0.21

ANNEX C: CONVERSION TO MANURE CONCENTRATES, KUMAC MINERALEN

C.1: Introduction

The Netherlands has the highest livestock density in the EU, equal to 226 kg N in livestock manure per ha agricultural land in average, and statistics says that in addition to that there is a consumption of 636 kg N per ha agricultural land in the Netherlands (Foged 2009). The following Figure 1 illustrates the situation on basis of figures from 2010.

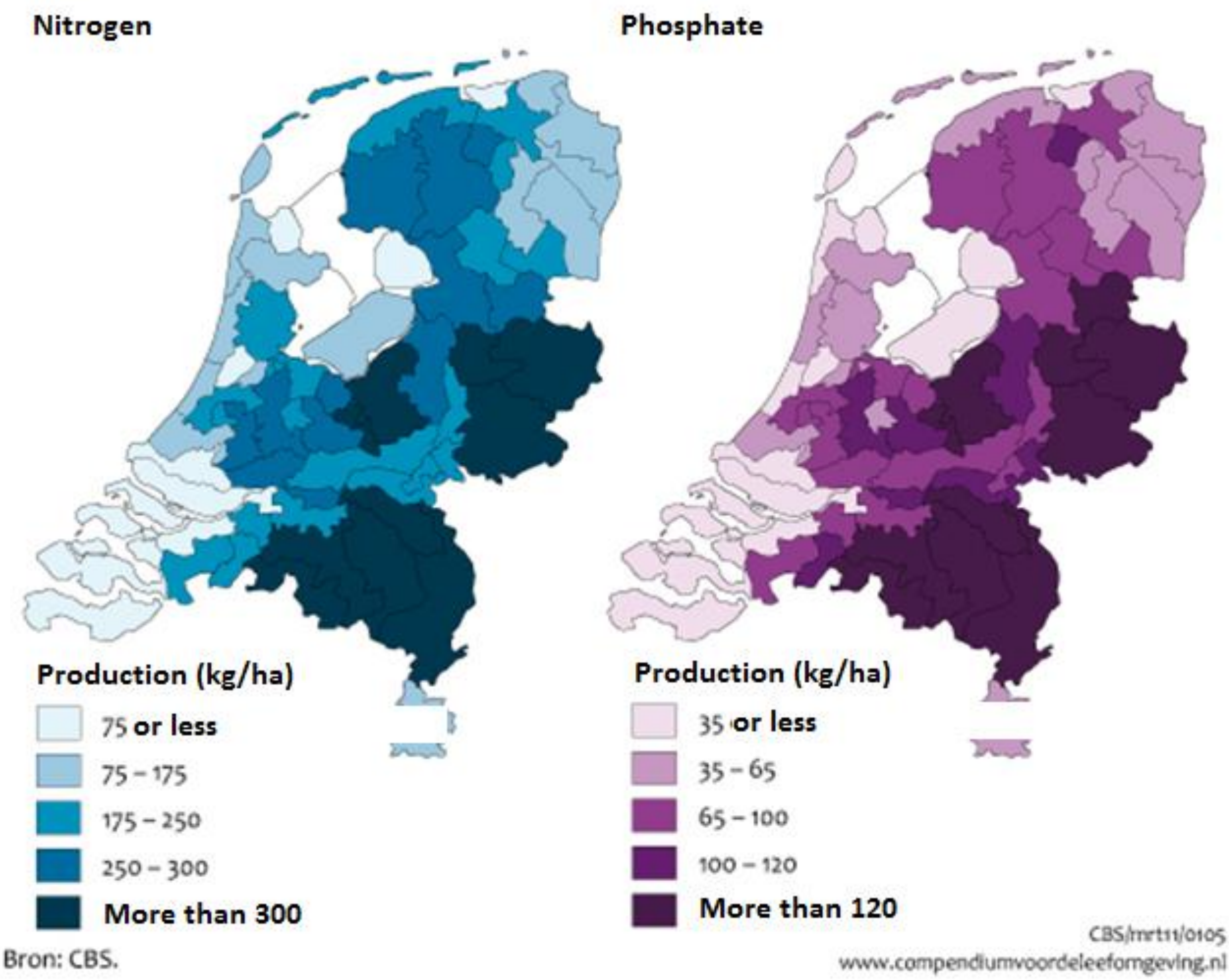


Figure C.1: Production of N and P in the Netherlands distributed regionally.

The situation can only be maintained due to re-distribution and processing of the livestock manure, and because the Netherlands were granted a derogation from the Nitrates Directive, so that the spreading of livestock manure can be as high as 250 kg N per ha on cattle farms that use grazing, under strict conditions which are specified in the derogation decision[13].

[13] Commission decision 2010 / 65 / EU, OJ L 35, 6.02.2010, p. 18

The Kumac Mineralen is established in connection to the machine pool company Loonbedrijf Kuunders, who is involved in the transport business concerning livestock manure and has 10 trucks for that purpose.

Picture C.1: Mr Kuunders runs a large machine pool, among other having 10 trucks for servicing farmers with transport of slurry.

Kumac Mineralen receives around 70,000 tonnes of pig slurry annually from 43 farms in the region. 70% of the received slurry is from production of fattener, the rest from sow units. Farms in the region normally pay 15 - 25 € per m^3 to dispose their slurry; the price is highest in the winter time because the manure then has to be loaded and unloaded (and also sampled / analysed) two times. In the Netherlands, livestock manure can only be spread in the period from 1 February till 1 September, wherefore it has to be kept in an intermediate storage during the winter time. Renting of intermediate storage capacity in the wintertime costs 4-5 € per tonnes (for the whole winter). Typically the slurry is taken to stores or farms in the northern part of Holland (app. 150 km away), while a part is pasteurised and exported, especially to Germany.

It should also be mentioned that the P content in the soils in the region is too high in relation to national legislation, which allow a maximum phosphorus balance[14] of 70 kg per ha.

Loonbedrijf Kuunders is only dealing with field spreading activities in the local area. The received pig slurry holds a dry matter of about 8 %, which compared to pig slurry in many other countries is very high. The reason for this is the widespread use of wet-feeding systems in Holland, whereby dripping from drinking nipples is avoided.

[14] Nutrient balances generally describe the difference between added (through mineral fertiliser, green manure etc.) and removed nutrient (the harvest, for instance grain, straw) from the field in one harvest year.

The establishment of Kumac Mineralen has the purpose to reduce the high costs for disposal of livestock manure in the region.

Picture C.2: Trucks for slurry transport.

C.2: General description of the plant

Kumac Mineralen is situated in the Brabrant region – see figure C.2, which with reference to figure C.1 is one of the most livestock dense regions in the Netherlands. 7 million pigs are kept within a radius of 50 km, in addition to cattle and other livestock.

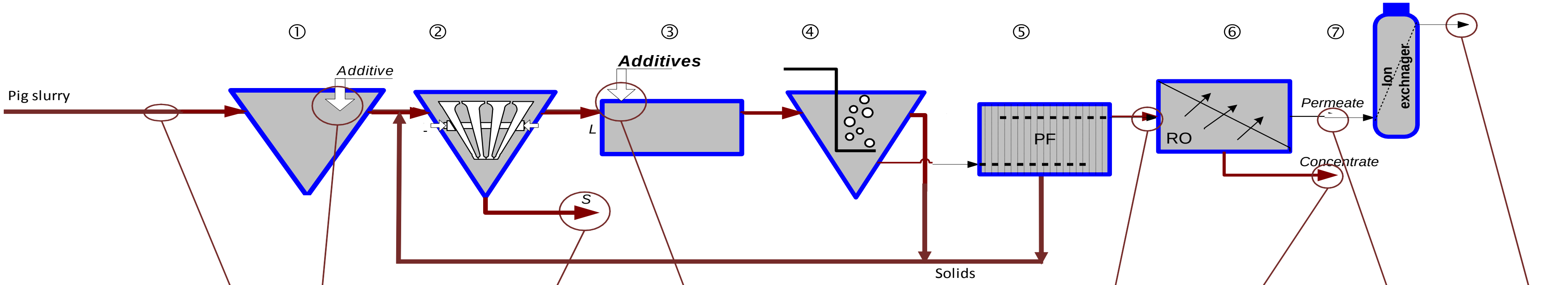
Figure C.2: Kumac Mineralen is located in the Brabrant region at Loonbedrijf Kuunders, Lupinenweg 8A, 5753 SC Deurne, Netherlands.

Some further details about Kumac Mineralen is presented in the following table.

Table C.1: Details about Kumac Mineralen

Issue	Description
Name and address	Kumac Mineralen Lupinenweg 8A 5753 SC Deurne Netherlands
Tel.	Tel: 0493-312721 Fax: 0493-310379
E-mail	info@kumac.nl
Web	http: / / www.kumac.nl
Owners and organisation	▪ Loonbedrijf Kuunders (50%) organises the daily management and the transports in and out of the plant. ▪ Demac (Deurnese Mineralen Afzet Coöperatie) (50%) handles the trade agreements concerning slurry delivery agreements and sale of the products.
Design and construction	Mr Henry van Kaathoven, an engineer that has specialised in manure processing and runs his own company – see http: / / www.mestverwerking.eu. Mr van Kaathoven has since 2006 worked for Kumac Mineralen, and has built up the plant with components from different suppliers.
Daily management of the plant	It is claimed that the daily operation of the plant itself only requires a labour input of max. 1 hour per day. The daily management is coordinated by Loonbedrijf Kuunders.
Year of start-up	2006

The following figure illustrates the configuration of the Kumac Mineralen livestock manure processing plant.



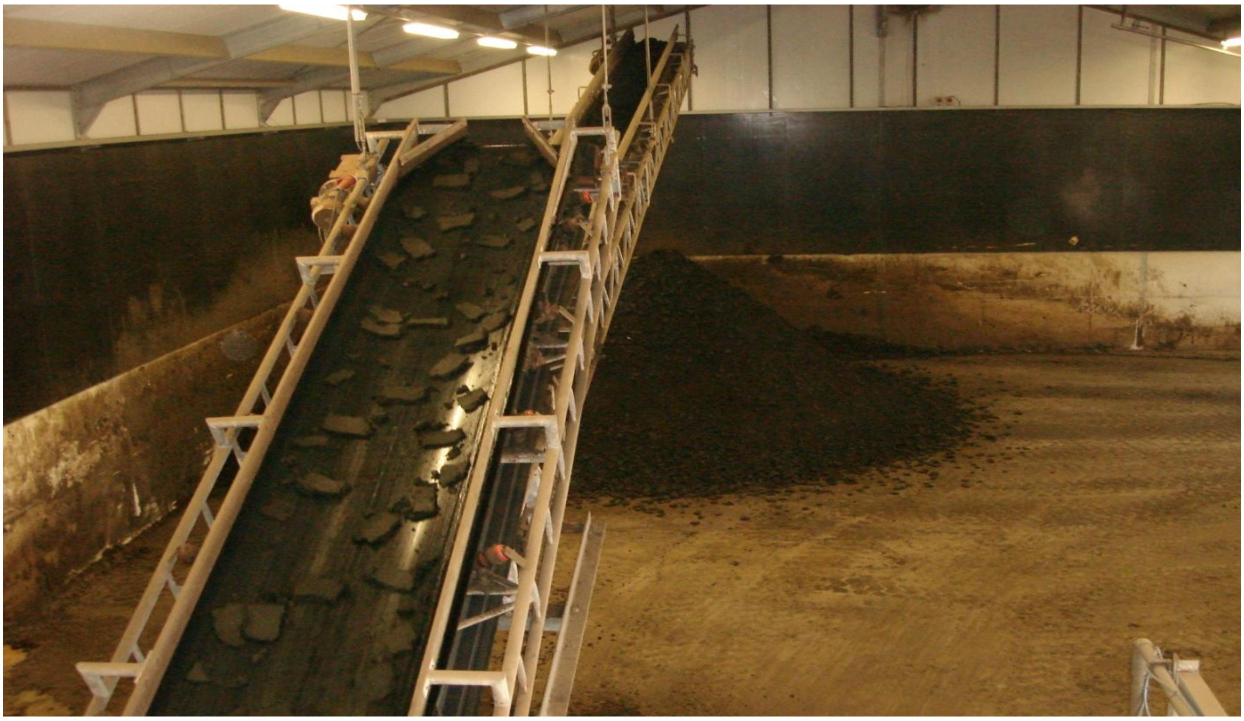
Flow rate, ton/year	80000	9	16002	91		64007	24003	40005	40005
Total solids, ton/year	6314		4910			1403	1389	14	8
Ntotal, ton/year	509		231			277	274	4	
Ptotal, ton/year	134		134			1	1		
Ktotal, ton/year	342		92			250	245	5	
Natotal, ton/year	74		16			58	58		
NH_4^+-N (ammonium), ton/	338		76			262	259	3	1
Crude ash, ton/year	1753		944			809	799	10	
Cl, ton/year	118		115	120	estimated	123	85	38	1
B, kg/year	576		310			266	205	61	36
Ca,kg/year	144800		138935			5865	5669	196	191
Cd, kg/year			< 1			< 1			
Co, kg/year	4		155	*160*	estimated	9	9		
Cr, kg/year	31		31			< 1			
Cu, kg/year	1751		1740			11	7	4	
Fe, kg/year	14040		11155			2885	2842	43	23
Mg, kg/year	75226		55902			19324	19301	24	17
Mn, kg/year	3730		3393			338	338		
Mo, kg/year	38		38			< 1			
Ni, kg/year	43		16			27	27		
Pb, kg/year			< 1			< 1			
S, kg/year	56222		333227	*500000*	estimated	222995	222564	431	42
Se, kg/year			< 1			< 1			
Zn, kg/year	5753		4741			1012	484	528	2
SO42– (sulphate), kg/year	33		440	*1900*	estimated	1493	1484	9	
NO3--N (nitrate), kg/year									
El. conductivity, mS/cm	29					40	39	1	0

Figure C.3: Flow diagram of the processing plant, including mass balance. Incoming pig slurry is processed by the following treatment technologies: 1) Flocculation with use of polymer. 2) Filter belt press, 3) An additive is used, among other to reduce smell. 4) Flotation (using 20 litres of air per m^3), 5) Paper filtration, 6) Reverse osmosis, 7) Ion exchange. Liquids are after de-mineralisation disposed of in the nature. The mass balances are based on 12 analysis datasets provided by Kumac Mineralen, sampled in the period from 25 June 2009 to 27 August 2010.

Picture C.3: Slurry tank for reception of slurry.

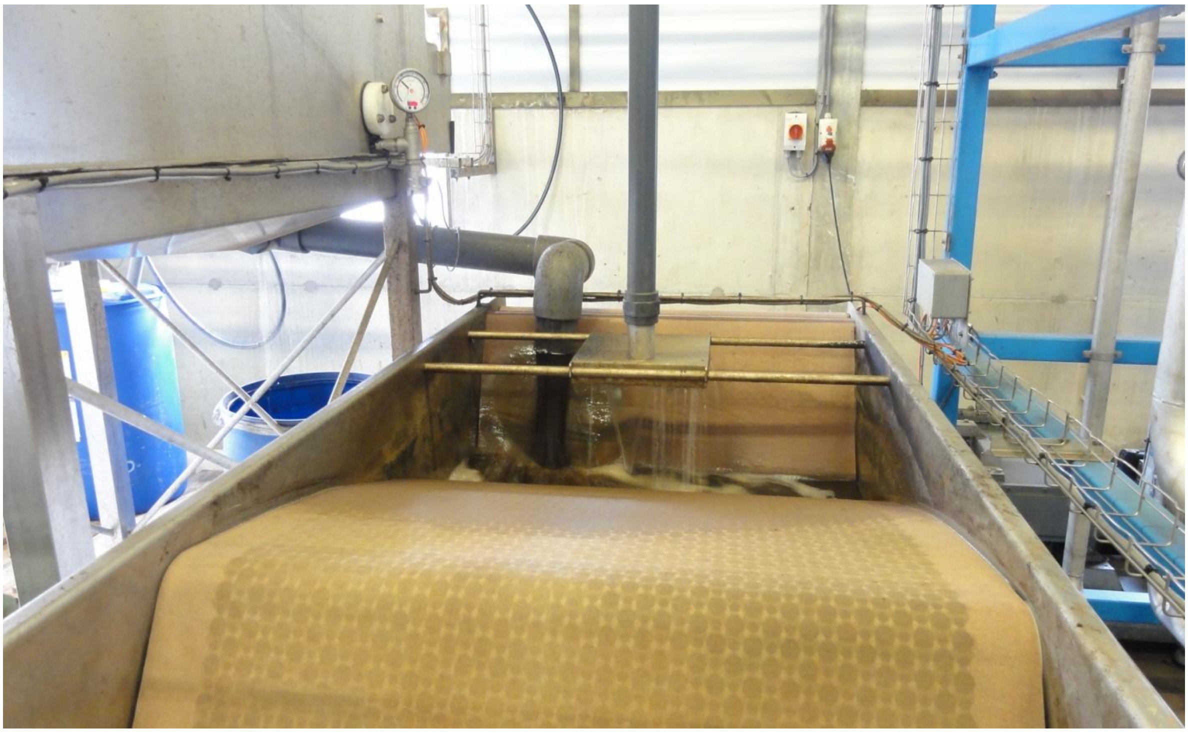
Picture C.4: Separation with filter belt press, after treatment with an additive and a polymer.

Picture C.5: Separation solids are scraped off the filter belt press.



Picture C.6: Separation solids are placed in a roof-covered manure clamp via a conveyor belt.

Picture C.7: Scrapers remove the flotation sludge from the flotation unit.



Picture C.8: The liquid from the flotation treatment pass a filter paper before the reverse osmosis unit.

Picture C.9: Reverse osmosis unit.

Picture C.9: The liquid fraction is de-mineralised in the final step before being deposited in the nature.

Picture C.10: The nitrogen rich fraction is kept in covered storage tanks, and here loaded by a truck. A representative sample is taken during loading.

C.3: Technical data

C.3.1: Mass balance

Figure C.3 shows a flow diagram with the mass balance for the Kumac Mineralen livestock manure treatment plant.

The used additive (see figure C.3) is informed to contain iron (Fe) and has an acidifying effect on the slurry, whereby it reduces evaporation of ammonia, methane and other greenhouse gasses and smelling compounds.

The end products are:

- Roughly 50% of input amounts come out as purified water, which can be discharged in nature – Kumac Mineralen has on basis of analyses been allowed to dispose the water in the nature by the Dutch environmental authorities.
- Approximately 30% of input amounts come out as a liquid fraction holding 7-12 kg N and 7-10 kg K per tonnes. Kumac Mineralen is marketing this liquid end-product under the name Fertraat.
- Almost 20% of input amounts come out as a concentrate from the reverse osmosis. Kumac Mineralen is marketing this under the commercial name Fertex, which they claim is comparable to a 12-17-5 NPK fertiliser.

C.3.2: Energy balance

The livestock manure treatment plant does not produce energy.

Kumac Mineralen informs that the electricity consumption is 9.2 kWh per m^3 treated pig slurry. This is the total energy consumption while consumption for the individual technological processes has not been registered. The energy consumption appears to be low, considering the use of reverse osmosis alone normally consume 1.5 to 10 kWh per m^3 (Flotats et al., 2011).

As the treatment plan, in comparison to the reference situation, saves 816,000 km truck transport per year with an energy consumption of 0.718 kWh / km – see section C.4, there is a saving of 585,888 kWh per year, or a saving of 7,3 kWh per m^3 input slurry.

The net energy consumption is therefore only 9.2 minus 7.3 = 1.5 kWh per m^3 treated slurry.

C.4: Environmental data

There has not been registered or measured airborne emissions from the Kumac Mineralen livestock manure treatment plant. The estimates presented in the following table are based on Flotats et al. (2011).

Table C.2: Environmental data for the livestock manure processing plant of Kumac Mineralen, based on indications by Flotats et al. (2011).

Process	1: Flocculation	2: Filter belt press	3: Adding “pre-polymer”	4: Flotation	5: Paper filtration	6: Reverse osmosis	7: Ion exchange
Estimated CH_4 emissions (kg / year)	-	-	-	-	-	-	-
Estimated	-	-	-	-	-	-	-

Process	1: Flocculation	2: Filter belt press	3: Adding “pre-polymer”	4: Flotation	5: Paper filtration	6: Reverse osmosis	7: Ion exchange
N_2O emissions							
Estimated NH_3 emissions	-	-	-	Would normally be high, but difficult to quantify. It is claimed that the use of a special “pre-polymer” prevents ammonia emissions.	-	-	-
Estimated equivalent CO_2 emissions of greenhouse gases	-	-	-	-	-	-	-
NOx	-	-	-	-	-	-	-
Other	Polymers in the form of PAM (polyacrylamide) may degrade to momomers in the nature and produce toxic, even carcinogenic compounds.	There can be some emission from the store with separation solids, similar to emissions from composting[15].	-	-	Emissions are estimated to be low because of a short exposition of the liquid fraction to the atmosphere.	Emissions are considered to be almost zero because reverse osmosis happens in closed tubes.	

All in all the Kumac Mineralen livestock manure treatment plant is estimated to produce a minimum of emissions, seen from a theoretical point of view. This estimate is also backed by several visits to the plant, giving the impression of a relatively low smell and nuisance level, which is an indicator for the

[15] I.e. ammonia, methane, and nitroux oxide (Flotatas et al., 2011), but this is not measured at this plant, and the emissions might be small as the solid fraction is removed with few days interval.

level of airborne emissions of ammonia and other. The plant is, in line with this, not installed any air cleaning system.

However, in the reference situation, there are transported 80,000 m^3 slurry for 150 km to the northern part of the Netherlands, i.e. 300 km both ways, and as each truck can hold an average of 25 m^3 , which gives 960,000 km of truck transport per year. In the present situation the transport only concerns slurry into the plant (for a distance of approximately 30 km); consequently, transport of slurry to Kumac Mineralen takes 96,000 km per year. Additionally 40,000 ton of separation solids and manure concentrates (Fertraad) is transported back to farms and this require around 48,000 km truck transport. Therefore, in comparison with the reference situation, the Kumac Mineralen treatment plant saves 960,000 km minus 96,000 km minus 48,000 km truck transport per year, equal to 816,000 saved km truck transport per year. A truck has an energy consumption of 0.718 kWh / km (based on OCCC (2011), assuming 11.6 kWh / l diesel), with an equivalent CO_2 emission of 675.27 g CO_2 / km (OCCC, 2011).

