INVESTIGATION AND ANALYSIS THROUGH MODELLING OF THE POTENTIAL FOR RENEWABLE ENERGY PRODUCTION AND MITIGATION OF GREENHOUSE GAS EMISSIONS FROM ANAEROBIC DIGESTION IN CYPRUS

A thesis submitted in fulfilment of the requirements
for the degree of Doctor of Philosophy

by

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May, 2014

Abstract

Biodegradable wastes cause high emissions of greenhouse gases (GHG) if not properly treated. The emissions can be reduced by the development of an effective waste management strategy. Waste-to-energy technologies, such as anaerobic digestion (AD) can be utilised for this purpose. Biomass energy from wastes is of particular interest to Cyprus that has to meet legal commitments for reducing its GHG emissions by 5% compared to 2005 levels and increase the contribution of renewable energy sources to 13% by 2020.

This research project is making a significant contribution to this effort.

The research considered the quantities and distribution of biodegradable waste in Cyprus and developed the necessary methodologies and tools for their estimation and determination of the potential for energy production through AD.

The study identified that the predominant biodegradable wastes in Cyprus are the biodegradable fraction of municipal solid waste (MSW), sewage sludge, solid and liquid agricultural residues and solid and liquid wastes from the food and drinks industries. According to the estimated amount of solid and liquid biomass from these waste streams, at least 4,200 TJ of energy can be produced through AD, which represents 4% of the national energy demand.

Livestock production is a very important source of waste due to the high potential of biogas production with the aid of AD. The produced energy can satisfy the needs of a farm, reduce the consumption of fuel and provide renewable energy to the national grid. Simple methodologies were developed and implemented for the estimation of energy consumption of the farm and the respective GHG emissions. It was found that in Cyprus the annual energy consumption per animal is lower than most other countries, due to favourable weather conditions which reduce the energy needs for heating. The emissions from energy use in livestock production contribute 16% to the total agricultural energy emissions.

Literature review on AD, confirmed the complexity of the process, due to the many microorganisms involved. To estimate the potential of biogas production from animal waste through AD, three methods were developed based on the accepted relations that exist between Chemical Oxygen Demand (COD), volatile solids (VS), waste digested and biogas production. The results show that livestock production could cover the complete agricultural energy demand and make a considerable contribution to the renewable energy targets of Cyprus.

Due to the identified importance that AD could have for Cyprus and to overcome deficiencies of existing models, the software FARMS was developed. The tool can be used by any farmer, consultant or policy maker for the estimation of the potential of biogas production, associated costs, reduction in GHG emissions and comparison of scenarios for waste management. Furthermore, the validation of the tool is presented. This was done through comparison against data collected from existing AD plants and through testing by potential users.

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List of Abbreviations

AD	Anaerobic Digestion
BaU	Business as Usual
CH_4	Methane
CHP	Combined Heat and Power
CO_2	Carbon Dioxide
COD	Chemical Oxygen Demand
EU	European Union
EU ETS	European Union Emissions Trading System
Gg	Gigagram (≡ 10^6 kilograms ≡ 10^3 tonnes)
GWP	Global Warming Potential
GHG	Greenhouse gas
H_2S	Hydrogen Sulphide
HFCs	Hydrofluorocarbons (HFCs)
IPCC	Intergovernmental Panel on Climate Change
IPPC	Integrated Pollution Prevention Control
KP	Kyoto Protocol
LPG	Liquid Petroleum Gas
LULUCF	Land Use, Land Use Change and Forestry
MSW	Municipal Solid Waste
N_2O	Nitrous Oxide
PFCs	Perfluorocarbons
PWF	Present Worth Factor
SF6	Sulphur Hexafluoride

TJ	Terajoule
UN	United Nations
UNFCCC	United Nations Convention on Climate Change
US EPA	United States Environment Protection Agency
VOC	Volatile Organic Compounds
VS	Volatile Solids
WM	With Measures

List of Accompanying Material

Attached on the front cover of the thesis, is a compact disc which contains the software application FARMS.

Acknowledgements

"Η Ιθάκη σ' έδωσε τ' ωραίο ταξείδι.
Χωρίς αυτήν δεν θάβγαινες στον δρόμο."

Constantine P. Cavafy, Greek Poet, 1863-1933

The great words of CP Cavafy perfectly describe what this PhD has been to me: my Ithaka. It was all about the journey; this long journey through time and knowledge.

I would first like to thank my parents who made me a warrior. My other half, Fotis who was always there to listen and push me when I needed a push. My sisters, my lovely sisters, who have their own unique support mechanism and are wonderful in so many ways.

Thank you Dr. Florides for taking me under your wing back in 2008 and Prof. Tassou for your simple and so accurate comments. Your experience in research has taught me so more than books and journals.

Of course I could not forget to express my great appreciation to my old friend Andreas for the development of the software and my colleague Antis for willingly helping me every time I needed his help.

Special thank you to all the farmers who provided me with information for their anaerobic digesters and to all the people who tested FARMS.

Thank you all, this work could not have been completed without you.

CHAPTER 1. Introduction

Cyprus is a small island country, located in the eastern Mediterranean Sea. The population of the country is less than 1 million and has been a member of the European Union (EU) since 2004. The focus of Cyprus' economy since the early 1980s has been gradually shifting from agriculture to services. Nevertheless, livestock production still plays an important role in the economy, due to the large demand of meat and other animal products.

One of the biggest problems of livestock production is waste management and the associated environmental impacts. Another problem is the unavailability of information regarding the amount of biodegradable waste produced in Cyprus. This information is vital for the development of effective waste management strategies.

The introduction of intensive farming operations has increased the density of livestock in certain areas and the amounts of manure produced. Inadequate management of this manure has resulted in many negative environmental impacts, health concerns and public nuisances that require attention (Fatta *et al.* 2007). Moreover, the spreading of untreated manure and improperly stored waste on farm sites results in nitrates from manure contaminating soils and seeping into the groundwater and surface waterways. Ammonia and volatile organic compound (VOC) emissions from farm sites also contribute to the deterioration of air quality (Filipy *et al.* 2006). VOC emissions from manure are quite high in Cyprus because of the hot and dry climate (Fatta *et al.* 2007).

Land application of animal manure is an efficient utilisation of nutrients in the manure (Fatta *et al.* 2007). However, it is crucial to follow the national guidelines on amounts and frequency of application of manure on soil, since uncontrolled application could result in the intensification of nitrate pollution (Athanasiades, 2011). Alternatives to manure spreading that can provide the homogenisation and stabilisation needed to successfully compete against chemical fertilizers, include composting, pelletisation, and anaerobic digestion (AD). AD offers the opportunity to generate power from the biogas produced, reduce water pollution and odours and increase the value of fertiliser produced. CH_4 can be emitted in all stages of manure management – from the housing area, to the treatment. According to Chadwick *et al.* (2011) the contribution of manure management to the total agricultural CH_4 emissions of a country ranges from 12% to 41%. Differences in emission of CH_4 from manure management between countries reflect differences in the duration of manure storage (Haeussermann *et al.* 2006; Sommer *et al.* 2009). The production of CH_4 from manure is also affected by environmental factors such as temperature (Clemens *et al.* 2006; Sommer *et al.* 2007), biomass composition and method/ technology used for the management of manure (Hill *et al.* 2001; Ni *et al.* 2008). During storage of manure, some manure nitrogen is converted to N_2O. It has been estimated that N_2O from manure management contributes 30 to 50% to the global N_2O emissions from agriculture (Oenema *et al.* 2005). Emissions occur from bedding in the housing areas and manure storage (Chadwick, 2005; Thorman *et al.* 2006).

Additional greenhouse gas (GHG) emissions from livestock production are caused by other activities at the farm, such as on-farm energy use. At present, these emissions according to the Intergovernmental Panel on Climate Change (IPCC) methodology (IPCC, 1996) are attributed to the energy sector and are not estimated separately. To estimate these emissions, the energy consumption of the farms should be estimated. The lack of systematic research on energy use in agriculture has in general hindered the development of “rules of thumb” to provide first approximations. The absence of benchmarking data and guides has also made investment calculations and decisions on best available technologies and approaches for energy reduction difficult (Baillie and Chen, 2010). Therefore, a methodology is necessary to estimate the energy consumption at the farm based on the animal population, which would then make possible the estimation of the GHG emissions from on-farm energy use.

In recent years, the issues of climate change, energy and sustainability have gained increased attention. The EU has set new legally binding targets on climate and energy in 2009 (Council of the European Union, 2009). Additionally, climate and energy targets are also included in the new sustainability and financial strategy of the EU (European Commission, 2010). Part of the European “climate and energy” policy, is Decision No. 406/2009/EC, which is known as “Effort Sharing Decision”. This Decision sets new reduction targets for greenhouse gas emissions to the Member States, for the period 2013-2020 (European Union, 2009b). These targets should be achieved from the sectors of agriculture, waste, and fuel combustion for domestic, commercial and industrial uses. The Effort Sharing Decision is part of the EU target to reduce GHG emissions by 20% in 2020 compared to 1990. Another constituent of the climate and energy package is Directive 2009/28/EC where renewable energy targets have been set for member states (European Union, 2009c).

Because of the above legal instruments, Cyprus is facing, for the first time, legally binding targets for the contribution of renewable energy sources to its overall energy balance. By 2020, 13% of the total energy consumption of the country should be produced from renewable energy sources. Furthermore, by 2020, the national greenhouse gas emissions should reduce by 5% compared to 2005.

Even though, the most important emission sources from agriculture are enteric fermentation and manure management, the approach for reducing emissions from agriculture should be an integrated one and all emission sources should be considered. With current energy targets, it should be investigated how livestock production can become self-sufficient in energy. This could be achieved by using animal waste produced in the farms, for energy production through anaerobic digestion. Using this approach, most of the GHG emissions from manure management can be avoided primarily through collection of the wastes in a sealed tank and collection and use of the CH_4 generated for energy production. These opportunities have increased interest in the exploitation of biomass energy from animal waste.

The utilisation of biomass energy from animal waste is of particular interest to Cyprus, since the majority of the animal population is concentrated in specific areas of the country and centralised anaerobic digestion plants can be considered. To assess the potential and viability of such systems, information is needed on many parameters such as quantities of waste production, waste management practices, on-farm energy use amongst others.

In recent years, several software tools have been developed for the analysis of the potential of anaerobic digestion for on-farm energy production. However, these have been designed for the specific conditions of the particular country. Such a tool and data for its use are not available for Cyprus. A tool that could be used by any farmer or consultant for the estimation of the potential of biogas production, associated costs, reduction in GHG emissions and comparison of scenarios for waste management for the specific conditions of Cyprus would help accelerate the implementation of AD for both waste management and energy demand reduction for the island.

1.1 Aim and objectives

The aim of this work is to study the quantities and distribution of biodegradable waste in Cyprus and develop the necessary methodologies and tools for their estimation and determination of the potential for energy production through anaerobic digestion.

The main objectives of the project therefore are:

(a) Assessment of biodegradable waste in Cyprus

The current practices for the management of biodegradable wastes will be identified and the potential amount of solid and liquid biomass of the specified waste streams will be estimated. The potential contribution of biodegradable waste will be assessed with regards to GHG emissions and renewable energy production.

(b) Estimation of on-farm energy consumption in agriculture and respective GHG emissions

Methodologies for the estimation of the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport) and the associated GHG emissions will be developed. These methodologies will then be used to estimate on-farm fossil fuel and electricity consumption for livestock production in Cyprus and the GHG emissions caused from on-farm energy consumption.

(c) Application of anaerobic digestion in Cyprus

The potential of biogas production and the respective thermal and electrical energy which could be produced will be estimated. Methodologies will also be developed to estimate the cost and area requirements for anaerobic digestion in Cyprus.

(d) Develop a software tool to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level

Available models for the estimation of biogas from livestock production will be assessed to examine their functionality and the methodologies and default values of parameters used. A tool will then be developed for Cyprus which will include plant sizing and financial analysis that will consider both the cost and the greenhouse gas emissions.

1.2 Structure of the thesis

Following this introduction, Chapter 2 examines the biodegradable waste production and management in Cyprus. The current situation with respect to greenhouse gas emissions and renewable energy targets is also examined. The contribution of biodegradable waste is assessed with regards to GHG emissions as well as its potential for renewable energy production.

Chapter 3 presents the methodology developed by the author for the estimation of the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport). The methodology for the estimation of GHG emissions from the on-farm energy consumption is also presented. The application of these methodologies to Cyprus is then presented and the results are compared to international data.

Chapter 4 presents the methodologies developed for the estimation of biogas production from livestock waste. The chapter also presents the methodologies adopted for the estimation of the cost and area requirements for anaerobic digestion in Cyprus.

Chapter 5 reviews the literature on models for the estimation of biogas from livestock waste and their deficiencies are identified. The chapter then proceeds to the description of the model developed to incorporate the specific characteristics of livestock production and waste in Cyprus and satisfy the requirements of potential.

Chapter 6 presents the results from the validation and verification stage of the model development process. This includes the results of test runs and also feedback from users which was captured through a questionnaire.

Chapter 7 outlines the conclusions drawn from this research and gives recommendations for further work.

CHAPTER 2. Biodegradable waste, greenhouse gas emissions and renewable energy production in Cyprus

In this chapter, the current practices for the management of biodegradable wastes in Cyprus are identified and reported. In Cyprus, biodegradable wastes are predominately the biodegradable fraction of municipal solid waste (MSW), sewage sludge, solid and liquid agricultural residues and solid and liquid wastes from the food and drinks industries. The contribution that biodegradable wastes make to greenhouse gas (GHG) emissions are also reported.

These wastes are an important source of biomass which can make a contribution to renewable energy production. This contribution has been estimated by first estimating the waste generated by the various waste streams.

2.1 Biodegradable waste production and management

Cyprus does not have a long track record on dealing with environmental issues. The necessary legislation has only been in place for less than a decade. However, during the last 3 to 4 years, significant progress has been made in waste management, which is slowly having an impact on everyday life. The current tendency in the countries of the EU and other developed countries, is to maximise the utilisation of natural resources by increasing efficiency, development of new technologies towards further exploitation of the available sources and utilisation of waste through material or energy recovery.

Being a relatively “young” country in terms of environmental policies and legislation, one of the first priorities in Cyprus is the quantification of waste streams. This section presents estimates on waste generation and outlines management practices for these wastes.

The need for data on biodegradable waste is triple: firstly, biodegradable waste can be used for the production of energy that contributes to the renewable energy target of the country; secondly, estimation of GHG emissions from waste treatment and disposal enables the design and implementation of greenhouse emissions reduction measures; and thirdly, data availability enables assessment of the current status of waste management in the country and provides information towards the progress of implementation of the Landfill Directive (European Union, 1999), which requires biodegradable waste to be gradually eliminated from landfills.

Biodegradable waste in Cyprus predominately consists of the biodegradable fraction of municipal solid waste, sewage sludge, solid and liquid agricultural residues and solid and liquid wastes from food and drink industries.

2.1.1 Management of biodegradable waste

The management of biodegradable waste produced in Cyprus vary according to the waste stream as described below. The data presented has been collected through personal communication with installations of the specified activities and the Department of Environment that issues the waste disposal permits to the waste producers.

Biodegradable fraction of MSW: All biodegradable MSW is currently disposed in controlled and uncontrolled landfills.

Sewage Sludge: the majority is dried and used in agriculture as soil improver. A small fraction is used in anaerobic digesters and consumed in the incinerators of cement industry.

Agricultural residues: the majority of agricultural residues are sent to landfill whilst a small fraction is burnt on site in the fields even though this is prohibited by law since 2005.

Used cooking oils: the majority of used cooking oils are disposed in the sewerage system, thus undergoing the same treatment as any other urban wastewater in Cyprus. Most sewage treatment plants in Cyprus use secondary (biological) treatment, while newly constructed plants employ tertiary treatment. All the water produced by sewage treatment is reused for irrigation, recharge of aquifers and recharge of rivers and streams. A small portion of used cooking oils goes to two installations that use cooking oils for the production of biodiesel.

Food & drink industries. These include wastes from:

- Slaughterhouses: these are either treated at off-site treatment plant for industrial waste or are biologically treated on site.
- Olive mills: the majority of olive mills have mechanical separation equipment installed. The separated liquid is sent to evaporation lagoons or used for irrigation, while the solid fraction is used as feedstock or soil improver, or combusted for energy. Some olive mills use off-site treatment plants for the treatment of industrial waste.
- Dairy industries: most dairy installations transfer their waste to off-site treatment plants for the treatment of industrial waste. Some small, family size installations discharge their waste into the sewerage system whereas one of the largest industries has installed an anaerobic digester.
- Wineries: most wineries use their liquid waste for irrigation. The solid fraction is used as feedstock, soil improver or for the production of a local alcoholic beverage “zivania”.

Livestock waste

- Waste from pig and cattle farms: most small-scale installations use evaporation lagoons for the treatment of their waste. The rest employ mechanical separation equipment. The separated liquid is sent to evaporation lagoons or is used for irrigation, and the solid fraction is used as soil improver. Nine large pig farms have installed a combination of anaerobic / aerobic treatment plants. The treated liquid fraction is used for irrigation or washing the housing areas or placed in evaporation lagoons.
- Poultry waste is characterised by high content of solids (almost dry). It is therefore collected, left to dry and then used as soil improver.

The main off-site installation used for the treatment of biodegradable waste is located in Vathia Gonia. It is a public installation managed by a private company on contract and has a capacity of 2,200 m^3 day^{-1} (WDD, 2000). The treated effluent is used for agricultural purposes in the surrounding area. Other installations used for off-site treatment of waste are anaerobic digesters located in farms, that are licensed to treat wastes other than the waste produced by the farm.

At present in Cyprus there is a growing interest in anaerobic digestion (AD), especially by large pig farms. AD followed by aerobic treatment allows the limits set in the liquid disposal permit and the air emissions permits to be satisfied. The reason for the large interest in AD is that there are incentives, through the various financial support schemes, for the production of energy from biomass.

2.1.2 Production of biodegradable waste

Information on biodegradable waste production for Cyprus is scattered in technical reports that are mainly available from relevant departments of the public sector. No information is available, however, on the total amount of liquid and solid biodegradable waste produced annually. The Department of Environment is currently in the process of preparing the waste disposal permits database, which is expected to improve the situation considerably.

Therefore, this work will contribute significantly to (a) the knowledge on biodegradable waste generation in Cyprus and (b) how data can be obtained and estimated where the national statistics are insufficient.

This section presents the data collected on waste generation coefficients and the resulting estimation of the total annual biodegradable waste production of the main producers for which activity data is available. The estimation includes both the liquid and solid fraction of waste, since both can be used as input to AD for biogas production. The biodegradable waste fraction does not include the waste streams that are biodegradable but according to the legislation should be recycled (i.e. paper and cardboard).

The methodology for the estimation of biodegradable waste generation consists of two steps: determination of biodegradable waste generation coefficients, and estimation of biodegradable waste generation.

2.1.2.1 Determination of biodegradable waste generation coefficients

Biodegradable waste generation coefficients were available only for some waste streams. For the others the biodegradable waste generation coefficients were estimated by dividing the waste production by the relevant population for a particular year. It is noted that the biodegradable fraction of MSW was considered to be 40% (Palpanis, 2011). Details on the methodology followed to collect the data are available in Kythreotou *et al.* (2012). The paper is given in Appendix A.

All the biodegradable waste generation coefficients estimated from available data for Cyprus are presented in Table 2.1. Most of the coefficients show a very large variability: 0.217-0.269 tonnes of biodegradable fraction of MSW per capita, 8.38-19.0 kg of sludge from wastewater treatment plants per capita, 2.57-3.43 tonnes pig slurry per pig, 2.35-2.90 tonnes cow manure per cow, 12-13 kg manure per bird during poultry breeding, 0.4-6.98 kg waste per litre beer produced, 7.9-16.0 tonnes slaughterhouse waste per tonne meat produced. This could be due to difference in the production process or the type of product. The difference could also be due to the type of wastes included in the waste generation coefficient.

Table 2.1. Biodegradable waste generation coefficients from data collected, applicable to Cyprus

Waste stream	**Generation coefficients**
Biodegradable fraction of MSW	0.269 t cap^{-1} (Statistical Service, 2009)
	0.250 t cap^{-1} (Koneczny and Pennington, 2006)
	0.217 t cap^{-1} (Nicolaides, 1998)
	0.249 t cap^{-1} (Palpanis, 2011)
Sewage sludge	12.1 kg cap^{-1} (Statistical Service, 2007b)
	8.38 kg cap^{-1} (Department of Environment, 2011)
	19.0 kg cap^{-1} (Stylianou, 2010)
Livestock - Pigs	2.57 t pig^{-1} (Papanastasiou, 2006)
	3.28 t pig^{-1} (Monou, 2006)
	3.43 t pig^{-1} (Department of Environment, 2011)
Livestock - Cattle	2.62 t cow^{-1} (Fatta *et al.* 2007)
	2.90 t cow^{-1} (Department of Environment, 2011)
	2.35 t cow^{-1} (Papanastasiou, 2006)
	2.63 t cow^{-1} (Fatta, 2004)
	2.45 t cow^{-1} (Monou, 2006)
Livestock - Poultry	0.012 t $bird^{-1}$ (Papanastasiou, 2006)
	0.013 t $bird^{-1}$ (Department of Environment, 2011)
Vegetable & fruit industries	19.0 t t^{-1} product (European Commission, 2006)
Dairy products	57.5 t t^{-1} product (European Commission, 2006)
Breweries	0.40 kg l^{-1} product (European Commission, 2006)
	6.98 kg l^{-1} product (Fatta, 2003)
Slaughterhouse	7.90 t t^{-1} product (Fatta, 2003)
	16.0 t t^{-1} product (Department of Environment, 2011)
Olive mills	7.50 t t^{-1} product (CRES[a], 2009)
Wineries	3.39 kg l^{-1} product (Karagiannides *et al.* 2006)
Agricultural residues - fruit bearing trees	0.434 kg m^{-2} (CRES, 2009)
- citrus trees	0.319 kg m^{-2} (CRES, 2009)
- vines	0.497 kg m^{-2} (CRES, 2009)
- olive trees	0.282 kg m^{-2} (CRES, 2009)

[a] Centre of Renewable Energy Sources

For other waste streams the Cypriot data is limited to only one coefficient: Vegetable & fruit industries 19.0 t/t product (European Commission, 2006), dairy products 57.5 t t^{-1} product (European Commission, 2006), olive mills 7.50 t t^{-1} product (Centre of Renewable Energy Sources (CRES), 2009), wineries 3.39 kg l^{-1} product (Karagiannides *et al.* 2006), agricultural residues from fruit bearing trees (m^2) 0.434 kg m^{-2} (CRES, 2009), agricultural residues from citrus trees (m^2) 0.319 kg m^{-2} (CRES, 2009), agricultural residues from vines (m^2) 0.497 kg m^{-2} (CRES, 2009) and agricultural residues from olive trees (m^2) 0.282 kg m^{-2} (CRES, 2009).

The average annual biodegradable waste generation coefficients estimated for Cyprus compared to coefficients from other countries with similar characteristics or European and international guidelines are presented in Table 2.2. As it can be seen from the values presented in the Table the waste generation coefficients chosen for Cyprus for biodegradable fraction of MSW, sewage sludge, pig farms, olive mills and wineries, appear reasonable and comparable to other countries. There are however certain waste streams (poultry and cattle waste) that there is a large difference from other countries. The difference could be associated to the less intensive livestock production that takes place in Cyprus compared to other countries, the smaller amounts of water used at the farm, the feed ratio and probably the high rates of evaporation that take place during the long summer period. For the waste streams of vegetable and fruit industries, dairy products, breweries, and slaughterhouse waste, the results cannot really be compared to other countries, since the production processes used may be very different. Finally, for the agricultural residues, data could not be obtained from other countries for comparison.

Table 2.2. Average annual biodegradable waste generation coefficients estimated for Cyprus compared to coefficients from other countries with similar characteristics or European and international guidelines.

Waste stream	**Cyprus**	**Other countries**
Biodegradable fraction of MSW (t cap^{-1} $year^{-1}$)	0.246	South Europe 0.244 (IPCC [a], 2006) Corfu 0.204 (Skordilis, 2004) Crete 0.164 (Gidarakos *et al.* 2006) Portugal 0.178 (Magrinho *et al.* 2006)

Table 2.2. Average annual biodegradable waste generation coefficients estimated for Cyprus compared to coefficients from other countries with similar characteristics or European and international guidelines (continued)

Waste stream	**Cyprus**	**Other countries**
Sewage sludge (kg cap^{-1} $year^{-1}$)	13.160	Greece 12 (Eurostat, 2012) Italy 12 (Eurostat, 2012) Croatia 12 (Eurostat, 2012)
Livestock – Pigs (t pig^{-1} $year^{-1}$)	3.094	Switzerland 2 (Menzi *et al.* 1998) Sweden 4.7 (Menzi *et al.* 1998) Italy 2.37 (Fabiola *et al.* 2004)
Livestock – Cattle (t cow^{-1} $year^{-1}$)	2.591	USA 19.949 (US EPA [b], 2009) Canada 12.349 (Hofmann, 2009) Spain 16.425 (Fabiola *et al.* 2004)
Livestock – Poultry (t $bird^{-1}$ $year^{-1}$)	0.013	USA 0.046 (Goldammer, 2008; Tritt and Schuchardt, 1992) 0.042 (Burton and Turner, 2003)
Vegetable & fruit industries (t t^{-1} product $year^{-1}$)	19.040 [c]	35.605 (WBG [d], 1998)
Dairy products (t t^{-1} product $year^{-1}$)	57.540 [c]	3.4 (Verheijen *et al.* 1996)
Breweries (kg l^{-1} product $year^{-1}$)	3.690	6.5 (Briggs *et al.* 2004)
Slaughterhouse (t t^{-1} product $year^{-1}$)	11.950	0.73 (Tritt and Schuchardt, 1992)
Olive mills (t t^{-1} product $year^{-1}$)	7.500 [e]	Greece 6.25 [f] Spain 5 (Tritt and Schuchardt, 1992) 8.282 (Eleftheriadis, 2007)
Wineries (kg l^{-1} product $year^{-1}$)	3.390 [f]	0.512 (Bories and Sire, 2010) 11 (Melamane *et al.* 2007)
Agricultural residues - fruit bearing trees (kg m^{-2} $year^{-1}$)	0.434 [e]	n/a
- citrus trees (kg m^{-2} $year^{-1}$)	0.319 [e]	n/a
- vines (kg m^{-2} $year^{-1}$)	0.497 [e]	n/a
- olive trees (kg m^{-2} $year^{-1}$)	0.282 [e]	n/a

[a] IPCC = Intergovernmental Panel on Climate Change; [b] US EPA = United Stated Environment Protection Agency; [c] European Commission, 2006; [d] WBG = World Bank Group;[e] CRES, 2009; [f] Karagiannides *et al.* 2006

2.1.2.2 Estimation of biodegradable waste generation

The waste generation coefficients estimated for each waste stream for Cyprus (Table 2.2) were multiplied by the respective activity data to estimate the annual biodegradable waste generation of each waste stream for the year 2011. The total biodegradable waste generation was the sum of the biodegradable waste generated by the streams under consideration. The results are presented in Figure 2.1.

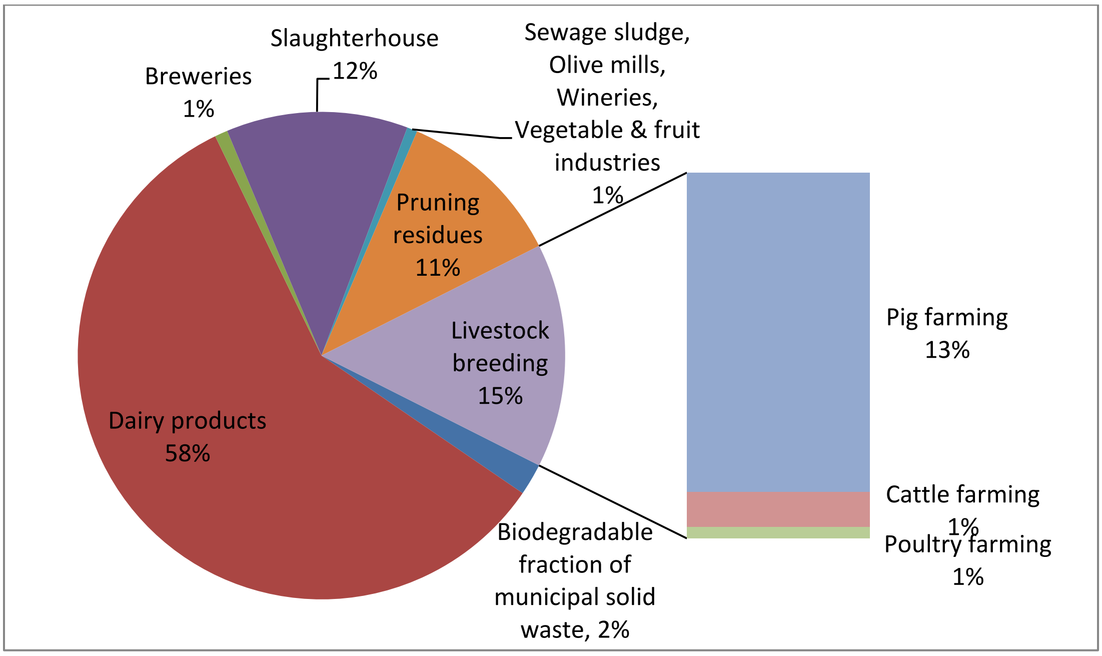


Figure 2.1. Contribution of waste streams to the annual biodegradable waste generation in Cyprus (percent fresh weight)

Production of dairy products and livestock production are the two larger producers of waste. The annual amount of wastes produced are 6097 Gg[1] and 1555 Gg respectively (for the year 2011).

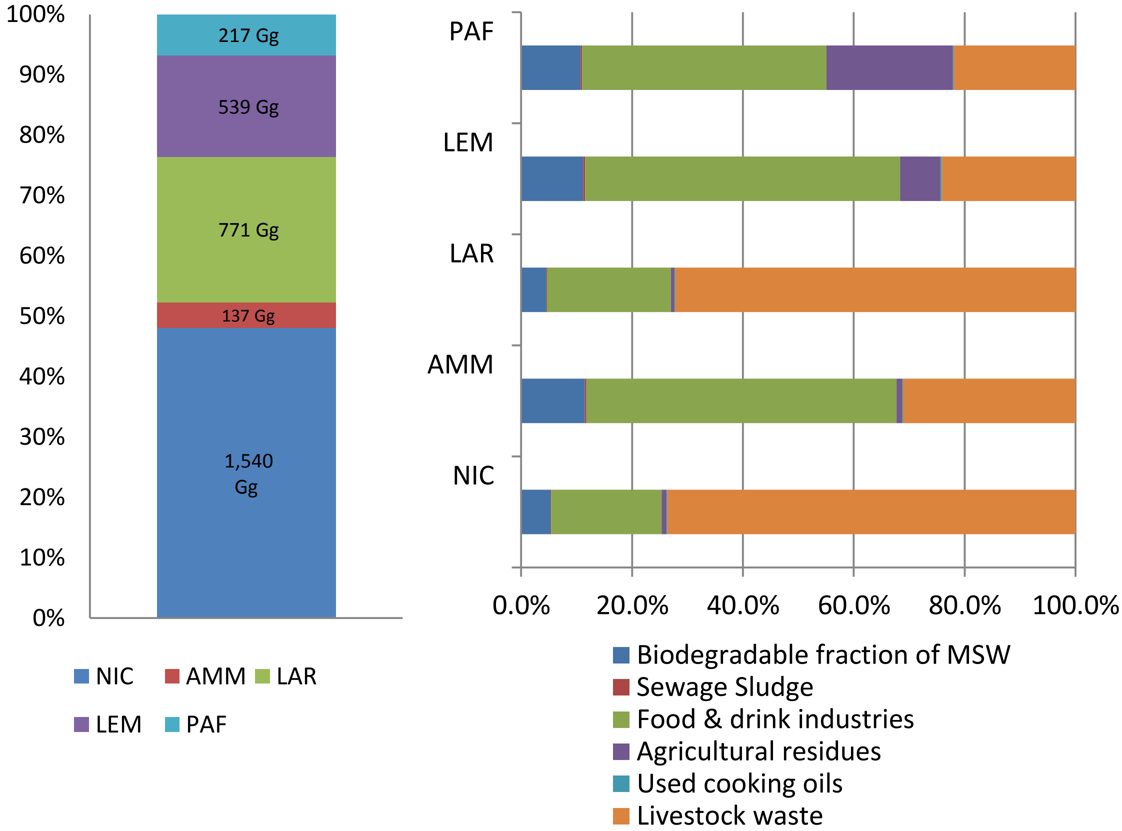
Spatial distribution of biodegradable waste in Cyprus

The area under the effective control of the Republic of Cyprus is divided into five administration districts: Nicosia, Lemesos, Larnaca, Pafos and Ammochostos.