This means, that the saved transport saves 551 ton CO_2 emission per year. This is equal to 6.89 kg saved CO_2 per m^3 treated slurry, or 0.92 kg saved CO_2 per kg treated N in the influent. However, as the CO_2 emissions per consumed kWh is estimated to 0.527 kg/kWh[16] and that the Kumac Mineralen plant consume 9.2 kWh electricity per m^3 treated slurry, then the processing increases the CO_2 emissions with 4.85 kg CO_2/m^3 treated slurry. The net influence on CO_2 emissions is therefore a saved emission of 2.04 kg CO_2 per m^3 treated slurry, equal to 0.27 kg CO_2 per kg treated N in the influent.

The noise level inside the plant is quite high, and persons supervising the plant are recommended to wear earmuffs.

C.5: Economical data

C.5.1: Investments

Investments in the plant are made equally by the two owners, Loonbedrijf Kuunders and Demac.

The total investment in the livestock manure processing technology amounts to M€ 1.1. The technology is situated in an un-insulated building of 400 m^2, also containing a 300 m^3 under-floor intermediate store (in 6 compartments) for the concentrate, and an in-house clamp for temporary storage of the separation solids. It is estimated that the building costs at least € 700,000, including building ground, access roads, piping and connections. The building of a separate reception tank for slurry of a size of 2,000 m^3 has cost € 125,000, including cover, reception tank, pipes and pumps.

The gross investment is therefore around € 1,925,000 for the plant with an annual capacity of 80,000 m^3.

The building ground as well as connection roads and connections etc. were already available, therefore there were no extra costs associated to those items.

The following table shows the fixed costs, assuming the above investment prices.

Table C.3: Investment costs of the Kumac Mineralen livestock manure treatment plant.

	Installations in house
Gross investment price, €	1,925,000
Average depreciation time, years	15
Depreciation, % per year of the gross investment	6.75

[16] http://www.carbonindependent.org/sources_home_energy.htm

	Installations in house
Depreciation, € per year	129,937
Real interest rate, %	3.25
Annual interest payment, €	62,562
Maintenance, costs, % of gross investment	2.5
Maintenance costs, €	48,125
Total capacity costs	240,625

C.5.2: Operational costs

The following table shows the operational costs.

Table C.4: Operational costs of the Kumac Mineralen livestock manure treatment plant, based on information provided by Kumac Mineralen.

	Unit	Unit cost, €	Units per year	Total cost, €
Dry polymer	Kg	2.50	9,100	22,750
"Pre-polymer"	kg	0.12	91,000	10,920
Electricity	kWh	0.12	733,333	88,000
Labour	Man-hours	22.5	365	8,213
Transport costs, slurry	ton	2,00	80,000	160,000
Transport costs, end products	ton	2.00	40,005	80,009
Spreading costs, Fertraat	ton	5.00	24,003	120,014
Disposal of separation solids	ton	12.50	16,002	200,023
Total operational costs	€			689,928

The separation solids should theoretically have a value due to its content of plant nutrients and organic matter, but presently Kumac Mineralen pays a biogas plant € 12.5 per ton for taking it, which seems a high price, but it should be kept in mind that there is a high livestock density in the region and that the normal price for disposal of slurry is 15-25 € per ton.

C.5.3: Income

The following table shows the income.

Table C.5: Income of the Kumac Mineralen livestock manure treatment plant, based on information provided by Kumac Mineralen.

	Unit	Unit price, €	Units per year	Total income, €
Fertraat	ton	7.5	25,475	152,850
Total income	€			152,850

C.5.4: Net cost per m^3 slurry and per kg N removed or per kg N recovered and sold

Based on the above, the following table shows the net costs.

Table C.6: Net costs of treating livestock manure at the Kumac Mineralen livestock manure treatment plant.

	€
Capacity costs per year, €	240,625
Operational costs per year, €	689,928
Income per year, €	152,850
Net costs per year, €	777,703
Net costs at 70,000 m^3 treated per year, € / m^3	9.72
Net costs at 509,000 kg N_{total} treated per year, € / kg N_{total}	1.53

The price of 9.72 € / m3 slurry treated at the Kumac Mineralien livestock manure treatment plant is less than half of the normal costs in Brabrant region in the Netherlands for disposal of slurry, which is around € 20 per ton (average for winter and summer). The price of € 1.53 per kg N_{total} for re-circulated nitrogen is comparable to the market price for nitrogen in mineral fertiliser.

The largest challenge for Kumac Mineralen is to realise a higher income from sale of the end-products.

It has to be mentioned that currently concentrates are used above the limit of 170 kg N / ha / year established by the Nitrates Directive, given that their application to land is also part of the above mentioned pilot project, which means that the market value might be higher than if the products fall under the scope of the standard of 170 kg N / ha. According to the directive, processed manure is still considered as livestock manure to which the standard of 170 kg N/ha applies.

C.6: Social aspects

The Kumac Mineralen livestock manure treatment plant is well accepted by the neighbours. There have been problems with smell from the plant, but this problem was solved by use of the self-invented additive, informed to contain iron and have acidifying effect, as one of the first treatments – see figure C.2.

The effect on the local job creation is marginal.

C.7: Other

The Kumac Mineralen livestock manure treatment system is part of a pilot project financed by the Dutch Government and undertaken by Wageningen University, with the purpose to investigate the possibilities for total removal of organic compounds from livestock manure, and thus have end and by-products with characteristic comparable to those of mineral fertilisers.

Henry van Kaathoven, who has developed the livestock manure treatment system for Kumac Mineralen has met a large interests from other investors.

C.8: Summary

Henry van Kaathoven has for Kumac Mineralen developed a livestock manure treatment system, which converts pig slurry into app. 20% separation solids, 30% concentrates, and 50% purified water.

The processing comprise 7 livestock manure treatment technologies, which by various separation and filter technologies splits the slurry in a fraction with high concentration of organic matter, a fraction with high concentration of plant nutrients, and a purified water fraction.

The net cost for the livestock manure treatment is calculated at € 9.72 per m^3 treated slurry, equal to € 1.53 per kg N_{total} in the pig slurry.

The treatment plant thus makes it possible to dispose of pig slurry in a much cheaper way than the normal for the Brabrant region in the Netherlands, which is as high as around € 20 per m^3 for raw livestock manure due to the high livestock density. This is, of course, also influenced by the fact that concentrates are used above the limit of 170 kg N / ha / year established by the Nitrates Directive, given that their application to land is also part of the above mentioned pilot project

The following table summarize technical, economical and environmental key performance of the plant.

Table C.7: Technical, economical and environmental key performance of the Kumac Mineralen livestock manure treatment plant.

Issue	Parameter value
Technical performance	
Major processing technologies	A series of separation and filtration technologies
Mass balance	
Influent, m^3 per year	80,000
▪ Pig slurry	80,000
End and by-products, ton per year	
▪ Separation solids	16,002
▪ Concentrate from reverse osmosis	24,003
▪ Purified water	40,005
Energy balance	

Issue	Parameter value
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	1.5
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	-
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg / m^3 treated	0
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	- 2.04
Economical performance	
▪ Net cost of processing including subsidies, € / m^3	8.07
▪ Net cost of processing including subsidies, € / kg N_{total}	1.27
▪ Net cost of processing excluding subsidies, € / m^3	8.07
▪ Net cost of processing excluding subsidies, € / kg N_{total}	1.27

ANNEX D: NITRIFICATION AND DE-NITRIFICATION (NDN) AT CALLDETENES, SPAIN

D.1: Introduction

Catalonia is a Spanish region with a high concentration of livestock farms with more than 6 million pigs, 0.65 million cows, and 38 million poultry. Generation of livestock manure is about 19 million tons per year, which is equivalent to more than 100 million kilograms of nitrogen per year.

Osona is a Catalan county with one of the highest densities of farming. This fact results in an annual manure production of about 12 million kilograms of nitrogen. Lack of arable land may lead to negative environmental side effects linked to the existence of a nutrient surplus.

In order to improve land fertilization and minimize environmental pollution when applying manure, Decree 220 / 2001[17], Decree 50 / 2005[18] and Decree 136/2009[19] oblige farmers to establish Nutrient Managing Plans (NMP). These plans can be performed individually or collectively. In this context, farmers must design and validate a NMP according to dosage of nutrients applicable to fertilize crops, temporal constrains on the land-application, and manure storage capacity. Enhancements in animal feeding, manure transportation and treatments may be also considered.

When the farmer planned to build on-site the NDN facility, there already existed two centralized treatment plants of manure in Osona, based on thermal drying. However, he declined this option since he estimated that costs of manure transportation plus treatment in such facilities would be higher than the treatment cost linked to the new plant.

D.2: General description of the plant

D.2.1: Location

The treatment plant is located in the municipality of Calldetenes (Osona, Barcelona, Catalonia, Spain). This facility is part of a familiar farm focused on livestock production (Fig. 1-2).

[17] Decret 220/2001, d’1 d’agost, de gestió de les dejeccions ramaderes, modificat pel

[18] Decret 50/2005, de 29 de març, el qual es desplega la Llei 4/2004, d’1 de juliol, reguladora del procés d’adequació de les activitats existents a la Llei 3/1998, de 27 de febrer, de la intervenció integral de l’Administració ambiental, i de modificació del Decret 220/2001.

[19] Decret 136/2009, d’1 de setembre, d’aprovació del programa d’actuació aplicable a les zones vulnerables en relació amb la contaminació de nitrats que procedeixen de fonts agràries i de gestió de les dejeccions ramaderes

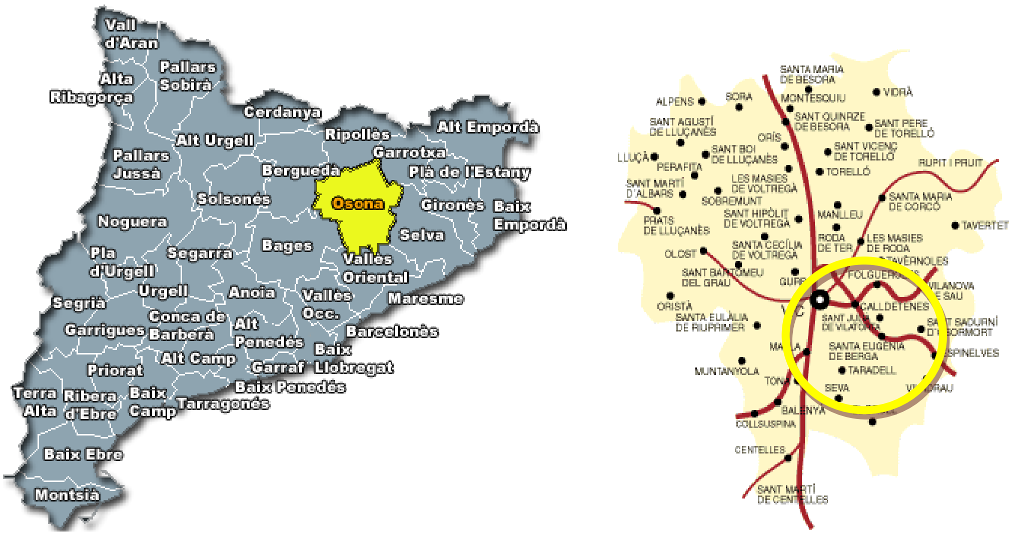


Figure D.1: Views of Catalonia and Osona (Spain).

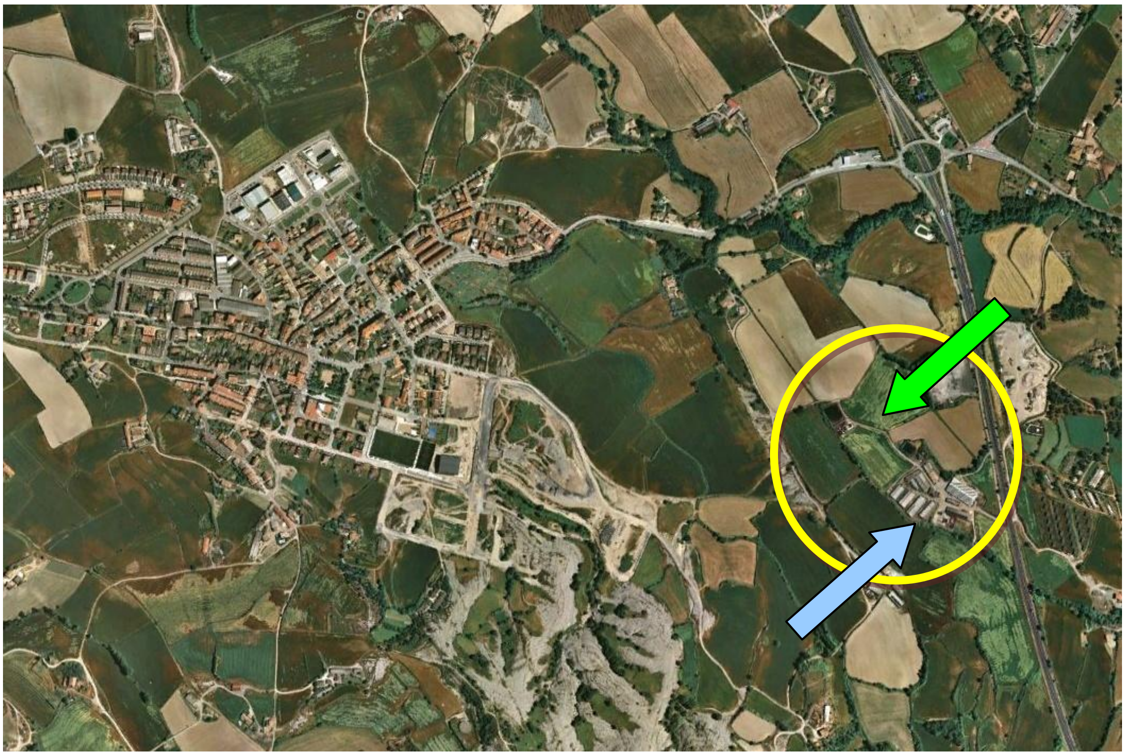


Figure D.2: Location of the treatment plant (green arrow) and the farm (blue arrow), near the municipality of Calldetenes (Spain).

D.2.2: Activity

In this farm there is pig and cattle livestock.

- Swine activity (4.200 heads): It is a sow-herd farm with 450 sows, including piglets and finishing pigs. The estimated amount of pig manure produced is 10,245 $m^{3/}$ year
- Cattle activity (250 heads): Focused on the production of milk. The estimated amount of cattle manure is 1,566 $m^{3/}$ year.

The sum of the two liquid manure flows has an average density of 1,024 kg / m^3 (GESFER, 2011), estimating an annual production of 12,094 tonnes / year (11,811 $m^{3/}$ year)

D.2.3: Companies involved in the construction and the maintenance of the plant

The plant was initially constructed by the Spanish company *ABT, Ingeniería y Consultoría Medioambiental S.A.* using technology of the French company *CARBOFIL* - http: / / www.carbofil.com / . At the moment, the company ABT is not longer active. Some technical staff of that company is now working for the company *EDARMA S.L.* (http: / / www.edarma.es). EDARMA commercializes a modified version of the initial CARBOFIL reactor (patented as EDARAC). EDARMA also provides technical assistance when needed to the farmer.

D.2.4: Operation of the treatment plant

The plant is successfully operating since 2004. The farmer was involved in its construction and start-up, learning about performance issues. The farmer considers the plant easy to manage and he has integrated its operation as a regular task of his work.

D.2.5: Description of the treatment plant

The target of this treatment plant is transferring the surplus of nitrogen existing in the farm to the atmosphere by its conversion to innocuous di-nitrogen gas (N_2). This is a nitrification-denitrification (NDN) facility working under configuration of pre-denitrification (also known as Modified Ludzack-Ettinger -MLE- system) (Figure D.3). Slurry flows through a pipeline from pits built inside farm houses to an outdoors reception tank, being subsequently separated in a solid and a liquid fraction by means of a screw press. The solid fraction is exported to a centralized composting plant (sometimes it is pre-composted in the farm) and the liquid fraction is treated through NDN. N-removal treatment is carried out in two separated tanks. Nitrification occurs in the aerobic reactor, which is the second stage of the system. Preceding the aerobic zone there is an anoxic reactor where denitrification will take place once dissolved oxygen is depleted. Since much of the organic and ammonium nitrogen is converted to nitrate in the aerobic reactor, denitrification will occur due to a nitrified flow recycled back to the anoxic reactor, and where there is also availability of biodegradable organic matter from the raw liquid fraction of pig slurry. The treated effluent is stored in a final lagoon (3,600 m^3) and used for the irrigation of adjacent crops. Although it would be possible to decant the biological sludge contained in the treated effluent, it is not usually done, and the sludge is sent to the lagoon also.

The treatment plant is designed to process 40 m^3 / day of raw slurry (14,600 t / year), and it is processing an average of 32.4 5 m3 / day in the farm, the total amount of slurry produced in the farm. Slurry is separated by means of a screw press unit (FAN Separator, 250 µm screen size, 4.20 kW total power including mixing and pumping), which works discontinuously and is manually operated. Liquid fraction is stored in a regulation tank of 100 m^3 (Ø = 7 m, h =2.6 m) which includes a submersible mixer (2.21 kW) and a submersible pump (1.00 kW). Denitrifying reactor has a working volume of 200 m^3 (Ø = 10 m, h = 2.6 m) and includes a submersible mixer (2.21 kW) and a submersible pump (2.5 kW). Redox potential in this tank is monitored through a specific probe.

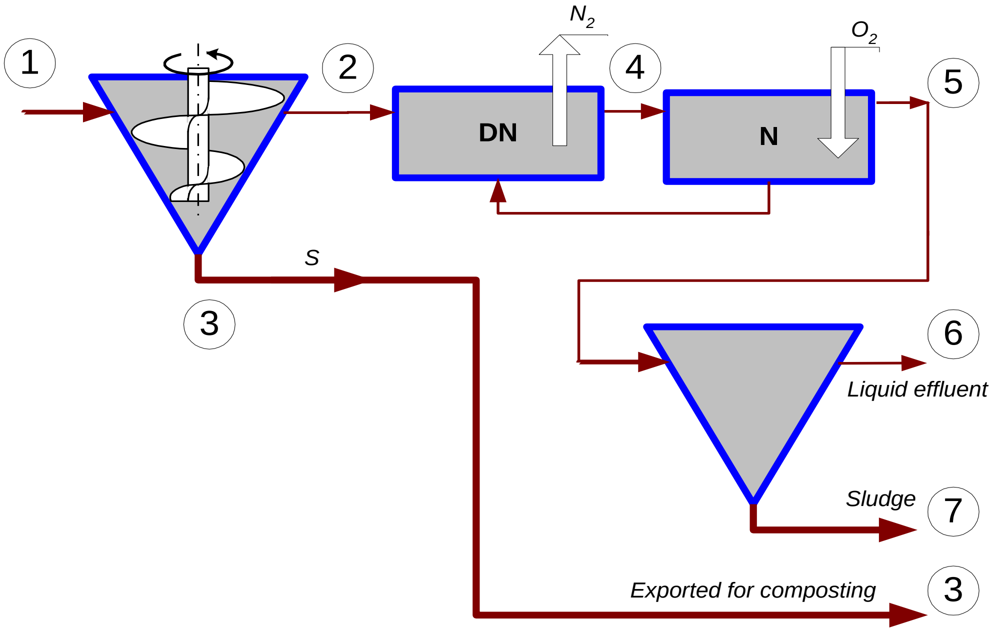


Figure D.3: Diagram of the treatment plant at Calldetenes (Spain).

The nitrifying reactor has a working volume of 240 m^3 (Ø = 6.5 m, h = 7.5 m) and includes a helix aerator (30 kW) controlled through a variable frequency drive and the signal of a dissolved oxygen probe (it also helps in monitoring temperature). Flow meters (n = 3) are installed in the inline and the outline of the anoxic reactor as well as in the outline of the aerobic reactor. Oxygen is absorbed from the atmosphere by Venturi effect, creating a negative pressure on the surface of part of the top layer of slurry in the reactor. This design is thought to decrease significantly NH_3 and N_2O emissions during nitrification.

The settler has a diameter of 3 m, with a height of the cylindrical part of 2m and a height of the conic part of 2.5 m. Total volume of the settler is 18 m^3. Nominal nitrogen loading rate (NLR) of the plant is of 0.25 kg N / m^3 / day, and hydraulic residence time (HRT) of about 12 days (final lagoon not considered). Some descriptive pictures of the plant are shown below (Figures D.4 and D.5):

D.2.6: Descriptive pictures

Picture D.1: Reception tank.

Picture D.2: Screw press separator

Picture D.3: Separated solid fraction

Picture D.4: Separated liquid fraction

Picture D.5: Denitrifying reactor

Picture D.6: Nitrifying reactor

Picture D.7: Settling separator

Picture D.8: Final lagoon

Picture D.9: Aerial views of the pig slurry NDN treatment plant at Calldetenes (Spain) (photo: ABT Ingeniería y Consultoría Medioambiental, S.A.).

D.3: TECHNICAL DATA

D.3.1: Mass balance

Results introduced in Table D.1 correspond to a weekly sampling programme followed during July 2004 (n = 4). Values correspond to averages, and standard deviations are shown between brackets.

Table D.1: Average concentration values obtained by LEA-ABT (2004). Numbers at first row are the sample points indicated in the simplified diagram of Figure D.3.

Parameter	Raw slurry (1)	Liquid fraction slurry (2)	Denitrifying reactor (4)	Nitrifying reactor (5)	Settler separator (6)
pH	8.02 (0.18)	8.08 (0.07)	8.11 (0.17)	8.00 (0.16)	8.03 (0.09)
EC (dS / m)	18.0 (3.3)	18.6 (2.5)	-	-	7.6 (0.8)
Alk ($CaCO_3$) (kg / m^3)	7.8 (0.0)	8.1 (0.7)	2.5 (0.3)	1.8 (0.6)	1.9 (0.7)
TS (kg / m^3)	22.8 (7.0)	22.2 (4.7)	19.6 (1.6)	21.0 (2.0)	7.0 (0.5)
VS (kg / m^3)	14.0 (5.0)	13.2 (3.1)	10.7 (1.0)	11.7 (1.3)	2.33 (0.4)
TSS (kg / m^3)	16.1 (5.7)	15.9 (2.6)	14.7 (1.0)	15.34 (2.5)	1.22 (0.6)
VSS (kg / m^3)	12.2 (4.2)	11.3 (2.3)	10.3 (0.9)	11.1 (1.8)	-
COD (kg / m^3)	23.3 (10.7)	23.0 (8.5)	14.7 (2.6)	15.3 (2.2)	2.4 (0.9)
SCOD (kg / m^3)	5.1 (2.7)	6.4 (3.0)	1.5 (0.4)	1.2 (0.1)	1.3 (0.3)
NTK (kg / m^3)	2.75 (0.66)	2.90 (0.51)	0.97 (0.16)	0.82 (0.19)	0.21 (0.13)
NH_4-N (kg / m^3)	2.03 (0.43)	2.09 (0.30)	0.28 (0.07)	0.10 (0.06)	0.11 (0.06)
NO_2-N (g / m^3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	45 (56)	18 (21)
NO_3-N (g / m^3)	0.00 (0.00)	0.00 (0.00)	0.00 (0.00)	54 (63)	27 (34)
P (kg / m^3)	0.56 (0.17)	0.59 (0.19)	-	0.56 (0.17)	0.15 (0.03)

Based on data obtained by LEA-ABT (2004) and GESFER (2011), and on the estimated total nitrogen excreted by animals in farm, the mass balance of the plant has been estimated as indicated in Tables D.2.

Table D.2: Estimated mass balance of the plant, representative of the average performance of the plant. Numbers in first raw reference the points indicated in Figure D.3.

Estimated Concentrations	units	1	2	3	4	5	6	7	6+7 (after 48 h)
Flow rate	tonnes / day	33.13	31.15	1.99	31.15	31.15	23.15	8.00	31.15
TS	kg / t	35.42	22.20	242.55	19.60	21.00	7.00	59.74	20.54
VS	kg / t	22.72	13.20	171.86	10.70	11.70	2.33	38.80	11.69
COD	kg / t	35.23	23.00	226.8	14.70	15.30	2.40	51.38	14.82

				6					
NTK	kg / t	3.19	2.90	7.75	0.97	0.82	0.21	2.58	0.82
NH_4^+-N	kg / t	2.14	2.09	2.85	0.28	0.10	0.10	0.10	0.10
P	kg / t	0.95	0.59	6.57	0.56	0.56	0.15	1.86	0.59
NO_3^+-N	kg / t	0.00	0.00	0.00	0.00	0.05	0.03	0.00	0.00
NO_2^+-N	kg / t	0.00	0.00	0.00	0.00	0.05	0.02	0.00	0.00
Mass flow rate	**units**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**6+7 (after 48 h)**
TS	kg / d	1,173.65	691.44	482.21	610.46	654.07	162.02	477.95	639.83
VS	kg / d	752.80	411.13	341.67	333.26	364.41	53.93	310.41	364.20
COD	kg / d	1,167.36	716.36	451.01	457.85	476.53	55.55	411.06	461.48
NTK	kg / d	105.73	90.32	15.41	30.21	25.54	4.86	20.68	25.54
NH_4^+-N	kg / d	70.76	65.10	5.66	8.72	3.11	2.31	0.80	3.11
P	kg / d	31.43	18.38	13.06	17.44	17.44	3.47	14.90	18.38
NO_3^+-N	kg / d	0.00	0.00	0.00	0.00	1.68	0.62	0.00	0.00
NO_2^+-N	kg / d	0.00	0.00	0.00	0.00	1.40	0.42	0.00	0.00

According to Table D.1, nitrogen removal efficiency was 90% when comparing raw slurry with liquid effluent after settling, whereas such removal efficiency was of about 70% when comparing liquid fraction of slurry with the mixed liquor (aerated effluent) at the outlet of the aerobic reactor. About 60-65% of the nitrogen initially present in the slurry was estimated to be transferred to the atmosphere (N_2 as the expected form).

Catalan authorities in manure management financed a monitoring campaign (n = 6) elapsing approximately one year of plant performance (2008-2009), especially focused on controlling nitrogen removal efficiencies attained in the plant (GESFER, 2011). The solid / liquid separation unit and nitrification-denitrification (NDN) unit were followed-up with different criteria. The obtained efficiency on solids separation showed a variation coefficient of 55% and the nitrogen removal efficiency of the NDN unit showed variations of 48%. These variations are thought to be due to the elapsed time between sampling, which makes difficult to close the mass balance.

The efficiency and performance of the settling separator is influenced by a non-controlled denitrification process that takes place in it, favoured by an anoxic media, the initial presence of NO_x-N and ready biodegradable COD. LEA-ABT (2004) indicates a fast denitrification of samples taken from points 5 and 6, with a removal of 85% of the NO_4^+-N and NO_2^+-N in 24 h at ambient temperature. Due to the operation difficulties of the settler, it is not usually used nowadays, and the flow that could enter the settler is send to the lagoon. It is considered that oxidized form of nitrogen at the lagoon are fast denitrified, based on the observations of LEA-ABT (2004) and taking into account that the ratio COD / NOX-N is as high as 155. This flow, considering complete denitrification after 48 hours, is estimated in Table D.2, column "6+7 (after 48 h)"; this will be considered the outflow of the NDN unit for further estimations.

The estimated distribution of components is shown in Table D.3. 14.6% of nitrogen is exported and 61.27% is removed, remaining 24.2% at farm. If farm exports the sludge fraction, the total exported nitrogen could be around 39%.

Table D.3: Estimated distribution of mass among: separation solids exported to a composting plant; mass remaining in farm as liquid treated and sludge; and mass removed as consequence of the nitrification – denitrification process.

	Separation Solids Exported (3)		Sludge and Liquid Effluent (6+7)		Mass Removed	
Parameter	Mass / day	% of initial mass	Mass / day	% of initial mass	Mass / day	% initial mass
TS	482.21 kg / d	41.1 %	639.83 kg / d	54.5 %	51.61 kg / d	4.40 %
VS	341.67 kg / d	45.4 %	364.20 kg / d	48.4 %	46.93 kg / d	6.23 %
COD	451.01 kg / d	38.6 %	461.48 kg / d	39.5 %	254.88 kg / d	21.83 %
NTK	15.41 kg / d	14.6 %	25.54 kg / d	24.2 %	64.78 kg / d	61.27 %
NH_4^+-N	5.66 kg / d	8.0 %	3.11 kg / d	4.4 %	61.98 kg / d	87.60 %
P	13.06 kg / d	41.5 %	18.38 kg / d	58.5 %	0.00 kg / d	0.00 %
NO_3^+-N	0.00 kg / d	- %	~0.00 kg / d	- %	~0.00 kg / d	- %
NO_2^+-N	0.00 kg / d	- %	~0.00 kg / d	- %	~0.00 kg / d	- %

D.3.2: Energy balance

Main electrical equipment installed in the treatment plant is listed below (Table D.4).

Table D.4: Electrical devices installed.

Unit	Electrical power
Screw press separator	Mixer (2.2 kW) + pump (1 kW) + separator (1 kW), functioning 8 hours per day
Regulation tank	mixer (2.21 kW) + pump (1.00 kW)
Denitrifying reactor	mixer (2.21 kW) + pump (2.5 kW)
Nitrifying reactor	helix aerator (30 kW) controlled through a variable frequency drive

GESFER measured electrical consumptions of this NDN unit of 3.14 kWh / m^3 slurry treated, which was estimated very low. Considering average time functioning all equipment, an electrical consumption of 15.8 KWh / tonne slurry is estimated (average consumption of 523.5 kWh / day). Energy required for aeration (nitrification) may account up to 80% of the total needs.

D.4: Environmental data

No measurements regarding emissions of greenhouse gases (GHG: CO_2, CH_4, N_2O and NO_x) and ammonia (NH_3) have ever been done in the treatment plant of Calldetenes. Thus, the estimation must be done based on assumptions and on emission factors proposed by IPCC (2006) guidelines and ICCC (2011).

Based on these guidelines, the estimation of net emissions will be done comparing the reference situation with the situation that the plant aims to attain, that will be named as the reference situation.

Recent studies have demonstrated that NDN treatment allows reducing emissions of GHG and ammonia with respect to conventional management (based on 6 months storage before spreading), especially when manure is processed as soon as generated (Loyon *et al.*, 2007). Also trading of GHG emission reductions achieved by means of this kind of processing has been demonstrated as an attractive approach to help producers to implement such on-farm treatment technology (Vanotti *et al.*, 2008).

Reference situation

The farmer considers that the alternative to build the plant was to transport the nitrogen surplus out of Osona county, estimating the distance between 50 and 100 km, after storing during the minimum time regulated depending of crops and climate of the receiving land (4 – 6 months). This scenario is characterized as follows:

- Transport of raw pig manure to 75 km distance is done by a 10 tonnes track, with an equivalent CO_2 emission of 427.04 g CO_2 / km (OCCC, 2011). Track transports pig slurry and return to the farm (2 x 75 km per trip). Manure transported will be considered to be the fraction corresponding to the nitrogen surplus that is exported or removed in the current situation, which is 75.8%. Average pig slurry amounts to be transported are 25.1 tonnes / day.
- Pig manure is stored in farm for 4-6 months in pits under the animal houses, with a CH_4 emission factor of 20%, based on IPCC (2006) and an average temperature of 12ºC.
- Ammonia losses by volatilization during the storage are estimated with an emission factor of 0.4 (Table 10.22, chapter 10, IPCC guidelines 2006).
- Direct N_2O emissions are not considered since manure storage media at farms is anaerobic (EF3=0).
- Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006), that is 1% of the ammonia nitrogen emitted.

Current situation

- CO_2 equivalent emitted due to electrical energy consumption: an emission factor of 181 g / kWh consumed is adopted (ICCC, 2011), corresponding to the Spanish electrical mix during 2010.
- There is a loss of a resource in the current scenario (67.78 kg N / day) and energy should be required to re-produce this resource. Considering a consumption of 80 MJ / kg N fixed from the atmosphere, the energy required to produce the equivalent amount of fertilizing nitrogen is estimated in 22.2 kWh / kg N. With an equivalent emission corresponding to the Spanish electrical mix, the CO_2 equivalent emitted is 260.57 kg CO_2 / day.
- Transport of separation solids to 5 km distance is done by a 7 tonnes track, with an equivalent CO_2 emission of 300.74 g CO_2 / km (OCCC, 2011). The track goes to the farm void and returns to the composting plant after collection (2 x 5 km per trip).
- Methane emissions:
  - The emission factor for the pit storage for less than one month is 3% of the methane potential (IPCC, 2006) of the volatile solids, for 12ºC average temperature.
  - For the final lagoon, considered anaerobic without cover, the emission factor could be 70% of the maximum methane potential (IPCC, 2006) of the volatile solids entering the lagoon. Considering the lower biodegradability of the VS and COD after the NDN process, and the cool temperatures (annual average is 12ºC), a methane potential of

30% of the maximum is adopted. Loyon et al. (2007) adopted a low value of methane potential also, based on the lower biodegradability.

- Ammonia emissions during storage:
    - Average storing time at farm has been decreased from 6 months to 15-30 days, and an emission factor of 0.05 is adopted.
    - Average storage time in the lagoon is 4 months. In this lagoon, an emission factor of 0.4 will be adopted.
- Ammonia emissions during manure processing: same values found by Loyon et al. (2007) are adopted: 28.9 g N / tonne·day of solids separated for a screw press unit and no ammonia emissions during NDN process. Considering a storage time of separation solids of 3,5 days average, the emission is estimated in 201 g N / day.
- Direct N_2O emissions:
- Risk of nitrous oxide emission may exist under certain conditions in an NDN plant, such as deficiency of biodegradable organic carbon during denitrification and inappropriate aeration control. This is not the case when the process is well operated, even when it is orientated via nitrite aiming to the reduction of energy requirements for aeration and carbon consumption during denitrification (Rajagopal and Béline, 2011). The assumptions made for the estimations of direct emissions of N_2O are:
    - Considering the kind of aeration system, by absorption due to Venturi effect, the factor found by Loyon et al. (2007) is adopted for surface aerators (0.03% of the ammonia nitrogen content in the nitrifying reactor) as the maximum value that could be attained. (EF3=0.03% of 3.11 kg NH_4^+-N / day).
    - During denitrification, accumulation of nitrites and nitrates are not detected or are under the detection level, both from measurements of LEA-ABT (2004) and GESFER (2011), being difficult a N_2O emission. Bernet et al. (1996) found that when the ratio organic carbon / NOx-N is higher than 3.4, denitrification usually performs without N_2O emissions. Considering that COD in the denitrifying reactor (4) is maintained high without detectable concentrations of oxidized nitrogen forms, N_2O emissions will be adopted as zero.
    - Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006), that is 1% of the ammonia nitrogen emitted.

D.4.1: Estimated NH_3-N and equivalent CO_2 emissions balance

Based on the assumptions explained previously, the NH3+N and equivalent CO2 emissions are estimated and shown in Table D.4.

Table D.4: Estimated NH3-N and equivalent CO2 emissions of the management system described.

Reference situation	Primary emission	units	Equivalent CO_2 [kg CO_2 / d]
Ammonia emissions	42.29	kg NH_3-N / d	
Transport to 75 km distance	2.83	kg CO_2 / d	2.83
Manure storage at farm	45.39	kg CH_4 / d	1,134.84
Indirect N_2O due to NH_3 emissions	0.66	kg N_2O / d	192.07

Direct N_2O emissions		~0	~0
TOTAL EQUIVALENT CO_2 EMISSIONS			**1,329.74**
Current situation		Primary emission units	Equivalent CO_2 [kg CO_2 / d]
Ammonia emissions during storage in farm	5.29	Kg NH_3-N / d	
Ammonia emissions during storage in lagoon	10.22	Kg NH_3-N / d	
Ammonia emission during processing	0.20	Kg NH_3-N / d	
Total ammonia emissions	15.70	Kg NH_3-N / d	
Electrical consumption	94.75	kg CO_2 / d	94.75
Manure storage at farm	6.81	kg CH_4 / d	170.23
Effluent storage at the lagoon	23.06	kg CH_4 / d	576.48
Transport of solids to 5 km	4.27	kg CO_2 / d	4.27
Indirect N_2O emissions	0.25	KG N_2O / d	71.32
Direct N2O emissions	0.93	g N_2O / d	0.27
CO_2 emitted due to energy consumption for producing the N removed	260.57	kg CO_2 / d	260.57
TOTAL EQUIVALENT CO_2 EMISSIONS			**1,177.89**
Equivalent CO_2 emissions balance			
CO_2 equivalent saved with the current management and treatment system	151.84 55.42	Kg CO_2 / day Tonnes CO_2 / year	
CO_2 equivalent saved per manure unit	4.58	Kg CO_2 / tonne manure	
CO_2 saved per kg N total managed	1.44	Kg CO_2 / kg N_{total}	
CO_2 saved per kg N exported + removed	1.89	Kg CO_2 / kg $N_{exported + removed}$	
CO_2 saved per kg N removed	1.53	kg CO_2 / kg N removed	

With the assumptions explained, the mitigation of equivalent CO_2 in the plant is estimated in 11.4% and the NH_3-N emissions reduction is estimated in 62.8% (-0.8 kg NH3-N / tonne manure). Loyon et al. (2007) estimated a reduction of 55% of CO_2 and 30-68% of ammonia emissions, with NDN plants. In the current situation, if sludge were recovered for compost production, instead of being sent to the lagoon, the CO_2 mitigation factor could increase up to 48.4%. Therefore, current management system of the described farm could be highly improved with the plant adopted, depending on the sludge management.

D.5: ECONOMICAL DATA

The investment initial cost of the plant was approximately 250,000 € (year 2004). GESFER (2011) studied the yearly cost of the plant, considering useful life of the plant to be 15 years, obtaining the values shown in Table D.5.

Table D.5: Summary of the operational costs of the plant.

Item	Separation unit (€ / year)	NDN unit (€ / year)	Plant (sum of separation and NDN) (€ / year)	Distribution of costs (%)
Investment (mortgage)	1,867	18,133	20,000	51.5
Labour costs	1,095	1,095	2,190	5.6
Equipment for moving separation solids	1,170		1,170	3.0
Electricity consumption	767	13,252	14,019	36.1
Maintenance	440	400	800	2.2
Other costs		600	600	1.5
TOTAL	**5,339**	**33,480**	**38,819**	100.0
Economical ratios				
Cost per unit of manure processed			3.21	€ / tonne manure
Cost per unit of N processes			1.01	€ / N_{total}
Cost per unit of N removed and recovered			1.33	€ / kg $N_{recoverd+removed}$
Cost per unit of equivalent CO_2 mitigated			0.70	€ / equiv.CO_2 mitigated

The farmer received a subsidy of 25% of the investment cost in 2004. Considering this subsidy and the consequent decrease on annual investment costs, the annual cost is estimated in 33,819 € / year, that represents an equivalent cost of 2.8 € / tonne manure processed and 0.87 € / kg N total managed.

D.6: SOCIAL ASPECTS

The treatment plant is operated by the farmer. The treatment facility is accepted by the neighbours. There are no problems related with the emissions of smells.

The farmer considers the plant as easy to manage and its operation has been integrated as a regular task.

D.7: OTHERS

In the evaluation made by GESFER (2011), with the monitoring campaign during one year (2008-2009), with 6 samples, the average yearly values considering N concentrations were: N separated in the solid fraction: 13%; N-removal by NDN: 46%; and N contained in the aerated effluent (not settled): 41%. The N removal measured in the sample taken during January 2009 was 25.1%, while the average obtained for the 5 samples taken in the period August-November 2009 was 50.3%, obtaining the lowest value in August (24.2%) and the highest in November (71.9%). These results indicate the sensitivity of the system to seasonal temperature variations, and the need to higher personnel dedication, or higher automation level, for regulation. Increasing the personnel dedication three times for this activity, the operational cost could be estimated 11% higher, till 3.6 € / tonne manure processed.

D.8: Summary

Table D.6. summarizes the main figures describing the Calldetenes plant.

Table D.6: Summary of the main data describing the plant performance

Issue	Parameter value
Technical performance	
Major processing technologies	Separation of solid / liquid fraction, exporting the solid fraction, and nitrogen removal by nitrification-denitrification
Mass balance	
Influent, m^3 per year	11,811
▪ Pig slurry	10,245
▪ Cattle slurry	1,566
End and by-products, tonnes per year	
▪ Separation solids	726
▪ Liquid fraction denitrified	11,334
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	16,2
▪ Net energy production per m^3 livestock manure treated, kWh / m^3	-
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg NH_3-N / m^3 treated	- 0.89
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3	-4.58

Issue	Parameter value
treated	
Economical performance	
▪ Net cost of processing including subsidies, € / m^3	2.86
▪ Net cost of processing including subsidies, € / kg N_{total}	0.87
▪ Net cost of processing excluding subsidies, € / m^3	3.29
▪ Net cost of processing excluding subsidies, € / kg N_{total}	1.01

ANNEX E: COMBINATION ANAEROBIC DIGESTION – EVAPORATION AND DRYING, GARRIGUES, SPAIN

E.1: Introduction

The huge growth of livestock farming in some geographical areas in Spain in recent years, has resulted in surpluses of animal manure, with soils receiving surpluses of nutrients such as phosphorus and nitrogen in these regions, while other areas show nutrients demand. Pig slurry is one of the most problematic types of livestock manure because its high water content and relatively low nutrients concentration. Redistribution of pig slurry between areas with nutrient surpluses and those with shortage is limited by transportation and spreading costs, due to its high water content and its relatively low nutrient concentration.

Water can be removed from slurry by evaporation, through the application of wasted heat from other processes. This removed water can be recovered by condensation. Apart of 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. The existence of a cheap source of heat is the main limitation for the practical application of this process. In this sense, the Spanish *Royal Decree 2818 / 1998 on energy, cogeneration and wastes* established a ”feed-in” tariff per $kW{\cdot}h_e$ generated by cogeneration if thermal energy, wasted heat, is used for reducing the volume of pig slurry, sewage sludge or other organic waste. This is an indirect economical help for CO_2 emissions reduction, nitrogen recovery and energy saving aimed at contrasting high CO_2 and ammonia emissions and high-energy consumption for the long storage time and transporting raw organic waste at long distances for nutrient redistribution. It also promotes the scattered and high efficiency energy production by small combined heat and power (CHP) plants in rural areas. There are other “feed-in” tariffs defined for other waste for decreasing its volume and for which transportation is a management limiting factor. The former *Royal Decree* was updated by the *Royal Decree 661 / 2007* on electrical energy production in special regime. These regulations established a framework for promoting pig manure treatment plants by thermal concentration in high nitrogen surplus areas in Spain, using natural gas as the main fuel by the associated CHP units, limiting the total number of plants by a given total electrical power installed, which was reached on 2010 and no more plants are allowed at this moment.

Nowadays, there are 28 plants in Spain following different schemes (Flotats et al., 2004) for thermal concentrating pig manure, treating around 2.5 Mtonnes pig manure / year and with 369.9 MWH_e total installed electrical power, with specific power values between 4.5 and 16.3 MW_e / plant. The engineering companies that developed the concept, designed the mentioned plants, and in some cases operate them, are grouped in the ADAP association (www.adap.org.es). This association was created on in 2000 in order to promote the technical and environmental quality of the projects and to avoid speculative practices, which were done by companies interested for the potential business that the *Royal Decree* could promote but not specially interested in solving the pig manure surplus problem. The code of ethics of ADAP (Flotats et al., 2004), which every associated company must observe, helped to clarify the market and to avoid projects without economical, technical and environmental feasibility. On 2003 and 2004, ADAP association contracted studies about the potential contribution of the associated plants to the greenhouse gases emissions (GGE) mitigation (IC, 2003; ECOFYS, 2004). These reports concluded an average positive mitigation contribution, being higher if the plants included an anaerobic digestion step and a part of the natural gas consumed were substituted by biogas.