The estimation of biodegradable waste production per district was based on the activity data and generation factors, with the exception of the food and drinks

[1] 1 Gg = 10^3 tonnes

industry. For this sector, the waste generation estimates were based on the industrial activity per district, which was obtained from the Department of Environment (Stylianou *et al.* 2010). These estimates proportion the total food and drinks industrial activity to 32% in Nicosia, 32% in Lemesos, 18% in Larnaca, 10% in Pafos and 8% in Ammochostos. On this basis, the waste generation per district was estimated (Figure 2.2a). The contribution of each waste sector to total waste generation varies according to the activities in each district (Figure 2.2b).



(a) (b)

Figure 2.2. (a) Contribution of each district to the total production of biodegradable waste of Cyprus; (b) Percent contribution of each biodegradable waste generation per district according to source (NIC is Nicosia, AMM is Ammochostos, LAR is Larnaca, LEM is Lemesos and PAF is Pafos)

Because of its relatively large population, industrial and livestock production activities, the district of Nicosia makes the largest contribution (48%) to biodegradable waste in the country. Livestock waste makes the greatest contribution (73.7%) to the total biodegradable waste of the district.

Larnaca makes the second largest contribution to the biodegradable waste in the island, 24%, even though it has almost half the population of Lemesos and smaller industrial activity. The relatively large contribution of Larnaca is due to its large livestock production activity, which contributes 72.2% of the total biodegradable waste of the district.

Pafos, a coastal mountainous area has large areas of vineyards and other agricultural activities but small activity in livestock production. The area has a large number of wineries, therefore waste from food and drink industries constitutes the largest proportion of biodegradable waste (44.1%) followed by agricultural residues (22.8%) and livestock production (21.9%).

Lemesos has similar economic activities as Pafos, but with a wider variety of food and drink industries in addition to wineries. It also has the second largest population after Nicosia. For Lemesos most of the biodegradable waste arises from the food and drinks sector (56.8%) followed by livestock waste (24.2%) and the biodegradable fraction of MSW (11.2%).

The contribution of Ammochostos to the total biodegradable waste of the island is very small at only 4%, with the food and drinks sector making the largest contribution (55.9%) due to the large number of dairy industries followed by livestock waste (31.1%).

Livestock production in the districts of Nicosia and Larnaca is concentrated in three areas: Aradippou, Orounta and Athienou. In addition to a large number of large livestock production installations, these areas also accommodate strong food and drinks industrial activities. These include dairy, juice and meat industries, slaughterhouses and olive mills. The total biodegradable waste in the three areas form livestock production and food and drinks manufacture represents approximately 25% of the total generation of biodegradable waste in Cyprus. Unfortunately, due to the concentrated activity the three areas are also particularly vulnerable to pollution and contamination.

2.2 Greenhouse gas emissions

Almost all energy that reaches the surface of the Earth is caused by the sun. Lashof (1989) estimated that the average temperature at the surface of the earth with only the energy input from the sun would be on average -18 °C. The resulting average of approximately +14°C has been estimated that is maintained by the recycling of heat from the surface of the Earth by the action of greenhouse gases (Kiehl and Trenberth, 1997). This process by which energy is recycled in the atmosphere to warm the Earth's surface is known as the greenhouse effect.

Water vapour, carbon dioxide, ozone, methane and nitrous oxide are the gases in the atmosphere that contribute to the greenhouse phenomenon, with water vapour being the most important (Forster *et al.* 2007). These gases are able to absorb and re-emit radiation, due to the characteristics of their molecular bonds (Orphardt, 2003).

The existence of the greenhouse effect was first argued for by Joseph Fourier in 1824 (Fleming, 1999). The human impact on climate change was acknowledged by the world leaders in 1992 during the Earth Summit in Rio, when the establishment of the United Nations Framework Convention on Climate Change (UNFCCC) was agreed. Since then, climate change has gained significant public attention due to its association to extreme climate events and political attention possibly due to financial incentives developed for the reduction of emissions.

Parties to the UNFCCC submit reports on the implementation of the Convention. Contents and timetables of the submissions are different for Annex I (industrialised) and non-Annex I (non-industrialised) parties. One of the core elements of these reports for both Annex I and non-Annex I Parties is information on emissions of greenhouse gases (UN, 1992).

The Kyoto Protocol (KP) is the legally binding agreement that followed the UNFCCC. KP is an international agreement that sets binding targets for 37 industrialised countries and the European community for reducing greenhouse gas emissions.

According to Annex A of the Kyoto Protocol (UN, 1998), greenhouse gases that have to be monitored are: carbon dioxide (CO_2), methane (CH_4), nitrous oxide

(N_2O), hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6). The impact of these gases to the greenhouse phenomenon is relatively measured by the global warming potential (GWP). GWP compares the heat trapped by a certain mass of specific gas to the heat trapped by a similar mass of CO_2. The GWPs illustrated in the UNFCCC website[2] the GWP with a time horizon of 100 years for CH_4 is 21 and N_2O is 310. This means that one kg of CH_4 has 21 times the impact of CO_2 to the greenhouse phenomenon and on kg of N_2O has 310 times the impact of CO_2.

The sources of the emissions to be monitored have also been agreed through the Protocol and are included in Annex A. They are separated into six sectors: Energy, Industrial Processes, Solvent and other Product use, Agriculture, Waste and Other. CO_2 emissions from Land Use, Land Use Change and Forestry (LULUCF) have to be reported but are not included in national totals.

Further details and clarifications on the sources of the emissions that have to be reported are provided in the revised Intergovernmental Panel on Climate Change (IPCC) guidelines for National Greenhouse Gas Inventories (IPCC, 1996; 2006). Different guidelines exist for non-Annex I parties that are more simplified. National inventory reports have to include the emissions from 1990 to two years before the submission year; i.e. the 2013 submission should be for the years 1990 – 2011.

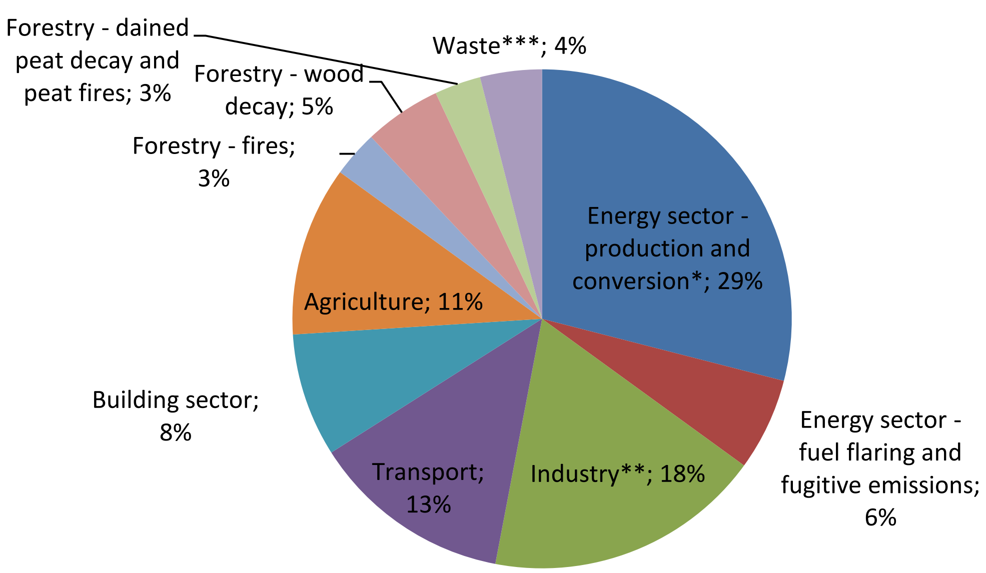
Parties may use more detailed methods than those proposed by the IPCC guidelines if they have the necessary data or national methodologies, provided that they provide sufficient scientific background on the methodologies they use. According to the conclusions of the Subsidiary Body for Scientific and Technological Advice at its thirtieth session in 2009 (FCCC/SBSTA/2009/3) the Parties should start using the 2006 IPCC Guidelines in 2015. Until then, Parties should continue the use of the revised 1996 guidelines.

The latest estimates for global greenhouse gas emissions have been published by United Nations Environment Program in November 2012 (UNEP, 2012). Total greenhouse gas emissions in 2010 (latest estimate) were estimated to be 50.1 $GtCO_2eq$. (JRC/PBL, 2012). This corresponds to an increase of 1.6% compared to

[2] http://unfccc.int/ghg_data/items/3825.php, visited 17/7/2014

2009 emissions and an increase of 30% compared to 1990 (which is the reference year for UNFCCC and KP). The breakdown of emissions by main sectors is presented in Figure 2.3. As it is shown in the Figure, the energy production is the largest source of greenhouse gas emissions with 29% of the total. Agriculture contributes 11% and is the largest source of methane and nitrous oxide emissions. The sections that follow give more details on the emissions from livestock production.

Since this work focuses on the conditions of Cyprus, section 2.2.1 presents a summary of the national emissions and targets for Cyprus. Section 2.2.2 presents information for the sources of GHG emissions from biodegradable waste and section 2.2.3 outlines the potential for reduction of emissions from biodegradable waste.



* Power generation, refineries, and coke ovens; ** Including non-combustion CO_2 from limestone use and from non-energy use of fuels and N_2O from chemicals production; *** Including wastewater.

Figure 2.3. Shares of sources of global greenhouse gas emissions in 2010 by main sector (JRC/PBL, 2012)

2.2.1 Cyprus' GHG emissions and targets

The latest information published on the GHG emissions of Cyprus is for the period 1990-2011 (Kythreotou and Mesimeris, 2013a). The total GHG emissions of the country in 2011 were 9078 Gg CO_2 eq. of which 83% was CO_2. The largest source of GHG emissions was the energy sector, with 78% of the total. Animal manure management contributed 3% to the total emissions in 2011, while waste contributed 6%.

The 28 Member States of the EU have made a unilateral commitment to reduce greenhouse gas emissions by 20% compared to 1990 levels, by 2020. There is a possibility to increase this reduction to 30% if other major economies agree to undertake their fair share of a global emissions reduction effort (European Commission, 2013). The 20% reduction commitment is ensured through the 'climate and energy package' which includes a number of legal measures taken towards the reduction of GHG emissions (European Union, 2009a). The EU is also committed to reduce its emissions by 20% under the Kyoto Protocol's second commitment period; i.e. 2013 to 2020 (UNFCCC, 2013).

To reach the 2020 reduction targets, emission cuts will be needed both in sectors covered by the EU Emissions Trading System (EU ETS) and areas of the economy outside the EU ETS (i.e. non-ETS sectors), such as buildings, agriculture, waste management and transport. Under the 'Effort Sharing Decision' all Member States have taken on binding greenhouse gas emission targets covering the non-ETS sectors for each year of the period 2013–2020. The national target for Cyprus according to this Decision is, by the year 2020, to reduce emissions to 95% of the emissions of 2005 (European Union, 2009b).

The achievement of the 5% reduction will depend not only on the implementation of the measures for the reduction of GHG emissions, but also on the financial situation of the country and economic activity. Figure 2.4 shows the projected emissions, calculated in 2011 for two scenarios: a) ‘With measures’ scenario (WM), and b) ‘Business as usual’ scenario (BaU) (Kythreotou and Mesimeris, 2011), To take into account the influence of the recent economic downturn in the country, the projected emissions were re-calculated in 2013 for the WM and BaU scenarios and are presented in Figure 2.5 (Kythreotou and Mesimeris, 2013b). It can be seen that the economic downturn is expected to lead a significant reduction in emissions which will reduce even further through the implementation of emission reduction measures. The implementation of the measures will not only enable Cyprus to meet its obligations, but will also move the country towards a greener and more sustainable economy.

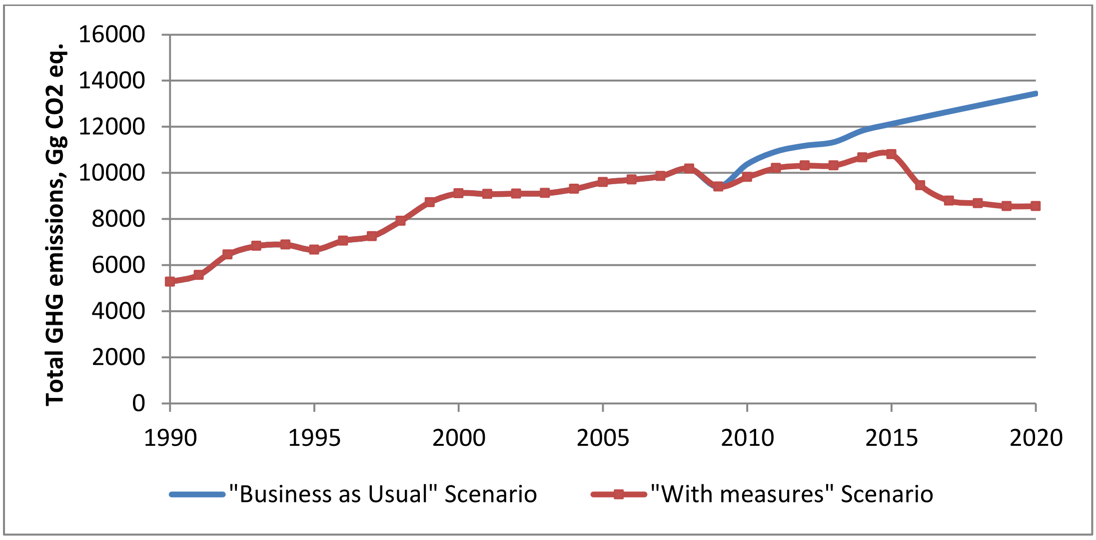


Figure 2.4. Projection of GHG emissions according to 2011 report (Kythreotou and Mesimeris, 2011)

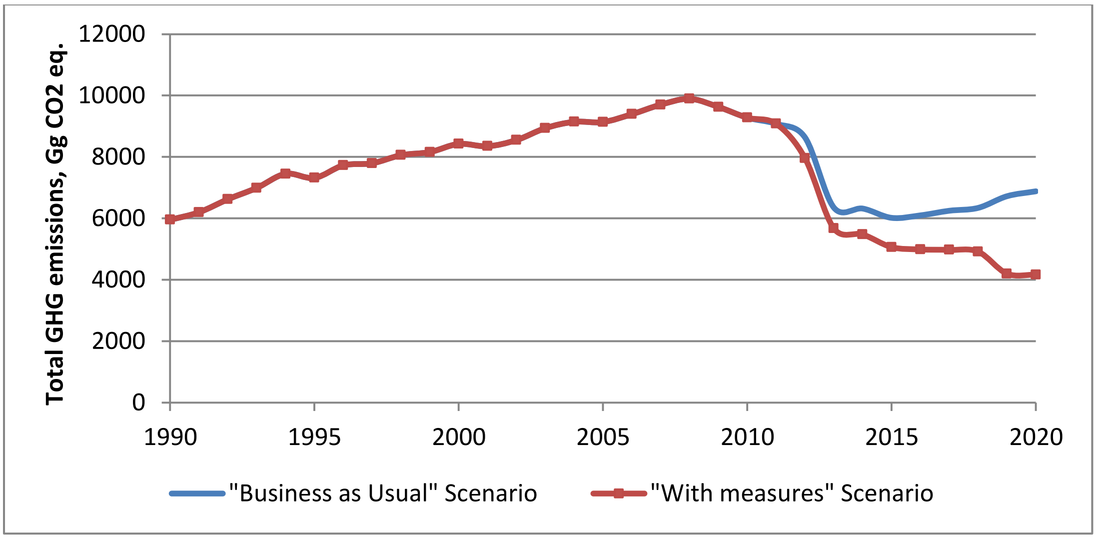


Figure 2.5. Projection of GHG emissions according to 2013 report (Kythreotou and Mesimeris, 2013)

2.2.2 GHG Emissions from biodegradable waste

The emissions from solid and liquid, domestic and industrial waste are included in the sector of waste, whereas emissions from animal waste are included in agriculture (IPCC, 1996).

CH_4 is produced from the bacterial decomposition of waste under anaerobic conditions (Gaudy and Gaudy, 1988). CH_4 from waste management is generated during anaerobic decomposition of organic matter in waste (Møller *et al.* 2004a). The production of CH_4 is also affected by environmental factors such as temperature (Sommer *et al.* 2007), biomass composition and method/ technology used for the management of the waste (Ni *et al.* 2008). Differences in emission of CH_4 from waste among countries reflect mainly differences in the duration of storage and technologies used for treatment (Haeussermann *et al.* 2006).

During storage of waste, some of the nitrogen in waste is converted to N_2O. The N_2O emissions during storage of waste, originate from the surface layer of the waste, where free oxygen is available (Sommer *et al.* 2000). Most inorganic nitrogen present in waste is in the form of ammonium and transformation from ammonium to nitrate via nitrification is the main source of N_2O (Fangueiro *et al.* 2008). The produced nitrate is a source of nitrogen for denitrification, which is the biological reduction of nitrate to nitrogen gas. During this process N_2O is also produced if denitrification remains incomplete (Chadwick *et al.* 2011).

2.2.3 Potential for reduction of emissions from biodegradable waste

Many practices can be implemented to reduce or avoid emissions (Smith *et al.* 2007). The net benefit will depend on the combined effect on all greenhouse gases, since often, a practice will affect more than one gas, and sometimes in opposite ways (Koga *et al.* 2006). In addition, the time frame of the influence can vary among practices or among gases for a specific practice; some emissions can be reduced indefinitely while others only temporarily (Six *et al.* 2004).

According to Smith *et al.* (2007), two potential measures to mitigate emissions from manure management are the improvement of storage and handling and the introduction of AD.

Animal manure can release significant amounts of CH_4 and N_2O during storage. The magnitude of these emissions depends on parameters such as the characteristics of the waste and the climate. Methane emissions from manure stored in lagoons or tanks can be reduced by cooling, use of covers, mechanical separation of solids from slurry, or by CH_4 capture (Amon *et al.* 2006; Clemens and Ahlgrimm, 2001).

AD of the manure can maximise CH_4 collection and its use as a renewable energy source (Clemens *et al.* 2006). The state of the manure during handling can also affect the emissions: e.g. handling manures in solid form can reduce CH_4 emissions, but may increase N_2O formation (Paustian *et al.* 2004).

In cases where the animals live in pastures (therefore excretion happens in the field), reduction of emissions from improvement of waste management is negligible (Gonzalez-Avalos and Ruiz-Suarez, 2001). However, to some extent, emissions from manure might be reduced by changing the feeding practices (Kreuzer and Hindrichsen, 2006).

As for the other biodegradable wastes, a wide range of mature technologies is available to mitigate GHG emissions. These technologies include landfilling with landfill gas recovery that reduces CH_4 emissions to the atmosphere, composting which avoids GHG generation, and thermal processes that reduce GHG generation compared to landfilling: these include incineration, industrial co-combustion, and AD (Bogner *et al.* 2007).

An active landfill gas extraction system using vertical wells or horizontal collectors is the most important mitigation measure to reduce emissions, since it has proven that at least 90% of the landfill gas can be recovered (Spokas *et al.* 2006).

AD is particularly appropriate for wet wastes, while composting is often appropriate for drier waste. Composting decomposes waste aerobically into CO_2, water and a humic fraction, while some carbon is stored in the residual compost (Hobson *et al.*

2005). However, efficient application of AD or composting, require source-separated waste fractions.

AD produces biogas, which is a mixture of CH_4 and CO_2, and biosolids. The resulting biogas can be used for process heating, on-site electrical generation and other uses. Even though CH_4 can be vented from digesters during start-ups, shut-downs and malfunctions, the GHG emissions from controlled biological treatment are small in comparison to uncontrolled CH_4 emissions from landfills without gas recovery (Detzel *et al.* 2003).

Incineration and other thermal treatment technologies reduce the mass of waste and can offset fossil-fuel use, while avoiding GHG emissions, except for the small contribution from fossil carbon (Consonni *et al.* 2005).

2.3 Renewable energy sources

According to EU Directive 2009/28/EC (European Union, 2009d), "energy from renewable sources" is defined as "energy from renewable non-fossil sources, namely wind, solar, aerothermal, geothermal, hydrothermal and ocean energy, hydropower, biomass, landfill gas, sewage treatment plant gas and biogases". The EU aims to get 20% of its energy from renewable sources by 2020. More renewable energy will enable the EU to reduce greenhouse emissions, become more energy secure and will encourage technological innovation and employment in Europe.

2.3.1 Current production and national targets for renewable energy

With no oil, gas or electricity interconnections, Cyprus has an isolated energy system, which depends on fuel imports and therefore it is associated with high cost of primary energy import. Another issue that has to be dealt with is the large fluctuation in energy demand between seasons, which is caused by the high temperatures and the large tourist population arriving to the country during the summer. In 2010, the total final energy consumption was 2,033 ktoe, of which the majority was electricity (20%). Electricity is produced by heavy fuel oil and some diesel. Approximately 6% of the final energy consumption during 2011 was generated from renewable energy sources (Energy Service, 2012). Cyprus is currently facing the challenge of increasing the contribution of renewable energy sources to the final consumption of 13%, as this was set in the new renewables' directive of the EU, Directive 2009/28/EC (European Union, 2009d). This Directive, establishes a common framework for the promotion of energy from renewable sources in the EU. Among others, it sets mandatory national targets for the overall share of energy from renewable sources in gross final consumption of energy and establishes sustainability criteria for biofuels and bioliquids.

Renewable energy sources have been experiencing a rapid growth during the recent years in Cyprus (Figure 2.6). While investments in wind and solar energy have been increasing mainly because of the financial incentives given by the government, the investments in biomass energy have also been increasing because of the waste disposal environmental requirements. According to IPPC directive (Directive 2008/1/EC) and the respective national legislation (Laws No. 56(I)/2003, No. 15(I)/2006 and No. 12(I)/2008), the waste disposed by pig farms has to meet a specific standard in concentration of nitrates, while at the same time maintain the ammonia emissions under a certain limit. This can be achieved in a financially viable manner through AD. Consequently, AD of biomass has increased from 1 installation in 2007 to 12 in 2012, of which 8 have been installed for the treatment of animal wastes.

2.3.2 Potential for renewable energy production from biodegradable waste

Considering the current trend in Cyprus for the promotion of waste-to-energy processes, two possibilities have been examined for the production of energy from biodegradable waste. The first is the estimation of potential energy when biodegradable wastes are thermally treated, and the second when they are anaerobically digested.

(a) Potential energy production from thermal treatment

The energy content that could be obtained from a particular type of waste varies considerably according to the treatment used and whether any pre-treatment takes place. To increase the efficiency of treatment, the waste should be as dry as possible. However, data for all waste streams was not available for the solids content. Therefore the minimum net calorific value proposed by the IPCC (2006) was used for all waste streams; i.e. 11.6 TJ/Gg. Moreover, it was assumed that the efficiency of the treatment reduced to 50% due to the high water content in the wastes.

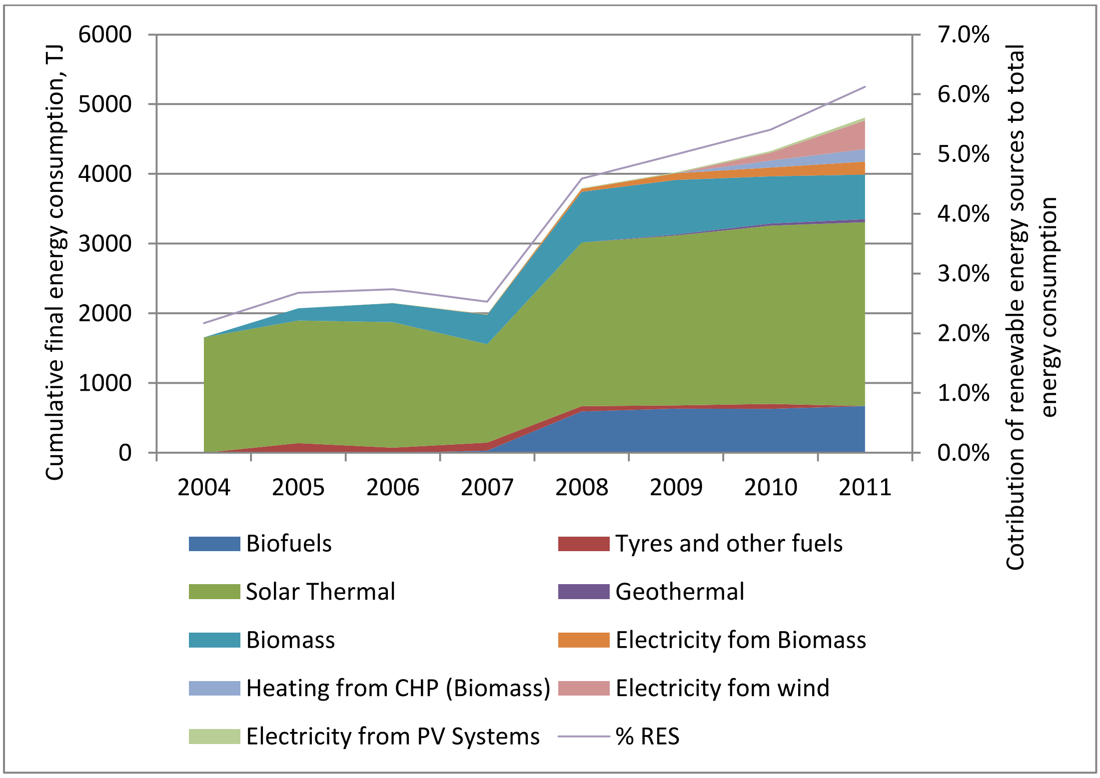


Figure 2.6. Final energy consumption in Cyprus from renewable energy sources (Energy Service, 2012)

Based on these assumptions, it was estimated that the amount of energy that could be obtained from thermal treatment of biodegradable waste, based on the waste production in 2011, is 60,700 TJ.

(b) Potential energy production from AD

Energy production from anaerobic treatment depends on the quantity and quality of the biogas produced. Potential biogas generation was estimated using two methods: (a) Chemical Oxygen Demand consumed and (b) mass of digested waste. In both cases, it is assumed that the available biomass is fully digested.

(i) Chemical Oxygen Demand

The total waste produced from a specific waste stream was divided by its bulk density, to estimate the bulk volume of the waste. This was then multiplied by the COD concentration of the waste, to estimate the annual mass of COD produced. In theory, all the COD available should be consumed by anaerobic organisms during AD. Therefore, according to the biochemical reactions taking place, for each kg of COD consumed, in theory, 0.58 m^3 biogas is produced, assuming that methane is 60% of the volume (Sperling and Chernicharo, 2005). The COD concentrations and the bulk densities for each waste stream used are presented in Table 2.3.

The equation applied to determine the biogas produced is:

$$BG_{wst}\ (m^3) = M_{wst}\ (kg) / BD_{wst}\ (kg/l) \times COD_{wst}\ (kg/l) \times GF_{BG}\ (m^3/kg\ COD) \quad (2.1)$$

where BG_{wst} is the volume of biogas produced in m^3 from the AD of a particular waste stream, M_{wst} is the mass of waste of a particular source in kg, BD_{wst} is the bulk density of a particular waste stream in kg l^{-1}, COD_{wst} is the COD concentration of a particular waste stream in kg l^{-1} and GF_{BG} is the m^3 biogas produced per kg COD consumed (0.58 m^3/kg COD).

The total biogas potential (BG) is the sum of the potential biogas production from all waste streams. The biogas produced was then multiplied by the methane content in the biogas, the efficiency of the generator, the energy content and the density of methane, to estimate the total energy that could be produced by the combustion of biogas. The equation applied to estimate potential energy production is the following:

$$ENPROD\ (TJ) = BG\ (m^3) \times CH_4\ (\%) \times EF\ (\%) \times \rho_{CH4}\ (kg/m^3) \times EN_{CH4}\ (MJ/kg) / 10^6\ (MJ/TJ) \quad (2.2)$$

where ENPROD is the total energy production in TJ, BG the total biogas produced in m^3, CH_4 is the percent methane content in the biogas, EF the efficiency of the generator in %, ρ_{CH4} is the density of methane in kg m^{-3} and EN_{CH4} is the energy density of methane in MJ kg^{-1}. The assumed values used for these parameters, for the estimation of the potential energy generation are presented in Table 2.4.

Table 2.3. COD concentration, bulk density and biogas potential per unit mass of waste, for waste streams examined

Waste stream	**COD[b] ($g\ l^{-1}$)**	**Bulk density ($kg\ l^{-1}$)**	**Biogas / unit mass waste ($l\ kg^{-1}$)**
Biodegradable fraction of MSW[a]	30.92 (Naddeo *et al.* 2009)	0.497 (Mahar *et al.* 2009)	112 (Rapport *et al.* 2008)
Sewage sludge	38.40 (Kythreotou, 2006)	1.300 (Fowler *et al.* 1997)	100 (Sanchezs *et al.* 1995
Livestock - Pigs	40.00 (Kythreotou, 2006)	0.973 (Kerr *et al.* 2006)	36 (BSRCA[c], 2010)
Livestock - Cattle	191.0 (Kythreotou, 2006)	1.551 (Achkari-Begdouri and Goodrich, 1992)	25 (BSRCA[c], 2010)
Livestock - Poultry	190.0 (Kythreotou, 2006)	0.546 (Bernhart and Fasina, 2009)	80 (BSRCA[c], 2010)
Dairy products	11.19 (Monou, 2006)	1.500 (WBG [d], 1999)	55 (Navickas, 2007)
Breweries	3.00 (Monou, 2006)	0.385 (Levic *et al.* 2006)	114 (ARR [e], 2010)
Slaughterhouse	4.08 (Fountoulakis *et al.* 2008)	0.507 (MIS [f], 2002)	50 (Esteves, 2009)
Olive mills	81.2 (Fountoulakis *et al.* 2008)	1.050 (Zervakis and Balis, 1996)	171 (Zafiris and Sioulas, 2009)
Wineries	40.0 (Borja *et al.* 1993)	0.500 (Zervakis and Balis, 1996)	34 (Chamy and Jeison, 2004)
Vegetable & fruit industries	7.60 (Monou, 2006)	0.200 (Fraser, 2006)	268 (ARR [e], 2010)
Agricultural residues	1.81 (Fraser, 2006	5.04 (Cecil and Jolin, 2005)	150 (Sternstein, 2011)

[a] MSW = municipal solid waste; [b] COD = Chemical Oxygen Demand; [c] BSRCA = Bavarian State Research Centre for Agriculture; [d] WBG = World Bank Group; [e] ARR = Agency for Renewable Resources; [f] MIS = Meat Industry Services

Table 2.4. Assumptions used for the estimation of potential energy production

Parameter	Assumed value
Methane content in biogas	60%
Thermal efficiency of energy generator	50%
Electrical efficiency of energy generator	35%
Methane energy density	55.6 MJ kg^{-1} *
Methane density	0.6556 kg m^{-3} *

* O'Connor, 1977

<u>(ii) Mass of waste digested</u>

The total waste produced from a specific waste stream was multiplied by the theoretical production of biogas per kg of waste digested (Table 2.3). The equation applied is the following:

$$BG_{wst}\ (m^3) = M_{wst}\ (kg) \times GF_{BG}\ (m^3\ kg^{-1}\ waste) \qquad (2.3)$$

where BG_{wst} is the volume of biogas produced in m^3 from the AD of a particular waste stream, M_{wst} is the mass of waste of a particular source in kg and GF_{BG} is the m^3 biogas produced per kg of waste, which varies according to the waste stream.

As with the previous method, the total biogas potential (BG) is the sum of the potential biogas production from all waste streams and to estimate the potential energy production, equation (2.2) should be applied.

The potential amount of energy that could have been produced in 2011 based on these two methods and the assumptions presented is 4,200 TJ using the COD method and 29,000 TJ using the digested amount of waste respectively. This large difference has been caused by the assumptions made for the development of the biogas production factors, such as specific characteristics of the waste for which the factor was developed for.

2.4 Conclusions

The work in this chapter has shown that there is a great potential in Cyprus to utilise biodegradable waste for the production of energy. This should be further considered by the policy makers of the country, since there is a significant possibility that further GHG emission reduction targets will be imposed by the EU. Policy makers should take into consideration the cost per unit reduction of GHG emissions that could be achieved and identify appropriate support mechanisms. The GHG emissions from both (agriculture and waste) can be reduced from the introduction of waste to energy technologies.

It has been estimated that introducing biodegradable waste to energy technologies in Cyprus could contribute 4,200 TJ (minimum of AD) to 60,700 TJ (thermal treatment) of energy to the energy balance of the country from a renewable energy source. The gross inland consumption of primary energy in Cyprus during 2011 was 112,000 TJ (Eurostat, 2013). Therefore, the utilisation of biodegradable waste for the production of energy could contribute 4% - 54% of the total energy demand of the country. Such energy production would contribute considerably towards the achievement of the national renewable energy targets.

Comparing the two available options for the production of energy from animal wastes; i.e. thermal treatment Vs. anaerobic digestion, anaerobic digestion could be considered more appropriate for Cyprus as, not only allows farmers to meet the waste disposal obligations, but also provides high quality fertiliser.

Given the spatial distribution of biodegradable waste production in the country, policy makers should consider the promotion of centralised systems in areas of large biodegradable waste production. Such installations would particularly benefit the farmers financially since (a) more than one farm would have to make the investments for the installation and (b) the transport of waste could take place through pipelines due to the short distances.

To obtain the necessary information regarding the impact on AD to on-farm energy consumption and GHG emissions, the necessary methodologies have been developed and are presented in the next Chapter.

CHAPTER 3. Methodologies developed for the estimation of the on-farm energy consumption and relevant GHG emissions

This Chapter presents the proposed methodologies for the estimation of (a) the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport) and (b) the GHG emissions from the on-farm energy consumption. These methodologies are used in the software tool that is developed to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level. Both methodologies are applied to the conditions and activity data of Cyprus to estimate the contribution of livestock production to national energy consumption. The results are also compared to international data. Having identified that animal waste is the most attractive to consider for anaerobic digestion in Cyprus, the practices applied in breeding and the management of their waste are examined in detail since such information is not available and has not been previously published.

3.1 On-farm energy consumption

On-farm energy consumption is becoming increasingly important in the context of rising energy costs and concerns over greenhouse gas emissions. For farmers throughout the world, energy inputs represent a major and rapidly increasing cost (Dahiya and Vasudevan, 1986; Baillie and Chen, 2009). Energy analysis and estimation of energy consumption, therefore, allow farmers to compare the energy cost of existing process operations with that of new or modified production lines (Heidari *et al.* 2011).

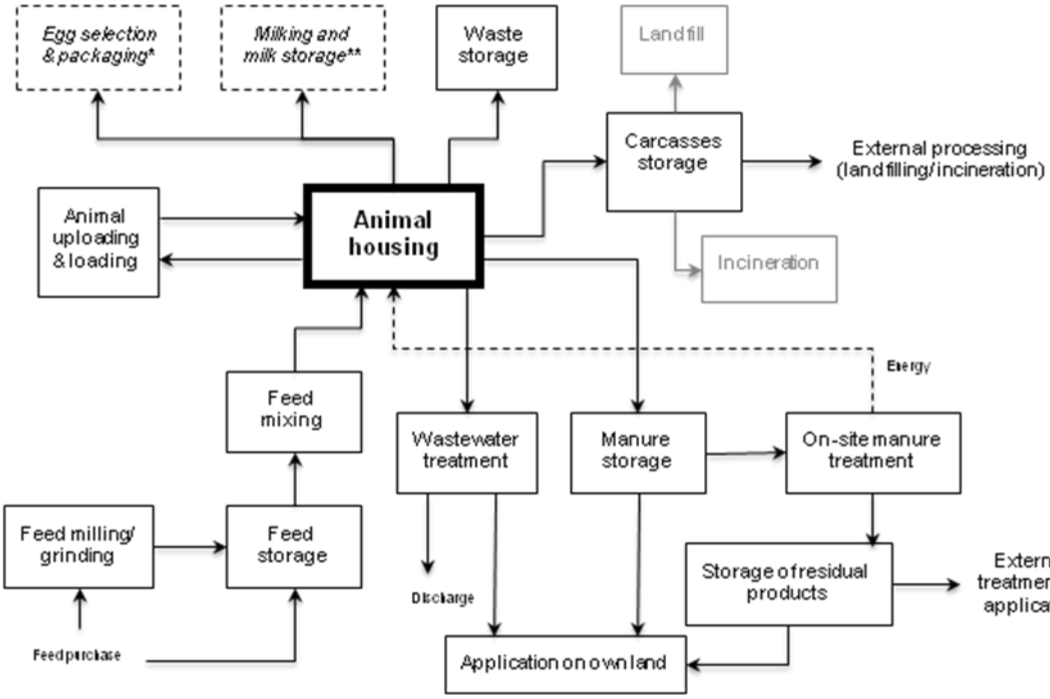
Intensification of animal production systems has required external inputs in order to achieve the high yields expected from the investment in facilities, equipment and breeding stock. In contrast to integrated mixed farming, where most of the resources including energy used are generated on the farm itself, intensive production requires a variety of outside inputs, which directly or indirectly require fossil fuels.

Energy is used for the production of feeds (land preparation, fertilizers, pesticides, harvesting, drying, etc.), their bulk transport (land and/or sea freight), storage (ventilation), processing (milling, mixing, extrusion, pelleting, etc.) and their distribution to individual farms. Once on the farm, and depending on location (climate), season of the year and building facilities, more energy is needed: i) for the movement of feeds from the storage to the animal pens; ii) for control of the thermal environment (cooling, heating or ventilation); and for animal waste collection and treatment (solid separation, aerobic fermentation; drying; land applications, etc.); iii) transport of products (meat animals to abattoirs; milk to processing plants; eggs to storage), iv) processing (slaughtering, pasteurisation, manufacture of dairy products), storage and refrigerated transport also require fossil fuels.

On-site operational energy is not necessarily the dominant energy user in agriculture. Fuel use, rather than electricity, is in most cases more important. Additionally, agriculture is much more significantly influenced by seasons than other sectors. Energy use profiles for agriculture varies on both annual and daily basis. Moreover, much more diverse types of machinery are also used than other sectors, which makes it difficult to provide default values for energy consumption.

The lack of systematic research for energy use in agriculture has in general hindered the development of "rules of thumb" to provide first approximations, and the absence of benchmarking data and guides has made investment calculations and decisions on best available technologies and approaches for energy reduction difficult (Baillie and Chen, 2009).

The uses of energy in a farm can be classified into direct and indirect (Hulsbergen *et al.* 2001). Direct energy use is associated with the consumption of fuels in a farm. Indirect energy use is the energy consumed for the production and transport of materials used in a farm (e.g. feed and machinery). Meul *et al.* (2007) estimated that 70% of total energy use on dairy cattle and pig farms is for indirect uses.



* for egg chicken farms; ** for dairy cow farms

Figure 3.1. Main processes taking place in a livestock production farm. Boxes with dotted line are processes that depend on the type of the farm (adapted from European Commission, 2003)

The main activities in livestock production is rearing, growing and finishing of animals for meat and/or egg and/or milk production, depending on the type of the farm. Thus, the centre of the activity of a farm and the essential part of all activities is the animal housing system. This system includes the components shown in Figure

3.1. The additional possible activities that could be encountered in a farm depend on land availability, farming tradition or commercial interest.

A number of energy calculators have already been developed to estimate the energy uses in agricultural systems. To complement the energy calculation software, various hardware / technologies are also available for undertaking field measurements. These include fuel flow meters, electricity power meters, data logging and monitoring equipment and various sensors for measuring temperature, pressure, torque, travel speed etc. Because of the wide variety of machinery being used across the intensive livestock-breeding sector, it may be difficult to prescribe a universal set of tools that will cover all the different operations. However, it has been suggested that fuel flow meters, electricity power meters, and data loggers are essential for all cases (Baillie and Chen, 2009).

3.1.1 Methodology

One objective of this work was to establish a methodology for calculation of direct on-farm consumption of fossil fuels and electricity for livestock production. The activities considered for the estimation of energy are feed preparation, ventilation, lighting, heating and waste management. Transport is not accounted for, since the amount of energy required for transport is very large compared to other uses on the farm (Steinfeld *et al.* 2006). The aim of the methodology was to be as simple as possible to be useful to farmers with limited scientific knowledge. Therefore the goal was to develop a methodology based on animal population, which is information available to all farmers. Consequently, the aim of the methodology was to obtain national estimates for annual energy consumption per animal.

The methodology developed for estimation of energy consumption by livestock production where no national statistics are available consists of the steps presented in Figure 3.2. This methodology is used in the developed software tool to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level.

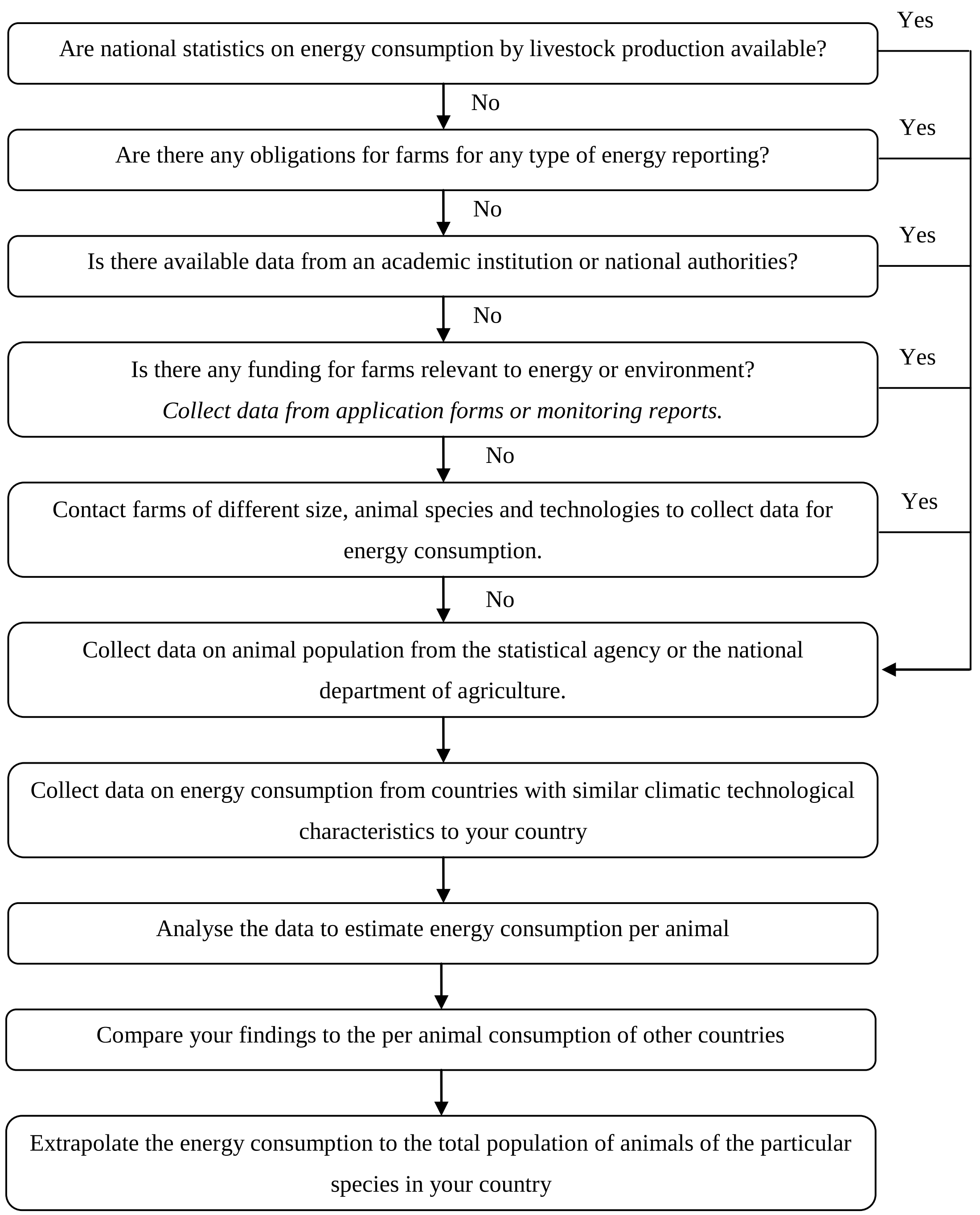


Figure 3.2. Proposed methodology for estimation of energy consumption by livestock production where no national statistics are available

3.2 GHG emissions from on-farm energy consumption

During the last decade, there has been a growing interest on the real impact of livestock production in GHG emissions. It can be argued that the IPCC categorisation (IPCC, 1996) does not represent the actual impact of livestock production. According to the IPCC methodology in practice, emission sources from livestock production are enteric fermentation and manure management. There are, however, considerable GHG emissions caused by supporting activities, such as energy use on the farm and fertilizer use for the production of feed. Another important supporting activity, especially in developing countries, is deforestation, where predominately forests are burnt to produce grazing land. Land use change is causing not only reduction of CO_2 absorption, but also very often emission of GHG from forest fires. At present, the emissions of these supporting activities are "hidden" in other sectors of the IPCC methodology.

Steinfeld *et al.* (2006), argue that the 'hidden' emissions caused by livestock production are as presented in Figure 3.3 (excluding deforestation which contributes the remaining 86% of the "hidden" emissions). These emissions are additional to the GHG reported for livestock production in the agricultural sector according to the IPCC methodology (IPCC, 1996).

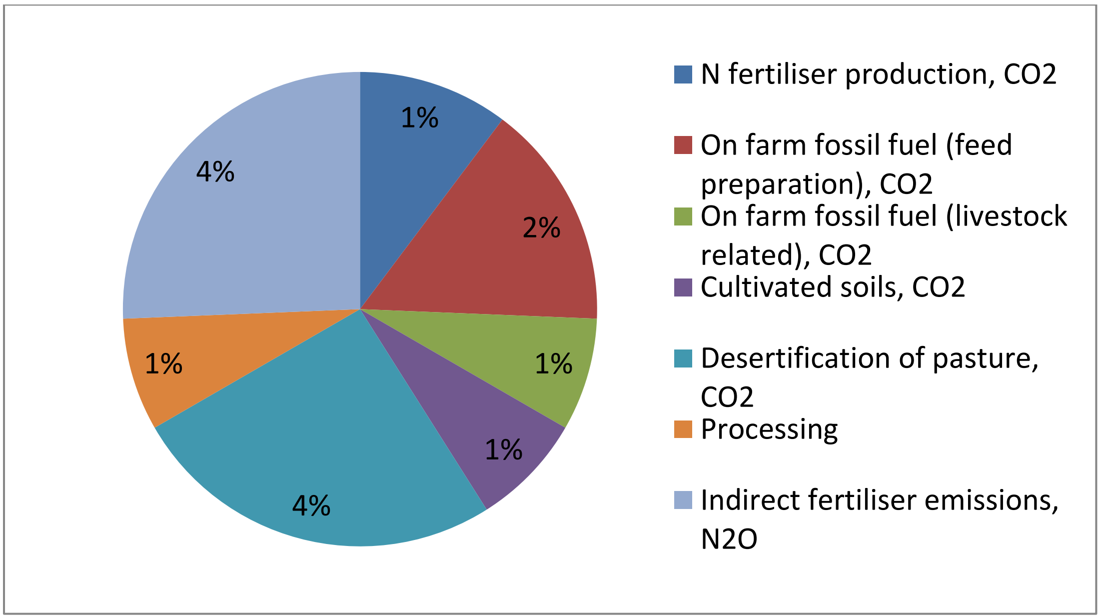


Figure 3.3. 'Hidden' emissions caused by livestock production (Steinfeld et al. 2006)

Lymbery (2009) showed that if the indirect emissions are taken into consideration, 9% of global CO_2 emissions, 37% of global CH_4 emissions and 65% of global N_2O emissions are caused by livestock production. CO_2 contributes the most to the livestock related GHG emissions, (34%) and is mainly caused by the land-use change. GHG emissions due to livestock production are also caused by the use of large amounts of chemical fertilisers for the production of animal feed (6.2%), by the energy use (2%) and by manure related emissions (30.4%).

According to calculations performed by Leip *et al.* (2010), the total GHG fluxes of European Livestock production amount to 661 Tg[3] of CO2 eq. 29% of these emissions are caused by the production of beef, 29% by cow milk production and 25% by pork production. All other animal products together do not account for more than 17% of total emissions. 323 Tg (49%) of total emissions are created in the agricultural sector, 136 Tg (21%) in the energy sector, 11 Tg (2%) in the industrial sector and 191 Tg (29%) are caused by land use and land use change. Depending on the scenario used, total emissions from land use and land use change, can be in the range 153 to 382 Tg (Leip *et al.* 2010).

3.2.1 Methodology

The GHG emissions from on-farm consumption of energy can be estimated by the implementation of the steps listed below. This methodology is used in the software tool developed to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level. For this methodology, it is a prerequisite, that annual energy consumption of the farm is available (see section 3.1.1).

(a) Define the energy mix used for livestock production activities

(b) Obtain sufficient data for emission factors and characteristics of fuels used according to national specific data. If no national specific data is available internationally accepted sources (e.g. IPCC methodologies) could be used.

(c) Estimate the GHG emissions from breeding specific animal species by the application of the following equation:

[3] 1 Tg = 10^6 tonnes

$$GHG_{ANM} = (EF_{GHG})_F \times (\%_F)_{ANM} \times EC_{ANM} \times GWP_{GHG} / 1000 \text{ kg t}^{-1} \quad (3.1)$$

Where:

GHG_{ANM} are the emissions of a specific greenhouse gas by the type of animal ANM, t CO_2 eq.

$(EF_{GHG})_F$ is the emission factor for a specific gas GHG for a specific energy source F, kg TJ^{-1};

$(\%_F)_{ANM}$ is the per cent contribution of a specific energy source F to the total energy consumption of an animal type ANM, %;

EC_{ANM} is the total energy consumption of the animal type ANM, TJ; and GWP_{GHG} is the global warming potential of a specific gas.

The total GHG emissions from energy consumption for livestock production, is estimated by the sum of the GHG emissions from each animal species and energy source.

3.3 The livestock production sector of Cyprus

Livestock production is widely practiced throughout the island of Cyprus. The general practice is that cows, pigs and poultry are accommodated in farms, whereas sheep and goats are mostly in pastures. The spatial distribution of livestock population is presented in Figure 3.4. This research focuses on cows, pigs and poultry that are the species with the largest population. Moreover, these species are confined in farms and the large amount of waste produced is therefore a problem that has to be resolved.

According to information from the Department of Agriculture (Hadjiantoniou, 2013), Nicosia in 2011 had the largest population of pigs (62%) and poultry (65%). Cattle population in Nicosia is 33% of the total. Larnaca has the largest population of cattle (51%), 30% of pig population and 20% of poultry population. The remaining population of livestock is distributed among the other districts of the country. It should be noted that these numbers are only for the areas under the effective control of the Republic of Cyprus. The animal population per district is presented in Table 3.1.

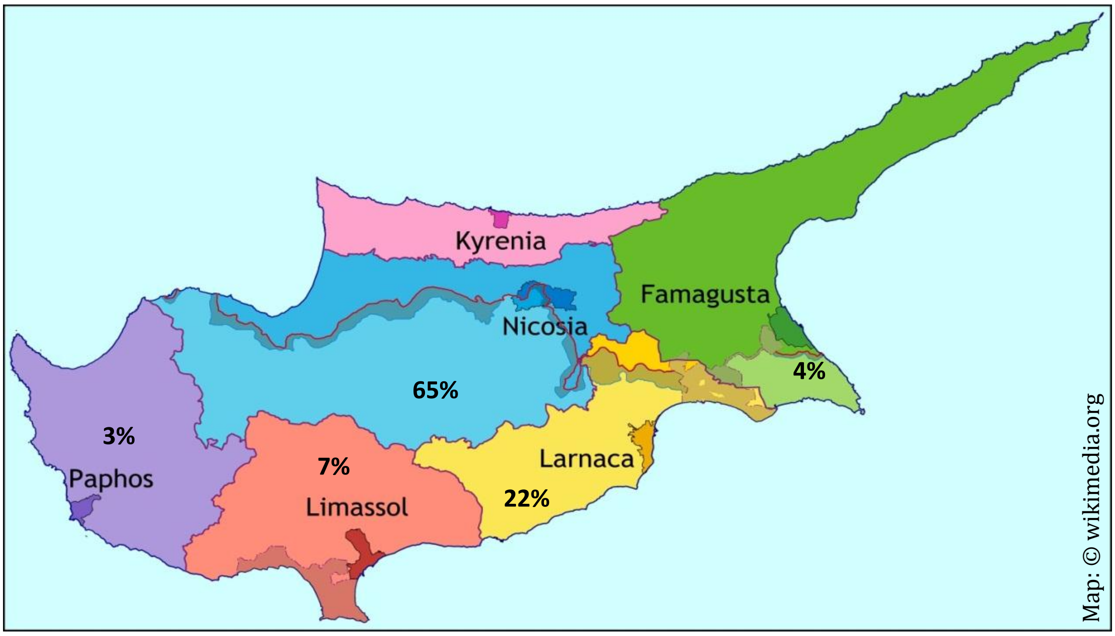


Figure 3.4. Distribution of total animal population in Cyprus for 2011 (see Table 3.1 for details)

Table 3.1. Animal population in Cyprus per district and animal type (2011)

Animal	Nicosia	Lemesos	Larnaca	Paphos	Ammochostos	Total
Cattle	18559	3,274	28941	667	5474	56,915
Pigs	272099	24,078	130054	7070	6099	439,400
Poultry	2,250,390	247,000	700,815	114,900	128,470	3,441,575
Total	2541048	274352	859810	122637	140043	3937890

Even though livestock production in Cyprus is already competitive compared to other agricultural products, the sector has problems, such as insufficient production to meet the demand of the country in animal products. As a consequence, there is a need for imports of meat. In addition, there are problems in the supply of grains used for feed.

The largest environmental problem of the sector is waste management. The problem is more intense in large installations that have to comply with the Integrated Pollution Prevention Control (IPPC) law. These installations have to meet the minimum requirements in waste management by using the best available technologies proposed by the European Commission.

Poultry farming in Cyprus is threatened by imports from Israel. Israel has large, modern poultry installations with high productivity. Due to the proximity with Cyprus, it is considered a large competitor to poultry farming in Cyprus. On the contrary pig farming is not threatened by neighbouring countries, since there is no significant pig farming taking place in the region. Simultaneously, due to the low consumption of pig products in the neighbouring countries, there are also limited opportunities for exports. For cattle farming, the largest problem is the high cost of fresh grass which is due to low availability caused by the dry and warm climate of Cyprus and the high water prices.

As it has already been presented in the Chapter 2, breeding of dairy and other cattle, pigs and poultry contribute 15% to the total biodegradable waste generation of the country.

Traditionally, animal farming in Cyprus was characterized by small, family ran units, spread in all the agricultural areas of the island. Slurry management was not a problem, since the amounts were sufficiently low to be spread as fertilizer in the surrounding areas. The increase in demand for meat and other animal products, as well as the production of genetic material and the automation introduced in the production, have caused an increase in animal farming.

A typical animal farm in Cyprus consists of one or more buildings grouped in three main types in terms of function. The first includes the animal breeding areas, the second is the support buildings, whereas the third is the waste treatment and storage areas. The data for the following sections was collected from personal communication with the responsible Environment Officer on livestock production waste, of the Department of Environment (Athanasiades, 2010). The information is summarised in Table 3.2.

The type of housing typically used for cattle farming in Cyprus is free stall (70%). Breeding areas are typically a combination of open covered areas and uncovered areas, with natural lighting. Feeding in all of the farms is performed manually and mainly consists of dry or fresh hay. Milking takes place on-site in specially designed areas. Animal waste (manure) from cattle in approximately 60% of farms is collected from the concrete floors by gravity in drains and is transferred with scrubbers at least once or twice a day to a homogenisation tank. The remaining 40% of the farms collect the waste manually with brooms. The open areas in all farms are cleaned with a tractor. After collection, 70% of the farms dry the manure on concrete platforms and use it for agricultural purposes. 20% of the farms use mechanical separation to separate the solid from the liquid fraction of the waste. The remaining 10% of the farms, mainly large farms, transfer the waste for combined anaerobic digestion with aerobic treatment. The resulting sludge is dried on concrete platforms and used for agricultural purposes. The liquid fraction is used for irrigation (30%), cleaning of the farm areas (30%) or evaporated in evaporation lagoons (40%).

Table 3.2. Animal waste management in Cyprus

Animal Species	Waste collection	Waste management	Sludge management	Treated liquid management
Cattle farming	Scrubbers 60%	Evaporation 70%	Drying and soil improver	Irrigation 30%
	Manually 40%	Mechanical separation 20%		Cleaning 30%
		Transfer to AD 10%		Evaporation 40%
Pig farming	Gravity 80%	Mechanical separation 80%	Drying and soil improver	Irrigation 30%
		Transfer to AD 10%		Cleaning 30%
	Suction 20%	Evaporation 10%		Evaporation 40%
Poultry farming	Through gritted floor to concrete platform and collected by tractor at end of breeding cycle	Evaporation 80%	Drying and soil improver	
		Transfer to AD 20%		

In pig farming, breeding areas are typically closed buildings for which artificial lighting and ventilation is required throughout the year. Heating is only used in areas where the weaners (piglets 3-4 weeks to 60 days old) are housed. Cooling however, is used for some days in the summer when temperatures rise above 37-38^{o}C. It should be noted that new pig farms, install automated centralised systems for the control of temperature and humidity. Feeding in 70% of pig farms is automated and connected with the feed preparation system. In the remaining 30% feeding takes place manually. Both dry and liquid feed is used, with the liquid being dairy industry wastewater. 80% of the installations prepare feed on-site, while the remaining 20% only store the feed on-site. Animal waste (manure and urine) from pig farms is collected through gritted floors by gravity (80%), whereas the large installations have automated suction systems (20%). Waste is transferred to a waste homogenisation tank where mixing takes place. 80% of the farms have mechanical separation installed after the homogenisation tank. 10% of the farms, mainly small farms, then transfer the waste through a piping system to evaporation lagoons. The remaining 10% of the farms use a combination of anaerobic/aerobic treatment of their waste: 8% of the farms have treatment installed on-site and 2% transfer their waste to off-site installations. The resulting sludge is dried on concrete platforms and used for agricultural purposes, while the liquid fraction is used for irrigation (30%), cleaning of the farm areas (30%) or evaporated in evaporation lagoons (40%).

Breeding areas in poultry farming are typically closed buildings (70%) for which artificial lighting and ventilation is required throughout the year. Heating is only used during winter and cooling is used during some days in the summer when temperatures rise above 35^{o}C. It should be noted that the new farms, install automated centralised systems for the control of temperature and humidity. Feeding in 80% of the poultry farms is automated and connected with the feed preparation system. In the remaining 20% of farms feeding takes place manually. 70% of the installations are preparing feed on-site, while the remaining 30% are only storing the feed onsite. Animal waste (manure) from poultry farms is collected through gritted floors to a concrete platform below and is collected once at the end of every breeding cycle by tractor. 20% of the farms, mainly large farms, transfer the waste for off-site biological treatment (combination of anaerobic/aerobic treatment). The remaining 80% of the farms dry the manure on concrete platforms and use it for agricultural purposes.

The qualitative characteristics of the waste of cows, pigs and poultry, are presented in Table 3.3.

Table 3.3. Characteristics of typical animal wastes (Kythreotou, 2006)

Waste stream	Cattle farming	Pig farming	Poultry farming
COD ($g\ l^{-1}$)	191.0	40.00	190.0
Bulk density ($kg\ l^{-1}$)	1.551	0.973	0.546
Total solids, TS (%)	14%	5%	39%
Volatile Solids, VS (%)	65%	70%	63%

3.4 Estimation of on-farm energy consumption and relevant GHG emissions for Cyprus and comparison to international data

3.4.1 On-farm energy consumption

Currently, in Cyprus, there is a need to provide estimates of energy consumption for livestock production due to climate and energy legislation of the EU (Council of the European Union, 2009). Until national statistics provide the necessary official data through the use of approved EU methodologies, the application of the proposed methodology could provide the required data.

The methodology presented in Figure 3.2, was applied to estimate the on-farm energy consumption for livestock production in Cyprus. The results obtained for the annual energy consumption per animal are presented in Table 3.4. To determine these results, the following data was considered:

- Annual reports available from the Department of Environment submitted according to the national law 56(I)/2003 on Integrated Pollution Prevention Control (IPPC) – data was available for annual energy consumption by source (i.e. electricity, diesel and LPG consumption).
- Environmental impact assessments available from the library of the Department of Environment submitted according to the national law 140(I)/2005 – data was available for total annual consumption.

- A study performed by private consultants for the Department of Environment, concerning the implementation of IPPC requirements for the poultry sector of the country – data was available for annual energy consumption per chicken.

Table 3.4. Annual energy consumption per animal in Cyprus

Animal species	Cattle	Pigs	Chicken
Annual energy consumption (kWh) per animal	178-908	18-1742	0.067-2.954
Average (kWh animal^{-1} year^{-1})	565	537*	0.677
Contribution by source			
Electricity	29%	29%	28%
Diesel	45%	48%	41%
LPG	27%	23%	30%

*per sow

It is generally accepted that energy consumption for livestock production varies considerably between farms mainly because of technologies used and climate, in addition to the purpose of the farm (i.e. the end product of the farm). Strictly speaking energy consumption should therefore be compared on the basis of technology, climate or product. However, there is a need for generalised, average data to perform simple calculations.

Energy consumption per cow estimated for Cyprus compares reasonably well to that of other countries (Table 3.5). As already mentioned, most of the energy consumption is for milk production operations. Other uses reported by Clarke and House (2010), include ventilation, water heating and lighting. In Cyprus, energy consumption for ventilation and lighting is small because the cows are housed in open but restricted areas with a roof. Moreover, the months of the year requiring heating are lower than countries with colder climates. Therefore energy consumption in Cyprus is predominantly for waste management, feed preparation and milk production operations. Lower energy consumption in Australia, Italy, New Zealand and one reference from UK, is possibly due to the use of more energy efficient technologies and less time for cows in the farm since in Australia, New Zealand and the UK cows are mainly in pastures.