In 1998, the Farmers Association of Garrigues County (Lleida, Spain) and the engineering companies SGt SA (former name of ABANTIA company, www.abantia.com) and SENER, studied the development of a project for the implantation of a plant of this kind in the county, characterized by a nitrogen surplus equivalent to around 220,000 tonnes pig manure per year. These companies contracted the University of Lleida the feasibility studies of the inclusion of an anaerobic digestion step in the flow sheet scheme and the impact of its combination on a vacuum evaporation process, in order to minimize ammonia emissions. These studies (Bonmatí, 2001; Bonmatí and Flotats, 2003; Bonmatí et al., 2003) concluded that the vacuum evaporation process performance, and its previous acidification step, was significantly enhanced by a previous anaerobic digestion. These results have been confirmed during the plant operation (Palatsi et al., 2005a, 2005b). The flow scheme adopted by ABANTIA and SENER companies were patented under the name VALPUREN®.

Nowadays, there are 5 plants in Spain designed by ABANTIA and SENER following “VAPUREN”® process. Three plants are in the LLeida province (Catalonia) and two in the Todelo province (Castilla la Mancha).The first plant on operation, at 2001, was TRACJUSA that is placed at Juneda municipality, Les Garrigues county (Lleida, Spain). In the same county there is another “VALPUREN”® plant (VAG, operative since 2004). At the North, Pla d’Urgell county, another “VAPUREN”® plant (named SAVA) began the operation on 2008. These plants are aiming to concentrate around 330,000 tonnes pig manure / year (110,000 t / y each) into pellets in order to allow the exportation of around 1,300 tonnes N / year to areas with nutrients demand.

The facilities TRACJUSA (acronym of *Tractaments de Juneda SA*) and VAG (acronym of *Valoritzacions Agroramaderes Les Garrigues*) allow treating the slurry surplus generated by 167 farms. The initial weighted average distance between farms and the TRACJUSA facility was 5.6 km, but after the start-up of VAG (2004) and the creation of an integrated nutrient management plan, that joins 196 agricultural farmers, it was possible to optimize transportation distances and costs, decreasing the average distance to 3.8 km to TRACJUSA in 2008. The integration of the centralized treatment plants into a global nutrients management system, combining treatment and soil bank management, is thought to be a key factor for the success of this experience (Flotats et al., 2009).

The TRACJUSA processing plant is based on the combination of anaerobic digestion and a subsequent thermal concentration by vacuum evaporation and further drying. Anaerobic digestion is found to be effective for reducing the need for acid addition, avoiding ammonia volatilization, and for the removal of volatile organic compounds (Bonmatí and Flotats, 2003; Palatsi *et al*., 2005a, 2005b), which allows water condensates reuse and preventing odour problems. An average of 95% of nitrogen (all tests have confirmed values higher than 94%) and all the phosphorous and potassium initially present in the slurry are recovered in the pelletized dried product, which is sold mainly out of Catalonia.

The Farmers Association of Les Garrigues county participates in the company holding which operates these plants, and the respective presidents of both TRACJUSA and VAG companies, are also farmers and the president and vice-president of the farmers association, respectively. Biogas production and economical efficiency depends also on the manure characteristics and, therefore, farmers improved manure management at farm-scale and the transport logistics was improved in order to minimize the storage time in farms before treatment (Palatsi *et al.,* 2005b). Water content of slurry was decreased by controlling drinking troughs and avoiding conduction of rain water to manure storages. Such control resulted in the increase of total solids in the slurry from 4.6% (year 2003) to 5.5% (year 2007) in average, despite of the observation of high standard deviations. In the last six years, the annual average of total solids has been moving between 4.2 and 5.2 %. The optimization of logistics also contributed to this issue, with a statistically significant yearly increase average of the ratio VS / TS (volatile solids versus total solids) from 61.7% (year 2002) to 68.2% (year 2006) as the result of decreasing the storage time in farms (Flotats et al., 2009).

E.2: General description of the plant

E.2.1: Plant localization

The plant is located between the towns of Juneda and Puiggrós, in the North area of *Les Garrigues* county (NE), Catalonia, Spain (NE). *Les Garrigues* county has an extension of over 800 km^2 and an average population of 20.000 hab., mainly dedicated to agriculture (olive, wine and cereals) and farming (piggery at the North where TRACJUSA is located, and bovine at the South).

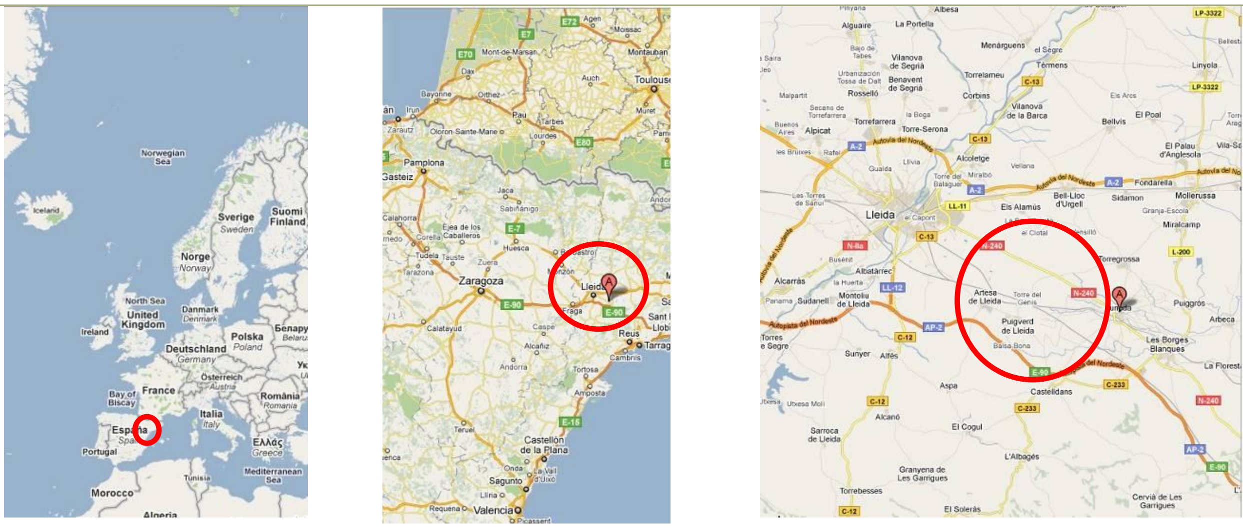


Figure E.1: Localization of the TRACJUSA plant.

The decision about the optimal location of the plants was a result of studies about the geographical distribution of livestock nitrogen production densities in the county (Teira and Flotats, 2003). TRACJUSA is located exactly at 0.76 km of the gravity centre of the livestock production, based on the geographical distribution of farms and its animal production capacity during year 2000 (Flotats, 2001). The location was decided by farmers in 1999, who knew the area and the distribution of routes that optimizes the transport. The active participation of farmers during the project of the plant and subsequent operation is thought to be a successful experience about how to manage these kinds of projects.

TRACJUSA is a legal constituted company, with the following logotype:

TRACJUSA
TRACTAMENTS de JUNEDA, S.A.

Address: Camí de Juneda-Arbeca s / n
E-25430 Juneda, Lleida (Spain)
Phone: +34 973 170 874
Fax: +34 973 170 872
E-mail: tracjusa@tracjusa.com
General manager: Mr. Antonio Badia,
E.mail: antonio.badia@tracjusa.com

E.2.2: Characterization of the farms

TRACJUSA treats the pig slurry generated in about 87 pig farms. The farms are of all types: reproduction farms, feeders and fattening. Consequently, there is a high variability in the slurry characteristics. Table E.1 summarizes the main characteristics of pig slurries sampled during a year (more than 50 samples), from farms that were initially feeding the TRACJUSA plant (adapted from Bonmatí, 2001).

Around 50% of the pig slurry treated is coming from 10 farms. The logistics of transport to the plant prioritizes weekly or bimonthly collection of manure from these farms, in order to maintain an average storage time in farms less than one month. To shorten storage time in farm was reported as a main issue in order to increase the biogas production potential and the economical profitability (Palatsi et al., 2005b).

Farmers providing manure are operating a joint nutrients management plant, lead by the technician of the Farmers Association located at TRACJUSA offices. Manure distribution to the field crops or to the treatment plant (TRACJUSA or VAG) is based in a decision making system defined by seasonal nutrients requirements of the soils belonging to the 196 agricultural farmers and distances from pig farm to crops.

A Geographical Information System (GIS) helps to these objectives. The collective nutrients management plan and the optimization of logistics allowed decrease the initial weighted average distance from farms to TRACJUSA from 5.6 km to 3.8 km at 2008.

Table E.1: Main chemical characteristics of pig slurries initially considered as TRACJUSA inflow

Parameter	Units	Minimum	Maximum	Mean
Total solids (TS)	g / kg	13.68	169.00	62.16
Volatile solids (VS)	g / kg	6.45	121.34	42.33
Chemical oxygen demand (COD)	g / kg	8.15	191.23	73.02
Ammonia nitrogen (NH4+-N)	g / kg	1.65	7.99	4.54
Total Kjeldhal nitrogen(TKN)	g / kg	2.03	10.24	5.98
Phosphorous(P)	g / kg	0.09	6.57	1.38
Potassium (K)	g / kg	1.61	7.82	4.83
Cupper (Cu)	mg / kg	8.94	191.79	39.75
Zinc (Zn)	mg / kg	7.13	130.67	65.71

E.2.3: Companies that designed and built the plant

The engineering companies that designed and built the plant were *ABANTIA Energía y Medio Ambiente* and *SENER Ingeniería y Sistemas*, both Spanish companies based on Barcelona and Bilbao respectively, with some offices around Spain and in several countries.

***SENER** Ingenieria y Sistemas*
www.sener.es

SENER Ingeniería y Sistemas S.A. is an Engineering, Construction and Systems Integration company backed by more than 50 years' experience. Founded in Spain, today the company is an international leader in Civil Engineering and Architecture, Aerospace Engineering, Aeronautics and Vehicles, Actuator and Control Systems, Power and Processes and Marine Engineering.

The company is constituted by more than 2,500 professionals and 13 offices located in Algiers, Argentina, the United Arab Emirates, Japan, Mexico, Poland, Portugal and Spain.

SENER was the company responsible of the project of two plants following VALPUREN® patent at Toledo province (Spain) and currently is taken care of its operation.

***ABANTIA** Energía y Medio Ambiente*
www.abantia.com

***ABANTIA** Energía y Medio Ambiente* is a company belonging to the group **ABANTIA.** The ABANTIA Group is made up of nine companies specializing in different fields of applied engineering. Process system engineering, biogas, waste treatment, cogeneration and trigeneration, and solar energy plants are some of the main business areas of *ABANTIA Energía y Medio Ambiente*.

ABANTIA group has different operational centres, workshops and offices distributed throughout Spain, with some offices at Poland, Italy, Mexico and Abu Dhabi.

E.2.4: Operation of the plant

The plant is operated by a specialized management company, also called TRACJUSA, formed by a multidisciplinary staff (chemical engineers, electricians, mechanicals,…) of over 20 people. The main operational tasks are equipment maintenance (including CHP engines). The plant is fully automated and, consequently, during nights and weekends the supervised activities are performed by only two operators.

The directive board of the company is formed by representatives of the following owners of the company:

- Farmers Association of Les Garrigues (private)
- SENER (private Engineering company)
- EFIENSA –Eficiència Energètica SA (public company promoting energy facilities)
- Gas Natural (private energy company)
- EON (private Engineering and Energy company)

The president of TRACJUSA, Mr. Teofil Camí, is also the president of the farmers association.

E.2.5: Diagram of the plant and description of the process

The plant diagram is quite complex. Figure E.2 shows a simplified scheme of the plant, which is the general scheme of the VALPUREN® system. Although it is simplified, it is useful to understand the importance of the main processes constituting the combined treatment system.

The plant is designed to treat 110,000± 8% tonnes pig slurry / year, with small amounts of organic waste from local food industry for increasing biogas production by co-digestion. Current regulations limit co-substrates to 10% maximum (weight basis), since the “feed-in” tariff to the electrical energy production is aimed to solve the pig manure surpluses problems only, in this geographical area.

Reception

Reception is constituted by 1200 m^3 total volume storage tanks. From these tanks, slurry is pumped to the anaerobic digestion process.

Anaerobic digestion

Anaerobic digestion is operated in two 3000 m^3 concrete continuous stirring tank reactors (CSTR), mechanically stirred and operated at mesophilic conditions with 20 days retention time. The system has a flexible gasholder of 500 m^3 capacity. After anaerobic digestion, digested slurry is conducted to a degassing and buffer tank, mechanically stirred, with a retention time of 8 hours.

Anaerobic digestion has the objective to produce biogas for energy recovery and to decrease easily biodegradable organic matter content. A pH decrease in the further acidification process can ensure a low free ammonia concentration, for avoiding its volatilisation at the evaporation / concentration stage. Anaerobic digestion ensures the decrease of total organic acids concentration and other non-ionizable forms of organic matter and, therefore, a low pollution of condensed water from the vacuum evaporation system by organic matter is obtained.

Phase separation

From the degassing tank, slurry is pumped to two centrifuges where the phase separation is done. Solid fraction is sent directly to the dryer and the liquid fraction is stored in a buffer tank.

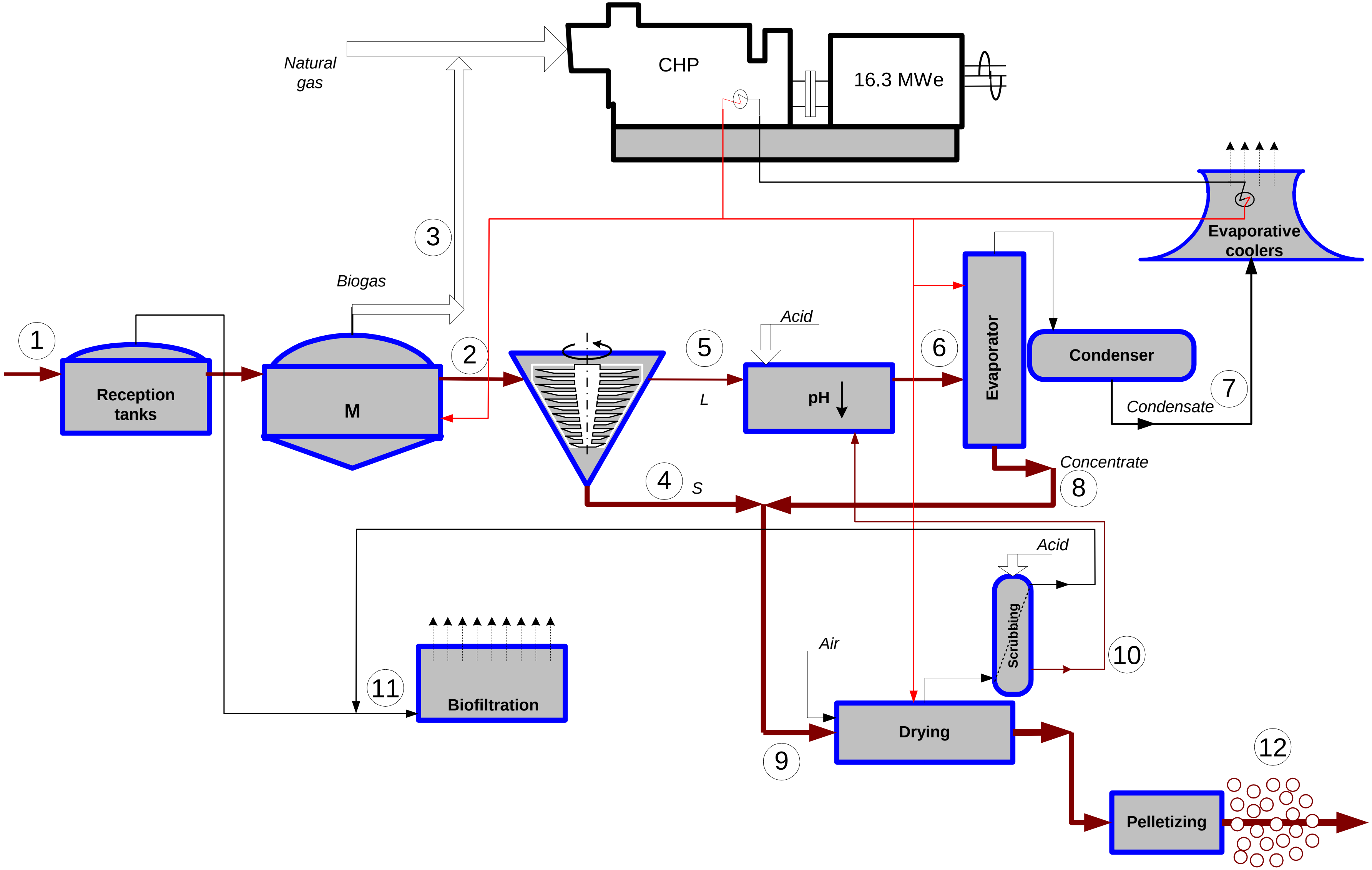


Figure E.2: General flow-sheet of TRACJUSA treatment plant. Figures indicate points described in the mass balance section.

Acidification

In order to decrease pH to or below 5.5, for immobilising nitrogen ammonia and avoiding its further loss in the thermal treatment, sulphuric acid is added to the liquid fraction in a specific reactor with foaming and degassing control. Produced gasses are conducted to a biofilter.

Evaporation / concentration

The acidified and degassed liquid is concentrated by means of a continuous low temperature vacuum evaporation process, till a total solid concentration around 25 - 30%. Evaporated water is recovered in a condenser, stored and reused in the cooling system of the power plant. pH control at acidification stage is regulated for minimising ammonia transfer to condensed water.

Drying and pelletization

Concentrated flow from the vacuum evaporation stage is mixed with the solid fraction from the phase separation, which feed the drying process. The dryer is an enclosed system working at temperatures between 85 – 90 ºC. The main heat source is saturated steam produced in a boiler fed with exhaust gas from the cogeneration engines. Dryer is completed with a scrubber for ammonia recovery and particles separation, which are send back to the acidification step previous to evaporation. Air from the scrubber, and also from headspace of reception tanks and degasification stage are sent to a biofilter.

The dehydrated product has a total solid content around 85 - 90% and is pelletized in a pelletizing unit.

Biofiltration

The aim of the biofilter, filled with wood chips as packing material, is to adsorb and transform volatile organic carbon and ammonia emissions coming from different plant units. The air flows through the packed bed where the biofilm, a collection of bacteria and fungi adhered to the wood chips, degrades organic carbon and nitrify ammonia, with a consequent denitrification.

Electrical power plant

Power plant is constituted by six 2,720 kWe gas engines. They are fuelled by a blending of natural gas and biogas produced at the anaerobic digestion stage. The waste heat from the exhaust gas is recovered as energy source for the dryer. The high temperature engine cooling circuit water is used as heat source for the evaporator and for maintaining anaerobic digesters temperature. The wasted heat at low temperature is dissipated in the air cooling system.

E.2.6: Descriptive pictures of the plant

Picture E.1: Reception Tanks

Picture E.2: Anaerobic digestion reactors

Picture E.3: Gas holder and flare

Picture E.4: S / L separation (centrifuges)

Picture E.5: Vacuum evaporation towers

Picture E.6: Dryer

Picture E.7: Pelletizer and product storage

Picture E.8: CHP engines

Picture E.9: Boiler (heat recovery)

Picture E.10: Evaporative coolers

Picture E.11: Discharge of pig manure

Picture E.12: View of the digesters top

Picture E.13: General view of the plant

E.3: Technical data

E.3.1: Mass Balance

The estimated mass balance is shown in Table E.2.

To establish the mass balance of the main pig slurry parameters in the process unit equipments, that constitutes the TRACJUSA plant, is not easy, because not all the parameters are followed-up with the same intensity and in all periods of time. For having an approximate approach of the mass balance analysis, the following data have been used:

- Detailed nitrogen mass balance performed with samples taken on June 22nd 2004, and contrast with average values input-output of nitrogen for the plant in 2007.
- Detailed sulphur mass balance performed with samples taken on June 4th 2004.
- Daily mass flow rates of the main units of the plant and daily biogas consumption, energy production and consumptions during June 2004.
- Daily average of total solids and volatile solids content of pig manure entering the plant and COD concentration of three samples, during June 2004.
- Data analyzing the dynamics of COD and ammonia in the acidification unit, vacuum evaporator and condenser in different periods of 2002, 2003 and 2004, but not during June 2004 (Palatsi et al., 2005a, 2005b)
- Data analysing biogas and methane production depending on characteristics of the pig manure entering the plant during summer (July-August) 2003 and 2004 (Palatsi et al., 2005b).
- Average values input-output of the plant for P, K, Cu and Zn in different periods of time, different to June 2004.

Analytical determinations and the studies indicated above have been done in the framework of a research and technical assistance agreement among TRACJUSA, SENER, ABANTIA and LEA-IRTA-University of Lleida or GIRO, in different periods of time since 2002, with the objective to analyze and optimize TRACJUSA plant performance.

Although not all sets of data are completed for June 2004, this period of time is the one found with more detailed information about the dynamics of the overall process. This helps to estimate the mass balance of the plant, but with some assumptions for parameters not measured during this period, or with significant variations respect to recent values.

It must be considered that Table E.2 expresses a static picture and that there are continuous variations in flow rates and parameters values. Nevertheless, values shown could be considered into the confident intervals in which the plant is working daily.

Only pig manure was treated during the period in 2004 when main data were obtained. When co-substrates are added, mainly sludge from industrial wastewater treatment plants and from industry up to 10 % / maximum (average value around 4-8%), biogas production increases and also the organic matter content and nutrients (N, P and K) in pellets.

The main characteristics of the estimated mass balance are:

- 265-295 m^3 of pig slurry are treated daily, with a total annual inflow around 100,000 tonnes of pig slurry.
- Average recovery, in the pellets produced, between 94% and 96% of the total nitrogen entering the plant. Table E.2 values indicate a recovery of 94.8% in pellets and the loss of 4.6% of initial nitrogen in the evaporation condensate and the cooling system. 0.6% of the initial nitrogen is sent to the biofilter.
- Recovery of all phosphorous and potassium entering the plant in the pellets.
- Biogas production from pig slurry amounts between 10 and 15 m^3 / tonne, and an increase up to 25 m^3 / tonne when co-substrates are added. Mass flow rate of biogas has been estimated considering biogas outflow saturated of water vapour at 35ºC and a content of 70% v / v of methane (usual values at plant in the range 70-72%).
- The estimated methane yield, based on SV values indicated at Table E.2, is 0.21 m^3 CH_4 / kg VS added and 0.36 m^3 CH_4 / kg VS removed. This last value is consistent with methane potential obtained by Bonmatí et al. (2001) during anaerobic biodegradability assays of pig slurry collected one day maximum after excreted (0.347 m^3 CH_4 / kg VS added), indicating an approximate VS efficiency transformation around 58-60% in the digestion step.
- The estimation of methane yield, based on the COD balance, is 0.14 m^3 CH_4 / kg COD added and 0.34 m^3 CH_4 / kg COD removed. This last value is consistent with the expected (0.35 m^3 CH_4 / kg COD removed), and the COD efficiency transformation could be around 40-42% in the digesters. Values of efficiency found are usual for 20 days hydraulic retention time.
- Heavy metals are also concentrated in the pelletized product, rising concentrations of 300-450 mg Cu / kg and 1100-1700 mg Zn / kg. Heavy metals concentration in pellets is high, limiting the direct soils application use. Pellets must be mixed with other organic fertilizers with low heavy metals content, which is done by the companies dealing with fertilization that buys the pelletized product.

The main losses / emissions concern ammonia nitrogen and volatile organic carbon.

Table E.2: Estimated average mass balance of the main components of the plant, based on daily average data of flow rates during June 2004 and analytical determinations performed during 2004 by LEA-University of Lleida and TRACJUSA, and contrasted with values provided by TRACJUSA during 2011. Values shown represent a picture for understanding the system performance. Numbers in the first raw indicate points in diagram shown in Figure E.2.

Parameter	Units	1	2	3	4	5	6	7	8	9	10	11	12
Q (flow rate)	tonnes / day	291,74	285,7	3,4	14,4	271,3	318,4	287,5	30,9	45,4	42,4	30182,4[1]	16,0
TS	kg / t	46,40	32,6		316,2	17,5	14,9	0,0	153,8	205,5	0,0	0,0	862,2
VS	kg / t	33,64	14,2		157,1	6,6	5,6	0,0	57,8	89,5	0,0	0,0	252,0
COD	kg / t	50,00	29,7	1.812,3	329,2	13,8	11,8	0,1	120,4	186,9	0,5	0,0	523,6
NTK	kg / t	4,11	4,2		17,9	3,5	3,3	0,2	32,0	27,5	2,5	0,0	71,2
NH_4^+-N	kg / t	2,35	2,8		2,8	2,8	2,7	0,2	26,5	18,9	2,5	0,0	49,2
Pt	kg / t	1,18	1,2		21,4	0,1	0,1	0,0	1,1	7,6	0,0	0,0	21,8
Kt	kg / t	3,17	3,2		57,7	0,3	0,3	0,0	3,0	20,4	0,0	0,0	58,0
St	kg / t	0,19	0,2		1,9	0,1	3,2	0,4	28,6	20,1	9,8	0,0	57,0
Cu	kg / t	0,02	0,0		0,2	0,0	0,0	0,0	0,1	0,1	0,0	0,0	0,3
Zn	kg / t	0,07	0,1		0,9	0,0	0,0	0,0	0,2	0,4	0,0	0,0	1,2

Mass flow rates of the considered parameters

Parameter	**Units**	**1**	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
TS	kg / d	13536,8	9315,1		4567,6	4747,6	4752,2	0,0	4752,2	9319,7	1,6	0,0	13760,7
VS	kg / d	9814,2	4052,1		2270,1	1782,0	1787,0	0,0	1787,0	4057,1	0,0	0,0	4022,3
COD	kg / d	14587,0	8490,6	6096,5	4756,6	3734,0	3755,1	34,5	3720,6	8477,2	21,2	31,8	8356,1
NTK	kg / d	1199,1	1197,3		258,6	938,7	1044,6	55,2	989,5	1248,1	106,0	7,2	1136,7
NH_4^+-N	kg / d	685,6	808,6		40,9	767,8	873,7	55,2	818,6	859,5	106,0	7,2	784,7
Pt	kg / d	344,3	344,3		309,8	34,4	34,4	0,0	34,4	344,3	0,0	0,0	347,3
Kt	kg / d	925,7	925,7		833,1	92,6	92,6	0,0	92,6	925,7	0,0	0,0	925,7
St	kg / d	54,0	54,0		26,9	27,1	1004,0	121,0	883,0	909,9	415,0	0,0	909,7
Cu	kg / d	4,8	4,8		3,1	1,7	1,7	0,0	1,7	4,8	0,0	0,0	4,8
Zn	kg / d	19,2	19,2		12,4	7,1	7,1	0,4	7,1	19,6	0,0	0,0	19,6

1: units of air and gases flow rate to biofilter, 11, are m^3 / d.

Estimated ammonia emissions, including ammonia entering the biofilters, are about 62.3 kg NH_3-N / day (5.2% of the input nitrogen and 0.21 kg N / tonne manure treated). Lower emissions could be expected, depending of biofilter efficiency. Ammonia emissions from the biofilter have not been measured, but ammonia smell is not usually identified.

COD emissions are estimated around 66.4 kg COD / d (0.45% of the COD entering the plant and 0.23 kg Cod / tonne manure), considering the pessimistic case that biofilter cannot completely remove the COD load. Efficiency values of the biofilter are not available. No odours problems have been identified in the neighborhood.

E.3.2: Energy balance

The average energy balance of the plant, based on registered data during the same period of time when the mass balance of the plant was performed, is shown in Table E.3.

Table E.3: Average energy balance of the plant.

Input energy	MWh / day	Comment
Natural gas consumption, 80,189 m^3 NG / d @ 39,397 kJ / m^3	877.55	a
Biogas produced, 2,961 m^3 biogas / d @ 27,578 kJ / m^3 *(All biogas is consumed)*	22.68	*b*
TOTAL INPUT ENERGY	900.23	c
Output energy		
Electrical energy		
Energy sold to grid	345.20	*d*
Manure treatment units consumption	21.25	*e*
Consumptions CHP and control equip.	6.70	*f*
TOTAL ELECTRICAL ENERGY	373.15	*g*
Thermal energy		
Consumption by manure treatment units	219.25	*h*
Dissipated energy in coolers	182.57	*I*
Energy losses (exhaust gases)	125.26	*J*
TOTAL THERMAL ENERGY	527.08	*k*
Energy balance		
Electrical efficiency of the CHP unit	41.45 %	*g / c*
Thermal energy for manure treatment	24.36 %	*h / c*
Total energy recovery	65.81 %	*(g+h) / c*
Equivalent electrical energy efficiency (EER)	59.20 %	*g / (a-(h / 0.9))*
Net energy used for manure processing	240.51 MWh / d	*e+h*
Net energy used per tonne manure treated	0.82 MWh / t	
Net energy used per kg N recovered	211.58 kWh / kg N	
Net energy used per kg N+P+K recovered	99.81 kWh / kg NPK	

E.3.3: Global energy balance of the management system

The coexistence of a CHP plant consuming natural gas (NG) with a processing plant concentrating manure in pellets in order to favour the nutrients transport to large distances, out of the nutrients surplus area, creates a scenario difficult to compare in the energy and environmental point of view. For the analysis, it is necessary to compare the current situation with the previous situation that the plant tries to improve. This is done in Table E.4. The two situations definitions are as follow:

Reference situation

In an early analysis of the economical interest of combining anaerobic digestion, vacuum evaporation and drying for exporting pig manure surpluses in the area of North Garrigues county, Bonmatí et al. (2003) determined that, in this area, pig manure should be transported to areas with nutrients demand at more than 100 km distance. The reference situation could be defined by the transport of surpluses to 100 km distance and by the interest to implant an independent electrical power fuelled by natural gas for electrical production, reinforcing the electrical grid of the county, for covering the increased electrical demand of the local food industry. The main characteristics of this situation are:

- Transport of pig manure to 100 km distance is done by 25 tonnes tracks, with an energy consumption of 0.718 kWh / km (Estimated based on OCCC (2011) and assuming 11.6 kWh / l diesel)
- Pig manure is stored in farms for 4-6 months
- The electrical power plant sells the same electrical energy as the current energy sold by the plant, with an electrical energy efficiency production of 55% (fraction of the input fuel that is converted to electrical energy, with a value usual in combined cycle systems). This efficiency is the minimum equivalent electrical efficiency (EER) that a CHP plant must fit for obtaining legal activity permissions by authorities.

Table E.4: Global energy balance of the manure management system

Energy consumption for the reference situation	
Natural gas consumption for electrical energy production	627.64 MWh / d
Energy consumption for transport pig manure to 100 km distance	1.67 MWh / d
TOTAL ENERGY CONSUMPTION	629.31 MWh / d
Energy consumption / final N	**830.99 kWh / kg N**
Energy consumption for the current situation	
Natural gas consumption for electrical energy production	877.55 MWh / d
Energy consumption for transport pig manure to plant (3.8 km)	0.06 MWh / d
Energy consumption for transport pellets to 100 km distance	0.060 MWh / d
TOTAL ENERGY CONSUMPTION	877.67 MWh / d
Energy consumption / final N	**772.12 kWh / kg N**
Global energy balance	
Net energy consumption	+ 248.4 MWh / d +0.85 MWh / tonne manure
Net energy consumption per final kg N	- 58.88 kWh / kg N

- Ammonia losses by volatilization during the storage are considered. Emission factor adopted: 0.4 / 40% (Table 10.22, chapter 10, IPCC guidelines 2006)

Current situation

- Electrical power plant is a CHP unit, producing the same electrical energy sold to the grid and using the waste heat for covering the energy demand of the manure treatment plant.
- CHP is fuelled by natural gas and biogas produced by manure. Estimated electrical efficiency production and EER values are 41.45% and 59.8% respectively (Table E.3)
- Pig manure is stored in farms for less than 1 month.
- Transport of pig manure from farms to the plant (3.8 km distance) is done by 25 tonnes tracks, with an energy consumption of 0.718 kWh / km (based on OCCC (2011) and assuming 11.6 kWh / l diesel).
- Transport of pellets to 100 km distance is done by 12 tonnes tracks, with an energy consumption of 0.454 kWh / km (based on OCCC (2011) and assuming 11.6 kWh / l diesel).
- Ammonia losses of the treatment plant are taken into account. Emission factor during the short storage time at farms is evaluated as 5% of the total nitrogen.

Based on the above assumptions, the global primary energy consumption for the situations considered and its comparison is shown in Table E.4.

Table E.4 shows that the primary energy consumption in the current situation is higher than the reference, but the higher recovery of nitrogen obtained by the plant contributes to a saving of 58.88 kWh per kg of final N useful for fertilization. Since the initial manure, phosphorous and potassium mass flow rate is maintained for the two scenarios, energy consumption per unit of P and K is higher for the current scenario. The current situation could be improved increasing biogas production with co-substrates not increasing significantly nutrients contents.

E.4: Environmental analysis

Environmental analysis is performed estimating equivalent CO_2 emissions due to: natural gas combustion for energy production, diesel consumption during transport, direct CH_4 emissions during manure storage, and indirect N_2O emissions due to NH_3 N + NO_x-N volatilization.

The two situations previously defined will be characterized in order to estimate the equivalent CO_2 emissions avoided, following IPCC guidelines (IPCC, 2006) when data must be estimated. The agricultural use of the final products (raw manure or pellets), and its soil dynamics, are not taken into account in the present analysis because it is out of the analysis boundaries.

Gaseous COD emissions are not considered in the present analysis. These emissions have been estimated in a maximum value of 66.4 kg COD / d, considering the pessimistic case that biofilter can not completely remove the COD load. Efficiency values of the biofilter are not available. No odours problems have been identified in the neighbourhood. Nevertheless, it is considered that current situation improves the reference scenario, decreasing volatile organic carbon emissions.

Assumptions made for estimating equivalent the CO_2 emissions are explained in the following sub-sections.

E.4.1: N emissions: NH_3-N + NO_x-N and N_2O emissions

Current situation

Ammonia emissions, included ammonia entering the biofilters, are about 62.3 kg NH_3-N / day, considering that biofilters are not decreasing these emissions as a pessimistic hypothesis.

Ammonia emissions at farms are evaluated as 5% of the total nitrogen. The reference nitrogen content value at farms is considered to be 5% higher than the concentration entering the plant. This value will be the same for the reference situation.

Direct N_2O emissions are not considered since manure storage media at farms and at plant is anaerobic (EF3=0).

Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006), that is 1% of the ammonia nitrogen emitted.

Recoverednitrogen, considering emissions losses at plant and at farms, is estimated as the nitrogen flow rate in pellets in Table E.2 (1136.7 kg N / d), that is 90% of the initial reference nitrogen.

NOx concentration in the exhaust gas from cogeneration engines where recently measured in 220 mg NOx / m^3 gases, at an exhaust gases flow rate of 21,614 m^3 / h (plant technical manager personal communication). This value corresponds to 35.2 g NOx / GJ primary energy consumed, which is a low value in the range 22-350 g NOx / GJ indicated in Table 24 of EMEP-CORINAIR (2007). This reference Guidebook indicates a range of indirect N_2O emissions due to combustion of natural gas of 0.1-3 g N_2O / GJ, and a range of 1.4-2.5 g N_2O / GJ for the combustion of biogas, both considering NOx emissions due to the N contents in the fuel and thermal NOx formation due to the combustion temperature. Considering the mean values of the emissions intervals (1.6 and 1.9 g N_2O / GJ for natural gas and biogas respectively), the equivalent CO_2 emission is 5.2 kg CO_2 equiv. / tonne of manure processed.

Reference situation

The ammonia emissions factor applied for the farm storage stage is 0.4 (Table 10.22; IPCC, 2006), using the initial nitrogen concentration indicated above (5% higher than the nitrogen entering the plant). Estimated ammonia emissions are 504.86 kg NH_3-N / d. With these emissions, the final nitrogen ready to be used is 757.30 kg N / d.

Direct N_2O emissions are not considered since manure storage media at farms is anaerobic (EF3=0).

Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006), that is 1% of the ammonia nitrogen emitted.

Final useful nitrogen, considering emissions losses at farms, is estimated 60% of the initial reference nitrogen.

Applying the average value for the estimation of indirect N_2O emission due to NOx production during combustion of natural gas (1.6 g N_2O / GJ, following EMEP-CORINAIR, 2007), the estimated equivalent CO_2 emission is 3.7 kg CO_2 equiv. / tonne manure processed. The difference with the current situation (1.5 kg CO_2 equiv. / tonne manure) is around 1.7% of the total estimated equivalent CO_2 emission per tonne of manure processed, while the uncertainty level is much higher, due to the wide intervals of possible N_2O emission values. Due to this uncertainty and the relatively low impact in the final results, thermal NOx emissions of the electrical power plants, and the consequent indirect N_2O emissions, are not considered for both the current and the reference scenarios.

E.4.2: Estimated CH_4 emissions

Current situation

The emission factor adopted is 3% of the methane production potential of the volatile solids, taken into account a storage time at farms less than 1 month in a pit storage below animal houses (IPCC, 2006).

The methane potential of volatile solids indicated by IPCC (2006) is 0.45 m^3 CH4 / kg VS. This value has never been measured in samples of fresh pig manure taken in the area, being the higher value 0.347 m^3 CH_4 / kg VS (Bonmatí et al., 2001). For pig manure stored for 4-6 months in the area, the methane potential decreased to 0.096 m^3 CH_4 / kg VS, that is 72% less, fraction supposed to be emitted to the atmosphere during the storage, in contrast with values proposed by IPCC (Table 10.17 from IPCC (2006) guidelines), which are less in temperate temperature regions. 0.347 m^3 CH_4 / kg VS will be adopted in the present estimations and 3% emissions of methane during storage for the current situation.

Volatile solids flow rate are considered to be that entering the plant (Table E.2). The estimated emissions are 68.5 kg CH_4 / d.

Reference situation

As indicated in the current situation explanation, the emission factor adopted is that measured in samples taken from a farm in the area, with usual storage times in the range 4-6 months, which is 72% of the methane potential measured by Bonmatí et al. (2001). The estimated emissions are 2,701.5 kg CH_4 / d, considering the same methane potential production as in the current scenario.

Volatile solids flow rate are considered to be the estimated value that produces the same VS flow rate of that entering the plant (Table E.2), after the loss of the equivalent weight of biogas (considering 65% methane in the biogas and 1.02 specific weight, without moisture content).

E.4.3: Estimated equivalent CO_2 emissions by transport

Current situation

Transport of pig manure from farms to the plant (3.8 km distance) is done by 25 tonnes tracks, with an equivalent CO_2 emission of 675.27 g CO_2 / km (OCCC, 2011). Tracks collect at every farm, go to the plant and return void to the same farm or to another after disinfection. Two ways are considered (2 x 3.8 km per trip).

Transport of pellets to 100 km distance is done by 12 tonnes tracks, with an equivalent CO_2 emission of 427.04 g CO_2 / km (OCC, 2011). Tracks transport pellet and can return to the area with other charge. One way is considered (1 x 100 km per trip).

Reference situation

Transport of pig manure from farms to 100 km distance is done by 25 tonnes tracks, with an equivalent CO_2 emission of 675.27 g CO_2 / km (OCCC, 2011). Tracks collect at every farm, go to the receiving land and return void to the same farm, or to another if some kind of disinfection is applied. Two ways are considered (2 x 100 km).

E.4.4: Estimated equivalent CO_2 emissions for electrical production

Current situation

For the estimation of CO_2 emissions due to natural gas combustion in engines, an emission factor of 2.15 kg CO_2 / m^3 NG has been adopted (OCCC, 2011), with the natural gas consumption indicated at Table E.3.

It is considered that biogas produced and consumed, is not contributing to equivalent CO_2 emissions, but the electrical energy sold corresponding to the biogas produced is mitigating the equivalent CO_2 emission, following the CO_2 equivalence of the electrical mix in the country. This means a saving of 181 g CO_2 / kWhe (OCCC, 2011; for the Spanish electrical mix) produced from biogas, and a total estimated amount of 4,106 kg CO_2 / day saved for the adopted values at Tracjusa, not considering the addition of co-substrates. Obviously, increasing biogas production implies an increase in direct CO_2 emissions saving and a decrease of CO_2 emissions due to natural gas consumption.

Reference situation

With the same emission factor as above, the estimated flow rate of natural gas consumption has been calculated for obtaining the same electrical energy sold to the grid, with an electrical efficiency of 55%. The obtained value is 627.64 MWh / d of primary energy, equivalent to 123,307.6 kg CO_2 / d.

E.4.5: Estimated equivalent CO_2 emissions balance

The conversion of the above emissions to CO_2 equivalent emissions units are shown in Table E.5. Conversion factors adopted have been 25 kg CO_2 / kg CH_4 and 298 kg CO_2 / kg N_2O (Forster et el., 2007).

Although the global energy consumption in the current management system is higher than the reference situation, the estimated equivalent CO_2 emissions are significantly less with the assumptions made, saving an estimated amount of 8,784 tonnes CO_2 equivalent per year. In the CO_2 equivalent balance between the two situations, the CO_2 emissions saved per unit of useful final nitrogen (85.85 kg CO_2 / kg N) is highly influenced by the nitrogen mass balance between these two scenarios. While TRACJUSA plant, and the management system adopted by the farmers association, allows the recovery of around 90% of the nitrogen excreted by pigs (95% considering the N amount entering the plant), the reference situation only allows a final recovery of 60%, due to volatilization during the long storage time in farms, with higher CO_2 equivalent emissions.

Table E.5. Estimated equivalent CO2 emissions.

Reference situation	Primary emission	Equivalent CO_2 [kg CO_2 / d]
Electrical production (NG)	123,308 kg CO_2 / d	123,308
Manure storage at farm	2,701.45 kg CH_4 / d	67,536
Transport to 100 km distance	1,576.03 kg CO_2 / d	1,576
Indirect N_2O emissions	7.93 kg N_2O / d	2,364
Direct N_2O emissions	~0 kg N_2O / d	~0
TOTAL EQUIVALENT CO_2 EMISSIONS		**194,784**
Current situation	Primary emission	Equivalent CO_2 [kg CO_2 / d]
Electrical production (NG)	172,406 kg CO_2 / d	172,406
CO_2 saving due to electricity from biogas	- 4,106 kg CO_2 / d	- 4,106
Manure storage at farm	68.55 kg CH_4 / d	1,714
Transport to the plant	59.89 kg CO_2 / d	60
Transport of pellets to 100 km distance	56.79 kg CO_2 / d	57
Indirect N_2O emissions	1.97 Kg N_2O / d	588
Direct N_2O emissions	~0 kg N_2O / d	~0
TOTAL EQUIVALENT CO_2 EMISSIONS		**170,718**
Equivalent CO_2 emissions balance		
CO_2 equivalent saved with the current management and treatment system	24,066 8,784	Kg CO_2 / day Tonnes CO_2 / year

CO_2 equivalent saved per manure unit	82.49	Kg CO_2 / tonne manure
CO_2 equivalent saved per unit of final useful N	85.85	Kg CO_2 / kg N

Results are very sensitive to the assumptions made, and especially to the CH_4 methane emissions factor adopted and N dynamics. As an example, if CH_4 emissions at farms for the reference scenario were halved, the results of the balance indicate that there are not daily or annual CO_2 equivalent savings for the current situation and, actually, a net emission of 33.3 kg CO_2 equivalent / tonne manure treated. In the same way, if CH_4 emission factor and methane potential of VS are taken from IPCC (2006) guidelines, for 18ºC average temperature, the net emissions are also positive (14.3 kg CO_2 equivalent / tonne manure). In both cases, there is an equivalent CO_2 emission saving per unit of N recovered, due to the higher recovery compared to the reference scenario.