Table 3.5. Energy consumption per animal from international literature

	Country	Annual energy consumption	Source
Cattle	Cyprus	565 kWh cow^{-1}	
Dairy Cattle	Australia	281 kWh cow^{-1}	Warwick, 2007
	Canada	1100 kWh cow^{-1}	Meul *et al.* 2007
	Italy	466 kWh cow^{-1}	Hörndahl, 2008
	New Zealand	160 kWh cow^{-1}	Turco *et al.* 2002
	United Kingdom	330 kWh cow^{-1}	Murgia *et al.* 2008
		910 kWh cow^{-1}	Feeney, 2005
	U.S.A.	1000 kWh cow^{-1}	Barber and Pellow, 2005
		867 kWh cow^{-1}	Genesis Now, 2011
		2429 kWh cow^{-1}	Ludington and Peterson, 2005
	Sweden	1235 kWh cow^{-1}	Dick *et al.* 2008
	Switzerland	1165 kWh cow^{-1}	European Commission, 2003
		2900 kWh cow^{-1}	
Other Cattle[a]	Brazil	320 kWh cow^{-1}	Timble, 2009
	Canada	402 kWh cow^{-1}	Dahiya and Vasudevan, 1986
	Ireland	247 kWh cow^{-1}	Arey and Brooke, 2006
	United Kingdom	737 kWh cow^{-1}	Khakbazan, 1999
Pigs	Cyprus	537 kWh sow^{-1}	
	Denmark	250 kWh sow^{-1}[b]	Barber and Pellow, 2005
	Canada	330 kWh sow^{-1}[b]	Rotz *et al.* 2003
		1147 kWh sow^{-1}	Smith *et al.* 2009
	France	1272 kWh sow^{-1}	Dyer and Desjardins, 2006
	Italy	1314 kWh sow^{-1}[b]	Steinfeld *et al.* 2006
	Spain	1239 kWh sow^{-1}	Cederberg *et al.* 2009
	Sweden	650 kWh sow^{-1}	BDE[c], 2004
	United Kingdom	519 kWh sow^{-1}	de Saavedra *et al.* 2006
		1557 kWh sow^{-1}	Feeney, 2005
Chicken	U.S.A.	0.15 kWh $chicken^{-1}$	Cederberg and Flysjö, 2004
	Cyprus	0.677 kWh $chicken^{-1}$	

Table 3.5. Energy consumption per animal from international literature (continued)

	Country	Annual energy consumption	Source
Layer chicken	Canada	2.89 kWh chicken^{-1}	Ludington and Peterson, 2005
	Denmark	0.677 kWh chicken^{-1}	Wickham and Amstrong, 2011
	Estonia	0.921 kWh chicken^{-1}	
	Italy	0.5621 kWh chicken^{-1}	Steinfeld *et al.* 2006
	Sweden	3.1 kWh chicken^{-1}	Dick *et al.* 2008
	U.S.A.	0.167 kWh chicken^{-1}	ADAS, 1999
Broiler chicken	Brazil	0.1598 kWh chicken^{-1}	DMA [d], 2010
	Canada	0.17 kWh chicken^{-1}	Ludington and Peterson, 2005
	Italy	6.25 kWh chicken^{-1}	Steinfeld *et al.* 2006
	United Kingdom	1.76 kWh chicken^{-1}	Feeney, 2005

[a] Other cattle: heifers and bulls; [b] using ratio of 1 sow to 10 pigs; [c] BDE = Business Development and Economics; [d] DMA = Danish Meat Association

For pig farming, most energy demand is for maintaining suitable temperatures in the housing areas. Based on this fact, it was expected that Cyprus would have smaller energy consumption due to smaller time period requiring heating. This is not the case, however (Tables 3.4 and 3.5), may be due to the use of more efficient on-farm technologies in some countries with colder climates than Cyprus, such as Denmark, It should be noted, however, that there is a significant variability of data even for the same country due to the farming methods implemented.

Cyprus appears to have average to lower energy consumption per chicken, when compared to other countries (Table 3.5). Energy consumption in the USA, Canada and Brazil is smaller than Cyprus possibly because chicken are bred in larger farms. The differences with Italy and Denmark are possibly due to the technologies used for chicken farming. However, no clear pattern could be deduced from the comparison of the results, probably due to the large number of variables involved in the estimation of energy consumption of chicken farming.

According to the calculations performed, the breeding of the three species in Cyprus contributed 8% to the energy consumption for agriculture in 2011. The energy consumption by livestock production has shown a decrease since 2005. This decrease could be due to a decrease in the animal population, or an increase in energy efficiency at the farms.

3.4.2 GHG emissions from on-farm energy consumption

For the application of the methodology presented in section 3.2, emission factors, except CO_2 from electricity, were obtained from the IPCC 2006 guidelines (IPCC, 2006). The CO_2 emission factor used for electricity was based on the average of "specific emissions" submitted by the Electricity Authority of Cyprus in the annual reports for the Emissions Trading System (Mesimeris, 2009). The fuel densities and global warming potentials used were according to the IPCC 2006 guidelines (IPCC, 2006).

The results show that on-farm energy use in agriculture contributed approximately 20 Gg CO_2 eq. to the greenhouse gas emissions of Cyprus in 2011. This corresponds to 3% of the emissions from enteric fermentation and manure management. The contribution of emission sources for the three most important species of animals is shown in Figure 3.5.

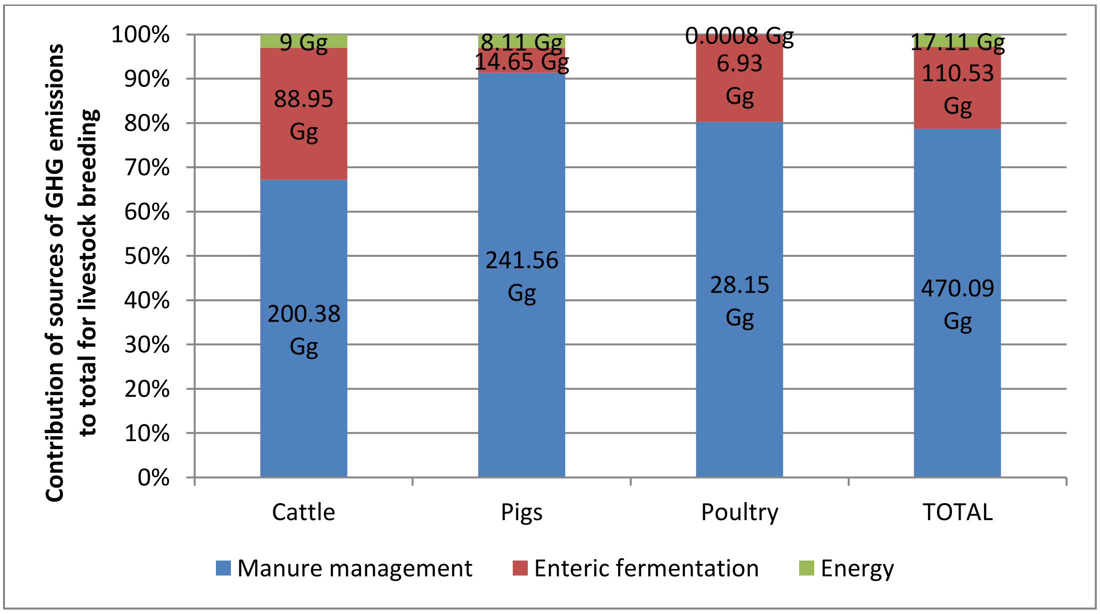


Figure 3.5. Contribution of GHG emissions for livestock production in Cyprus.

The emission of greenhouse gases by livestock production is predominately due to manure management (79% of total). Considerable emissions are also caused by enteric fermentation (18% of total). For cattle, the contribution of enteric fermentation is much higher (30%) compared to the other animal species. One could therefore conclude that the area on which emission mitigation strategies should be focusing is manure management. Direct energy use is a small but important source of greenhouse gas emissions on a farm. Improvements in energy efficiency and renewable energy can help reduce farm-operating costs, improve air quality and reduce GHG emission levels. Energy conservation is especially important in Cyprus, where fossil fuels, particularly fuel oil, remain the primary fuel for electricity generation.

The results above agree with the findings of Steinfeld *et al.* (2006) who estimated that 3.2% of the total farming related emissions globally is from on-farm fossil fuel use. Lymbery (2009) however, concluded that 1.27% of the total livestock production emissions globally are from energy consumption. This difference is due to the approaches used to estimate this figure.

The energy consumed for livestock production and the respective emission of greenhouse gases, depend on the type of farming and the technologies used in the farm. Additional parameters that affect the energy consumption in a farm are climatic conditions, and in particular heating and cooling degree days.

3.5 Conclusions

On-farm energy consumption is becoming increasingly important in the context of rising energy costs and concerns over greenhouse gas emissions. For farmers throughout the world, energy represents a major and rapidly increasing cost. It has been identified that there is a lack of systematic research on energy use by agriculture in Cyprus, which makes benchmarking and decisions on investment to improve energy efficiency difficult.

This Chapter presented the methodology developed for the estimation of the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport). GHG emissions from on-farm energy consumption are also presented.

The methodology employed is simple and uses internationally accepted emission factors for the estimation of emissions (IPCC, 1996; 2006).

The methodology has been applied to the conditions and activity data of Cyprus to estimate the contributions of: (a) livestock production to national energy consumption and, (b) on-farm energy consumption to the total GHG emissions from livestock production.

Overall, the estimated annual energy consumption per animal was found to be lower than most other countries, due to favourable weather conditions in Cyprus which reduces the energy consumption for heating.

The results for GHG emissions showed that the emissions from energy use in livestock production contribute 16% to the total agricultural energy emissions. Even though GHG emissions from direct energy use is small, considerable improvements in energy efficiency can be achieved , including application of renewable energy technologies, to reduce farm-operating costs, improve air quality and reduce GHG emissions. Energy conservation is especially important in Cyprus, where fossil fuels, particularly fuel oil, remain the primary source of electrical generation.

Anaerobic digestion can play a significant role in reducing energy use and greenhouse gas emissions from livestock production operations. Its potential contribution will be investigated in the next Chapter.

CHAPTER 4. Anaerobic digestion and its potential for application to Cyprus for the treatment of animal waste

As it has already been mentioned in previous chapters, anaerobic digestion (AD) is one of the best measures for the mitigation of greenhouse gas (GHG) emissions from biodegradable waste. To apply AD, it is important to know the potential of biogas production and the respective thermal and electrical energy which could be produced. The first part of this chapter presents information on AD. The second part presents the methodologies developed for the estimation of biogas production from livestock waste. The estimation of the respective thermal and electrical energy which could be produced if the biogas was combusted follows. The chapter also presents the relations adopted for the estimation of the cost and area requirements for AD of animal waste in Cyprus.

4.1 Anaerobic digestion

As discussed in Chapter 2, solid and liquid waste excreted by animals cause considerable methane and nitrous oxide emissions. These emissions may be “captured” with an AD system that flares the mixture of gases or uses it for energy purposes (Bracmort, 2010). AD is a combination of processes through which microorganisms disintegrate biodegradable material in the absence of free oxygen. The process depends on the symbiotic relationship of different types of microorganisms, of which the majority are bacteria (Gerardi, 2003). The technology is considered as one of the most important mitigation options for GHG emissions from animal waste.

Alternative treatment technologies to AD emit uncontrolled GHG emissions to the atmosphere. Lagoons emit CO_2 from their upper layers where aerobic conditions exist. In the case that anaerobic conditions prevail in large depths, CO_2 and CH_4 are also emitted. Aerobic treatment causes the emission of considerable amounts of carbon dioxide due to the large amounts of energy required for aeration and/or mixing.

The typical ratio of methane to carbon dioxide in biogas is 60:40. If the biogas generated is of sufficient quality and quantity, it can be combusted to generate electricity or heat or both. This prohibits methane to be released to the atmosphere, and instead, carbon dioxide is emitted from the combustion process. Since carbon dioxide has a smaller contribution to the greenhouse phenomenon compared to methane, AD has a smaller impact to climate change compared to other technologies.

AD is used for the treatment of industrial or domestic, solid or liquid waste. It is a process that occurs naturally, in areas where free oxygen is not available, such as deep lakes, sediments lying under water and deep soil layers. In recent decades, AD has gained significant attention as a wastewater treatment technology, due to its ability to treat wastewaters with very high organic content and produce energy. AD is more suitable for the treatment of industrial wastewater with high organic content than any aerobic treatment because it is less expensive since the aeration costs are avoided (Etheridge, 2001).

Biomass consists of complex macromolecules that through disintegration are made available to hydrolysing microorganisms. Hydrolysing microorganisms convert complex organic compounds to simpler organic compounds. Acidogenic microorganisms, then convert some simpler organic compounds to volatile fatty acids, while other organic compounds are converted directly to hydrogen, carbon dioxide and acetate. Volatile fatty acids are converted to hydrogen, carbon dioxide and acetate by acetogenic microorganisms. The final stage is methanogenesis, where methanogenic microorganisms convert hydrogen, carbon dioxide and acetate, to methane and carbon dioxide. Figure 4.1 presents the main conversions that take place during AD when complex biomass is converted to methane and carbon dioxide.

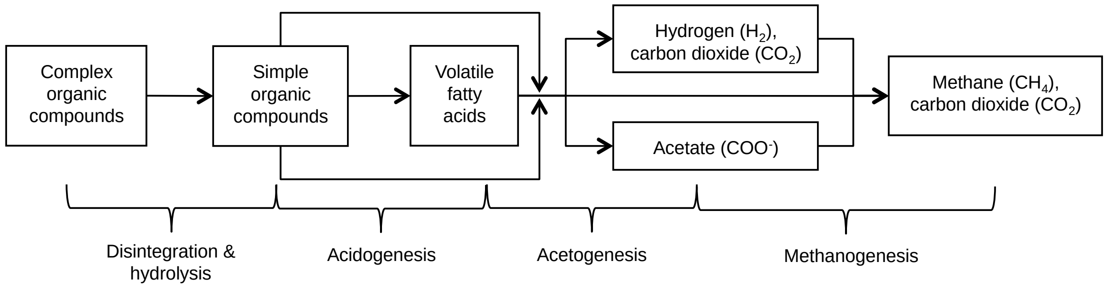


Figure 4.1. The main conversions of compounds during the stages of AD

The time required for the completion of AD can vary from a few seconds to several days. The duration depends primarily on the quality of the wastes in terms of the organic polymer content and their biodegradation, in addition to the presence or absence of particular microorganisms, and their behaviour (Pind *et al.* 2003). For AD to be completed successfully, the degradation rates of all stages have to be equal. If this is not the case, compounds could be insufficient or could build up, reducing the efficiency and consequently cause inhibition of AD. The most commonly disturbed stage is methanogenesis, due to the sensitivity of the methanogenic microorganisms to many parameters, such as pH.

The conversion processes during AD can be biochemical or physicochemical. Biochemical processes are those during which microorganisms with the aid of enzymes digest organic matter. These processes are further distinguished into intracellular and extracellular. During physicochemical processes no biology is involved (Batstone *et al.* 2002). Liquid – gas conversions, precipitation and other physicochemical conversions take place during all the stages of AD. As digestion progresses from disintegration to methanogenesis, the intensity, involvement and importance of biochemical processes increase.

4.1.1 Substrate

AD can be used for the treatment of organic wastes, such as sewage sludge, organic farm waste, municipal solid waste, green waste, biodegradable industrial and commercial wastes, and any other waste with high organic content. In the cases that the waste has a specific characteristic that does not allow AD to take place, pre-treatment, suitable operational conditions and type of anaerobic technology applied, can "help" the digestion. Therefore, the type of waste is among the factors that influence the amount of biogas produced. The substrates are complex, composite particulates and particulate carbohydrates, proteins and lipids. Organic matter can be separated into easily biodegradable compounds (storage carbohydrates, lipids, and proteins) and poorly biodegradable compounds (structural carbohydrates, humic and fulvic acids) (Batstone *et al.* 2002). The composition of the substrate is crucial for the microbial growth and therefore efficiency of the process (Jerger and Tsao, 2006). Table 4.1 presents the biogas potential and methane content according to digested substrate (BSRCA, 2010).

According to Angelidaki and Ellegaard (2003) the substrate in AD should produce a methane yield of more than 20 m^3 CH_4 per t biomass to be economically effective.

Pig manure specific methane potential in volatile solids (VS) basis obtained by Álvarez *et al.* (2010) was between 570 and 620 ml CH_4 g^{-1} VS, which is almost twice that reported by Moller *et al.* (2004) (356 ml CH_4 g^{-1} VS) and Ferreira *et al.* (2007) (375 ml CH_4 g^{-1} VS). Inoculum characteristics and substrate/inoculum ratios can influence the manure methane potential. Cattle manure has a lower methane potential than pig manure, as indicated by Callaghan *et al.* (1999) (300 ml CH_4 g^{-1} VS) and Moller *et al.* (2004) (148 ml CH_4/g VS).

Table 4.1. Potential biogas yield in m^3t^{-1} and methane content in % for various substrates (BSRCA, 2010)

	Potential biogas yield, m^3t^{-1}	CH_4 content (%)
Baking wastes	657	
Waste grease	600	
Waste bread	486	
Skimmed grease	400	
Brewer's grain silage	291	
Food waste	220	
Grass silage, first cut	195	54
Rye silage (whole plant)	163	52
Sudan grass	128	55
Feeding beet	111	51
Sweet sorghum	108	54
Grass	103	
Biowaste	100	61
Common beet	88	53
Poultry manure	80	60
Beet leaves	70	54
Pressed pulp	67	72
Pig manure	60	60
Cattle manure	45	60
Grain silage	40	61
Liquid swine manure	36	65
Liquid cattle manure	25	60

4.1.2 Microorganisms involved in AD

AD requires the combined and coordinated activity of a consortium of bacteria for complete degradation of complex organic matter to be converted to methane and carbon dioxide. The conditions of operation of AD do not need complete sterility of pure microbial cultures (Stronach *et al.* 1986), but initial inoculum in many cases originates from the waste itself (Hobson, 1982).

Two types of organisms are involved in AD, obligate anaerobes and facultative anaerobes. An anaerobic microorganism is an organism that does not need oxygen for survival (Lowrie and Wells, 1994). Obligate anaerobes are inactive in the presence of free molecular oxygen, whereas facultative anaerobes are active in the presence or absence of free molecular oxygen. The majority of microorganisms isolated during AD are obligate anaerobes in a ratio of 1:10 up to 1:100 compared to facultative anaerobes (Mah and Sussman, 1967). In cases, however, that animal wastes are treated, approximately half of the microorganisms identified are facultative (Hobson *et al.* 1982).

Microorganisms are also categorised according to the temperatures at which they are more active. Temperatures 45-70^{o}C are favourable for thermophilic microorganisms, 20-45^{o}C for mesophilic microorganisms (Hobson *et al.* 1982), and temperatures lower than 20^{o}C favour psychrophilic microorganisms (Lowrie and Wells, 1994) (Table 4.2). Sudden temperature changes cause rapid accumulation of acid which subsequently reduces significantly biogas production (Man-Chang *et al.* 2006). This, however, is restored when the temperature is returned to normal operational levels.

Table 4.2. Types of microorganisms involved in AD according to temperature (Lowrie and Wells, 1994)

Type of microorganism	Temperature
Psychrophilic	< 20 ^{o}C
Mesophilic	20-45 °C, optimal around 37-41 °C
Thermophilic	≤ 70 °C, optimal around 50-52 °C

4.1.3 Conditions and variables influencing AD

Temperature

Temperature is an important design parameter. Digesters can operate under psychrophilic, mesophilic or themophilc conditions. The optimum "limit" of thermophilic AD appears to be 60^{o}C (Kim *et al.* 2006). Regardless of temperature range, the temperature should be uniform throughout the digester, since even small changes in temperature can cause significant changes to the microbial populations.

Typically, the growth rate increases with temperature until the maximum survival temperature is reached after which, a sudden decrease of growth rate takes place Cooney, 1981). Methanogens are considered the most sensitive microorganisms of AD (Stronach *et al.* 1986). Therefore, a decrease in temperature is usually accompanied by increase in concentration of volatile fatty acids, which in some cases can cause the pH value to decrease due to a reduction of the activity or the population of methanogenic microorganisms (Speece, 1996),. Many of the parameters that control the design of the system such as the specific growth rate of the microorganisms, decay, biomass yield and substrate removal rate are temperature sensitive Speece, 1996).

pH

pH is another important parameter for microbial activity since most microorganisms have a pH value at which their growth is at a maximum. In most cases the pH range of higher microbial activity is 6.5 to 7.5 (Stronach *et al.* 1986). Even though there are some rare exceptions, inhibition of AD commonly occurs at pH values smaller than 5 and larger than 8.5 (Stronach *et al.* 1986). Methanogens are the most pH sensitive microorganisms involved in AD and can only survive within a limited range around neutral pH (pH 7). A generally accepted optimum range for methanogens is between 6.5 and 8.2 (Speece, 1996). When pH increases above or decreases below this range, the impact on methane production is direct (Angelidaki and Ahring, 1994).

In cases where the material treated has high concentrations of total ammonia nitrogen (e.g. animal waste), the pH is affected and therefore the growth of microorganisms is also affected (Hansen *et al.* 1999). 150 mg NH_3l^{-1} is usually reported as the threshold above which the pH is affected (Braun, Huber and Meyrath, 1981). Increasing pH favours conversion of ammonium ion (NH_4^+) to ammonia that is considered toxic to AD (Borja *et al.* 1996). The result is process instability and therefore accumulation of volatile fatty acids (VFAs), which again lead to a decrease in pH and thereby declining concentration of free ammonia. This relation between free ammonia, VFAs and pH may lead to an "inhibited steady state", a condition where the process is running but with a lower methane yield (Angelidaki *et al.*

1993). Aceticlastic methanogens are the trophic group most sensitive to free ammonia (Heinrichs *et al.* 1990).

Retention time

There are two significant retention times during AD, hydraulic retention time (HRT) and solids retention time (SRT). HRT is the time that the wastewater or sludge is in the digester (Gerardi, 2003). HRT is directly proportional to the size of the reactor and therefore the cost. Many digestion systems are designed to allow microorganisms to remain in the reactor longer than the HRT (Speece, 1996). SRT is the average time that the bacteria are in the digester. SRT is the most important factor controlling the conversion of solids to gas. It is also the most important factor in maintaining digester stability. Typical HRTs of conventional mesophilic (35^{o}C) digesters for treating animal wastes are usually controlled at 10–20 days, depending on the solids content of the wastes (Keshtkar *et al.* 2003). For thermophilic conditions typical are HRTs 12-14 days (Siripong and Dulyakasem, 2012). The long retention time required for animal manure digestion may be attributed not only to the presence of complex organic compounds, but also to high concentrations of ammonia nitrogen that affect the anaerobic decomposition process (Zeeman *et al.* 1985). The relation between SRT and gas production rate is directly proportional, i.e. by increasing the SRT the gas production rate increases (Nges and Liu, 2010).

Loading Rate

Loading rate is the amount of fresh, untreated waste added to the digester, and depends on the volume and frequency of addition. In addition to volumetric and mass terms, loading rate can be measured in terms of total or volatile solids, COD, or total organic matter. Loading rate is one of the most significant operational parameters of the process. The factors controlling the loading rate according to Speece (1996) are the following:

- Concentration of viable biomass that can be retained in the anaerobic reactor.
- Mass transfer between incoming and retained biomass.
- Biomass proximity for the metabolism of hydrogen intermediate.
- Ease of metabolism of organic pollutants.
- Temperature within the reactor.

- Toxicity of the substrate.
- pH
- Reactor configuration.

As with other parameters, there is an optimum loading rate for maximum biogas production. If that loading rate is exceeded the process is inhibited and/or overloaded (Salminen and Rintala, 2002). This is indicated by the accumulation of volatile fatty acids and long-chain fatty acids and the decline in the methane yield. Nevertheless, the inhibition can be reversible.

Mixing

Mixing can enhance AD, since mixing distributes bacteria, substrate, nutrients and temperature throughout the digester (Gerardi, 2003; Vedrenne *et al.* 2007). Mixing creates a homogeneous substrate preventing stratification and formation of a surface crust, and ensures solids remain in suspension. Mixing also enables heat transfer, reduction of particle size as digestion progresses, release of produced gas from the digester contents and also prevents the formation of Volatile Fatty Acids (VFA) pockets (Meynell, 1976; Keshtkar *et al.* 2003). It is also recognised, that homogeneities in the medium can have a profound influence, especially on production of metabolites (Nielsen and Villadesen, 1992).

4.1.4 Anaerobic co-digestion

Research has shown that the organic animal wastes produced from animal farming, are substrates of very good quality for co-digestion. This is due to the high humidity, high nutrient content, and high alkalinity (Angelidaki and Ahring, 1997). The high alkalinity concentration provides good buffer capacity for wastes that are in the extreme low or high pH range, thus avoiding the inhibition of methanogenesis. Moreover, the high concentration of lipids in animal wastes increases the methane generation potential (Ahring *et al.* 1992).

Anaerobic co-digestion of animal waste with other types of biomass results in a higher methane yield due to the synergistic effects of the co-substrates (Mata-Alvarez *et al.* 2000).

The advantages of co-digestion of animal waste with other substrates are:

a. pH value can be maintained at optimum conditions within the methanogenesis stage, due to the increase in the buffering capacity during digestion (Campos *et al.* 1999);
b. high concentrations of ammonia that often occur during the AD of animal waste can be avoided (Xie, 2012);
c. co-digestion can provide better nutrient balance and therefore better digester performance and higher biogas yields (Angelidaki and Ahring, 1997);
d. waste with poor fluid dynamics, aggregating wastes, particulate materials, floating wastes or materials with high disturbing or inhibiting components can be utilised more effectively as co-substrates when co-digest with well performing sewage sludge or liquid manure (Braun, 2002);
e. co-digestion can provide organisational and economic benefits, by the higher production of biogas and therefore energy, which will provide additional income to the biogas plants (Brolin and Kattstrom, 2000).

Some of the co-digestion disadvantages reported by Barun (2002) are the following: increase in effluent COD, additional pre-treatment and post-treatment necessary and increased mixing needs.

The recent interest in renewable energy production through AD has rapidly increased the use of crops as co-substrate in farm-scale digesters, since co-digestion of crops with animal waste results in a higher methane yield than digestion of only waste (Neureiter *et al.* 2005). As the findings of Muyiiya and Kasisira (2009) have shown, co-digesting pig with cow waste generally increases biogas yield in comparison to pure samples, with the maximum biogas yield being obtained with mixtures of 1:1 ratio. At this ratio, there is a biogas yield increase of seven and three times compared to pure samples of cow and pig manure respectively.

Nnabuchi *et al.* (2012) showed that co-digestion of poultry waste and cow waste increases biogas yield as compared to pure samples. The maximum biogas yield was achieved with mixtures consisting of 20% poultry waste and 80% cow waste. Other researchers however, have achieved maximum biogas yield at 33% of poultry waste combined with 67% of cow waste (Canas and Manuel, 2010; Callaghan *et al.* 2002; Magbauna *et al.* 2001).

The anaerobic co-digestion experiments of Magbanua *et al.* (2001) of pig and poultry waste showed that the highest biogas yield is when poultry waste is limited to 20% of the mixture (130±20 ml g^{-1} VS destroyed). Nevertheless, all mixtures tested by Magbanua *et al.* produced more methane compared to single waste. According to Angelidaki and Ahring (1993), the combination of only these two particular types of waste (pig and poultry) are often avoided, due to the high concentrations of ammonia that can inhibit the AD.

4.1.5 AD in practice

The application of AD requires a unique plant process design, which depends primarily on the qualitative and quantitative characteristics of the waste to be treated. Nevertheless, the steps almost always included in the process are waste collection, AD, gas recovery, and residue treatment (Figure 4.2). Figure 4.3 shows the process train in a flow chart with the available options for each flow of material from the collection of waste to the use of the end products.

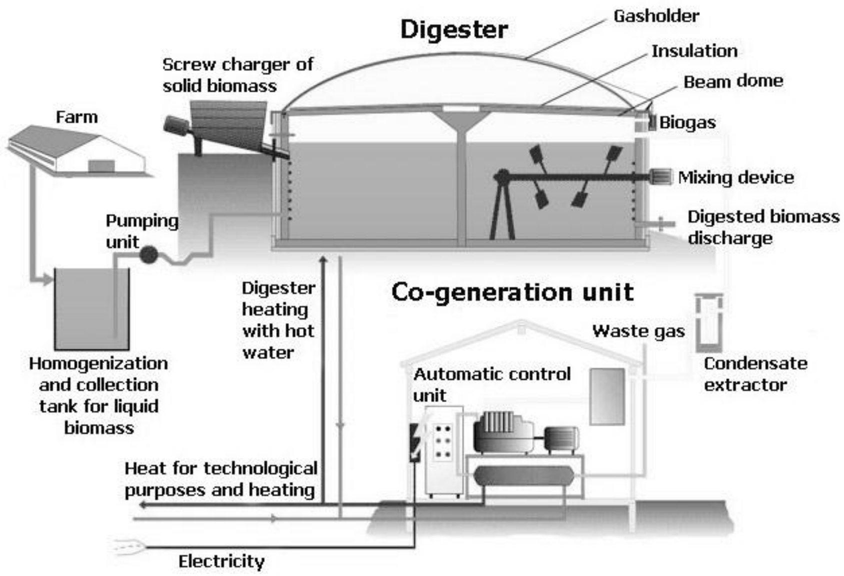


Figure 4.2. Stages of AD, with energy production from the biogas produced (Zorg Biogas, 2010)

Waste is collected in a collection tank or pond for homogenisation. Pre-treatment is then applied if a particular substance is present that is toxic to anaerobic microorganisms or for increasing the efficiency of the AD process. Pre-treatment enhances digestion and the rate and quantity of biogas generated, while reducing the retention time requirement to approximately half (Elliott and Mahmood, 2007). Technologies that can be applied for pre-treatment include ultrasound, thermal ozone oxidation, mechanical and chemical. In case that pre-treatment is not applied, waste is transferred directly to the anaerobic digester.

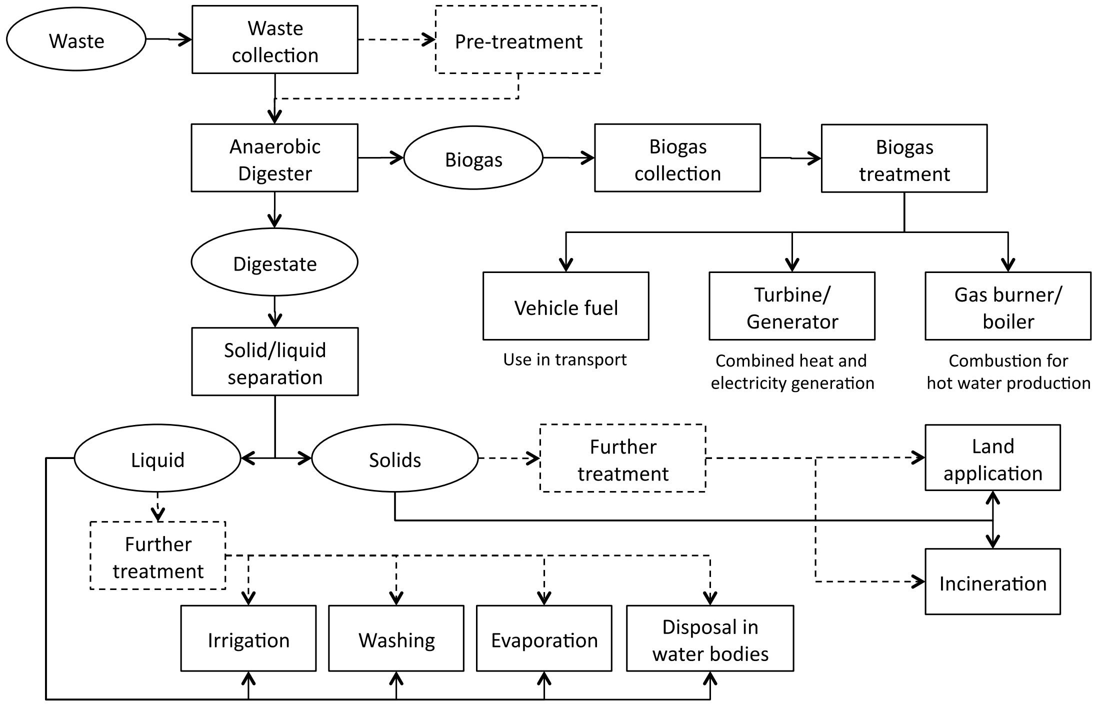


Figure 4.3. Stages of AD from waste collection to use of end product

The effluents from the digester are digestate and biogas. Digestate is separated into liquid and solid fraction with a solid-liquid process. This can be a slope screen, rotary drum thickeners, centrifugal, electro-coagulation and screw-press separators. Common solid-liquid processes can produce digestate solid fraction with moisture content of 18 to 30% (Kirk and Gould, 2010), depending on the technology used.

Further treatment of the solid and liquid fractions after the solid liquid separation depends on the use of the final products and the standards permitted according to the national guidelines. The liquid fraction can be used for irrigation, washing of areas in the farm, left to evaporate in evaporation tanks or disposal in water bodies (lakes, rivers, streams or sea). Similarly, the solid fraction can be further treated (e.g. composting) and further used as fertiliser or for energy production via incineration.

The initial collection of the biogas takes place in the fixed rigid top, a flexible inflatable top, or a floating cover, depending on the type of digester. The biogas is then directed to the handling sub-systems via plastic piping. There, the biogas may be treated for the removal of moisture or H_2S, or even CO_2 if the end usage is for biomethane. Depending on the application, biogas may be stored either before or after processing, at low or high pressures. Recovered biogas can be used directly as fuel for heating or it can be combusted in an engine to generate electricity or flared. If the biogas is upgraded to biomethane, additional uses may be possible, such as vehicle fuel or distribution via the gas grid.

The estimation of biogas potential can be very useful for a farm owner to decide whether the amount and quality of the waste produced by its farm is sufficient for further investments. The next section provides the estimates for biogas production from animal waste in Cyprus.

Further details on anaerobic digestion are available in the papers "A review on anaerobic digestion (Part 1): The fundamentals of the process" and "A review on anaerobic digestion (Part 2): Conditions and variables influencing anaerobic digestion" in Appendix A.