What can explain the high CH_4 losses measured, during the long manure storage in the area, are the high temperatures during summer, moving in the range 30º - 40ºC. This fact explains the low biogas productivities in summer 2003, reported by Palatsi et al. (2005a, 2005b), and motivating the rearrange of the manure collection logistics, and a subsequent significant increase on biogas production during summer 2004 (Palatsi et al., 2005b).

With other assumptions, ECOFYS (2004) estimated an equivalent CO_2 emissions saving of 0.609 kg CO_2 / tonne manure when comparing with electricity produced by a coal electrical power plant, and a saving of 0.096 kg CO_2 / tonne manure when comparing with the average electrical mix in Spain, considering the average plant model of ADAP association. ECOFYS (2004) report indicates that the plants including biogas production could slightly increase these values, depending on biogas yield.

E.5: Economical data

The building of a centralized plant for solving the manure surplus problem at the North area of the Garrigues county was initially an initiative of the farmers association, which was studying possible management and technological alternatives to be adopted since early the nineties. In this sense, the initiative was private, and adopted with the view of increasing future opportunities for the young people in such a rural area.

In the final owners structure of TRACJUSA, only 10% is owned by a public company (EFIENSA), participated 100% by the Government of Catalonia, which has the objective to promote feasible energy projects.

The main income of the plant is the electrical energy sold, which has a regulated price by Spanish laws. A stable energy prices framework (for 15 years since the operation start-up) is the main contribution of the public / governmental institutions.

E.5.2: Financing aspects

The TRACJUSA company is participated nowadays by:

- 12% Farmers Association (private)
- 10% EFIENSA (Catalan public company)
  http: / / www20.gencat.cat / portal / site / icaen / menuitem.897a4be85d3b580ec644968bb0c0e1a0 / ?vgnextoid=cbae8a206017c110VgnVCM1000000b0c1e0aRCRD&vgnextchannel=cbae8a206017c110VgnVCM1000000b0c1e0aRCRD&vgnextfmt=default
- 10% Gas Natural (Energy company, private)
  http: / / www.gasnatural.com
- 26% EON (Engineering and Energy company, private)
  http: / / www.eon.com /
- 42% SENER (Engineering company, private)

http: / / www.sener.es

Initial participants provided part of the investment cost and obtained a bank loan for the rest. The mortgage period was 15 years, coincident with the stable electrical subsidies for this kind of plants, following Royal Decrees 2818 / 1998 and 661 / 2007.

E.5.2: Investment costs

The TRACJUSA treatment plant cost referenced to year 2001 was around 18 M€.

The investment cost of a new similar plant, in 2011, is estimated in 25-30 M€.

An electrical substation, constructed in 2001, added 3 M€ to the investment cost. Nowadays, this distribution facility serves two similar treatment plants in this area (VAG, 2004, and SAVA, 2008), and some solar energy power plants, which help to share the initial investments costs.

E.5.3: Operative costs

The estimated operative costs were in the interval 11.3 – 13.06 M€ / year in the period 2004-2005 (Flotats et al., 2009). The approximate distribution of these costs is:

- 20% operation and maintenance
- 10% investment / financial costs
- 10% personnel, administration and transport
- 65% natural gas consumption

During 2010 – 2011, the detailed distribution of costs is not available, but the cost of natural gas is expected to be between 31-33 € / MWh, with an annual cost between 9.9 and 10.6 M€ / y, which is the main operative cost.

E.5.4: Incomes

The estimated incomes due to electrical energy sales were in the interval 9.52 – 13.24 M€ / year in the period 2004-2005 (Flotats et al., 2009). With the current electrical energy market prices and the subsidy to electricity produced, this income is about 115 – 130 € / MWh, that is in the range 14.49 – 16.38 M€ / year.

Another income is due to the fertilizer product sales, which were 34 € / tonne pellets in the period 2004-2005 and is moving in the range 45-55 € / tonne during 2011 (expected income of 0.26 – 0.32 M€ / year).

E.5.5: Economical balance and general indexes

The fee paid by farmers is 1.9 € / tonne manure managed, that is the same for all farmers participating in the nutrients management plan, with or without treatment, allows to balance the economy of the manure management system of the farmers association. This is the treatment cost for farmers and is aiming to finance the transport of all manures, those entering the plant and those transported and applied to the agricultural land of the 196 agricultural farmers participating in the manure management plan.

The expected internal return rate (IRR) of the plant for the owner companies is around 8 – 9%, although it was around 5 – 5.5 % during the firsts years of operation (personal communication of the general manager of the plant), including the farmers association.

Since the difference between the electrical “feed-in” tariff for this kind of plants (category d.1 facilities, with regulated electrical prices during 2011) and the usual cogeneration plants (category a.1.1 facilities, with a minimum electrical price defined and a maximum depending on the market energy prices) is variable, it is difficult to define the additional treatment cost covered by the incentive established by

Royal Decrees 2818 / 1998 and *661 / 2007* for treatment plants producing energy and concentrating manure. The two categories have a fixed regulated tariff, which could help to estimate the maximum specific subsidy, comparing with regular cogeneration systems in industry.

- The regulated tariff for category a.1.1 (cogeneration in industries) is 89.54 € / MWh_e for 2011.
- The regulated tariff for category d.1 (cogeneration aiming to use thermal energy for concentrating pig manure) is 128.49 € / MWH_e for 2011.
- The regulated tariff for category b.7.2 (electricity produced from biogas obtained from manure and agro-industrial organic waste) is 141.14 € / MWh_e.

Based on the above prices and the electrical energy production indicated in Table E.3, the contribution of the economical incentive of the regulated electrical prices to the category d.1 facilities is estimated in Table E.6.

Based on the results shown in Table E.6, the income corresponding to the incentive to electrical energy production for concentrating pig manure in surplus areas is estimated in 13,106 € / day maximum, for the case of TRACJUSA plant.

Table E.6. Estimation of the maximum value of the incentive to electrical energy produced by the plant.

Facility type	Electrical price (€ / Mwhe)	Electrical sales (MWh / d)	Daily income (€ / d)
Category d.1	128.49	336.50	43,237.13
Category b.7	141.14	23.27	3,284.34
Category a.1.1	89.54	336.50	30,130.38
Incomes			Daily income (€ / d)
Categories d.1+b.7			46,521.47
Categories a.1.1 + b.7:			33,414.72
DIFFERENCE			**13,106.75**
RATIOS			
Incentive per tonne of manure processed	41.82	€ / tonne manure	
Incentive per estimated kg CO_2 equivalent saved	0.54	€ / kg CO_2 saved	
Incentive per kg N recovered	11.53	€ / kg N recovered	
Incentive per kg N saved	34.55	€ / kg N saved	

This excess income over the standard cogeneration tariff covers the cost of:

- Recycling and converting the organic material and NPK content of the manure into biogas and into a solid fertilizer that is commercialized with great success in non surplus agronomic areas, thus saving the energy of the equivalent natural gas and the energy employed in the manufacture of the substituted synthetic fertilizers;
- Avoiding methane emissions to the atmosphere that occurs in the traditional manure management system;
- Avoiding the contamination of surface and underground waters with N and P;
- Modernization of the electrical grid in a rural area and the scattering of electrical energy generation sites.

The following ratios could represent an estimation of the treatment cost, not considering geographical general benefits due to scattered electrical energy generation and modernization of the electrical grid. Therefore, the following values could be considered the maximum costs estimated.

Kind of cost	Value	
Estimated theoretical cost not considering the existence of the "feed-in" tariff:	43.72	€ / tonne manure
	11.22	€ / kg N recovered
	33.62	€ / kg N saved
	0.53	€ / kg CO_2 saved
Cost for farmers considering the existence of the "feed-in" tariff:	1.90	€ / tonne manure
	0.48	€ / kg N recovered
	1.46	€ / kg N saved
	0.02	€ / kg CO2 saved

It must be taken into account that the processing cost has been estimated based on current regulated electrical tariffs, not considering daily electrical market price values, that could decrease slightly the cost values estimated, without considering an increase on biogas production due to industrial organic waste, and considering that the TRACJUSA economy is balanced at this moment, although with a fair IRR.

E.6: Social aspects

The plant maintains 22 direct employers and 18 indirect employers.

The neighbourhood of the plant considers the facility as an industry producing useful products (electricity, pellets) and solving an environmental problem that limited the economical development of the county. The modernization of the electrical grid and the existence of the electrical power plant have promoted the area as an interesting place for new industries implantation. The fact that two similar facilities have been constructed in the same zone (VAG in 2004 and SAVA in 2008), obtaining the local permissions, demonstrates the acceptance of neighbours and municipal authorities.

About smells, no incidents have been detected and neighbours accept the light smell generated. A smell reduction, compared with the previous situation when manure was stored at farms and applied without control, has been appreciated also.

Farmers are fully participating in the manure management planning and in continuous improvements. Actually, farmers are partially owners of the plant also.

The experience of this plant, where farmers participate in the decision making process, and where the plant operation and profitability serves to the global interests of the farmers association, is considered a model to be followed by other associations. Farmers are proud to participate in this successful project.

E.7: Others

The TRACJUSA plant was awarded with the *Agricultural Innovation Award year 2003,* by the Government of Catalonia.

ICAEN (Catalan Institute of Energy), ARC (Catalan Agency of Wastes) and ACA (Catalan Water Agency) supervise operation through periodical controls.

E.8: Summary

Table E.6 summarizes the main figures describing TRACJUSA plant.

Table E.6: Summary of the main data describing the plant performance

Issue	Parameter value
Technical performance	
Major processing technologies	Combination of anaerobic digestion, and concentration by vacuum evaporation, drying and pelletizing
Mass balance	
Influent, m^3 per year	110,000
▪ Pig slurry	106,500
End and by-products, tonnes per year	
▪ Concentrate in pelletized form	5,825
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	851
▪ Net consumption of energy per kg N final recovered, kWh / kg N	-58.88
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg NH_3-N / m^3 treated	-1.3
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	-82.49
Economical performance	
▪ Net cost of processing including subsidies, € / m^3	1.90
▪ Net cost of processing including subsidies, € / kg $N_{recovered}$	0.48
▪ Net cost of processing excluding subsidies, € / m^3	43.72
▪ Net cost of processing excluding subsidies, € / kg $N_{recovered}$	11.22

ANNEX F: MANURE ANAEROBIC DIGESTION AND CO-DIGESTION BIOGAS PLANT. IHAN, DOMŽALE (SLOVENIA)

F.1: Introduction

The pig farm company **Farme Ihan d.d.**, was the first agricultural organization in Slovenia that in 1993 began with the biogas production from pig slurry. From 1993 to 2005, all the electricity production from biogas was used for conventional needs of the nearby Wastewater Treatment Plant (WWTP) Domžale-Kamnik (200,000 habitant equivalent). In return, the WWTP provided the anaerobic digestion (AD) biogas plant with free of charge laboratory analysis, solid waste removal and knowledge support in order to run the AD reactor (the WWTP have its own AD reactor). Pig slurry was used as the only digestion substrate from 1993 up to 2006. After that date, the biogas plant started adding agro-industrial organic wastes as co-substrates, such as glycerin, dried bread, etc. in order to improve biogas production.

The company **FI-ECO d.o.o.** (Ltd Company) was founded in 2005, as the existing treatment plant was not properly registered and had no conditions for obtaining the status of qualified electricity producer. By establishing a subsidiary company which was 100% owned by Farme Ihan d.d., the condition to have the right to get subsidies for electricity was fulfilled. From 1993 to 2006 the biogas processed only the pig slurry from the Ihan farm. Co-digestion of raw materials was introduced due to the electricity production subsidies, but also because of the growing energy prices. In the past three years, gas production increased by 300%. Of particular interest is that the biogas plant not only processes the pig manure from the Ihan farm, but also accepts blood of pigs slaughtered in their own slaughterhouse in Šentjur, as well as bovine blood from Meat Kamnik d.d. and butcher's shop in Litija, for which the farm Ihan is the major stakeholder. Nowadays, the share of biogas produced from the pig slurry has less than 30%. Due to the EU IPPC Directive[20], a phosphorous removal unit and a stripping tower for nitrogen removal was built during the period 2007-2010.

F.2: General description of the plant

F.2.1: Location

The biogas plant FI-ECO d.o.o. is located in the municipality of Domžale (see Figure F.1), at approximately only 500 meters from the village of Ihan next to the municipal WWTP (address: Ihan, Breznikova 89, 1230 Domžale, Slovenia). The municipality total area is of 72.3 km^2 with an average population of 32,205 habitants. Domžale is known today for its flourishing small businesses, agriculture, and light industry. The municipality lies near the foothills of the Kamnik Alps and is crossed by the river Kamniška Bistrica . Its landscape is characterized by forested hills and agricultural plains.

[20] Directive 2008/1/EC of the European Parliament and of the Council of 15 January 2008 concerning integrated pollution prevention and control

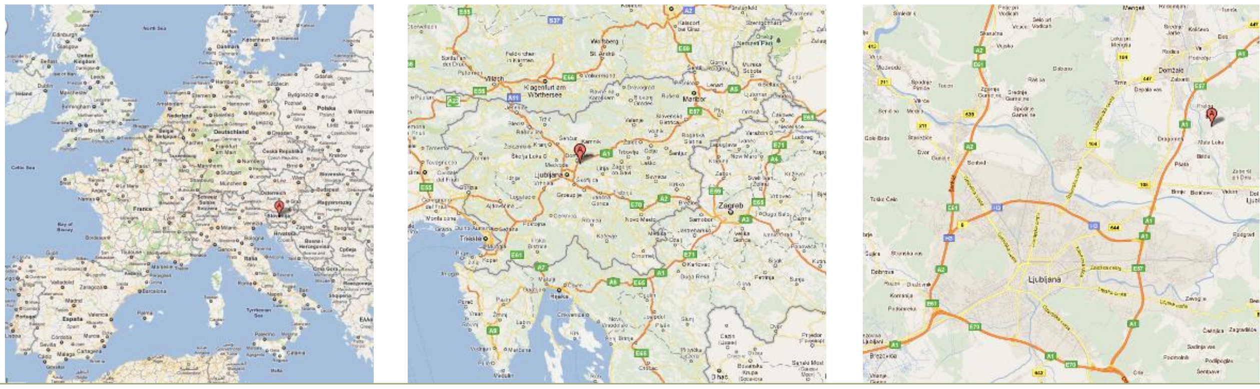


Figure F.1: Maps location of Farm Ihan plant (Domžale, Slovenia).

F.2.2: Characterization of the farm

In 1980, due to the increasing public awareness of environmental issues, the state of the ex-Yugoslavia has imposed a 90% reduction of COD over all the pig farms manure effluents. Until 1980, the slurry was directly discharged into a tributary of the river Sava (Kamniska Bistrica). Farm Ihan d.d. was build in 1959 and since then, it was the biggest closed-loop pig farm in Slovenia. It covers an area of 16 hectares and has had about 85,000 pigs of an average weighing of 115 kg until 2006. The farm production decreased to 26,000 pigs in 2008.

The farm does not own agriculture land fields and that was the main reason for the construction of the biogas plant in order to satisfy the new requirements of environmental norms. A closed recycling wastewaters system (investment of 1 M€) was build in 1993. The main reason for the recycling system was to reduce the flow of pig slurry and increase the manure concentration. With those changes the amount of slurry treated at the anaerobic digestion plant was reduced from 900 m^3 / d to 350 m^3 / day.

F.2.3: Companies involved in the plant

The design and construction of the biogas plant were made by the local government bureau **Planum**. At that time, the only objective of the biogas plant was to reduce the organic waste effluents produced by the Ihan pig farm. The operation of the plant since 2010 was done by the company FI-ECO d.o.o.

In November 2010 the FI-ECO d.o.o. has been acquired by the energy company **Petrol d.d.**, which proceeds with the co-digestion policy of the old owners.

F.2.4: Description of the treatment plant

The main units of the biogas plant are represented in Figure F.2, F.3 and F.4.

As it is said before, the Ihan treatment plant is located next to the WWTP, for this reason some equipments are shared with WWTP (grey box in Figure F.3).

Pre-treatment of pig slurry

The pig slurry produced in the Ihan farm, before entering the anaerobic reactors, is settled in a natural decanter placed at the WWTP site. The dense part is treated in a mechanical separator, and the solid fraction obtained is sold as organic fertilizer. The liquid fraction of the natural settler and the mechanical separator, with a total solid contend below 3%, is then conduced back to the treatment plant.

Anaerobic digestion

The liquid fraction coming from the WWTP after settling is then conduced to the anaerobic reactors. The plant has two concrete bio-reactors with a total volume of 5,000 m^3. Each bio-reactor consists of two serial reactors: primary (1,250 m^3) and secondary reactor (1,250 m^3).

The operation of the anaerobic digestion is described for two different periods: pig slurry period (1993-2006), and co-digestion period (2007-2010).

Pig slurry period (1996-2006)

During the full capacity period of the Ihan pig farm, the inflow rate was of 350 m^3 / d, with a concentration of 26 gCOD / L. The hydraulic retention time (HRT) was around 12-14 days and the operation temperature was between 38°C and 40°C. Under these operating conditions, 85% COD reduction efficiency was achieved. Efficiencies of 90% were obtained with a HRT of 20 days. However, the operators decided to operate at lower HRT in order to process all the incoming pig slurry produced in the farm. The estimated amount of biogas produced form the pig slurry was between 3,000 and 3,400 m^3 / day. The produced biogas was a mixture of methane (70%) and CO_2 (30%), which was captured on the top of the bio-reactor and filtered through sand filters before the biogas storage tank (1000 m^3). The total and organic effluent nitrogen concentration was of 3 gNtot / L and 1.5 gNorg / L, respectively. The effluent was directly discharged into a river, since at that time there were no limits established in the legislation for N and P concentrations.

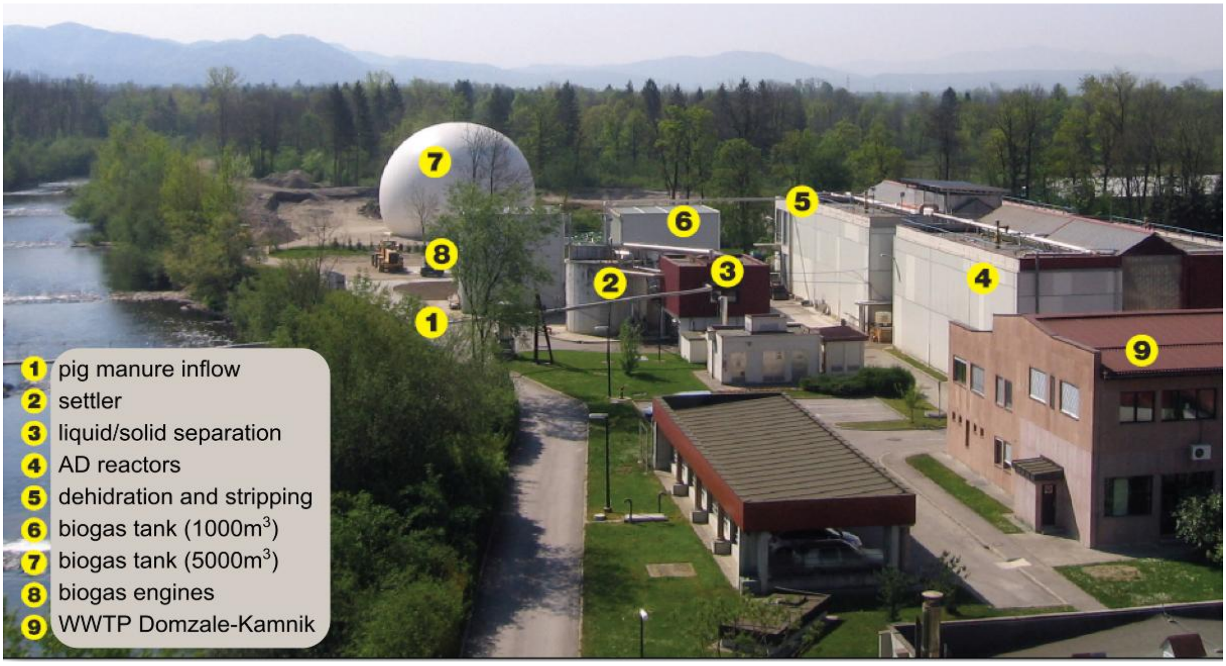


Figure F.2: Photographic description of the biogas plant FI-ECO d.o.o.

Agro-industrial organic wastes co-digestion with pig manure

In 2006, with the decision to decrease the pig farm capacity from 85,000 to 26,000 pigs, a very ambitious plan for an increase of the biogas production started. With the introduction of organic waste as co-substrate, from the 2006 to the end of the 2008, the biogas increased by almost 300%, while the daily volume of the pig slurry was reduced to 50 m^3 / day. A biogas balloon tank of 5,000 m^3 was build in order to store the produced biogas.

Co-substrates such as glycerin (purchased), slaughterhouse waste, bread, etc. (Table F.1), were added to the anaerobic reactor in order to maintain a positive balance of biogas production. In the case of glycerol addition, the biogas production increased to 12,000 m^3 / day. In the case of slaughterhouse waste from industry (1,200 ton / year), biogas production was of 7,000 m^3 / day. Recently, the consumption of glycerin has been decreased significantly due to its price, and other co-substrate as dry bread are used. In this case, with an inflow of 2 ton / day, it was observed that for each ton of co-substrate added it was able to produce up to 600 m3 of biogas. Nevertheless, the methane content was only 55% v / v, which was on a lower limit for a good biogas aggregate efficiency. Moreover, the operator of the plant gained 60 € / ton (costs of transport not included) for the bread co-substrate treatment. Because of the co-digestion, the HRT was extended 2-3 times (40-60 days) in order to work at normal loading conditions of 6-8 kgSS / m^3.

The plant operator reported the importance and usefulness of pilot-plant tests (reactor volume of 160 L) in order to determine the economic and practical feasibility of the potential co-substrates. Through the pilot-plant results, the biogas plant operator and their customers were able to reach faster and better compromises over the price of the organic waste treatment fees (Table F.1). In any case, the volumetric inflow of pig manure was always higher than 30%, minimum percentage required to benefit from the state green bonus of 0.013 € / kW of electricity produced.

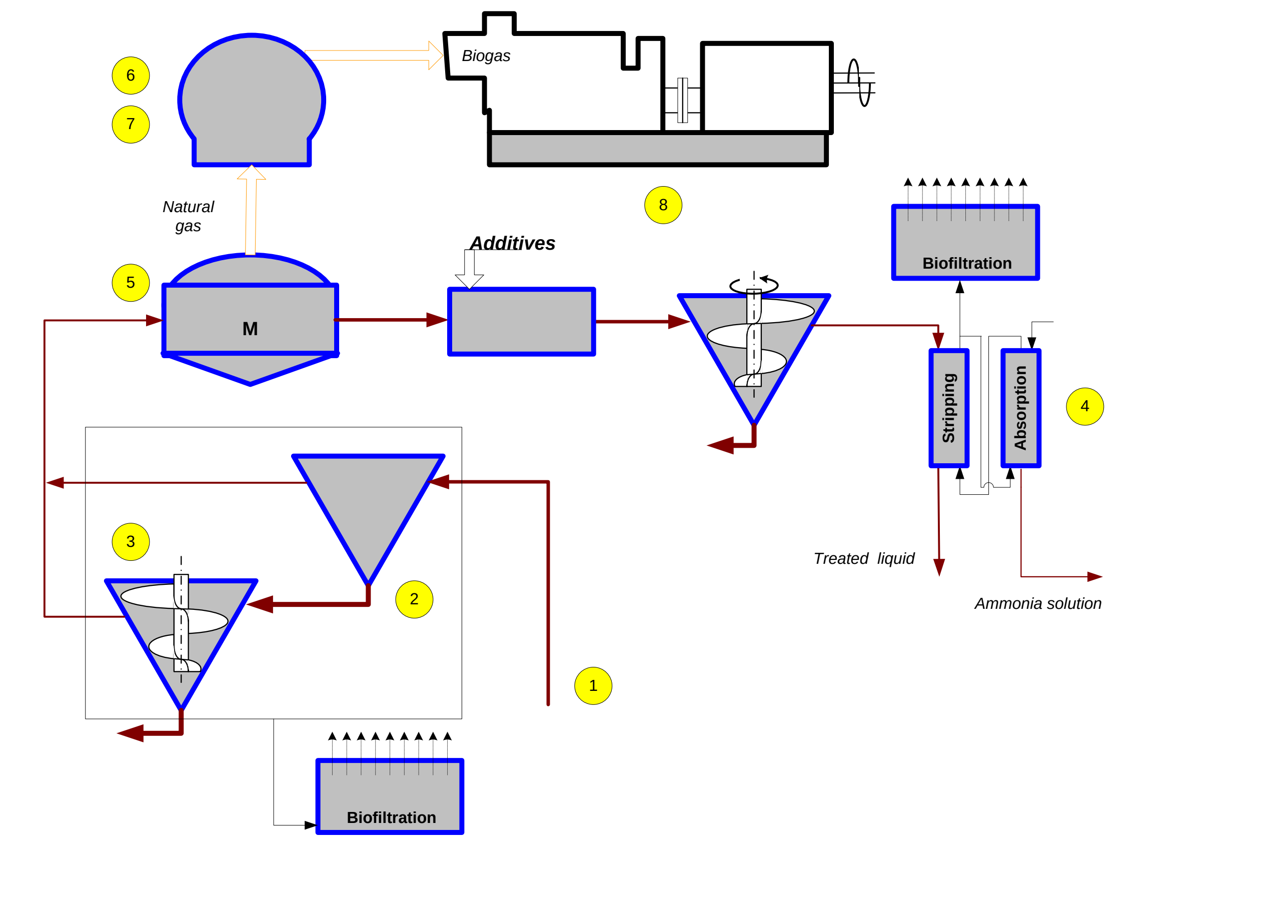


Figure F.3: Plant diagram.

Table F.1: Economic balance for pig manure co-digestion with agro-industrial wastes

Co-substrates	Transport	Supplier charged	Supplier paid	Storage	Waste amount	Electricity produced	Benefits	Losses
	[€ / ton]	[€ / ton]	[€ / ton]	[€ / ton]	[m^3 / y]	[kW / y]	[€ / y]	[€ / y]
Lecithin / soap	20	40	0	3	1971000	4533300	0	219000
Washing water	0	0	0	0	40150	92345	nd	nd
Lecithin	0	0	0	0	146000	335800	nd	nd
Bread	0	0	60	0	182500	173375	21900	0
Dough	0	0	20	0	182500	208050	18250	0
Fl / blood	0	0	20	0	87600	166440	21900	0

FI / floats	0	0	0	0	146000	277400	0	0
FI / skins	0	50	0	0	32850	68985	0	1825
Oil sediment	0	0	150	0	346750	797525	54750	0

Nd: no data

Other organic wastes tested (in addition to those in Table F.1) are listed below (in brackets shows the company):

- Effluent from septic tanks and oil interceptor (Dars d.d.).
- Different organic waste (Ekol d.o.o.).
- Expired foodstuffs and other organic waste (Mercator d.d.).
- Dairy sludge, waste org. dairy industry (Pomurske Mlekarne, Ljubljana).
- Oil sediment (Gea d.d., Prochaka mbH).
- Different organic wastes (Port of Koper d.d.).
- Separately collected organic waste (Prodnik, Ltd.,Kostak d.d.).
- Swill and used cooking oils (Ekol Ltd. Biotera d.o.o.).
- Biodegradable waste from food processing Industry (Eta Kamnik, Droga Kolinska, ...).
- Animal by-products category 3 (slaughterhouses).
- Floating (oil separators), organic waste (smaller suppliers-Fležar SpA,...).

Mechanical separator and nitrogen recovery unit (Stripping / Absorption)

The treated wastewaters contain considerable amounts of nitrogen and phosphor concentrations that should be removed before disposal. In 2008 a stripping tower was built. The treated slurry was filtered by the Bird Humboldt centrifuge with a capacity of 15 m^3 / h, where a free of charge lime was added (waste product of a near electrodes manufacture facility). Lime was found to be a relatively successful chemical substitute for the ad-hoc flocculants. Apart from the positive economic impact, phosphorus was retained successfully during flocculation and the pH of the treated slurry was increased to 12. The high alkalinity was beneficial to the next step of the nitrogen stripping process.

The liquid phase was fed to the stripping tower, without any pre-heating. The plastic random tower packing of 3.5 cm diameter was used, while sulfuric acid was necessary for further absorption of nitrogen. The efficiency of the stripping tower was of 90-95% (concentration dropped from 2500 mgN_{tot} / L to 80 mgN_{tot} / L). Since the resulting nitrogen concentration was not below the legislation limits, the treated liquid was disposed into the influent channel of the near WWTP Domžale-Kamnik, while the ammonia solution concentrate was disposed into a near pond.

Electricity production

Electricity is produced with two biogas CHP engines *GE Jenbacher* with 40% tolerance electrical efficiency, where the maximum biogas flow to the turbine was set to 250 m^3 / h, and 526 kW power. The permissible methane variation was 20%.

F.2.5: Descriptive pictures of the plant

Picture F.1: Reception pig manure pipe

Picture F.2: Settler

Picture F.3: AD reactors

Picture F.4: Biogas tank

Picture F.5: Biogas baloon

Picture F.6: CHP engines

Picture F.7: Screw pressing

Picture F.8: WWTP Domžale-Kamnik

Picture F.9: Biogas and WWTP

F.3: Technical data

F.3.1: Global Mass balance

Data in table F.2 and Table F.3 show average influent characteristics and removal efficiencies during pig slurry period (no co-substrates used). As can be seen, COD removal efficiency was over 85-90%, most of the phosphorous was recovered in the screw press (95% in solid fraction), and 90-95% of the nitrogen was recovered in the stripping / absorption unit (liquid fraction).

Table F.2: Mass balance (1993-2006)

Parameter	Raw slurry
pH	8.1
Alk ($CaCO_3$) (kg / m^3)	10.1
COD (kg / m^3)	26
NH4-N (kg / m^3)	1.5
NTK (kg / m^3)	3
Flow (m^3 / day)	350

Table F.3: Removal efficiencies (1993-2006)

Parameter	Removal in AD	Recovery screw press	Recovery stripping

COD	85-90	n.d.	n.d.
N	-	n.d.	90-95
P	-	95	-

F.3.2: Global Energy balance

During the year 1993 to 2006, the two biogas CHP engines generated an average of 4,500,000 kWh_e per year. A slightly higher amount of heat energy (5,475,000 kWh / year) was produced and used for AD reactor heating. The power consumption (electricity) of the plant itself was of 700,000 kWh / year, while the annual delivery of electricity to the electric grid company was of 3,800,000 kWh per year (Table F.4)

Table F.4: Energy balance

Parameter	Produced	Consumed
Electricity energy (MWh / year)	4,500	700
Heat energy (MWh / year)	5,475	5,475

F.4: Environmental data

No measurements regarding emissions of greenhouse gases (GHG: CO_2, CH_4, and NO_x) and ammonia (NH_3) have ever been done in this treatment plant. Some qualitative considerations are summarized in the next sub-sections.

F.4.1: Estimated CH_4 emissions (kg / year)

No emissions of CH_4 are considered, slurry storage time in the plant is less than 1 day.

F.4.2: Estimated NO_x-N emissions

The process is performed in anaerobic conditions, thus NO_x emissions are not considered.

F.4.3: Estimated NH_3 emissions

Ammonia emissions are not considered because storage of slurry in the plant is less than 1 day, and the ammonia contained in the digested is removed and recovered in the stripping / absorption unit.

F.4.4: Saved equivalent CO_2 emissions

The net production of electricity with the CHP engine fuelled with biogas is 3,800,000 kWh_e / y. hence, the production of this amount of electricity, avoids 1,575 ton CO_2 / y, according to the CO_2 equivalent electrical mix of Slovenia (350 gCO_2 / kWh).

F.5: Economical data

The estimated initial investment to build the biogas plant was around 3-4 M€. The government infrastructure subsidy was 20% of the total initial investment cost. The economic balance of the plant during the period 1993 to 2006 (only pig manure substrate) was in deficit, since no benefits were gained from energy sales to the local network. Anyway, after FI-ECO d.d. was certified as a qualified electricity producer, the economic balance was maintained neutral. The current electricity price from qualified producers in Slovenia is of 12.89 € / MWh. The organic fertilizer obtained from the AD treatment was sold at 5 € / m^3.

The investment cost of the stripping tower was estimated around 250,000 € (2.0 € / m^3) of treated wastewater. The cost of disposal is about 4.5 € / m^3 and therefore the total cost of processing wastewater from the digester is 6.5 € / m^3. The stripping tower costs for removal of 1 kg nitrogen is 2.7 € / kgN_{tot}.

The stripping process with disposal to the near WWTP had been estimated to be a competitive alternative to a SBR treatment. The main reason for the stripping tower solution was the reduced space available. Moreover, the operators believe that there is a reasonable market opportunity for the derived mineral concentrate, which can be a byproduct of the stripping process: a local fertilizer industry has shown interest to acquire the product for a price of 1.5 € / kg. Nevertheless, the mineral concentrate trade was not feasible because of the low productivity capacities of the biogas plant.

Table F. 4: Investment cost

Treatment unit	Cost (M€)
AD plant construction	3-4
Stripping construction	0.25

Table F.5: Operational cost / benefit

Parameter	Income	Cost
Electricity sales (€ / year)	48,754	-
Organic fertilizer (€ / m^3)	5	-
Stripping treatment (€ / kgN_{tot})	-	2.7
Stripping treatment (€ / m^3)	-	6.5
Stripping nitric salts (€ / kg)	1.5	-

F.6: Social aspects

F.6.1: Jobs created

The main operational tasks are equipment maintenance (2 operators) and process supervision activities (2 operators).

F.6.2: Neighbours acceptance and odour

The biogas plant facility has been criticized by the neighbors because of odor emissions pollution. The problem is the relative proximity of the Ihan village and other private houses.

The presence of multiple potential sources of unpleasant odors on the same location makes the delineation of responsibility a difficult task. In the proximity of the biogas plant there are the WWTP Domžale-Kamnik and a big poultry farm.

In order to attenuate the public pressure over the unpleasant odors, different action has been undertaken:

- A biogas filter system has been installed.
- The inflow pig manure channel from the pig farm to the treatment plant, and its mechanical separation chamber are maintained depressurized, and
- One-half of the air mass flow from the stripping tower is sent to the bio-filter.

F.7: Acknowledgements

Information provided by Dr.Jože Jurkovič (ex-director of the FI-ECO biogas plant).

F.8: Summary

Table F.6 summarizes the main figures describing APERGAS plant.

Table F.6: Technical, economical and environmental key performance of the Ihan treatment plant.

Issue	Parameter value
Technical performance	
Major processing technologies	Anaerobic digestion and stripping / absorption
Mass balance	
Influent, ton per year (1993-2006)	127,750
▪ Pig slurry	127,750
Influent, ton per year (2006-2010)	60,833
▪ Pig slurry	18,250
▪ Co-substrates	42,583
End and by-products, ton per year	
▪ Solid fraction	*n.d.*
▪ Treated digested liquid fraction	*n.d.*
▪ Ammonia solution	*n.d.*
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	-
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	29.7
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg / m^3 treated	*n.d.*
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	*n.d.*
Economical performance	
▪ Net cost of processing including subsidies, € / m^3	6.5
▪ Net cost of processing including subsidies, € / kg N_{total}	2.7
▪ Net cost of processing excluding subsidies, € / m^3	-
▪ Net cost of processing excluding subsidies, € / kg N_{total}	-

nd: no data

ANNEX G: COMBINATION ANAEROBIC DIGESTION – COMPOSTING, GIRONA, SPAIN

G.1: Introduction

Pla de l'Estany is a county of Girona province (Catalonia, Spain) designed as vulnerable zone according to Decree 283 / 1998[21] of the Catalan Government. In order to improve land fertilization and minimize environmental pollution when applying manure, it is compulsory to farmers to establish Nutrient Managing Plans (NMP) (Decree 220 / 2001, Decree 50 / 2005 and Decree 136/2009). Farmers must design and validate a NMP according to dosage of nutrients applicable to fertilize crops, temporal constrains on the land-application, and manure storage capacity. Enhancements in animal feeding, manure transportation and treatments may be also considered.

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

G.2: General description of the plant

G.2.1: Location

The plant is located in the village of Sant Esteve de Guialbes, belonging to the municipality of Vilademuls (Girona, Catalonia, Spain). The municipality of Vilademuls, located in the eastern part of the Pla de l'Estany County, has an area of 61.1 km^2 and 766 inhabitants (Figure G.1).

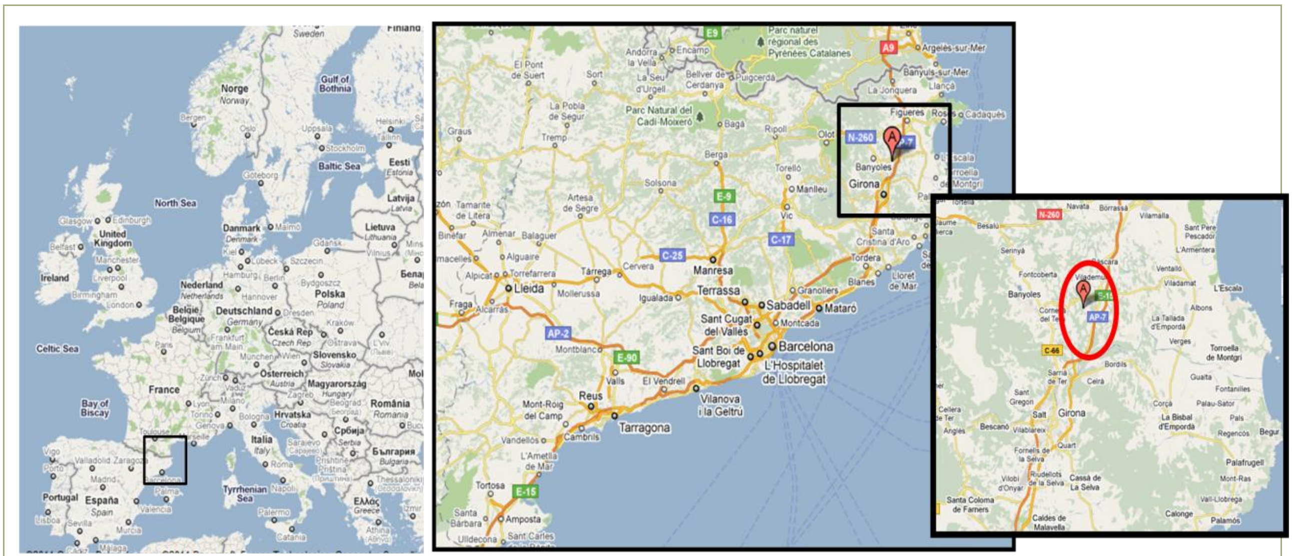


Figure G.1: Location of Apergas treatment plant.

G.2.2: Companies involved in the construction of the plant

The project of Apergas plant is the result of the synergy of three companies: SAT San Mer, EnErGi, and BIOVEC. The design of the plant was done in 2007, the construction during 2008 and the startup in 2009.

[21] Decret. 283/1998, de 21 d'octubre, de designació de les zones vulnerables en relació amb la contaminació de nitrats procedents de fonts agràries

SAT Sant Mer is a dairy farm located in Sant Esteve de Guialbes - Vilademuls (Girona) with 700 milk cows, a milk quota of 6.614 million kg / year milk, and about 400 ha of crop land (mainly cereals).

Energi (Enginyeria Energètica Gironina S.L.) is a company which offers support and technical advice in engineering projects related to energy supply and production. (www.energi.es)

BIOVEC is an environmental engineering consultancy. Its main activities are energy and feasibility studies, engineering projects and construction of biogas plants. (www.biovec.es)

G.2.3: Operation of the treatment plant

The biogas plant treats the slurry produced in the dairy farm SAT Sant Mer, together with organic wastes from agribusiness facilities of the county. During 2010, 18,771 m^3 of cow slurry and 3,129 m^3 of co-substrates were treated in the plant.

Since 2009, the owner of the plant is APERGAS (Aprofitaments Energètics Agrícoles, S.L.). This company is formed by three other companies, from the agricultural sector (**SAT Sant Mer**), the construction sector (**Assa Hidraulica I Electricitat S.L.**) and the engineering company **Energi**.

G.2.4: Description of the treatment plant

The aim of the plant is to maximise the production of biogas and sell to the grid the electricity produced with the CHP engine fuelled with biogas. The liquid phase of the digested is used as fertiliser in the nearby crop land, and the solid fractions is composted and sold to nearby farmers.

The plant consists in the following units (Figure G.2):

- Mesophilic anaerobic digestion in two serial reactors.
- Mechanical separation by sieve.
- Composting of the solid fraction in trenches with forced aeration.
- Storage and land application of the liquid fraction.
- Biogas valorisation in a combined heat and power engine (CHP).

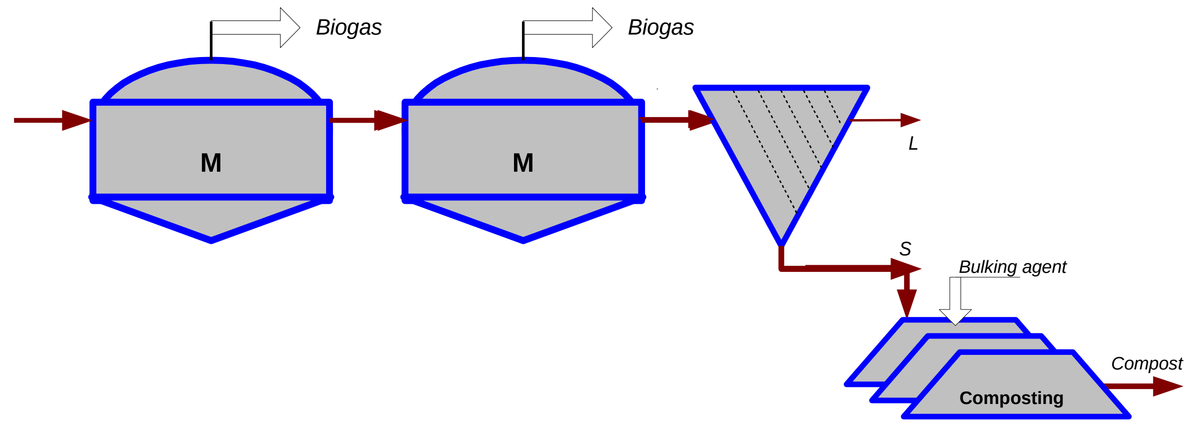


Figure G.2: Flow chart of Apergas treatment plant.

The main characteristic of the equipments and treatment units are:

- Slurry reception tank: closed tank mechanically stirred with a capacity of 129 m^3.
- Co-substrate reception tank: closed tank mechanically stirred with a capacity of 58.9 m^3.
- Anaerobic digesters: Two serial continuous stirred-tank reactor (CSTR) of 2,078 m^3 and 1,450 m^3, with two lateral mechanical sterriers each, isolateds and calafacted with hot water.
- Biogas storage: head space of the two reactors with a total capacity of 1,000 Nm^3 (600 Nm^3 and 400 Nm^3).
- Biogas desulfuration: Air injection in the reactor head space.
- Combined heat and power engine (CHP): 347 kWe, placed in a container of 15 m^2.
- Security torch with a 4-meter mast.
- Building with the control room and other services (18 m^2).
- Mechanical separator: Bauer S885.
- Effluent pond: storage capacity 10,000 m^3.
- Composting: 4 trenches (3.5 x 20 x 1.5 m) with forced aeration, total composting area of 346 m^2.
- Maturation area: concrete platform of 425 m^2.
- Compost storage: concrete platform of 15 m^2.
- Yard trimmings, straw, and other carbon-rich materials storage: concrete platform of 15 m^2.