4.2 Biogas potential

In addition to the two methods presented in Chapter 2 for the estimation of potential biogas production (Chemical Oxygen Demand consumed and mass of digested waste), the method based on volatile solids (VS) destroyed can be applied for animal waste since data is available for the total and volatile solids concentration of animal wastes in Cyprus (Table 4.3).

Table 4.3. Total and volatile solids for animal wastes in Cyprus (Kythreotou, 2006)

Waste stream	Total solids, TS (g l^{-1})	Volatile Solids, VS (g l^{-1})
Cattle farming	140	91
Pigs farming	50	35
Poultry farming	390	246

For this method, the total waste production of a specific waste stream is multiplied by the percent total solids, by the percent volatile solids content and by the theoretical production of biogas per kg of volatile solids destroyed. In theory, all the volatile solids represent organic compounds that can be converted to biogas and can be consumed during the process by anaerobic organisms, to produce, 0.867 m^3 biogas per kg volatile solids destroyed (Møller *et al.* 2004). The equation applied is the following:

$$BG_{wst}\,(m^3) = M_{wst}\,(kg) \times TS_{wst}\,(\%) \times VS_{wst}\,(\%) \times GF_{BG}\,(m^3 kg^{-1}\,VS) \qquad (4.1)$$

where BG_{wst} is the volume of biogas produced in m^3 from the anaerobic digestion of a particular waste stream, M_{wst} is the mass of waste of a particular source in kg, TS_{wst} is the total solids in the waste (%), VS_{wst} is the volatile solids in the waste (%) and GF_{BG} is the m^3 biogas produced per kg of VS destroyed, which varies according to the waste stream.

The potential biogas production from the AD of animal waste in Cyprus for 2011 ranges from 53 million m^3 using the method based on COD consumed to 73 million m^3 using the method based on volatile solids destroyed. The method based on the amount of waste digested results in 56 million m^3.

This biogas can be used for the production of energy through combustion. The next section presents the relationships that have been developed and can be applied to estimate the potential energy production from biogas combustion in Cyprus.

4.3 Potential for production of thermal and electrical energy

When biogas is combusted, the energy contained in methane is released while the carbon dioxide molecules remain unchanged. Therefore, the amount of energy produced depends on the amount of methane in the biogas and the efficiency of the generator.

The potential thermal energy can be estimated using equation (4.2):

$$ENPROD_{TH}\ (kWh) = BG\ (m^3)\ x\ CH_4\ (\%)\ x\ EF_{TH}\ (\%) x\ \rho_{CH4}\ (kg\ m^{-3})\ x\ EN_{CH4}\ (MJ\ kg^{-1}) / 3.6\ (MJ\ kWh^{-1}) \quad (4.2)$$

where $ENPROD_{TH}$ is the thermal energy production in kWh, BG the total biogas produced according to each method used in m^3, CH_4 is the percent methane content in the biogas, EF_{TH} the thermal efficiency of the generator in % ρ_{CH4} is the density of methane in kg m^{-3} and EN_{CH4} is the energy density of methane in MJ kg^{-1}.

The potential electrical energy can be estimated using equation (4.3):

$$ENPROD_{EL}\ (kWh) = BG\ (m^3)\ x\ CH_4\ (\%)\ x\ EF_{EL}\ (\%)\ x\ \rho_{CH4}\ (kg\ m^{-3})\ x\ EN_{CH4}\ (MJ\ kg^{-1}) / 3.6\ (MJ\ kWh^{-1}) \quad (4.3)$$

where $ENPROD_{EL}$ is the electrical energy production in kWh, EF_{EL} the electrical efficiency of the generator in %.

The assumptions used for the estimation of the thermal and electrical energy generation are presented in Table 4.4.

Table 4.4. Assumptions used for the estimation of potential energy production

Parameter	Assumed value
Methane content in biogas	60%
Thermal efficiency of energy generator	50%
Electrical efficiency of energy generator	35%
Methane energy density	55.6 MJ kg^{-1} *
Methane density	0.6556 kg m^{-3} *

* O'Connor, 1977

Using equations (4.2) and (4.3), the potential thermal energy production from the AD of animal waste in Cyprus for 2011 is 576-796 TJ, while the electrical energy is 403-432 TJ. The energy consumption for livestock production according to the data presented in Chapter 3 is 47 TJ electrical and 158 TJ thermal energy. Even though these are maximum estimates and the realistic production is lower, it gives an appreciation of the potential impact of AD. These values show that AD can make livestock production in Cyprus self-sufficient in energy, and excess electrical energy can be sold for distribution through the electricity distribution network of the island.

An additional factor that has to be considered for the installation of AD at a farm is land requirements. Even though there are detailed methodologies that can be used at the design phase of the AD, the next section presents a method that has been developed to be applied before the detailed studies. Thus, more information will be available to the farmer to assess whether AD can be applied at his/her farm, and therefore proceed to further studies.

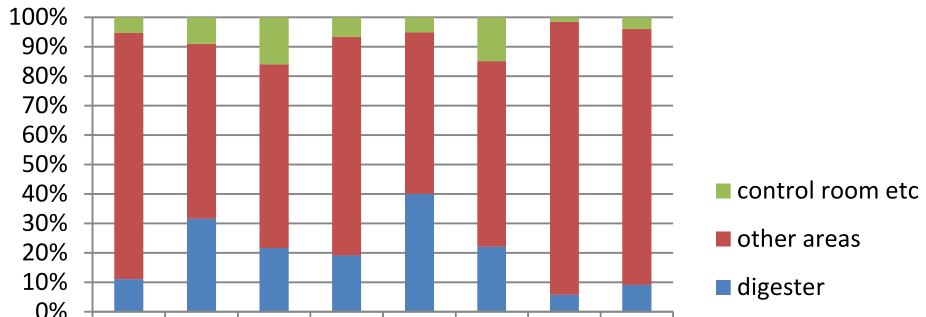
4.4 Estimation of area requirements for AD in Cyprus

The area necessary for the installation of an anaerobic digester depends on the technology chosen for the digester, the daily amounts of the waste entering the digester and the quality of the waste (Wilkie, 2005). To obtain the necessary information to develop a methodology, the architectural plans of eight anaerobic digesters under study in Cyprus were considered. Six of the digesters were completely mixed digesters and two were anaerobic lagoons. The data collected is presented in Table 4.5 and Figure 4.4.

Table 4.5. Area requirements for eight anaerobic digesters in Cyprus

	Completely mixed (m^2)						Lagoon (m^2)	
	D1	D2	D3	D4	D5	D6	D7	D8
Digester	500	1424	270	1718	2000	275	270	544
Control room etc.*	240	408	200	600	260	187	74	240
Other areas **	3760	2668	780	6682	2740	788	4351	5216
Total area	4500	4500	1250	9000	5000	1250	4695	6000

* control room, biogas scrubbing and generator room, office; ** roads, safety area, open space, sludge storage, homogenisation tank



	D1	D2	D3	D4	D5	D6	D7	D8
control room etc	5%	9%	16%	7%	5%	15%	2%	4%
other areas	84%	59%	62%	74%	55%	63%	93%	87%
digester	11%	32%	22%	19%	40%	22%	6%	9%

Figure 4.4. Area requirements for eight anaerobic digesters in Cyprus (D1-D6 are completely mixed, D7 and D8 are anaerobic lagoons)

Additional information necessary for the estimation of the area collected for the eight digesters are presented in Table 4.6.

Table 4.6. Other information for digesters according to the information collected

Parameter	Anaerobic Lagoon	Complete mixed
Retention time of waste in digester	100 days	20 days
Safety volume	20 days (20%)	5 days (20%)
Height (or depth)	6 meters deep	6 meters tall
Maximum height of waste in digester	4.5 meters	4.5 meters

The methodology developed to estimate the space requirements for the installation of the digester and supporting equipment is the following:

(a) Area for the digester = annual volume of waste (m^3) / 365 days * retention time in the digester (days) * [1 + safety volume (%)] / [height of digester (m) * active height (%)].

(b) Total area (m^2) = Area for the digester (m^2) / ratio of digester area compared to total area

(c) Other area (m^2) = Ratio of other area compared to total area * Total area (m^2)

(d) Control area (m^2) = Ratio of control area compared to total area * Total area (m^2)

The assumptions used for these calculations are according to the collected data (Table 4.5 and Table 4.6) and are presented in Table 4.7.

Table 4.7. Assumptions used for area calculations

Parameter	Anaerobic Lagoon	Complete mixed
Retention time of waste in digester	100 days	20 days
Safety volume	20%	20%
Height	6 meters	6 meters
Maximum height of waste in digester	75%	75%
Contribution of digester to total area	7%	24%
Contribution of control area to total*	3%	10%
Contribution of other areas to total**	90%	66%

* Control room, biogas scrubbing and generator room, office; ** Roads, safety area, open space, sludge storage, homogenisation tank

Land requirement is one of the parameters that should be considered for the estimation of the cost for the installation and operation of an AD. It should be noted that in Cyprus, the area used for the installation of the digester, is usually bought or rented and is not initially part of the farm. Subsequently, land use change issues are not considered in this thesis.

Additional parameters are presented in the next section, and are based on data collected for Cyprus (where available).

4.5 Estimation of capital and operational costs for AD in Cyprus

The costs for the construction, installation and operation of an anaerobic digester can be separated into: capital and operational. Table 4.8 presents the costs included in each category. Possible income from AD is also listed in Table 4.8.

One of the incomes included is “gate fees”, which is the charge levied upon a given quantity of waste received at an AD.

Additional operational expenses could include rent of land and loan repayment. These depend on the availability of land and capital investment for the development of the project. The parameter not considered is income from sale of thermal energy, effluent and treated sludge.

Table 4.8. Expenses and income from anaerobic digestion

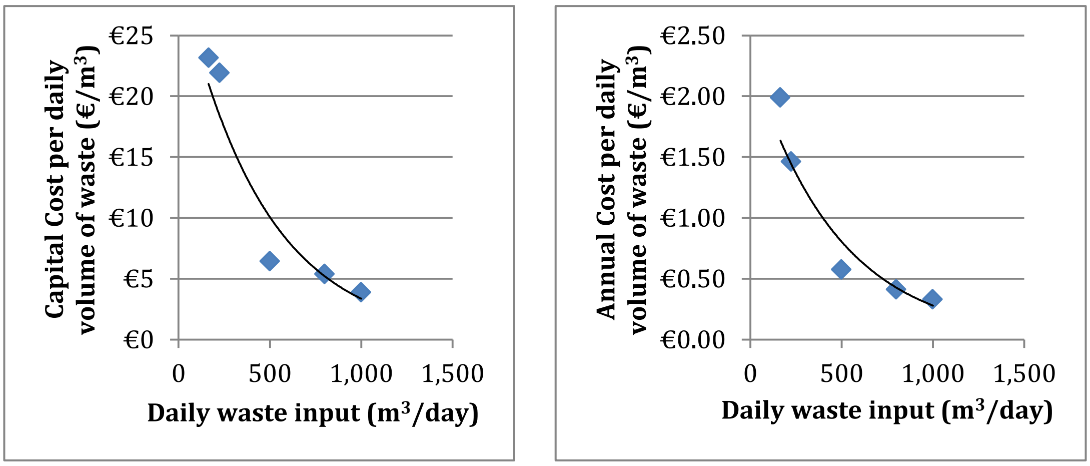
Capital expenses	Operational expenses	Income
Equipment	Energy consumption	Energy sales
Installation	Personnel	Gate fees
Construction	Maintenance	Effluent sales
Studies & licences (consulting)	Overheads	Treated sludge sales
Miscellaneous	Income tax	
Land purchase	Miscellaneous	
	Land rent	
	Loan repayment	

To obtain the necessary information for the development of a methodology, financial viability studies for five anaerobic digesters in Cyprus were considered. These digesters are completely mixed. The data collected is presented in Table 4.9. The daily waste input is the designed capacity of the digester and not the actual waste input.

Even though the data sample is small, there is a clear relationship between cost and volume of waste, both in capital and operational costs. These are presented in Figure 4.5. The R^2 values for these relationships are 0.9061 for the capital cost relation and 0.9285 for the operational cost relation.

Table 4.9. Financial data for 5 anaerobic digesters in Cyprus

	D1	D2	D3	D4	D5
Daily waste input ($m^3 day^{-1}$)	1,000	165	225	500	800
Capital costs (x10^3)					
Digester incl. installation	€786	€750	€990	€700	€750
Electrical equipment	€120	€120	€250	€150	€150
Consultants & permits	€170	€20	€80	€50	€170
Structures/buildings	€255	€500	€400	€255	€400
Landscaping	€80	€5	€80	€20	€100
TOTAL	€1,411	€1,395	€1,800	€1,175	€1,570
Cost per waste/day (€m^{-3})	€4	€23	€22	€6	€5
Operational (annual) costs (x10^3)					
Personnel	€65	€37	€60	€50	€65
Maintenance	€50	€76	€50	€50	€50
Other	€5	€7	€10	€5	€5
TOTAL	€120	€120	€120	€105	€120
Cost per waste/day (€/m^3)	€0.3	€2.0	€1.5	€0.6	€0.4



(a) capital cost per daily volume of waste treated

(b) annual operational costs per daily volume of waste treated

Figure 4.5. Relationships based on data for (a) capital cost per daily volume of waste treated and (b) annual operational costs per daily volume of waste treated

According to the plot presented in Figure 4.5(a), the relationship for the capital cost and daily waste input is:

$$y = 30.185\ e^{-0.002x} \qquad (4.4)$$

where y is the capital cost per daily volume of waste treated in (€ m^{-3}) and x is the daily waste input in m^3.

This relationship is applicable to completely mixed digesters. The main capital costs associated with a completely mixed digester are associated with the cost of equipment, installation and construction. Operational costs in addition to personnel are mainly associated with the maintenance of the equipment and energy consumption.

For the anaerobic lagoon, which is the other commonly chosen digester technology in Cyprus, no data is available. According to US EPA (2002), the capital cost for an anaerobic lagoon is approximately 25% lower than that of completely mixed digesters. Therefore the relationship in (4.4) becomes:

$$y = 22.6388\ e^{-0.002x} \qquad (4.5)$$

for anaerobic lagoons, where y is the capital cost per daily volume of waste treated in (€ m^{-3}) and x is the daily waste input in m^3.

The primary cost associated with the construction of an anaerobic lagoon includes the cost of the land, earthworks, required service facilities, excavation, costs for forming the embankment, compacting and lining. Operational costs in addition to personnel are mainly associated with the removal of sludge from the lagoon.

Overheads, land and other annual expenses are considered separately. According to the plot presented in Figure 4.5(b), the relation for the operational cost and daily waste input for both types of digesters is:

$$y = 2.3179\ e^{-0.002x} \qquad (4.6)$$

where y is the operational cost per daily volume of waste treated in (€ m^{-3}) and x is the daily waste input in m^3.

According to the information collected (averages of the data presented in Table 4.9), the contribution of different activities to the capital and operational costs are shown in Table 4.10.

In addition to the costs listed in the table, another capital expense that should be considered in some cases is the cost of land, if the land will be purchased or the opportunity cost for the land. Similarly, other operational (annual costs) that should be taken into account is the overhead cost, tax on profit, cost of emissions, loan repayment if cash funding is not available.

Table 4.10. Contribution of different activities to the capital and operational cost identified for Cyprus

Parameter	Contribution	Anaerobic Lagoon	Complete mixed
Capital cost	(100%)		
- Digester	65%	Earthworks, liner, embankments	Digester equipment and electrical installations
- Other	35%	Other equipment, permitting, consultants, construction	Constructions, other equipment, permitting, consultants, construction
Operational cost	(100%)		
- Personnel	48%		
- Maintenance	47%	Sludge removal	Equipment
- Other	5%		

Cost of land

The cost of land can be capital or annual cost depending on the arrangements. The cost of land ($COST_{LAND}$) is estimated by:

$$COST_{LAND} (€) = AREA_{RENT} (m^2) * RENT (€ m^{-2}) + AREA_{PUR} (m^2) * PUR (€ m^{-2}) \quad (4.7)$$

where $AREA_{RENT}$ is the area of land to be rented (m^2), RENT is the annual rent (€ m^{-2}), $AREA_{PUR}$ is the area of land to be purchased (m^2) and PUR is the cost for purchase of land per unit area (€ m^{-2}). The default value given to land rent for Cyprus is 10 € m^{-2} and for land purchase is 80 € m^{-2} (Ioannou, 2013). If the land is available, the cost for land is 0.

Overhead cost

The annual cost for overhead was estimated based on the assumption that they contribute 17.5% to the annual total running costs excluding loan payments and tax (Gebrezgabher *et al.* 2009). Overhead cost includes indirect costs such as salary of management, insurance cost and accountancy.

Tax

The cost for tax payments is annual and only on the profit made. Therefore, for the years that there is no profit from the sales of energy, the tax payment is € 0. The typical value given for tax for Cyprus is 5% (Nikolaides, 2011).

Income from energy sales

The income from energy sales depends on the product sold (thermal or electrical energy) and the price sold. As it has already been mentioned, in Cyprus only the electricity produced can be sold. The selling price of the electricity, depends on the "Renewable Energy Action Plan" in force at a given time. The current buying price for electrical energy produced from biomass is € 0.135 per kWh (Energy Service, 2013). The income from the electricity sales is estimated by:

$$INCOME_{EL}\ (€) = SOLD_{EL}\ (kWh) * BPRICE_{EL}\ (€\ kWh^{-1}) \qquad (4.8)$$

where $INCOME_{EL}$ is the income from electricity sales in €, $SOLD_{EL}$ is the electricity sold in kWh and $BPRICE_{EL}$ is the buying price of the electrical energy produced from biomass in € kWh.

Loan payment

The loan payment is the annual amount of money required to cover interest and repayment on the funds borrowed to install the system. The estimation of the annual loan payment can be found by dividing the amount borrowed by the present worth factor (PWF). The PWF is estimated by using the inflation rate equal to zero (equal payments) and with the market discount rate equal to the mortgage interest rate (Kalogirou, 2004).

Therefore the loan repayment can be calculated from:

$$COST_{LOAN} (€) = LOAN (€) / PWF \quad (4.9)$$

where $COST_{LOAN}$ is the loan payment (€), LOAN is the loan (€) and

$$PWF = \frac{1}{d}\left[1-\left(\frac{1}{1+d}\right)^N\right] \quad (4.10)$$

where d is the interest rate, and N is the number of years (equal instalments). The interest rate for Cyprus is assumed to be 10%.

CHP generator maintenance

Part of the annual operational cost is the maintenance cost for the operation of the CHP generator ($COST_{CHP}$). This is estimated by:

$$COST_{CHP} (€) = ENPROD_{EL} (kWh) * MAINT_{CHP} (€\ kWh_e^{-1}) \quad (4.11)$$

where $ENPROD_{EL}$ is the amount of electrical energy produced annually in kWh and $MAINT_{CHP}$ is the cost for maintenance per unit energy produced in € kWh_e^{-1}. The assumption for $MAINT_{CHP}$ for Cyprus is 0.011 € kWh_e^{-1} (Nikolaides, 2011).

4.6 Summary

The information presented in this Chapter concerning AD, confirms the complexity of the process, due to the many microorganisms involved. A small change in the conditions of the digestion or the type of wastes digested can affect considerably the process and result in a reduction of biogas production.

Nevertheless, there are general relationships that can provide estimates of biogas production from the process. Three methods were developed based on the relationships between COD, VS, waste digested and biogas production. These methods were applied to estimate the potential biogas production from animal waste in Cyprus. Consequently, the amount of potential thermal and electrical energy was estimated assuming that all biogas produced was combusted. The results show that livestock waste can have a considerable contribution to the renewable energy targets of Cyprus.

Two important parameters that need to be considered before investing in AD are capital and operational costs as well as area requirements. Data has been collected for AD installations in Cyprus and relationships between costs and land area have been developed.

The relations and methods developed and presented in this Chapter can be applied by farmers or stakeholders to preliminary assess investment in AD for a specific farm.

CHAPTER 5. Development of a software tool to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level

Having developed the necessary relations and methodologies that can be applied to the conditions of Cyprus, this Chapter presents the tool developed for Cyprus. First, the existing models for energy, biogas and greenhouse gas emissions from anaerobic digestion of livestock waste have been assessed to identify any deficiencies. Then the tool for Cyprus was developed. The goal was that the tool could be used by any farmer or consultant for the estimation of the potential of biogas production, associated costs, reduction in GHG emissions and comparison of scenarios for waste management for the specific conditions of Cyprus. This tool will help accelerate the implementation of AD for both waste management and energy demand reduction for the island.

5.1 Review of existing models

The application of a model is an important step in the assessment of the feasibility of the plant, since solid data needs to be available demonstrating the potential efficiency of such plant for the investor to proceed. The available models have a wide range of applications and are based on a wide range of objectives. Moreover, they have great variation in complexity: from simple calculators just estimating biogas production based on the number of animals, to detailed models simulating every stage of anaerobic digestion, requiring extensive databases of information.

The scientific models require considerably larger amounts of specialised data, thus making them inaccessible to farmers and other stakeholders with limited scientific knowledge. Given the large activity, however, in the recent years on the use of anaerobic digestion for treatment of waste, simple calculators have been developed to provide the necessary information, without the need to get involved extensively in the science of anaerobic digestion.

5.1.1 Scientific models for the simulation of anaerobic digestion

Due to the complexity of the process, each model has been developed for a different purpose. As a result existing models vary according to their objectives and complexity. Amongst them, there are comparatively simpler models developed exclusively for the calculation of the maximum biogas rate to be produced during digestion (e.g. Buswell and Mueller, 1952). Other models can calculate the biogas rate taking into consideration degradation or digestion rates of different components of the biomass (e.g. Baserga, 1998).

Because of the limitation of many models to present the dynamic nature of digestion, complex models have been developed to include the kinetics of growth of the microorganisms (e.g. Monod, 1949). The activity of microorganisms and consequently the biogas production rate can be investigated with these models for a variety of substrates, considering different mechanisms and intervals. When using these models, the death rate and the washout of microorganisms can also be taken into consideration (e.g. Siegrist *et al.* 2002). Some models include modifications to dependencies between the growth of microorganisms to other process parameters, such as the influence of the process temperature and inhibition effects of ammonia or hydrogen (e.g. Angelidaki *et al.* 1993; Knobel and Lewis, 2002).

Several models have been designed for a specific substrate or a small number of substrates, and are therefore not applicable to other types of substrate (e.g. Baserga, 1998). Nevertheless, most of the available models allow calculation of biogas and methane production rate (e.g. Amon *et al.* 2007). To design biogas plants and to evaluate the efficiency of such plants both these parameters are very important. However, there are also models, which yield only one of these parameters. Additionally, some models are quite specialised and aim exclusively at the assessment of an effect, for example the evaluation of the influence of mixing on biogas production (e.g. McKinney, 1962).

Further details on scientific models are available in the paper "A review of simple to use scientific models for anaerobic digestion" in Appendix A.

5.1.2 Simple calculators

Most of the simple calculators have been developed on the basis of very simple methodologies. In most cases, the outputs of such calculators are the energy and biogas that can be produced from the digestion of a certain waste stream. Another common output is financial analysis. Some models also determine the reduction in greenhouse gas emissions. A list of the calculators considered is given in Table 5.1, while further details on the scientific models are available in the paper "A review of simple to scientific models for anaerobic digestion" in Appendix A.

All of the described calculators provide estimates for biogas production, whereas all with the exception of GasTheo provide estimates for energy production and financial assessment. BEAT2 and FarmWare are the only calculators that also assess environmental impacts and reduction of greenhouse gas emissions. A comparison of the models for all applications is presented in Table 5.2.

Table 5.1. Simple calculators for anaerobic digestion applications

Title	Developer, reference
Anaerobic digestion decision support software	Poliafico, M. (supervised by J. D. Murphy) 2007. Anaerobic Digestion: Decision Support Software. MEng Thesis. Department of Civil, Structural and Environmental Engineering. Cork Institute of Technology. Ireland.
Biomass Environmental Assessment Tool	AEA Energy and Environment, North Energy Associates. 2008. Developed for DEFRA and the Environment Agency. UK.
BioGC	WFG Schwäbisch Hall, 2009 for the project Biogas Regions
GasTheo_Win32_1.1	Schlattmann, M., 2008. GasTheo - A program to calculate theoretical gas yields from anaerobic digestion of biomass, available from www.schlattmann.de/download/gastheo.php
The Anaerobic Digestion Economic Assessment Tool	Redman, G., 2010. A detailed economic assessment of anaerobic digestion technology and its suitability to UK farming and waste systems. The Andersons Centre for DECC and NNFCC
FarmWare	K.F. Roos, J.B. Martin, Jr., and M.A. Moser. 2004.

Table 5.2. Comparison of simple calculators

Model	Biogas production	Energy production	GHG emission reductions	Financial assessment	Environmental impacts
AD decision support software	✓	✓		✓	
Anaerobic Digestion Economic Assessment Tool	✓	✓		✓	
$BEAT_2$	✓	✓	✓	✓	✓
BioGC	✓	✓		✓	
FarmWare	✓	✓	✓	✓	✓
GasTheo	✓				

To evaluate the performance of the six simple models, they were tested for the production of biogas for a farm of 100 dairy cows and 50 sows, without changing the default parameters. The results are presented in Table 5.3. As shown, the estimation was not possible for GasTheo and $BEAT_2$, since they do not use as input the number of animals. The outcome for the remaining four models ranges from 50,592 m^3/y estimated by "Anaerobic Digestion Economic Assessment Tool" to 116,844 m^3/y estimated by FarmWare.

Table 5.3. Estimation of biogas production using the simple models outlined in Table 5.1 for a farm of 100 dairy cows and 50 sows

Model	Biogas production	Comments
AD decision support software	54,444 m^3 y^{-1}	2505 t waste y^{-1}
Anaerobic Digestion Economic Assessment Tool	50,592 $m^3 y^{-1}$	Using 2400 t/y dairy waste and 100 t y^{-1} pig waste
$BEAT_2$	Not estimated - Mass ratio	Anaerobic digestion on farm producing electricity and heat, 50% dairy manure, 50% pig manure
BioGC	86,048 m^3 y^{-1}	2650 t/y waste, 60 days hydraulic retention time
FarmWare	116,844 m^3 y^{-1}	Cattle: Free-stall scrape barn, complete mix digester, with storage tank and no separate solid storage or treatment Pigs: pull plug/pit recharge barn, combined storage and treatment lagoon, completely mix digester with no solid treatment
GasTheo	Estimation not possible	Does not use number of animals as input

All simple models presented above, provide estimates of biogas production but these estimates can vary widely and depend on the methodology employed. None of these models provide the option for the use of alternative methodologies. The default values employed are specific to specific countries and the financial and environmental viability of investment in a digester is not considered in sufficient detail.

5.2 FARMS: the software tool developed for Cyprus

This section presents the software tool developed to assess greenhouse gas mitigation and renewable energy production from anaerobic digestion in Cyprus, “FARMS”.

5.2.1 The principles of FARMS

To address the deficiencies of existing models outlined above, it was considered necessary to develop a model tailored to the specific conditions of Cyprus.

The principles taken into consideration in the development of FARMS are the following:

(a) Specific conditions of Cyprus

Due to the small size of the country and lack of funding, research activities in Cyprus are very limited. Therefore, the available scientific literature for Cyprus is very limited. Developing a model specifically for Cyprus, would not only allow local users to use it with ease, but also allow data for the country to be presented and made widely available.

(b) The model could be used both by users with limited data and users with detailed data

Usually the models developed have scientists and engineers as the target groups. Here, the aim was to develop a model that could easily be used by both farmers with no access to national or international information on the technology and more sophisticated stakeholders with access to detailed data. The farmers can employ the model to assess the suitability of anaerobic digestion for their farm whereas engineers, consultants can use the model to investigate different scenarios and waste management options.

(c) All parameters used for the calculations are available for the user to view and modify

In addition to obtaining a result for a scenario, FARMS provides the user with default values for a large number of parameters that are suitable for Cyprus, which allows it to be used as a reference tool. Moreover, the user can view and change all default values, making it suitable for investigation of site specific conditions.

(d) The financial analysis takes into consideration the cost of emissions and the cost of fines if the waste is not properly treated.

Even though the emissions from agricultural activities do not have a “price” in Cyprus, presenting the cost of emissions to the user (i) raises awareness about climate change, and (ii) provides an estimate of the financial impact if economic tools are employed to encourage the adoption of emissions mitigation actions.

Economic tools can either be in the form of a carbon tax or a “cap and trade” system. While a carbon tax is a tax levied on the carbon content of a fuel (Hoeller and Wallin, 1991), in a cap and trade system offsets are created through a baseline and credit approach; i.e. an aggregate cap on all sources is established and these sources are then allowed to trade emissions permits amongst themselves (Tietenberg and Johnstone, 2004).

In the European Union, all member states are obliged to participate in the EU Emissions Trading System (EU ETS) which has been in place since 2005. The activities regulated in the EU ETS are energy intensive industrial installations and power plants (EU, 2003). Even though there is no EU wide legislation, some member states (e.g. Denmark, Finland and France) also implement carbon tax.

With the discussions intensifying in the EU on the commitment for reduction of emissions to 30% by 2030 and 50% by 2050 compared to the levels of 1990 (European Commission, 2013), there is a large possibility that member states will impose measures such as carbon tax or cap and trade to additional activities (e.g. agriculture, waste management, transport) to meet the EU legal targets for reduction of emissions. This was the reasoning for adding the cost of emissions within the total costs assessed in FARMS.

(e) One can assess the greenhouse gas emissions and cost if the waste is treated by anaerobic digestion offsite.

Transferring the waste from a farm to an offsite anaerobic digester is a common practice in Cyprus. Having this option in the model, allows a comparison of costs and emissions to other possible options that include use of anaerobic digestion on site.

(f) FARMS can determine the optimum choice for a specific farm.

Having estimated the emissions and cost for all the scenarios involving anaerobic digestion, the model provides an outcome to the user on what is more appropriate for the farm. The parameters can be altered and the impact on the result can be studied to evaluate how each parameter affects the final outcome.

5.2.2 System definition

FARMS has been developed for three different systems: a farm without anaerobic digestion, a farm with anaerobic digestion onsite and a farm using an offsite anaerobic digestion. The connection between the three systems is the farm and the basic activities for its operation.

The three systems are presented in Figure 5.1. The only external input to the system is energy and the only output from the system is greenhouse gas emissions. A detailed description including inputs, outputs and boundaries / assumptions of each component follows.

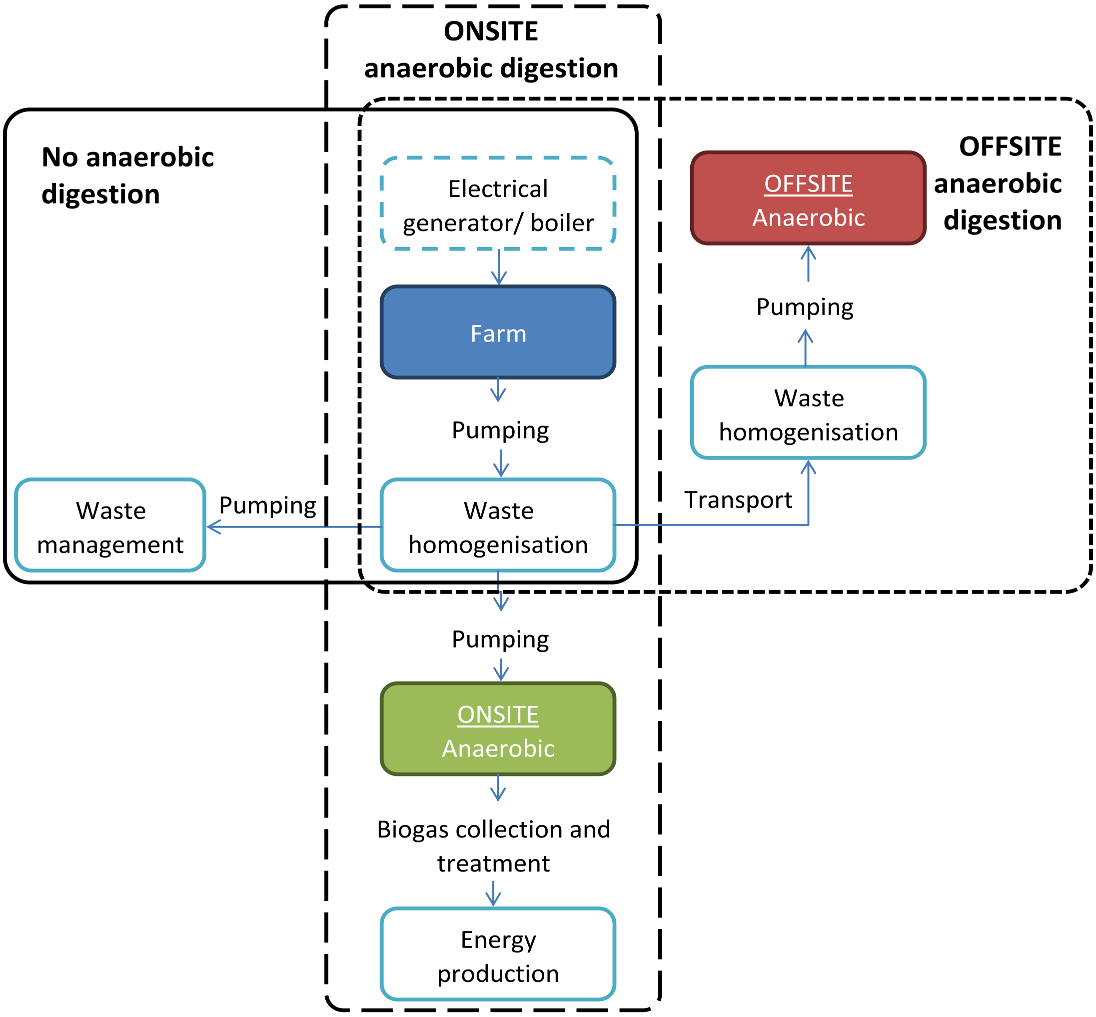


Figure 5.1. The System for the development of FARMS

Common for all systems

Farm: the input to the farm taken into consideration is energy consumption. Energy could originate from electricity or fuel. Therefore the emissions from the fuel consumption for the production of electricity or heating are also included in the system. The energy consumption at the farm includes the demand for feed preparation, housing activities, cleaning and waste collection equipment. Production of feed and transport are not included. Output is greenhouse gas emissions from energy consumption (CO_2, CH_4, N_2O), enteric fermentation (CH_4) and manure (CH_4, N_2O).

Pumping: it is assumed that for the transfer of the animal waste from the housing areas to the homogenisation tank, pumping is always necessary. The input is electrical energy for the operation of the pumps and the output is the emissions of greenhouse gases from energy consumption (CO_2, CH_4, N_2O). Waste transport to the pump is assumed to be in pipes. Therefore emissions from waste are not considered.

Waste homogenisation tank: the waste collected from the housing areas are collected in a homogenisation tank, prior to any other treatment. The tank is assumed to be a concrete tank with watertight liner to avoid leakages. The waste is mixed by mechanical means to avoid development of anaerobic conditions. Input for the operation of the tank is electrical energy and output is greenhouse gas emissions from energy consumption (CO_2, CH_4, N_2O) and the waste (CH_4, N_2O).

No anaerobic digestion

Pumping: additional pumping is considered for the transfer of the waste from the homogenisation tank to the waste management technology. The conditions and assumptions are the same as the pumping presented in the common process.

Waste management: this stage represents any technology for the treatment of the waste other than anaerobic digestion. Input is electrical energy and output is greenhouse gas emissions from energy consumption (CO_2, CH_4, N_2O) and the waste (CH_4, N_2O). The liquid and solid effluents from waste are not taken into account.

Onsite anaerobic digestion

Pumping: additional pumping is considered for the transfer of the waste from the homogenisation tank to the digester. The conditions and assumptions are the same as the pumping presented in the common process.

Anaerobic digestion: the wastes produced by the animals in the housing areas are transferred to the digester. Other types of waste produced on the farm such as animal carcases, pharmaceuticals, human waste or feed for disposal, are not transferred to the anaerobic digester. Only one digester is assumed for each farm. Electrical energy for the operation of the digester is the input and the output is the emissions of greenhouse gases from energy consumption (CO_2, CH_4, N_2O). The system is assumed to be completely airtight, therefore no leakage of biogas is considered.

Biogas collection and treatment: the biogas produced by the digester is collected and treated prior to any use. The treatment is applied for removal of humidity. Electrical energy for the operation of the system is the input and the output is the emissions of greenhouse gases from energy consumption (CO_2, CH_4, N_2O).

Combustion of biogas for the production of energy: all the biogas produced by the digester is assumed to be combusted immediately for the production of heat and/or electrical energy. No storage areas or collection for offsite use are included in the system. The output of the process is emissions of greenhouse gases from the combustion of biogas (CO_2, CH_4, N_2O). Biogas could be considered the input to the process.

Offsite anaerobic digestion

Transport: transport of waste from the farm to an offsite anaerobic digester takes place in a road tanker. The tanker is assumed completely sealed therefore no leakage of waste or emissions take place. The tankers are assumed to be fuelled with diesel oil. The input is the consumption of diesel and the output is the emissions of greenhouse gases from energy consumption (CO_2, CH_4, N_2O).

Waste homogenisation tank: the waste transferred to an offsite anaerobic digester, is temporarily stored in a homogenisation tank, prior to the digestion. The tank is assumed to be a concrete tank with watertight liner to avoid leakages. The waste is mixed by mechanical means to avoid development of anaerobic conditions daily. The duration of storage is assumed to be 1 day. Input for the operation of the tank is electrical energy and output is greenhouse gas emissions from the energy consumption (CO_2, CH_4, N_2O) and the waste (CH_4, N_2O).

Pumping: additional pumping is considered for the transfer of the waste from the homogenisation tank to the anaerobic digester, pumping is always necessary. The conditions and assumptions are the same as the pumping presented in the common process.

Anaerobic digestion: the same conditions as for the onsite anaerobic digester are assumed.

5.2.3 The methodology

As it has already been mentioned, the model developed has the capability of producing results with the least data provided by the user. This data is animal type and animal population. From this information, the energy consumption by the farm, the greenhouse gas emissions from enteric fermentation and manure management and amount of waste produced can then be calculated. Using the calculated energy consumption the relevant emissions can therefore be calculated. From the waste production estimated, the model can provide information on the area required for the digester and the supporting facilities and subsequently, the capital and running costs. Waste production can also be used to estimate biogas production, which then allows the calculation of potential energy that can be produced. The change in consumption of energy from external sources and the respective reduction in emissions are thus calculated.

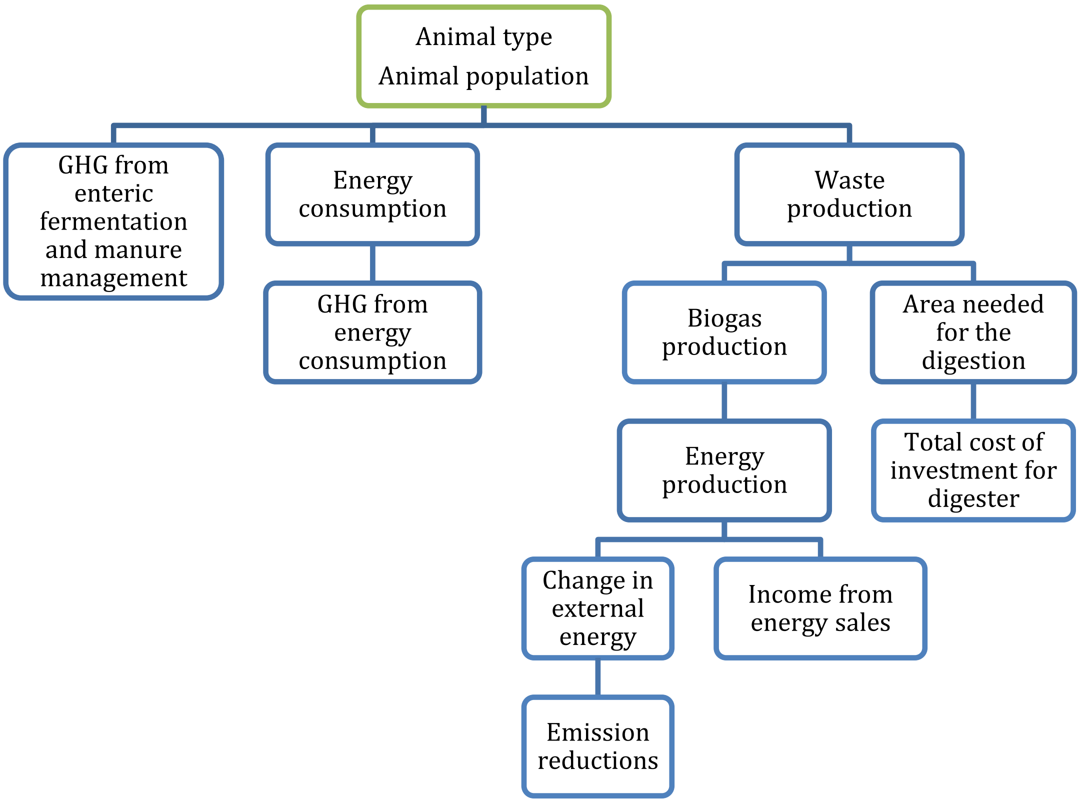


Figure 5.2. Simplified structure of the model: data inputs (green), results (blue)

The data needed from the user and the results that can be obtained from FARMS are presented in Figure 5.2. The basic calculations used are presented in Table 5.4.

Table 5.4. Calculations performed for the estimation of the results (simplified presentation)

Calculation	Result (annual)
Animal population * emissions from enteric fermentation per animal	GHG from enteric fermentation
Animal population * emissions from manure per animal	GHG from manure
Animal population * energy consumption per animal	Total energy consumption
Total energy consumption * % of energy from specific source	Energy consumption by source
Energy consumption to source * emissions per unit energy	GHG from energy consumption
Animal population * waste production per animal	Waste production
(a) Waste production * biogas per unit waste (b) Waste production in mass * % volatile solids * biogas per unit mass of volatile solids (c) Waste production in volume * COD concentration * biogas per unit mass of COD	Biogas production (*three methods)*
Biogas * CH_4 content in biogas * energy content in CH_4 * electrical efficiency of generator	Electrical energy production
Biogas * CH_4 content in biogas * energy content in CH_4 * thermal efficiency of generator	Thermal energy production
Energy consumed by farm without digester - Energy consumed by farm with digester	Change in external energy
(a) Electrical energy produced * selling price of electricity (b) Thermal energy produced * selling price of heating	Income from energy sales
Volume of the waste / 365 days * Retention time in the digester * (1 + safety volume) / height of the digester	Area for digester
Land cost + construction cost + equipment cost + licenses cost + studies cost	Cost – capital
Personnel cost + energy cost + maintenance cost + overhead cost + profit tax cost + emissions cost	Cost – operational

The necessary data for the calculations is listed in Table 5.5. For FARMS all the parameters are set with default values, which the user can view and change. The user manual also provides the details for the default values and choices available. Three animal species are provided for the user to choose from: cows, pigs and poultry. The default values for several parameters depend on the animal type.

Table 5.5. List of necessary information for the model

Type	Information
Waste	Annual waste production per animal
	Total solids in waste of the particular animal species examined
	Volatile solids of a particular species
	Bulk density of waste of a particular species
	COD concentration of waste of a particular species
Energy	Annual energy consumption per animal of a particular species
	Contribution of energy sources to total energy consumption of a particular species
	Energy content of the fuels used at the farm
	Fuel density of the fuels used at the farm
	Energy consumption for anaerobic digestion
	Electrical efficiency of generator
	Thermal efficiency of generator
	Energy content at 100% combustion of CH_4
Biogas	CO_2 and CH_4 content in biogas
	Biogas production per tonne waste of a specific species
	Biogas production per kg volatile solids destroyed
	Biogas production per kg COD* consumed
Greenhouse gases	CH_4 emission factor for enteric fermentation
	CH_4 and N_2O emission factors for manure management
	CO_2, CH_4 and N_2O emission factors for each energy source
	Global warming potentials for CH_4 and N_2O
	Combustion efficiency of conversion of CH_4 to CO_2

Table 5.5. List of necessary information for the model (continued)

Type	Information
Financial	Loan interest rate
	Loan repayment period
	Inflation rate
	Annual market discount rate
	Electricity buying price for electricity from biomass
	Gate fee for input waste
	Price for renting land or for land purchase
	Retention time according to type of digester
	Digester height
	Digester safety volume
	Project lifetime
	Income tax on profit
	Cost of emission allowances

* COD = Chemical Oxygen Demand

5.2.4 Software development

The application of "FARMS" to the conditions of Cyprus has been developed into a computer software application for easier implementation.

Several methods exist to develop a software application. Each has advantages and disadvantages, and it is up to the developer to adopt the most appropriate method for a specific project. In the case of FARMS, the "Waterfall" method was used (Figure 5.3).

In a strict Waterfall method, after each phase is finished, the team proceeds to the next one (TechRepublic, 2006). Reviews may occur before moving to the next phase. This allows for the possibility of changes, which may involve a formal change control process. Reviews may also be employed to ensure that the phase is indeed complete. Waterfall discourages revisiting and revising any prior phase once it is completed.

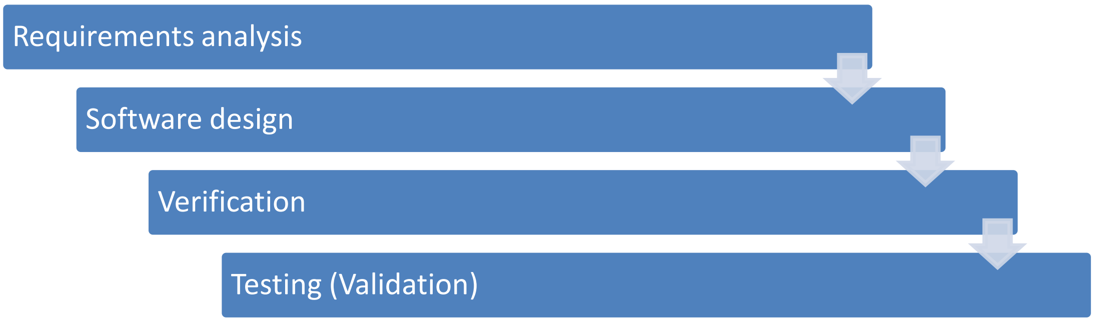


Figure 5.3. The activities of the software development process represented in the waterfall method (TechRepublic, 2006)

This "inflexibility" of the pure Waterfall method, was not applied in the development of FARMS. After identifying weaknesses or mistakes during implementation or testing, the design of the software was revised as explained below.

The development of the software was based on flow charts that were designed (a) to clearly illustrate the progression of the calculations and (b) to assist the programmer to understand issues such as the data necessary as inputs from the user or when and how the user would be allowed to change the results obtained by the software.

A simplified version of the flow chart used for the software development is presented in the figures that follow. Figure 5.4 shows the start of the program, Figure 5.5 the flow chart for option A, "Greenhouse gas emissions of a farm", Figure 5.6 the flow chart for option B, "Reduction of greenhouse gas emissions with anaerobic digestion in a farm", Figure 5.7 the flow chart for option C, "Cost for the installation and operation of an anaerobic digester", Figure 5.8 the flow chart for option D, "Optimum scenario for a farm with respect to cost and greenhouse gas emissions" and Figure 5.9 the flow chart for option E, "Potential energy production by an anaerobic digester treating animal waste and the reduction of waste emissions".

The complete flow chart is presented in Appendix B, while the user guide of the software is presented in Appendix C. The software is included in the thesis in a compact disc.

The points where data input from the user is essential, are presented with the green outline. The points where the user has to make a choice for the program to proceed is indicated with purple outline. The final output is indicated with red outline.

Additional processes were added to the software that have not been presented in the previous sections of this thesis. These are:

(a) Input waste from other farms to the anaerobic digester of a farm

(b) Cost and emissions for the lifetime of the digester for all scenarios – the life emissions and cost are estimated for the lifetime of the digester. For the life cost, the change of value of money is taken into consideration, using the equation below (Kalogirou, 2004):

$$PW_N = \frac{C(1+i)^{N-1}}{(1+d)^N} \tag{5.1}$$

where PW is present value (or discounted cost) of cost C at the end of year N; at a discount rate of d and interest rate of i. The total for the lifetime is the sum of the costs of all the years of the project's operation.

The section that follows presents the key characteristics of FARMS.

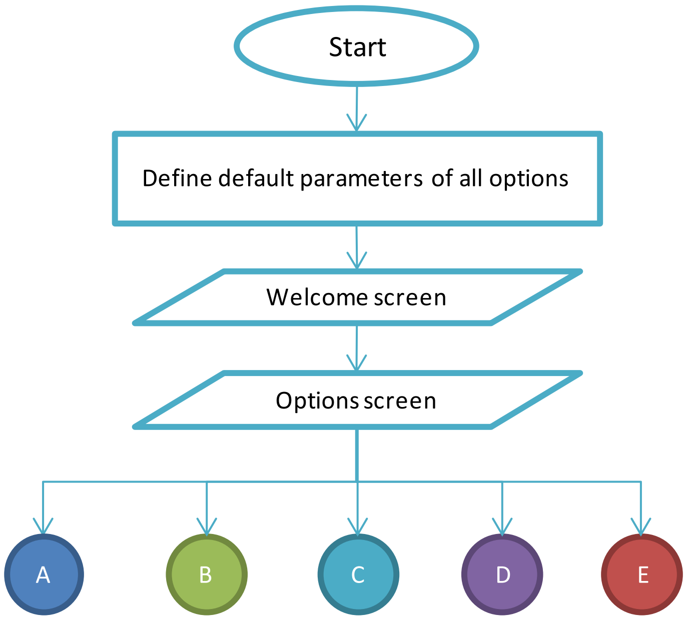


Figure 5.4. The flow chart for the start of the program "FARMS"

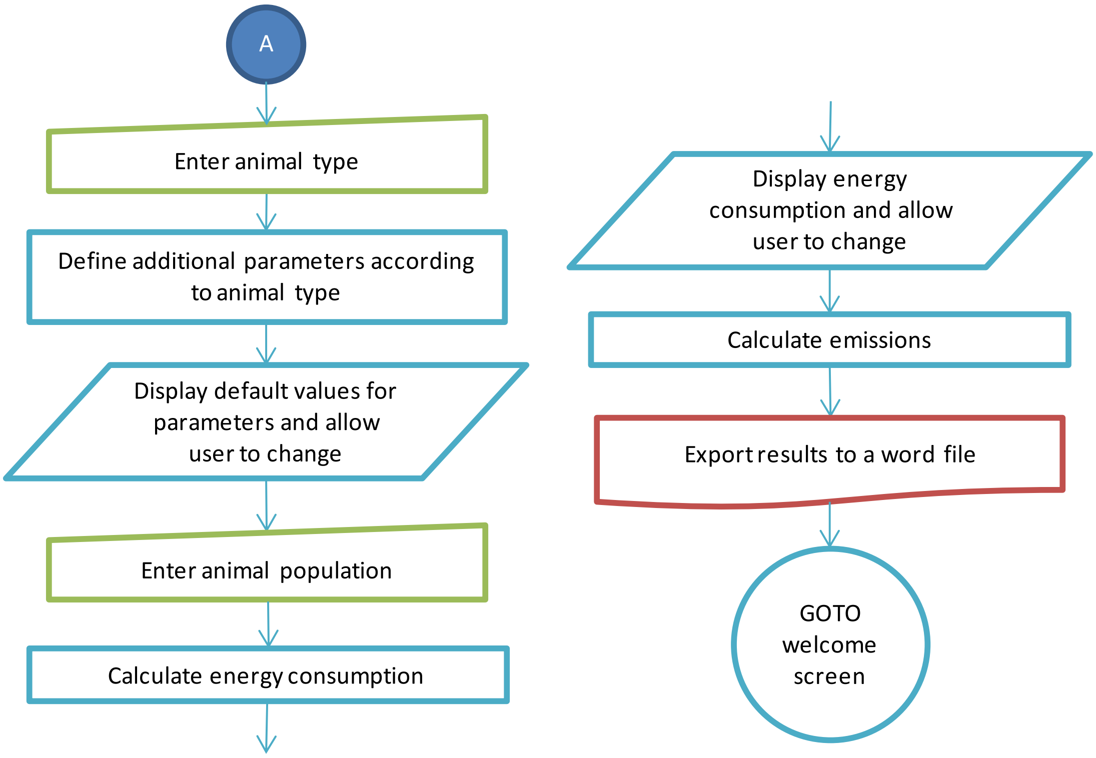


Figure 5.5. The flow chart for option A, "Greenhouse gas emissions of a farm"

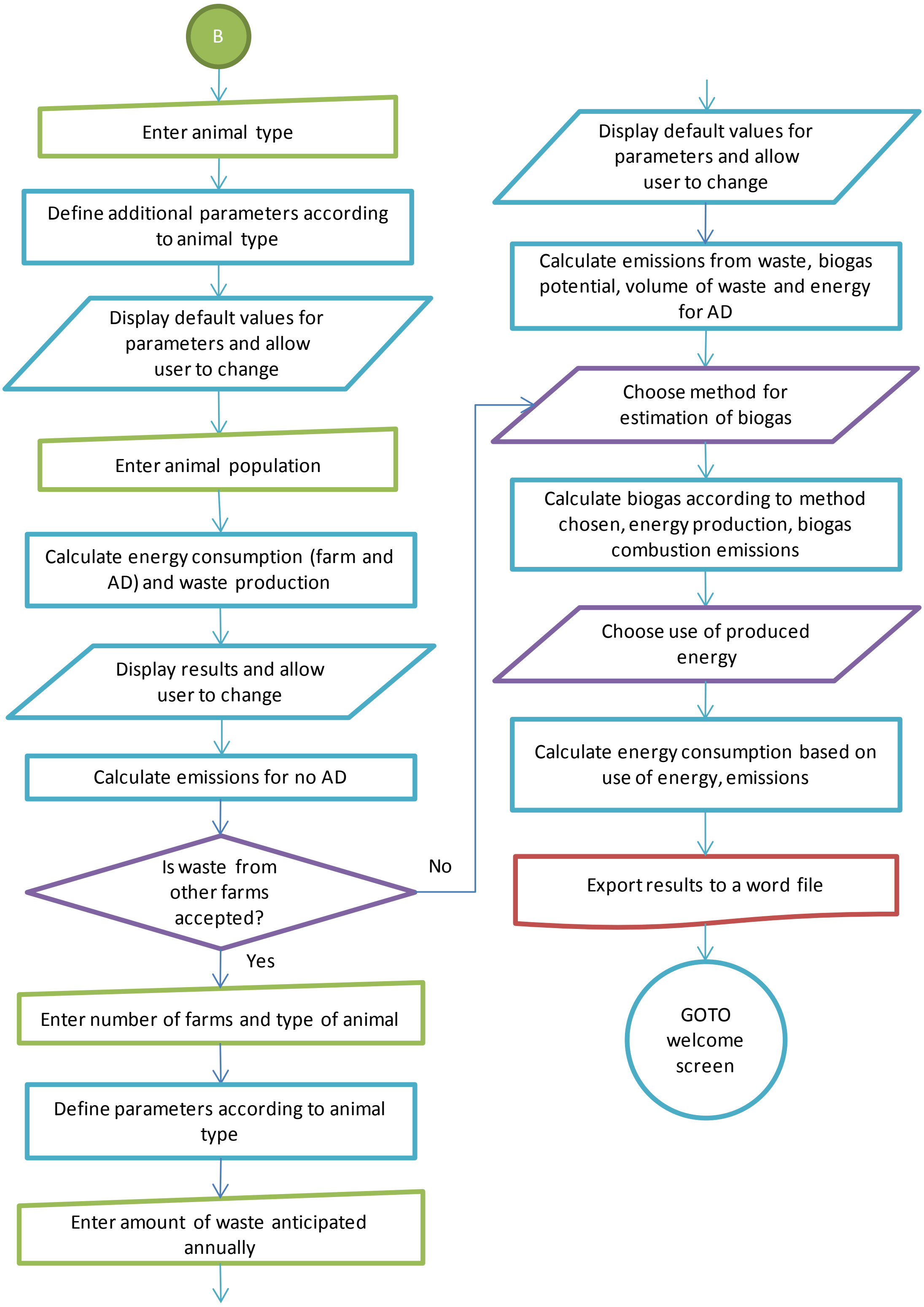


Figure 5.6. The flow chart for option B, "Reduction of greenhouse gas emissions with anaerobic digestion in a farm"

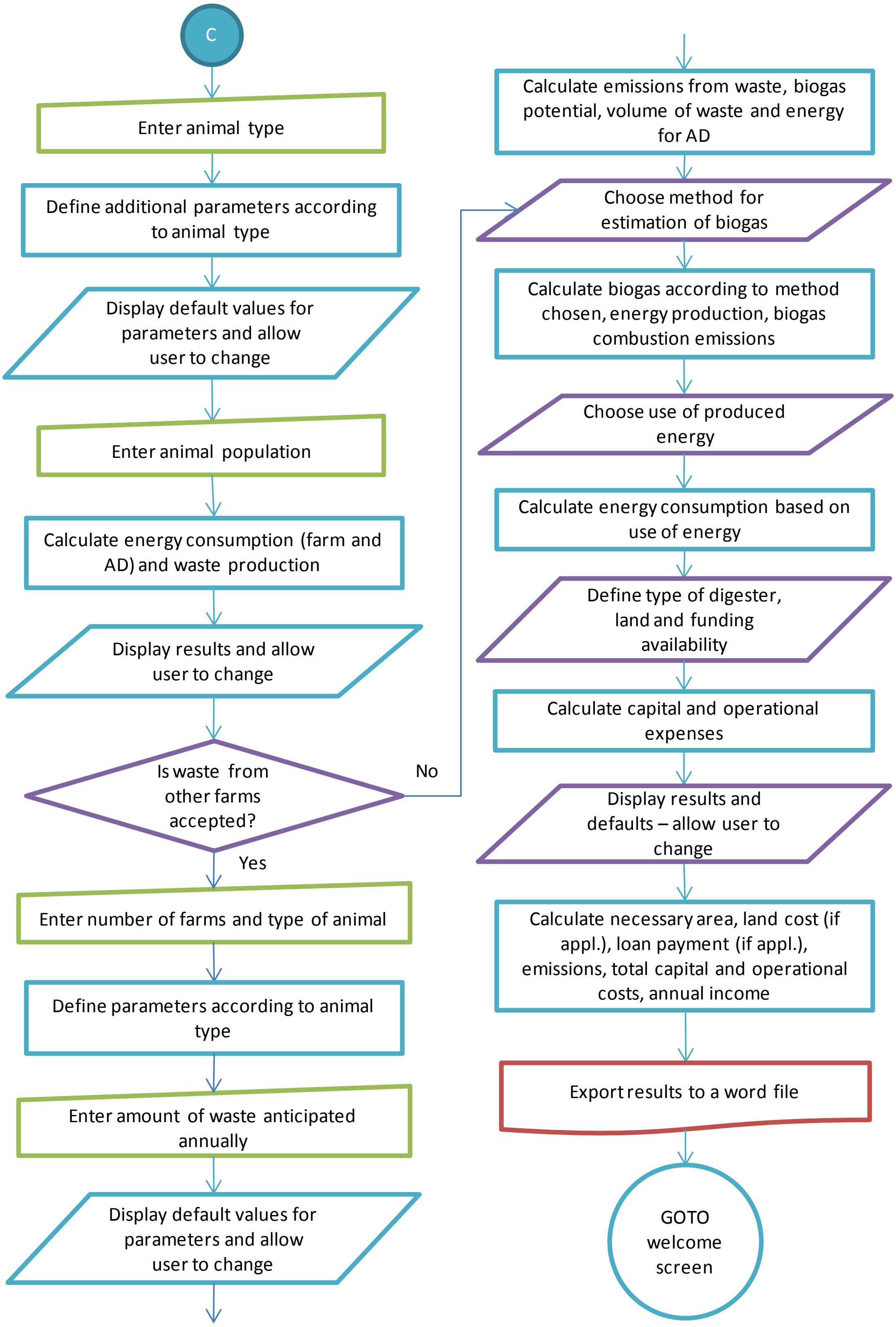


Figure 5.7. The flow chart for option C, "Cost for the installation and operation of an anaerobic digester"

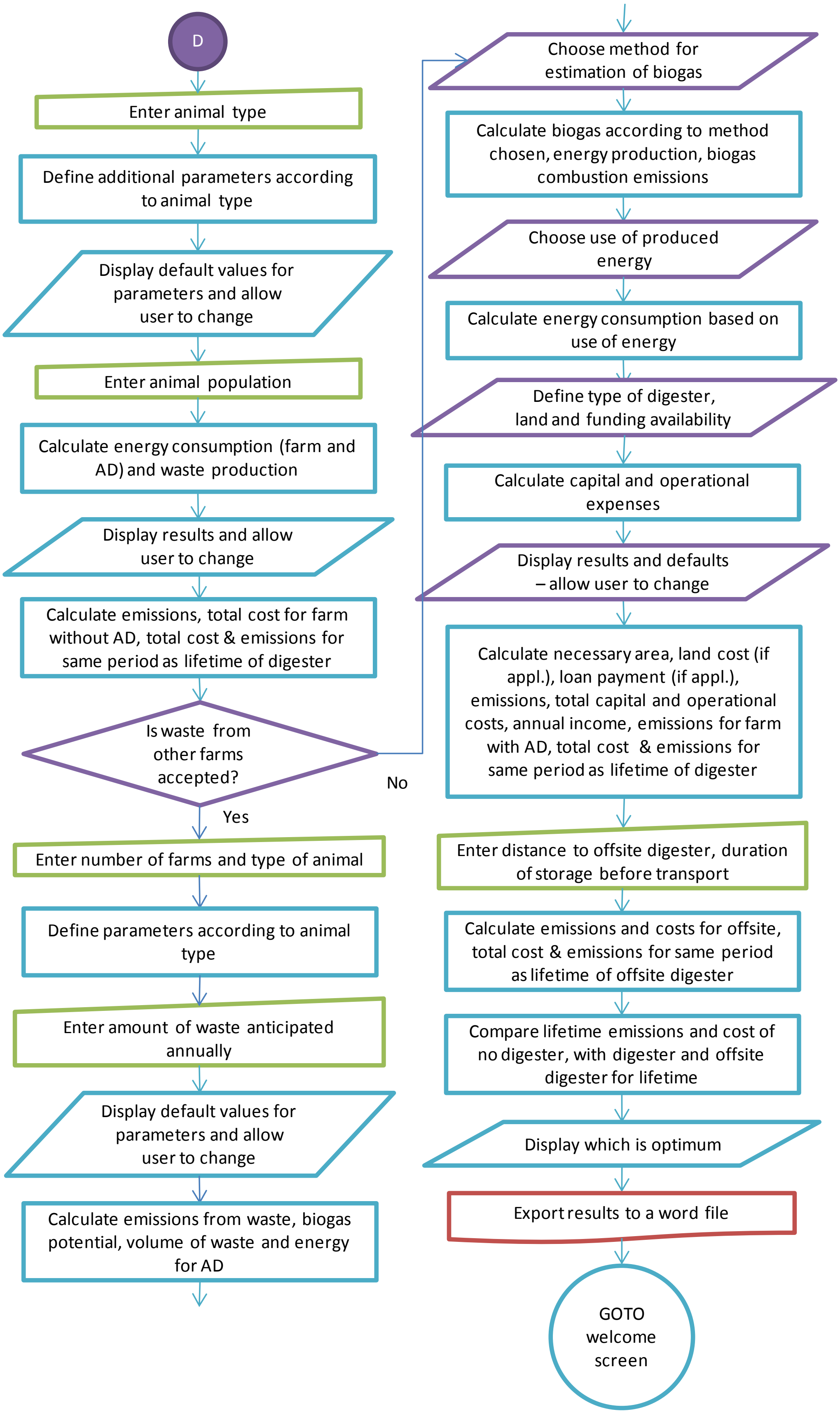


Figure 5.8. The flow chart for option D, "Optimum scenario for a farm with respect to cost and greenhouse gas emissions"

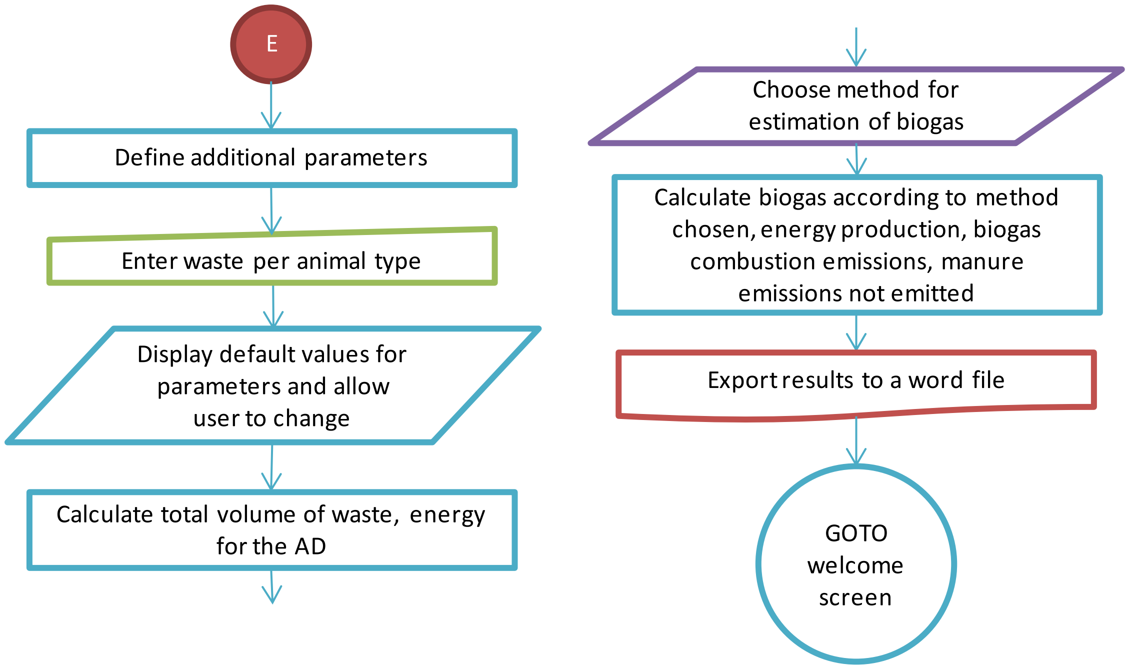


Figure 5.9. The flow chart for option E, "Potential energy production by an anaerobic digester treating animal waste and the reduction of waste emissions"

5.3 Presentation of FARMS

Figure 5.10. FARMS logo

The operating system requirements for FARMS are Windows XP or superior, 10 MB available in the hard disk, Microsoft .NET Framework 3.5 or higher and Microsoft Office 2003 or higher. Once the software has been installed, it can be launched as any other software, with the easiest being to double click on the FARMS' shortcut on the desktop (Figure 5.10).