Major technical modifications of the plants

- Replacement of the original CHP engine for a CHP with higher power, 500 kW (Deutz LM616k16).
- Control system of hydrogen sulphide by adsorption on activated carbon.

G.2.5: Descriptive pictures

Picture G.1: General view of Apergas treatment plant. *Picture G.2: General view of Apergas treatment plant.*

Picture G.3: Reception tanck of slurry *Picture G.4: Anarobic digesters*

Picture G.5: Mechanical separator *Picture G.6: Composting trenches*

Picture G.7: Container with CHP engine

Picture G.8: Final storage pond

G.3: Technical data

G.3.1: Mass balance and treatment efficiencies

Data in Table G.1 and Table G.2 correspond to a monthly sampling programme followed during 2010. Values correspond to averages of 12 samples in Table G.1 and 6 samples in Table G.2.

Table G.1: Chemical characterizations of influent and effluents (n=12).

Parameter	Units	Influent (Raw slurry + co-substrates)	Liquid Fraction	Solid Fraction
pH	-	6.5	7.8	8.7
EC	mS	10.73	16.3	2.5
TS	%	7.3	4.2	25.5
VS	%	6.0	2.8	21.1
COD	mgO_2 / kg	106,718	-	-
TN	mg / kg	3,730	3,655	7,898
NH_4-N	mg / kg	1,683	2,296	2,480
NO_3-N	mg / kg	30.4	5.2	460.7
P_{total}	mg / kg	1,732	1,121	9,665

Table G.2: Compost characteristics (n= 6).

Parameter	units	Compost
pH[1]	--	8.1
CE[1]	mS	2.7
TS	%	26.0
VS	%	21.1
TN	mg / kg	7,809
NH_4^+-N	mg / kg	1,291
NO_3^--N	mg / kg	544.3
C / N	--	12.5
Auto thermal test (Rottegrade Test)	--	V
P_{total}	$\%_{.db}$	1.1
K	$\%_{db}$	0.9
Cadmium (Cd)	mg / kg_{db}	<0,1
Copper (Cu)	mg / kg_{db}	49.0
Nickel (Ni)	mg / kg_{db}	6.0
Lead (Pb)	mg / kg_{db}	10.0
Zinc (Zn)	mg / kg_{db}	234.5
Mercury (Hg)	mg / kg_{db}	0.04
$Chrome_{total}(Cr_t)$	mg / kg_{db}	10.0
Chrome VI (Cr(VI))	mg / kg_{db}	<0,50

[1]Water extraction 1:5 *db: dry base*

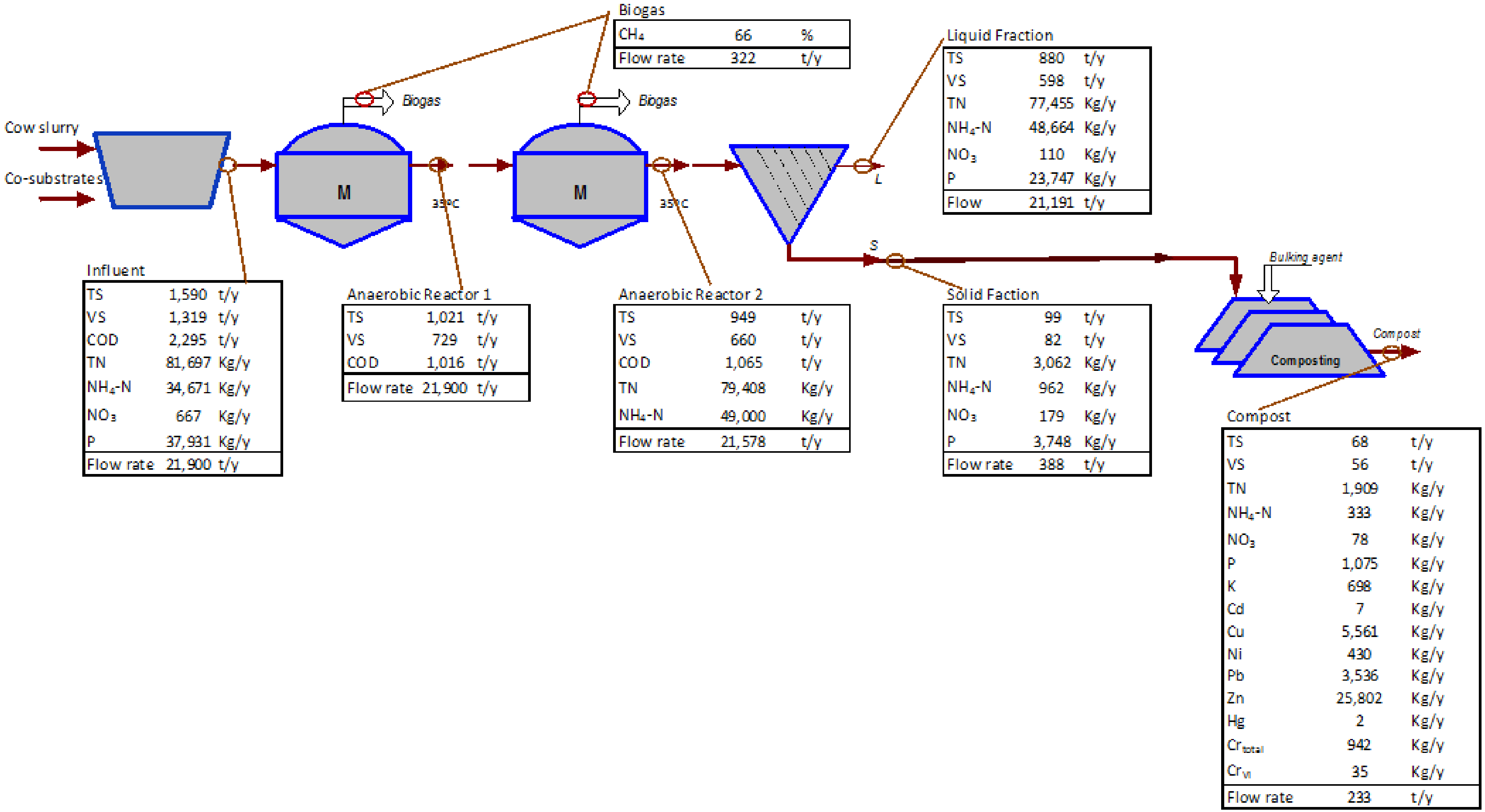


Figure G.5: Mass balance of Apergas plant.

The produced compost presents high stability, but with high moister content (65-78%). Regarding heavy metals, the presence of Zn classifies the compost as Class B (REAL DECRETO 824 / 2005, de 8 de Julio, sobre productos fertilizantes)

The mass balance (Figure G.5) was performed according to data in Table G.1 and G.2 and data from intermediate flows (data not show).The main figures from the mass balance are summarised in Table G.3.

Table G.3: Mass Balance (data from 2010).

	Parameter	Value
Inflow [22]	Total (t / y)	21,900
	Raw slurry (t / y)	18,772
	Co-substrates (t / y)	3,118
Removal efficiencies (%)	TS (%)	23-43
	VS (%)	34-52
	COD (%)	44-63
Liquid Fraction	(t / y)	21,191
Solid Fraction (t / y)	(t / y)	388
Compost (t / y)	(t / y)	233

G.3.2: Energy balance

Table G.4 summarizes the energy balance. As it can be seen, the electricity consumed is only a 6% of the production of electricity in the CHP engine, and the thermal energy recovered is close to the 34%.

Table G.4: Energy balance.

		2010	2011 (6 months)[23]
CHP engine	Power (kW)	370	500
Electricity energy	Production (kWh$_e$ / y)	**2,960,370**	**4,000,500**
	Consumption (kWh$_e$ / y)	**167,918**	**109,574**
	• Plant operation	83,716	37,168
	• CHP F mode[24]	65,922	65,955
	• CHP S mode[25]	18,279	6,452

[22] The daily flow during 2010 was 60 t / day with 14% of co-substrates. During 2011 (data from January 2011 to June 2011) the total inflow has increased till 80 t / d, and co-substrate represented 21% of the total inflow.

[23] Data from January 2011 to June 2011

[24] Note: CHP Mode F: CHP in operating mode

		2010	2011 (6 months)[23]
Thermal energy	Consumption (kWh_t / y)	419,040	
	Recovery (%)	33.62%	

As can be seen in Table G.4, the increase of the influent flow in 2011, from 60 t / d to 80 t / d, together with the increase of co-substrate from 14% to 21%, has had a strong influence on the amount of electricity produced.

G.4: Environmental data

No measurements regarding emissions of greenhouse gases (GHG: CO_2, CH_4, and NO_x) and ammonia (NH_3) have ever been done in this treatment plant. Environmental analysis is performed estimating equivalent CO_2 emissions using data from the mass balance and following IPCC guidelines (IPCC, 2006).

According to IPCC procedure, a ***reference situation*** must be defined in order to compare changes in GHG emissions. In this case, despite SAT Sant Mer dairy farm is located in a vulnerable zone, the farm has enough land to use all the manure produced for crop fertilization. Thus, management reference situation characteristics are:

- Storage in anaerobic lagoons (4 months)
- Crop fertilization (average distance 3 km).

And the main characteristics of the ***current situation*** are:

- Slurry storage at farm for less than 1 month.
- Treatment facility treats all the slurry produced (together with other organic wastes).
- Electrical power plant is a CHP unit fuelled with biogas. All the electricity produced is sold to the grid.
- Waste head from CHP unit covers thermal energy requirements (heating of the reactor).
- Digested storage in anaerobic lagoons (4-6 months).
- Digestate is used for nearby cropland fertilization (average distance 3 km).
- Compost is sold to nearby farmers (average distance 3 km).

Emissions considered are:

- CH_4 emissions during storage and composting.
- NH_3-N volatilization during storage and composting.
- Indirect N_2O emissions due to NH_3-N volatilization.
- Indirect CO_2 emissions due to energy production.
- Indirect CO_2 savings due to energy production with biogas.

CO_2 emissions during transportation to cropland are not considered. It has been assumed that the cropland fertilized with raw pig slurry, is nowadays fertilized with digested slurry. Thus no changes of CO_2 emissions can be expected.

Assumptions made for estimating equivalent CO_2 emissions in each situation are explained in the following sub-sections.

[25] CHP Mode S: CHP in idle mode

G.4.1: Nitrogen emissions: NH_3-N + NO_x-N and N_2O-N emissions

Reference situation

The ammonia emissions factor applied for the long term storage at farm (4-6 month) is 40% (Table 10.22; IPCC, 2006), using the initial nitrogen concentration indicated in the mass balance. Estimated ammonia emissions are 27,781 kg NH_3-N / y. With these emissions, the final nitrogen amount available for fertilisation is 41,672 kg N / y.

Direct N_2O emissions are not considered since manure storage at farm is anaerobic (EF3=0).

Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006), that is 1% of the ammonia nitrogen emitted.

Current situation

Ammonia emission has been considered to be produced in storage at farm (< 1month), the long term storage of the digested slurry (4-6 months) and during composting. The ammonia emission factor applied to farm storage was 3% (manure is stored 1-5 days), and the factor of the long term storage of the digested slurry 40% (Table 10.22; IPCC, 2006). A mass balance has been performed to calculate ammonia losses during composting.

The estimated ammonia emissions are 34,220 kg NH_3-N / y. With these emissions, the final nitrogen amount available for fertilization is 48,383 kg N / y.

Indirect N_2O emissions are estimated using an EF4 factor of 0.01 (IPCC, 2006) (Table G.5). Direct N_2O emissions are negligible (EF300). Thermal NO_x emissions and the consequent N_2O emissions are not considered for the current and the reference situations, due to similarity of values and the uncertainty in its estimation based on the possible interval values indicated in EMEP-CORINAIR (2007).

Table G.5: Estimated NH3-N and equivalent N2O.-N emissions.

Reference situation	Primary emission [kg NH_3 / y]	Equivalent N_2O [kg N_2O / y]
Reference situation		
• Manure storage at farm	27,781	277.8
Total	**27,781**	**277.8**
Current situation		
• Manure storage at farm	2,084	20.8
• Digested storage at farm	30,982	309.8
• Composting	1,154	11.5
Total	**34,220**	**342.2**

G.4.2: Estimated CH_4 emissions

Reference situation

CH_4 emission factor during raw slurry storage adopted is 46% of the methane production potential of the volatile solids (0.2 m^3 / kgVS), considering an average temperature of 21ºC (Table 10.17, IPCC, 2006). The estimated emissions are 69,687 kg CH_4 / y.

Current situation

Methane emission has been considered in three different points:

- Raw slurry storage at farm (< 1 month) in pit storage below animal confinements. The emission factor considered is 3% of the methane production potential of the volatile solids, following IPCC (2006).
- Digested slurry storage in an anaerobic lagoon (4-6 months). The emission factor considered is 46% of the methane production potential of the volatile solids (IPCC, 2006).
- Composting in static piles. The emission factor considered is 5% of the methane production potential of the volatile solids.

With these considerations, the estimate CH_4 emissions are 41,608 kg CH_4 / y (Table G.6).

Table G.6: Estimated CH4 emissions.

Reference situation	Primary emission [kg CH_4 / y]
	Reference situation
• Manure storage at farm	69,687
Total	**69,687**
Current situation	
• Raw manure storage at farm	5,302
• Digested slurry storage at farm	36,306
• Composting	0.05
Total	**41,608**

G.4.3: Estimated equivalent CO_2 electricity consumption and production

Reference situation

No-consumption of electricity has been considered in the reference situation.

Current situation

Equivalent CO_2 emission due to electricity consumption as well as CO_2 saving due to electricity produced using biogas as fuel, has been estimated using the emission factor of the average mix electric production in Spain 2010, 181 g CO_2 / kWh_e (OCCC, 2011).

Table G.7: Estimated Electricity consumed and produced and equivalent CO2 emissions.

Reference situation	Electricity [kWh_e / y]	Equivalent CO_2 [kg CO_2 / y]
Reference situation		
Total	-	-
Current situation		
• Electricity consumed	167,918	30,561
• Electricity produced (CHP – biogas)	2,960,370	-538,787
Total		**-508,226**

G.4.4: Estimated equivalent CO_2 emissions balance

The conversion of the above emissions to CO_2 equivalent emissions units are shown in Table G.8. Conversion factors adopted have been 25 kg CO_2 / kg CH_4 and 298 kg CO_2 / kg N_2O (Forster et el., 2007).

Table G.8: Estimated equivalent CO2 emissions.

124

Reference situation	Primary emission	Equivalent CO_2 [kg CO_2 / y]
Manure storage at farm	69,687 kg CH_4 / y	1,742,171
Indirect N_2O emissions	277.8 kg N_2O / y	82,788
TOTAL EQUIVALENT CO_2 EMISSIONS		**1,824,958**
Current situation	Primary emission	Equivalent CO_2 [kg CO_2 / d]
Manure and digested storage at farm	41,608 kg CH_4 / y	1,040,210
Composting	30,561 kg CO_2 / y	30,561
Electricity consumption	-538,787 kg CO2 / y	-538,787
Electricity production	342.2 Kg N_2O / y	101,976
Indirect N_2O emissions	41,608 kg CH_4 / y	1,040,210
Direct N_2O emissions	~0 kg N_2O / y	~0
TOTAL EQUIVALENT CO_2 EMISSIONS		**633,959**
Equivalent CO_2 emissions balance		
CO_2 equivalent saved with the current management and treatment system	1,190,999	Kg CO_2 / y

CO_2 equivalent saved per manure unit	63.45	Kg CO_2 / tonne manure
CO_2 equivalent saved per unit of total N	17.15	Kg CO_2 / kg N

G.5: Economical data

G.5.1: Investment and operational costs

The total investment cost of the plant was 1,410,800 €. Table G.9 shows the detailed cost of the plant. The owners of the plant received a subsidy from the Catalan Government of 502,000 €, the rest of the investment (908,800 €) was a bank funding.

Table G.9: Investment cost.

Units description	Cost (€)
Equipments (stirrers, pumps, valves, CHP engine, etc.)	522,800 €
Concrete works (Anaerobic digesters, composting platforms and trenches, etc.).	292,000 €
Facilities (gas, water, electricity)	132,000 €
Grid connection	136,200 €
Mechanical separator	28,300 €
Hydrogen sulphite control	18,000 €
Soil movement, levelling, etc.	89,500 €
Other (roads, fees, contingency, etc.)	63,000 €
Toilets, landscaping, etc.	15,000 €
Project engineering	114,000 €
Total investment	**1,410,800 €**

The annual operational cost during 2010 was 205,106 €; maintenance and other (roads, fees, contingency, etc. – see details in Table G.9: Investment cost) are the main operational cost (Table G.10).

Table G.10: Operational cost (2010.)

Concepts	Cost (€)
Salaries	33,100 € / y
Operational control (sampling, analysis, etc.)	27,830 € / y
Maintenance	61,200 € / y
Electricity	12,976 € / y
Other	70,000 € / y
Total operational cost	**205,106 € / y**

G.5.2: Incomes of the plant

Table G.11 shows the plant incomes during 2010. Data from the first half of 2011 are also included, in order to show the optimization of the plant.

As can be seen, incomes during the first half of 2011 are close to total incomes of 2010. The increase of biogas production (and electricity) due to the higher flow rate and co-substrates proportion, has resulted in this great increase of the incomes.

Table G.11: Annual plant incomes.

	Year	Incomes (€)
Electric power sales	2010	214, 293 €
	2011[1]	187, 675 €
Gate fees received	2010	78,225 €
	2011[1]	76,325 €
Compost Sales[2]	2010	- €
	2011[1]	- €
Total incomes	2010	**292,518 €**
	2011[1]	**264,000 €**

[1] *Data from January 2011 to June 2011*

[2] *Compost is sold with only the charge of transport (no-income has been considered)*

G.5.3: Economical balance and general indexes

The internal rate of return (IRR) is **19.24%**, and the amortization period calculated was **5.2 years**.

The treatment cost has been calculated with the economical data from 2010 and 2011:

- Manure treatment cost: 2010: +3.15 € / t manure

2011: -7.64 € / t manure

- Nitrogen management cost: 2010: +0.98 € / kg N

  2011: -2.39 € / kg N

During 2010, the cost of treating the manure was around 3 € per ton, but the increase of incomes in 2011 has completely changed the cost, and nowadays each ton of manure treated reported a benefit above 7€.

G.6: Social aspects

G.6.1: Jobs created

Direct jobs: 1 plant operator, ½-time waste manager.

Indirect jobs: ½ maintenance worker, ½-time administrative and 1 truck driver

G.6.2: Neighbours acceptance and odour

There have been neither odour problems, nor complaints from the neighbours

G.6.3: Farmer's opinion

There is an increasing interest in biogas plants and the acceptance that the digested manure is a good fertilizer. Nevertheless, the investment required to construct a biogas plant is too high to be supported by a small or medium size farms. While the possibility of grouping farmers into collective plants, is often limited due to distances requirements between farms and plant treatment (RD 324 / 2000).

G.7: Additional aspects

G.7.1: Organic products

The compost produced is included in the Spanish Fertiliser Register as *FERTIBON, 6002 Enmienda orgànica Compost. Register Nº F0001468 / 2020*.

G.7.2: Controls by authorities

Annual process control is done by the Catalan Waste Agency (Agencia de Residus de Catalunya).

G.7.3: Awards

1st award from Federation of Milk Companies (Espanyola d'Empresaris Productors de Llet (PROLEC))

1st award to Inovaton in the dairy sector. Expoaviga (Barcelona 2010)

G.8: Summary

Table G.12 summarizes the main figures describing APERGAS plant.

Table G.12: Technical, economical and environmental key performance of the Apergas treatment plant.

Issue	Parameter value
Technical performance	
Major processing technologies	Anaerobic digestion and composting of solid fraction
Mass balance	
Influent, ton per year	21,800
▪ Cow slurry	18,772
▪ Co-substrates	3,118
End and by-products, ton per year	
▪ Liquid Fraction	21,191
▪ Compost	233
Energy balance	
▪ Net consumption of energy per m^3 treated livestock manure and other, kWh / m^3	-
▪ Net energy production per m^3 treated livestock manure and other, kWh / m^3	128.1
Environmental performance	
▪ Net influence on emissions (leaching, evaporation, other) of nitrogen, kg / m^3 treated	1.6
▪ Net influence on production of greenhouse, gases, kg CO_{2e} / m^3 treated	28.9
Economical performance	
▪ Net cost of processing including subsidies, € / m^3	+3,15 (2010) -7.64 (2011)[1]
▪ Net cost of processing including subsidies, € / kg N_{total}	+0.98 (2010) -2.39 (2011)[1]
▪ Net cost of processing excluding subsidies, € / m^3	-

Issue	Parameter value
▪ Net cost of processing excluding subsidies, € / kg N_{total}	-

[1] Calculations with data from first semester 2011 / Negative figure means benefit (income).

Manure processing is presently a subject that enjoys considerable attention in the EU due to the ongoing revision of the Reference Document on Best Available Techniques for Intensive Rearing of Poultry and Pigs (BREF), as well as due to current efforts to implement policies and legislation on EU and Member State level, for instance concerning renewable energy targets, targets for reducing the loss of plant nutrients to the environment, targets for reduction of greenhouse gases, and targets for manure handling in agriculture in relation to legislation about water protection and manure surpluses in livestock intensive areas.

This report is prepared for the European Commission, Directorate General Environment, as part of the implementation of the project "Manure Processing Activities in Europe", project reference: ENV.B.1 / ETU / 2010 / 0007. The Report includes deliverables related with Task 4 concerning "Assessment of economic feasibility and environmental performance of manure processing technologies".