FARMS allows the user to choose one of the following five options:

(a) Greenhouse gas emissions of a farm – this option estimates the greenhouse gas emissions (GHG) of a farm. The activities causing the GHG are energy consumption, enteric fermentation and manure management. Data that should be provided are animal type and animal population.

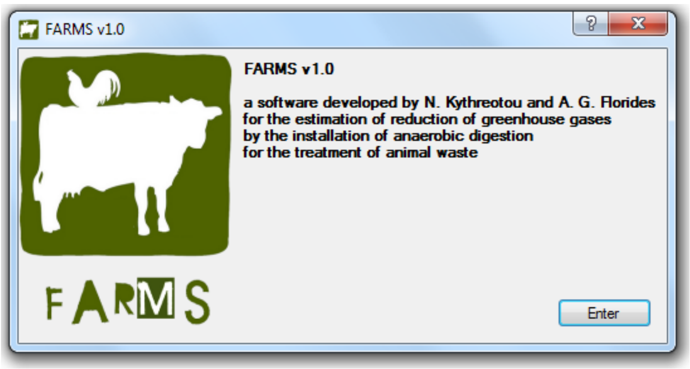
(b) Reduction of greenhouse gas emissions with anaerobic digestion in a farm – estimates the impact that an anaerobic digester (AD) will have on the GHG and energy consumption of a farm. Data that should be provided are animal type and animal population. If waste from other farms will be an input to the AD, the annual amount of waste anticipated in tonnes, and the animal type of each farm have to be known.

(c) Cost for the installation and operation of an anaerobic digester – provides an estimate of the capital and annual costs for the installation and operation of an AD in a farm. Data that should be provided are animal type and animal population. If waste from other farms will be an input to the AD, the annual amount of waste anticipated in tonnes, and the animal type of each farm have to be known.

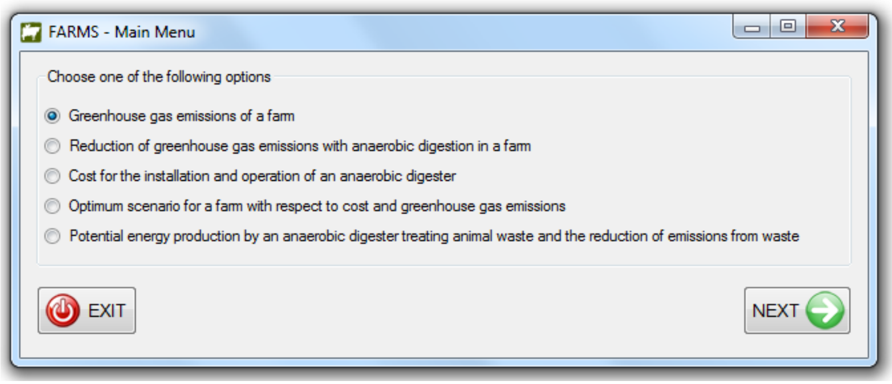
(d) Optimum scenario for a farm with respect to cost and greenhouse gas emissions. With this option three scenarios are assessed for a farm: without AD, with AD and using an offsite AD. Data that should be provided are animal type, animal population and distance between the AD and the farm. If waste from other farms will be an input to the AD, the annual amount of waste anticipated in tonnes, and the animal type of each farm have to be known.

(e) Potential energy production by an anaerobic digester treating animal waste and the reduction of waste emissions assessment of an independent AD. For this option annual waste input to the AD per animal type should be provided

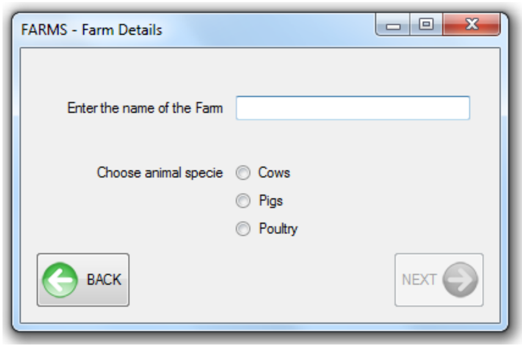
The user can move through the program with the back and next buttons and has the option to use the application more than one time choosing another option or entering information for another farm each time. Screen samples of the program's appearance are presented in Figure 5.11.



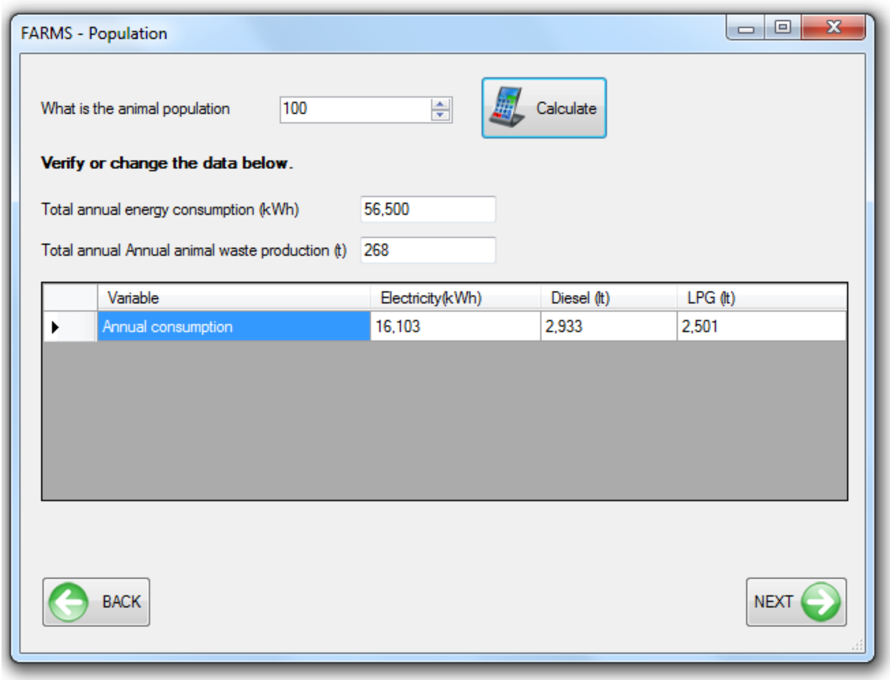
Welcome screen



Main menu



Window requesting the name of the farm and animal type



Window presenting information estimated on waste production and energy consumption

Figure 5.11. Screen samples of the FARMS' appearance

The final output is a word file containing summarised or detailed results depending on the option chosen. An example of an output file for each option is presented in Appendix D.

The animal species that are included in FARMS are cattle, pigs and poultry. The energy sources included in the application are diesel, electricity and LPG. Another option offered, is the method by which the biogas production will be estimated and which can be per volatile solids destroyed, per COD consumed or per volume of waste. Details of the methodologies used have been presented in Chapters 3, 4 and 5.

The user can also choose the use of the produced energy from the combustion of the biogas. The two options offered by FARMS are "All energy used onsite and remaining electricity sold" and "All thermal used onsite, all electrical sold".

For all options, the user is presented with default values and has the opportunity to change them. The default value window for the option "Greenhouse gas emissions of a farm" is presented in Figure 5.12.

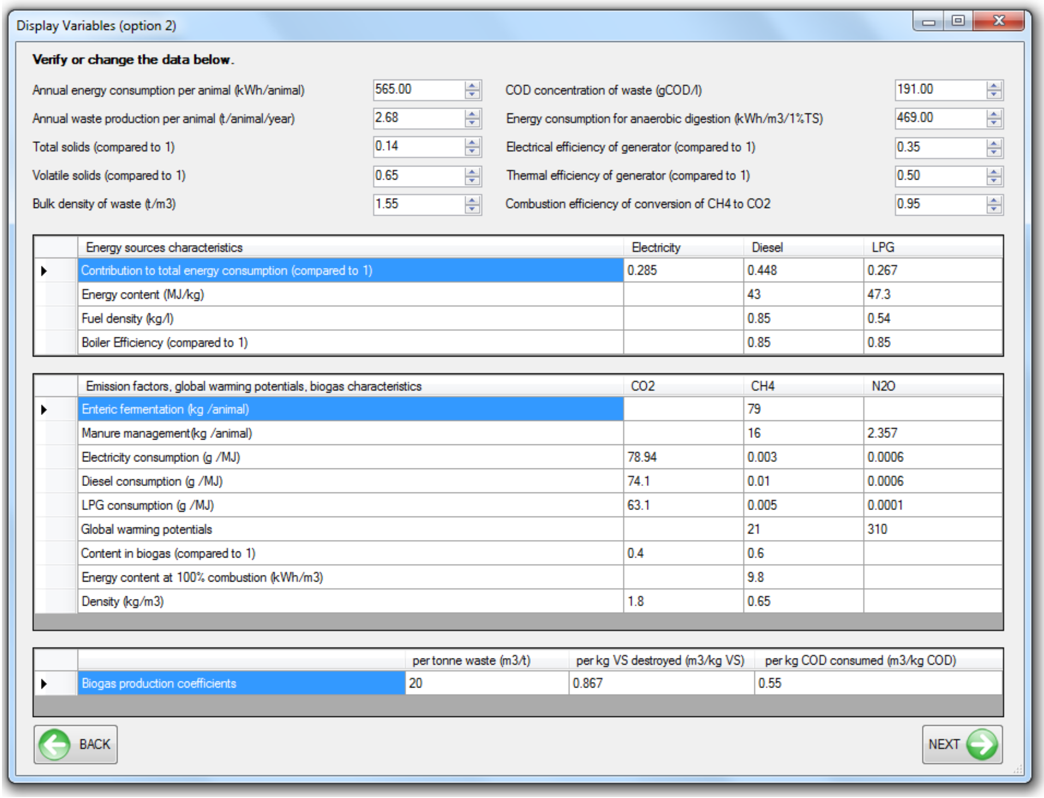


Figure 5.12. The default values window of option "Greenhouse gas emissions of a farm"

For the option "Cost for the installation and operation of an anaerobic digester", the user has to provide additional information that is associated to the cost, such as AD technology that will be used (e.g. "completely mixed" or "lagoon"). Other parameters that have to be confirmed by the user are retention time of waste in the digester, additional digester volume for safety, the height of the digester, active volume for the digester and area.

The user also has to provide information concerning land availability for the installation of the AD; i.e. if the land is available, if it is going to be rented or purchased. Similarly, information has to be provided for financing the AD; the options are "all available" and "loan". In the case the offsite treatment is assessed the user also has to provide the distance to the offsite AD and the duration of temporary storage of waste before transport to the offsite installation.

The default values considered by FARMS for the necessary calculations to take place are presented in Table 5.6. These values result from the collected data and/or methodologies presented in Chapters 2 to 4.

Table 5.6. The default values used by FARMS

Cows	Annual energy consumption per animal	565 kWh/animal	
	Contribution to total energy consumption	28.5% electricity	
		44.8% diesel	
		26.7% LPG	
	Enteric fermentation emission factor (/animal/year)	79 kg CH_4	
	Manure management (/animal/year)	16 kg CH_4	2.357 kg N_2O
	Annual waste production per animal	2.68 t $year^{-1}$	
	Solids concentration in waste	TS 14%	VS 65%
	Biogas potential of waste	20 m^3t^{-1}	
	Bulk density of waste	1.55 t m^{-3}	
	COD concentration	191 g l^{-1}	
Pigs	Annual energy consumption per animal	60.6 kWh $animal^{-1}$	
	Contribution to total energy consumption	28.7% electricity	
		48.3% diesel	
		23% LPG	
	Enteric fermentation emission factor	1.5 kg CH_4 $animal^{-1}$	
	Manure management (/animal/year)	10 kg CH_4	0.251 kg N_2O
	Annual waste production per animal	3.09 t $year^{-1}$	

Table 5.6. The default values used by FARMS (continued)

	Solids concentration in waste	TS 5%	VS 70%	
	Biogas potential of waste	$25\ m^3\ t^{-1}$		
	Bulk density of waste	$0.973\ t\ m^{-3}$		
	COD concentration	$40\ g\ l^{-1}$		
Poultry	Annual energy consumption per animal	$0.777\ kWh\ animal^{-1}$		
	Contribution to total energy consumption	28.3% electricity		
		41.3% diesel		
		30.4% LPG		
	Enteric fermentation emission factor	$0.03\ kg\ CH_4\ animal^{-1}$		
	Manure management (/animal/year)	$0.117\ kg\ CH_4$	$0.0188\ kg\ N_2O$	
	Annual waste production per animal	$0.01254\ t\ year^{-1}$		
	Solids concentration in waste	TS 39%	VS 63%	
	Biogas potential of waste	$40\ m^3\ t^{-1}$		
	Bulk density of waste	$0.546\ t\ m^{-3}$		
	COD concentration	$190\ g\ l^{-1}$		
GHG	GWP	CH_4 : 21	N_2O : 310	
	Transport EF	$774\ g\ CO_2\ km^{-1}$	$0.08\ g\ CH_4\ km^{-1}$	$0.30\ g\ N_2O\ km^{-1}$
Energy		Electricity	Diesel	LPG
	Energy content ($MJ\ kg^{-1}$)	-	43	47.3
	Fuel density ($kg\ l^{-1}$)	-	0.85	0.54
	Boiler Efficiency	-	85%	85%
	CO_2 emission factor ($g\ MJ^{-1}$)	78.94	74.1	63.1
	CH_4 emission factor ($g\ MJ^{-1}$)	0.003	0.01	0.005
	N_2O emission factor ($g\ MJ^{-1}$)	0.0006	0.0006	0.0001
AD	Energy consumption for anaerobic digestion	$469\ kWh\ m^{-3} 1\%TS^{-1}$		
Biogas	Production coefficient	$0.867\ m^3/kg$ VS	$0.55\ m^3\ kg^{-1}$ COD	
	Content	60% CH_4	40% CO_2	
	Density (kg/m^3)	CH_4 : 0.65	CO_2 : 1.8	
	Energy content at 100% combustion of CH_4	$9.8\ kWh\ m^{-3}$		
	Combustion efficiency of conversion of $CH_4$to CO_2	95%		
CHP	Efficiency	35% electrical	50% thermal	
Financial	Loan interest rate	10%		
	Loan repayment period	10 years		
	Inflation rate	1.83%		
	Annual market discount rate	6.5%		
	Electricity buying price for electricity from biomass	$0.135€\ kWh^{-1}$		
	Gate fee for input waste	$100\ €\ m^{-3}$		
	Price for renting land	$10\ €\ /m^2\ year^{-1}$		
	Price for land purchase	$80\ €\ m^{-2}$		
	Income tax on profit	5%		

Table 5.6. The default values used by FARMS (continued)

	Cost of emission allowances		2 € t^{-1} CO_2 eq.
	Annual generator/boiler maintenance cost		200 € $year^{-1}$
	CHP maintenance cost		0.011 € kWh_{el}^{-1}
	Overheads (salary management, insurance, accountants)		17.5% of annual cost
	Capital		
	Capital cost for the digester and its installation		65% of capital
	Other capital costs		35% of capital
	Operational		
	Personnel		48% of operational
	Maintenance		47% of operational
	Others		5% of operational
	Diesel price		1.419 € l^{-1}
	LPG price		0.68 € l^{-1}
	Electricity price		0.16953 € kWh^{-1}
	Fine for insufficient waste treatment		2000 €
	Waste transport		100 € km^{-1}
Digester		Complete mix	Lagoon
	Retention time	20 days	100 days
	Height	6 m	6 m
	Safety volume	25%	25%
	Active volume	75%	75%
	Lifetime	20 years	20 years
	Area		
	Digester	4%	9%
	Other areas	88%	87%
	Control room and biogas areas	8%	4%
Other	Lorry capacity		15 m^3

5.4 Conclusions

FARMS provides a very useful tool for farmers and other stakeholders in Cyprus that are investigating the possibility of installing, supporting or promoting AD in Cyprus. Validation and verification of FARMS have been performed and these are presented in Chapter 6.

CHAPTER 6. Validation and verification of the software tool, “FARMS”

This Chapter presents the results from the validation and verification of the developed software tool “FARMS”. This includes the results of test runs and also feedback from users which was collected through a questionnaire.

6.1 Introduction

Verification and validation, is the process of examining that a software application meets the specifications and it fulfils its intended purpose. Verification is the process of evaluating the software to determine whether the product of a given development phase satisfies the conditions imposed at the start of that phase (IEEE, 2013). Validation is the process of evaluating the software during or at the end of the development process to determine whether it satisfies specified requirements (IEEE, 2013). According to Boehm (1989) validation ensures that "you built the right thing" whereas verification ensures that "you built it right".

Both validation and verification activities took place throughout and after the software development phase. The development of the software started when the first version of the detailed flow chart was completed and took place at an option-by-option basis; i.e. each option was completed before the development of another option could start.

The presentation of the software had to be simple and clear to avoid confusion of the user. Emphasis was also given to the presentation of the results, so that maximum but not more than necessary information was shown. Based on the information presented in the windows of the software, the calculations and/or flow chart were also revised in cases where mistakes were detected.

The same process was repeated after the preparation of each option of FARMS; i.e. improvement of presentation of the software, intermediate and final results' checks and correction of any mistakes identified in the calculations.

Special attention was given to the development of the most appropriate screen for the data collection or validation of the default values. One of the most difficult cases was the screen with the data used for the estimation of area and cost of the anaerobic digester, since it involved the presentation of many parameters which change automatically according to the options chosen.

Verification at the completion of each option assessed the calculations performed in detail, by testing against different data. Moreover, any errors identified were corrected during the development of the software.

When the software development was completed, validation and verification continued through comparison of results from FARMS with data collected from existing farms and anaerobic digesters in Cyprus (section 6.2) and testing by potential users (section 6.3).

6.2 Comparison of FARMS predictions with real data

The results that can be obtained with FARMS have been verified by comparison with information collected from three different farms in Cyprus: a cattle farm that does not use AD to treat the animal waste produced, a poultry farm that uses an offsite AD and a pig farm that has an onsite AD to treat the produced animal waste. These three options have been chosen because they provide the three different systems for which FARMS was developed (see section 5.2.2). Moreover, FARMS' predictions have been compared to real data from farms with anaerobic digesters with regards to waste, biogas and energy production, area requirements for the anaerobic digestion and capital and operating costs for the anaerobic digestion. The results of the comparison are presented in section 6.2.4.

For all comparisons, there is a probability that the information provided by the farm owner is incorrect. However, it is assumed that the data provided has a low uncertainty to be able to reach some conclusions for the program developed.

6.2.1 A cattle farm that does not use AD to treat the produced animal waste

The first farm is a cattle farm that is located in the area of Athienou. The average annual population of the farm is 500 cattle. The animal waste produced by this farm is collected from the housing area by workers, once a month, using shelves and small quantities of water to push waste into collection channels that lead to a homogenisation tank. The homogenisation tank has a mechanical mixer which operates every 6-8 hours. After the temporary storage in the homogenisation tank of approximately 1 day, waste is transferred by pumping to a mechanical separator. The separated liquid is sent to evaporation lagoons, and the solid fraction is used as soil improver after it is left to dry for a minimum period of 3 months[4].

FARMS was used twice for this farm with the option “greenhouse gas emissions of a farm”. The first time all the default values of the program were used (with the animal population from the farm’s owner), while the second time the data obtained from the farm was used instead of the default.

The inputs and outputs of FARMS for the two cases are presented in Table 6.1 and Table 6.2 respectively.

[4] Drying could take upto six months between autumn and spring months

Table 6.1. Inputs to FARMS

	FARMS default values	Data from farm
Energy consumption per animal	565 kWh cow^{-1}	410 kWh cow^{-1} [a]
Electrical energy consumption	28.5% of total energy	205000 kWh $year^{-1}$
Diesel consumption	44.8% of total energy	0
LPG consumption	26.7% of total energy	0

[a] implied

Table 6.2. FARMS predictions with defaults and real data for a cattle farm without AD to treat animal waste

	FARMS predictions with	
	default values	data from farm
Total energy consumption	282500 kWh $year^{-1}$	205000 kWh $year^{-1}$
Electrical energy consumption	80513 kWh $year^{-1}$	205000 kWh $year^{-1}$
Diesel consumption	14665 l $year^{-1}$	0
LPG consumption	12507 l $year^{-1}$	0
GHG emissions	1446 t CO_2 eq.	1421 t CO_2 eq.

As it can be observed from the data presented in Table 6.2, at this particular farm only electricity is used and the implied energy consumption per animal is 410 kWh compared to 565 kWh which the default values of FARMS provides. Nevertheless, the impact on the total emissions is only 1.7% due to the small contribution of energy consumption to the total GHG emissions. Figure 6.1 shows that most of the GHGs (830 t CO_2 eq.) are emitted by enteric fermentation, while manure management also contributes considerably to the total (533 t CO_2 eq.).

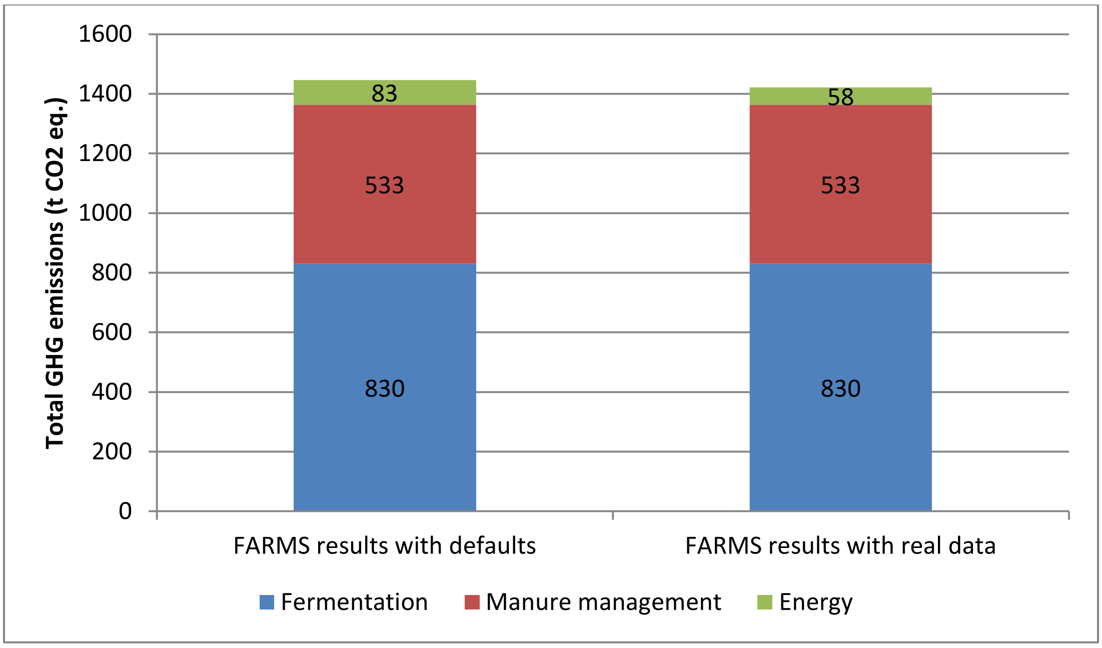


Figure 6.1. Difference in the predicted GHG emissions from FARMS from the use of actual data and default values in the software for a cattle farm without AD.

This test run can be considered successful since the difference in the total emissions is very small and the flexibility of changing various parameters to adapt to the conditions of the specific farm investigated has been demonstrated.

6.2.2 A poultry farm that uses an offsite AD to treat the produced animal waste

The second farm is a poultry farm also located in the area of Athienou. The farm has an animal population of 50500 chicken. The annual electricity consumption of the farm in 2011 was 13175 kWh. Some equipment is operated with diesel and the annual consumption was approximately 1000 l, while heating equipment consumes approximately 1500 l LPG annually. During the same year 425 t of manure was produced. The manure is collected through gritted floors onto a concrete platform and transferred by a tractor to a transfer lorry once a month. It is anticipated that the frequency of manure collection will allow the majority of CH_4 and CO_2 to escape to the atmosphere, particularly due to the warm climatic conditions that prevail. Therefore the implementation of AD for the treatment of this waste does not contribute considerably to the reduction of greenhouse gas emission

The manure is transferred to an offsite AD 1 km away. No gate fee for the treatment is charged; the farm owner however, has to pay for the transport of the waste with a rate of €75 per kilometre. The information collected from the farm is presented in Table 6.3 in comparison to the default values of FARMS. Table 6.4 presents the output of FARMS.

Table 6.3. Inputs to FARMS

	FARMS default values	Data collected
Animal population	n/a	50500
Energy consumption per animal	0.777 kWh $bird^{-1}$	n/a
Electrical energy consumption	28.3% of total energy	13175 kWh
Diesel consumption	41.3% of total energy	1000 l
LPG consumption	30.4% of total energy	1500 l
Waste production	n/a	425 t $year^{-1}$
Distance to AD	n/a	1 km
Gate fee	€100 m^{-3}	0
Transport cost	€100 km^{-1}	€75 km^{-1}
Temporary storage	1 day	30 days
Emissions cost	€2 t^{-1} CO_2 eq.	0
Lorry capacity	15 m^3	15 m^3

Table 6.4. FARMS predictions with default values and data collected from a poultry farm that uses an offsite AD to treat the produced animal waste

	FARMS predictions with	
	default values	data collected
Electricity consumption	11147 kWh	13175 kWh
Diesel consumption	1885 l	1000 l
LPG consumption	1986 l	1500 l
Waste production	505 t $year^{-1}$	425 t $year^{-1}$

For this farm, the option "optimum scenario for a farm with respect to cost and greenhouse gas emissions" was applied. This option includes in the assessment offsite anaerobic digestion, which is applied in this case. Information for GHG emissions have not been reported by the farm, therefore annual expenses are compared in this case.

The predictions obtained by FARMS without changing the default values give a total of €12436, while using FARMS with the values provided by the farm owner give a total of €8937 (Table 6.5). According to the farm owner, annual waste management cost (which is allocated mainly to the transport of waste) is approximately €5000, annual energy cost is €5000 and maintenance of the equipment running with LPG and diesel is €500. The total annual cost with these activities is €10500.

Table 6.5. FARMS predictions compared to data collected from a poultry farm that uses an offsite AD to treat the animal waste produced for annual expenses

	FARMS predictions		Reported (€)
	with default values (€)	with data provided by farm owner (€)	
Annual waste management cost	6121	3864	5000
Annual energy cost	5915	4673	5000
Maintenance of generators/ boilers	400	400	500
Total annual expenses	12436	8937	10500

The difference that exists between the data reported by the farm owner and the predictions obtained by FARMS without changing the default values is 18.4%, while when using FARMS with the values provided by the farm owner the difference is -14.8% (Figure 6.2). These differences are explained by the following:

(a) The farm owner has provided a rough estimate of the annual expenses, while FARMS predict the expenses in detail.
(b) The annual waste production reported by the farm owner is 425 t, while the annual waste production predicted by FARMS with defaults is 505 t (Table 6.4). This has as a result the overestimation of the expenses by FARMS with defaults compared to the data reported by the farm owner.
(c) FARMS overestimate the energy consumption compared to the data provided by the farm owner (Table 6.4). This resulted to overestimation of the energy cost

estimated by FARMS with defaults compared to the results when the farm's data is used.

These results show that FARMS can provide a good first financial assessment of offsite AD treatment, which can be further investigated in comparison to other options with more detailed studies.

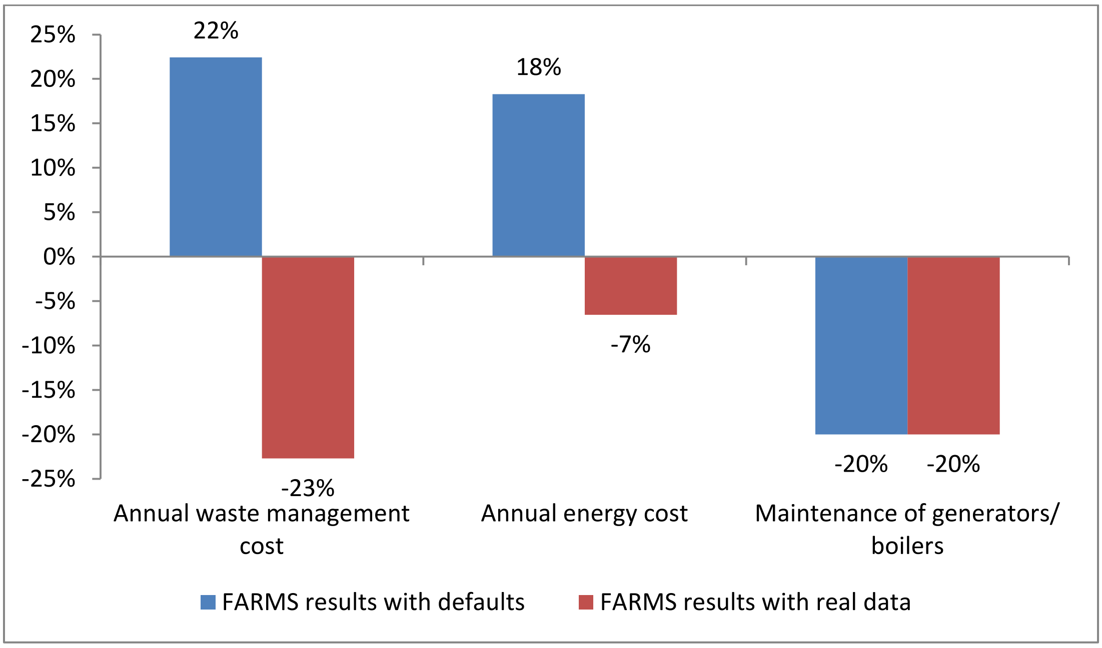


Figure 6.2. Percent difference between the FARMS predictions compared to real data for annual expenses for energy for waste management of a poultry farm that uses an offsite AD to treat the produced animal waste

6.2.3 A pig farm that has an onsite AD to treat the produced animal waste

The third farm considered, is a pig farm located in the area of Monagrouli. The farm has an average annual pig population of 25000 pigs. The pig waste is collected through gritted floors into open channels that lead into a homogenisation tank. The homogenisation tank has a mechanical mixer which operates every 6-8 hours. After the temporary storage in the homogenisation tank of approximately 1.0 day, waste is transferred by pumping to a completely mixed anaerobic digester operating at 37^{o}C. The biogas produced is combusted in a CHP generator. All the thermal energy produced is used to heat the housing areas and the digester. The electrical energy produced is used to cover the needs of the farm and the anaerobic digestion, and the remaining is sold to the Electricity Authority of Cyprus. The characteristics of the waste and other information for the digester are presented in Table 6.6.

Table 6.6. Information for a pig farm that uses an onsite AD to treat the animal waste produced, compared to the default values used in FARMS

	Reported	FARMS' default values
Energy consumption per animal	56 kWh pig^{-1} year^{-1} [a]	60.6 kWh pig^{-1} year^{-1}
Waste		
Production per animal	2.336 t year^{-1} [a]	3.09 t year^{-1}
COD[b]	25 g l^{-1}	40 g l^{-1}
TS[c]	4% - 5%	5%
VS[d]	68%	70%
CHP generator		
Electrical efficiency	38%	35%
Thermal efficiency	40%	50%
Digester		
Retention time	22 days	20 days
Digester lifetime	20 years	20 years
Financial		
Loan interest rate	6.5%	10%
Loan repayment period	7 years	10 years
Electricity selling price	€0.121 kWh^{-1}	€0.135 kWh^{-1}
Land cost	€17.78 m^{-2} [e]	€80 m^{-2}
Income tax	5%	5%
Electricity buying price	€0.14 kWh^{-1}	€0.16953 kWh^{-1}
Diesel buying price	€0.75 lt^{-1}	€1.419 lt^{-1}

[a] estimated by dividing the total energy consumption reported by the animal population; [b] COD: Chemical Oxygen Demand; [c] TS: Total Solids; [d] VS: Volatile Solids; [e] estimated by dividing the cost by the total land area purchased

The digester under study is one of the first two, built in Cyprus in 2007. The electricity selling price was consequently set by the first supporting scheme for the Renewable Energy Sources promotion of 2007 (€0.121 kWh^{-1}). This price is lower than the price set in 2013 (€0.135 kWh^{-1}). Since then there have been considerable changes in the economy of the country, and these are reflected in all the financial parameters presented in Table 6.6. In 2013 when the information was collected for FARMS, the economy of the country had already started deteriorating, which had as a consequence, the increase in the loan interest rates and the increase in fuel and electricity prices. Finally, the cost of land shows a considerable difference which according to the farm owner is due to the fact that the land was purchased in the mid-1990s when the land prices were not as high as in 2013.

FARMS was ran with two inputs; once with the information provided by the farm owner and the second with the default values. The inputs are presented in Table 6.6. In both cases the option "cost for the installation and operation of an anaerobic digester" was chosen. The method chosen to estimate the biogas production was "amount of waste digested". Regarding energy use, the option "all energy is used onsite and the remaining is sold" was chosen.

The results obtained in comparison to the information reported by the farm owner are presented in Table 6.7. As it can be seen from the comparison presented, even though the predictions of FARMS vary by upto 30% in some cases (e.g. annual waste production) from the data reported by the farm's owner, once the parameters of the program are adjusted to the farm ("FARMS predictions with data provided by farm owner" column), the predictions are very similar to the reported values for all categories of results. This shows that FARMS can be adapted very easily to the specific conditions of each farm, provided that the necessary information is available. Nevertheless, even if information is not available FARMS can provide sufficient information for a farmer to be informed on the prospects of anaerobic digestion for the specific farm.

Table 6.7. FARMS predictions and data collected from a pig farm that uses an onsite AD to treat the animal waste produced for digester characteristics and costs

	FARMS predictions		Reported
	with default values	with data provided by farm owner	
Annual waste production (t)	77250	58500	58400
Farm energy consumption (kWh /year^{-1})	1515000	1400000	1400000
Digester			
Total volume (m^3)	7272	6294	6000
Active volume (m^3)	5454	4595	4400
Area of digester (m^2)	1212	1049	1000
Other areas (m^2)	3838	4024	4000
Biogas production (m^3 year^{-1})	1931250	1462500	1440000
Financial			
Cost of land	€404055	€77765	€80000
Cost of digester and its installation	€1553821	€1850298	€1800000
Annual personnel cost for digester	€57272	€58217	€60000
Annual maintenance cost for the digester	€56079	€47213	€20000
Annual maintenance cost for the CHP generator	€43720	€33108	€40000

6.2.4 Comparison of FARMS predictions with data collected from existing anaerobic digesters in Cyprus

The first anaerobic digester in Cyprus was installed in 2007 for the treatment of pig waste (Ioannou, 2012). In 2013, there were 12 anaerobic digestion plants in operation, of which 8 were for the treatment of animal wastes. All plants are operating at mesophilic conditions. The digesters treating animal wastes are connected to the power distribution grid and export electricity produced to the grid. Even though all digesters were initially installed for the treatment of pig waste, currently, they are accepting waste from other animal types as well.

The data for the anaerobic digesters was collected during site visits and apply to the period that the digesters were operating only with pig waste. This data was used in the FARMS validation step and were compared with FARMS predictions.

The sections that follow present comparisons between FARMS predictions and actual data from the eight digesters for waste (D1 to D8 in the tables that follow), biogas and energy production, and capital and operating costs.

6.2.4.1 Prediction of waste production

Waste production is estimated for all the choices of FARMS, except "greenhouse gas emissions of a farm". The only information needed for FARMS to provide a prediction of annual waste production is animal population and animal type. Waste production is estimated assuming annual waste production per pig 3.09 t year^{-1} (default). Table 6.8 presents the animal population entered and the predicted waste production by FARMS in comparison to the data on waste production collected from the owner of the farm. The comparison is also presented in Figure 6.3 for better presentation of the results.

Table 6.8. Comparison of annual waste production between data collected and FARMS predictions

Farm	Animal population	Reported annual waste production per animal (t animal^{-1})*	Waste production (t year^{-1})		Difference
			Reported	FARMS	
D1	10000	2.95	29505	30940	4.6%
D2	17500	3.00	52500	54145	3.0%
D3	6700	3.13	21000	20730	-1.3%
D4	14500	3.14	45500	44863	-1.4%
D5	14000	2.50	35000	43316	19.2%
D6	7000	3.50	24500	21658	-13.1%
D7	6400	2.52	16100	19802	18.7%
D8	31200	3.48	108500	96533	-12.4%

* The reported annual waste production per animal has been estimated by dividing the annual waste production reported by the animal population reported.

The results show that for four digesters (D1, D2, D3 and D4) the difference between predicted and actual data is less than 10%. The smallest difference is for digesters D3 and D4, of 1.3% and 1.4% respectively, with the estimation of FARMS being slightly lower than actual data. For two digesters, D6 and D8, FARMS underestimates the waste by 13% and 12% respectively, and for digesters D5 and D7, FARMS overestimates waste by 19%. These differences could be due to differences in feeding regimes, waste collection practices and associated evaporation rates, as well as the amount of water used during cleaning.

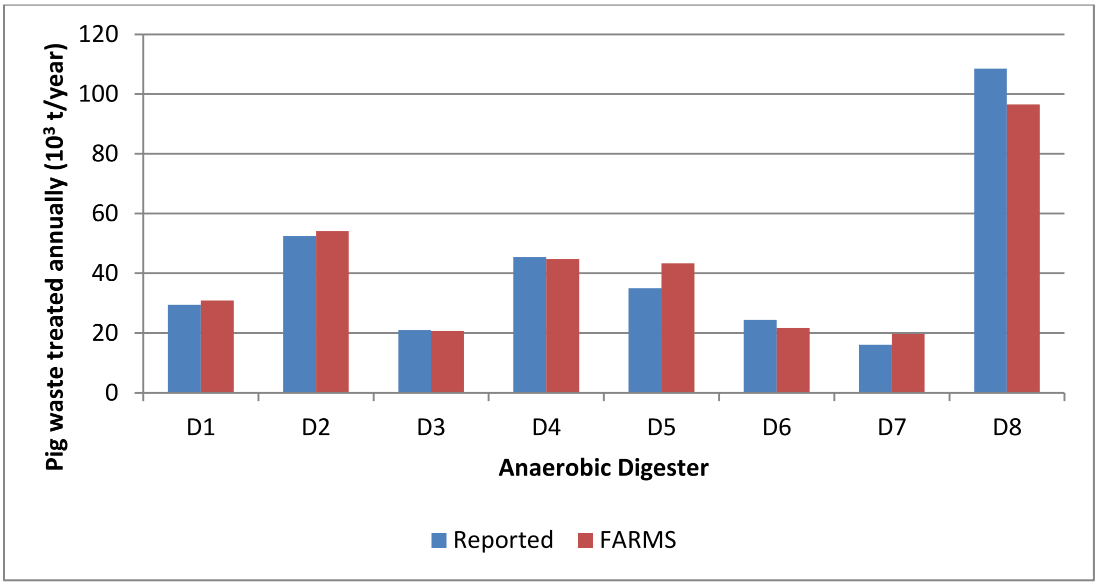


Figure 6.3. Comparison of annual waste production between data collected and FARMS predictions

6.2.4.2 Prediction of biogas production

Biogas production is estimated for all the choices of FARMS, except "greenhouse gas emissions of a farm". FARMS offers three methods to the user to predict the biogas production: volatile solids (VS) destroyed, Chemical Oxygen Demand (COD) consumed and amount of waste digested. All methods use default values for the qualitative characteristics of the waste and biogas production coefficients, unless the user chooses to provide the required data.

Method 1: volatile solids destroyed

The information necessary for prediction of biogas production with the "volatile solids destroyed" method are animal population, waste production, total solids concentration (%) and volatile solids concentration (%).

The default total solids concentration for pig waste is assumed to be 5%, while the default for volatile solids concentration 70%.Waste production is estimated assuming an annual waste production per pig of 3.09 t year^{-1}, as presented in section 6.2.4.1. The data input to FARMS to predict biogas production with default values and the method of volatile solids destroyed, along with the resulting biogas production are presented in Table 6.9.

Table 6.9. Information used for the prediction of biogas production by FARMS using volatile solids destroyed, based on default values

Farm	Animal population	Waste production (t year^{-1})	Biogas production (10^3 m^3 year^{-1})
D1	10000	30940	939
D2	17500	54145	1643
D3	6700	20730	629
D4	14500	44863	1361
D5	14000	43316	1314
D6	7000	21658	657
D7	6400	19802	601
D8	31200	96533	2929

In cases that the user has quantitative and qualitative characteristics of the waste production, all the defaults and the estimations by FARMS can be replaced by the available data. The data collected from the farm owners that were input to FARMS to estimate the biogas production are presented in Table 6.10.

Table 6.10. Information used for the prediction of biogas production by FARMS using volatile solids destroyed, based on data collected

Farm	Waste production (t $year^{-1}$)	Total solids (%)	Volatile solids (%)	Biogas production ($10^3 m^3 year^{-1}$)
D1	29505	6.2	66.8	1054
D2	52500	6.4	61.7	1789
D3	21000	4.0	65.0	473
D4	45500	5.1	66.8	1354
D5	35000	5.0	65.0	986
D6	24500	6.0	62.0	790
D7	16100	4.1	69.9	401
D8	108500	5.4	62.0	3149

A comparison between the biogas production reported by the farm's owner, the FARMS prediction with defaults and FARMS prediction with farm's owner data is presented in Table 6.11. The percent difference between these values is also illustrated in Figure 6.4.

Table 6.11. Biogas production reported by the farm owner, compared to FARMS predictions using the defaults and the data from the farm (volatile solids destroyed method)

Farm	Reported biogas production ($10^3 m^3 year^{-1}$)	FARMS with defaults		FARMS with data from farm	
		Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported	Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported
D1	1000	939	-6%	1054	5%
D2	1500	1643	10%	1789	19%
D3	500	629	26%	473	-5%
D4	1200	1361	13%	1354	13%
D5	1000	1314	31%	986	-1%
D6	600	657	10%	790	32%
D7	460	601	31%	401	-13%
D8	2500	2929	17%	3149	26%

As it is illustrated in Figure 6.4, in almost all cases FARMS overestimates the biogas production. The difference in the results ranges from -13% (D7, data from farm) to 32% (D6, data from farm). The average difference between the predictions of FARMS with defaults, compared to the biogas reported by the farm owner is 15.0% with a standard deviation[5] of 11.9% and standard error[6] of 4.2%. Similarly, the average difference between the predictions of FARMS with the data from the farm owner, compared to the biogas reported by the farm owner is 14.1% with a standard deviation of 15.4% and standard error of 5.4%.

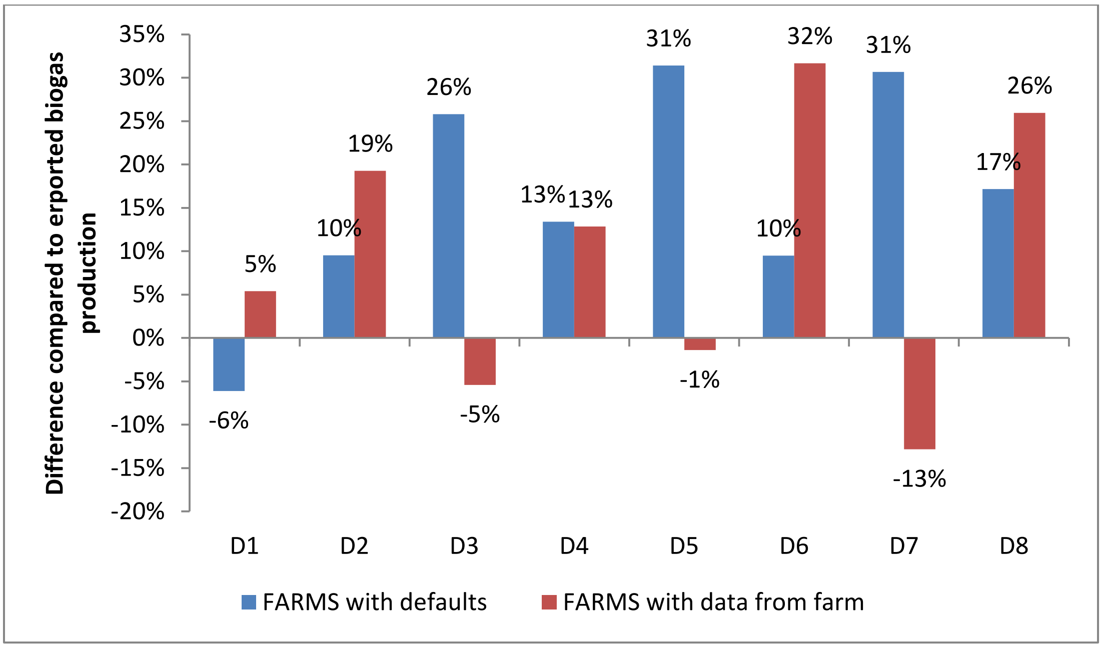


Figure 6.4. Percent difference between biogas production reported by the farm owner, estimated with FARMS using the default values and with FARMS using the data from the farm (volatile solids destroyed method)

Method 2: Chemical Oxygen Demand consumed

The information necessary for the prediction of biogas production with the chemical oxygen demand consumed method are animal population, waste production, chemical oxygen demand (COD) concentration and bulk volume of the waste.

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[5] Standard deviation (SD) describes the variability between individuals in a sample (Nagele, 2003)

[6] Standard error of the mean (SEM) describes the uncertainty of how the sample mean represents the population mean (Nagele, 2003)

The default COD concentration for pig waste in FARMS is 40 g l^{-1}, while the bulk density 0.973 t m^{-3}.Waste production is estimated assuming an annual waste production per pig of 3.09 t $year^{-1}$, as presented in section 6.2.4.1. The data input to FARMS to predict biogas production with default values and the method of COD consumed, and the resulting biogas production are presented in Table 6.12.

Table 6.12. Information used for the prediction of biogas production by FARMS using chemical oxygen demand consumed, based on default values

Farm	Animal population	Waste production (t $year^{-1}$)	Biogas production (10^3 m^3 $year^{-1}$)
D1	10000	30940	667
D2	17500	54145	1224
D3	6700	20730	469
D4	14500	44863	1014
D5	14000	43316	979
D6	7000	21658	490
D7	6400	19802	448
D8	31200	96533	2183

In cases that the user has quantitative and qualitative characteristics of the waste production, all the defaults and the estimations by FARMS can be replaced by the available data. The data collected from the farm owners that were input to FARMS to estimate the biogas production are presented in Table 6.13. No data were available for waste bulk density so the default provided by FARMS was used (0.973 t m^{-3}).

Table 6.13. Information used for the prediction of biogas production by FARMS using chemical oxygen demand consumed, based on data collected

Farm	Waste production (t $year^{-1}$)	Chemical Oxygen Demand (g l^{-1})	Biogas production ($10^3 m^3 year^{-1}$)
D1	29505	50	834
D2	52500	38	1128
D3	21000	40	475
D4	45500	35	900
D5	35000	45	890
D6	24500	42	582
D7	16100	40	364
D8	108500	38	2331

A comparison between the biogas production reported by the farm's owner, the FARMS prediction with defaults and FARMS prediction with farm's owner data is presented in Table 6.14. The percent difference between these values is also illustrated in Figure 6.5.

Table 6.14. Biogas production reported by the farm owner, compared to FARMS predictions using the defaults and the data from the farm (chemical oxygen demand consumed method)

Farm	Reported biogas production ($10^3 m^3 year^{-1}$)	FARMS with defaults		FARMS with data from farm	
		Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported	Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported
D1	1000	667	-33%	834	-17%
D2	1500	1224	-18%	1128	-25%
D3	500	469	-6%	475	-5%
D4	1200	1014	-16%	900	-25%
D5	1000	979	-2%	890	-11%
D6	600	490	-18%	582	-3%
D7	460	448	-3%	364	-21%
D8	2500	2183	-13%	2331	-7%

As it is clearly presented in Figure 6.5, in all cases FARMS is underestimating the biogas production, irrespective of whether the default values or data from the farm's owner is used. Even though there are large differences of up to 33% (D1 with defaults), most results have a difference from the reported biogas production ranging between 0 and 15%. The average difference between the predictions of FARMS with defaults, compared to the biogas reported by the farm owner is -14.7% with a standard deviation of 9.6% and standard error of 3.4%. Similarly, the average difference between the predictions of FARMS with the data from the farm owner, compared to the biogas reported by the farm owner is -14.3% with a standard deviation of 8.4% and standard error of 3.0%.

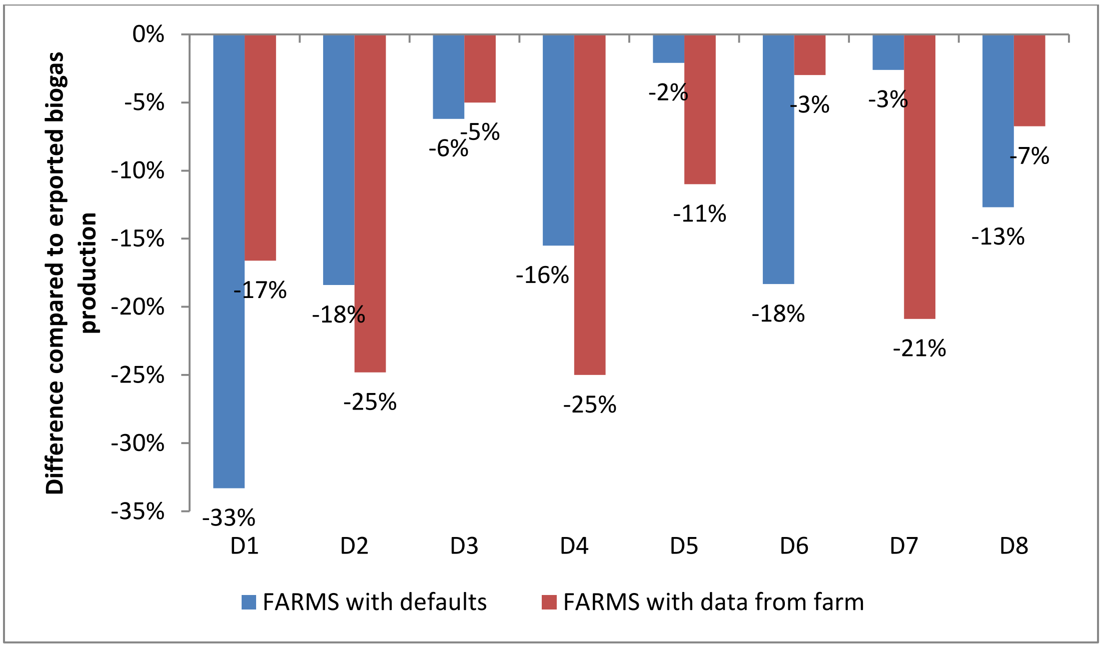

Figure 6.5. Percent difference between biogas production reported by the farm owner, estimated with FARMS using the default values and with FARMS using the data from the farm (chemical oxygen demand consumed method)

Method 3: amount of waste digested

For the last method of biogas estimation, the necessary information is animal population and waste production.

Waste production is estimated as presented in section 6.2.4.1. The data input to FARMS to predict biogas production with default values and the method of amount of waste digested, and the resulting biogas production are presented in Table 6.15.

Table 6.15. Information used for the prediction of biogas production by FARMS using amount of waste digested, based on default values

Farm	Animal population	Waste production (t $year^{-1}$)	Biogas production (10^3 m^3 $year^{-1}$)
D1	10000	30940	774
D2	17500	54145	1354
D3	6700	20730	518
D4	14500	44863	1122
D5	14000	43316	1083
D6	7000	21658	541
D7	6400	19802	495
D8	31200	96533	2413

The biogas production as estimated by FARMS when data from the farm's owner was used is presented in Table 6.16.

Table 6.16. Waste production used for the prediction of biogas production by FARMS using amount of waste digested, based on data collected

Farm	Waste production (t $year^{-1}$)	Biogas production ($10^3 m^3 year^{-1}$)
D1	29505	738
D2	52500	1313
D3	21000	525
D4	45500	1138
D5	35000	875
D6	24500	613
D7	16100	403
D8	108500	2713

The biogas production reported by the farm owner, estimated with FARMS using the defaults and with FARMS using the data from the farm, is presented in Table 6.17. The percent difference between these values is also illustrated in Figure 6.6.

Table 6.17. Biogas production reported by the farm owner, estimated with FARMS using the defaults and with FARMS using the data from the farm (using amount of waste digested method)

Farm	Reported biogas production ($10^3 m^3 year^{-1}$)	FARMS with defaults		FARMS with data from farm	
		Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported	Biogas production ($10^3 m^3 year^{-1}$)	Difference from reported
D1	1000	774	-23%	738	-26%
D2	1500	1354	-10%	1313	-12%
D3	500	518	4%	525	5%
D4	1200	1122	-7%	1138	-5%
D5	1000	1083	8%	875	-13%
D6	600	541	-10%	613	2%
D7	460	495	8%	403	-12%
D8	2500	2413	-3%	2713	9%

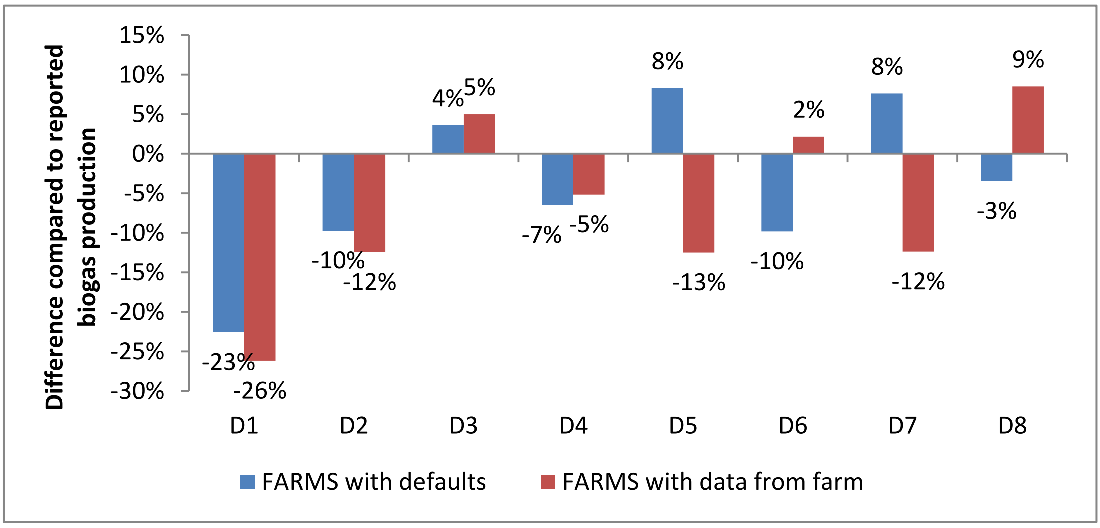

Figure 6.6. Percent difference between biogas production reported by the farm owner, to FARMS predictions using the defaults and with FARMS predictions using the data from the farm (using amount of waste digested method)

As it is presented in Figure 6.6, in most cases FARMS is underestimating the biogas production, regardless whether the defaults or data from the user is used. Even though there are differences of up to 25% (D1), most results have a difference from the reported biogas production ranging between 0 and 13%. The average difference between the predictions of FARMS with defaults, compared to the biogas reported by the farm owner is -5.3% with a standard deviation of 10% and standard error of 3.5%. Similarly, the average difference between the predictions of FARMS with the data from the farm owner, compared to the biogas reported by the farm owner is -5.0% with a standard deviation of 10.9% and standard error of 3.8%.

The difference between actual biogas production and predictions of FARMS can be attributed to the following main reasons:

(a) FARMS, in all predictions assumes that biomass is fully digested; i.e. all biomass available in the waste is converted to biogas.
(b) Differences in predicted and actual waste production result in increased differences between actual and predicted biogas production.
(c) The default values chosen for FARMS are not representative for all farms, due to differences that exist in feeding regimes and waste collection practices.
(d) The seasonal variations that occur every year cause changes in feeding regimes and waste characteristics. For example in spring when the food in cattle breeding is fresh grass, the amount of water in the waste is higher. As a result the concentration of solids and COD decreases. Similarly, in summer, when the temperatures are higher, the evaporation rate is higher and therefore the concentration in parameters such as solids and COD increase. However, these fluctuations cannot be represented in FARMS since only one value is used.

All these issues could be addressed with more detailed modelling during the next phase of the design of an anaerobic digester. However, the comparisons presented have shown that FARMS can provide predictions of sufficient quality for a farmer or a policy maker to form an opinion on the appropriateness of the application of AD for a particular case.

6.2.4.3 Prediction of energy production

Energy production is estimated for all the choices of FARMS, except "greenhouse gas emissions of a farm".

Energy production is first calculated using the default values in FARMS using the amount of waste digested method and then with the biogas production reported by the farm's owner. In both cases, the defaults in FARMS are biogas methane content of 60%, efficiency of CHP generator of 50% thermal and 35% electrical, methane energy content at 100% and combustion energy of 55.6 MJ kg^{-1} and methane density of 0.6556 kg m^{-3}. The input values to the program are presented in Table 6.18.

Table 6.18. Energy generation potential from biogas production predicted by FARMS

Farm	Reported biogas production ($10^3 m^3 year^{-1}$)	Predicted using waste digested method and FARMS defaults ($10^3 m^3 year^{-1}$)
D1	1000	774
D2	1500	1354
D3	500	518
D4	1200	1122
D5	1000	1083
D6	600	541
D7	460	495
D8	2500	2413

The outputs are presented in Table 6.19 (electrical energy) and Table 6.20 (thermal energy). The differences between predictions by FARMS and reported actual energy production are presented in Figures 6.7 and 6.8 for electrical and thermal energy respectively.

Table 6.19. Electrical energy production

Farm	Reported electricity production (10^6 kWh year^{-1})	With reported biogas production		With waste digested method and FARMS defaults	
		Electricity production (10^6 kWh year^{-1})	Difference from reported	Electricity production (10^6 kWh year^{-1})	Difference from reported
D1	1.70	2.13	25%	1.64	-4%
D2	2.97	3.19	7%	2.88	-3%
D3	1.51	1.06	-30%	1.1	-27%
D4	2.33	2.02	-13%	2.38	2%
D5	2.51	2.13	-15%	2.3	-8%
D6	1.42	1.28	-10%	0.77	-46%
D7	1.12	0.98	-13%	1.05	-6%
D8	5.34	5.32	-0.4%	5.13	-4%

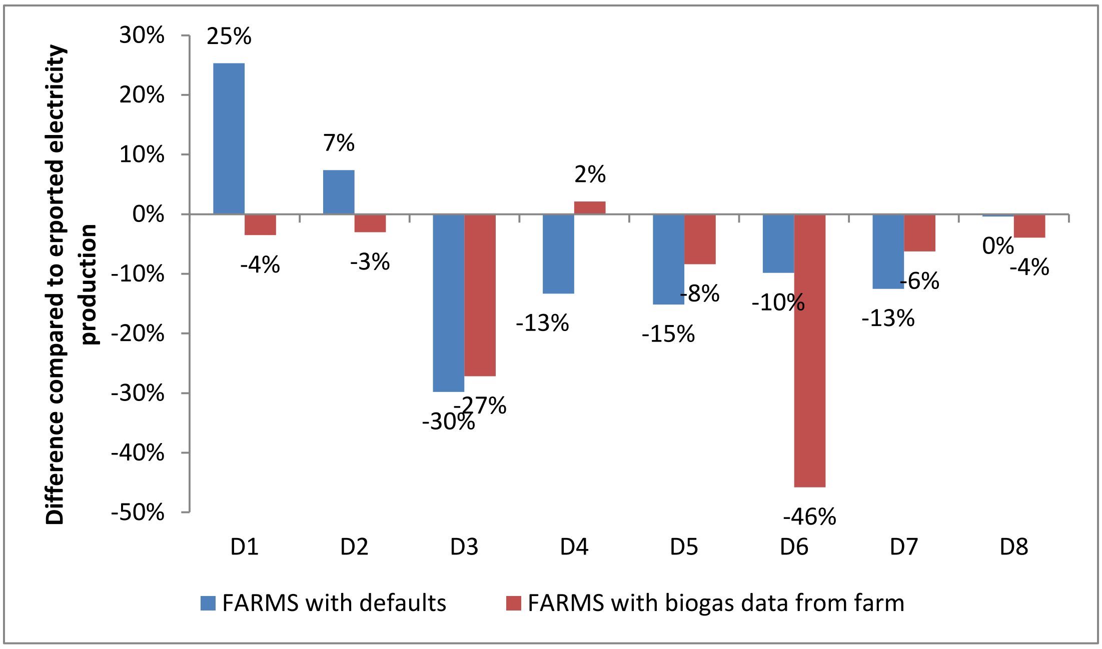

Figure 6.7. Percent difference between FARMS predictions with defaults and with biogas data from the farm, compared to reported electricity production

As can be seen in Figure 6.7, most of the predictions of FARMS underestimate the actual electrical energy reported by the farm's owner. FARMS predictions have a difference ranging from 0% to 15%, while only in four cases are larger (D1, D3 with defaults; D3, D6 with biogas data from farm). The average difference between the predictions of FARMS with defaults, compared to the electricity production reported by the farm owner is -4.2% with a standard deviation of 15.7% and standard error of 5.5%. Similarly, the average difference between the predictions of FARMS with the data from the farm owner, compared to the electricity production reported by the farm owner is -8.7% with a standard deviation of 15.5% and standard error of 5.5%.

Table 6.20. Thermal energy production

Farm	Reported heat production (10^6 kWh year^{-1})	With reported biogas production		With waste digested method and FARMS defaults	
		Heat production (10^6 kWh year^{-1})	Difference from reported	Heat production (10^6 kWh year^{-1})	Difference from reported
D1	2.42	3.04	26%	2.35	-3%
D2	3.40	4.56	34%	4.11	21%
D3	1.99	1.52	-24%	1.57	-21%
D4	3.32	3.65	10%	3.41	3%
D5	2.65	3.04	15%	3.29	24%
D6	1.82	1.82	0%	1.64	-10%
D7	1.28	1.4	9%	1.5	17%
D8	7.62	7.59	-0.4%	7.33	-3.8%

For thermal energy production, most the predictions of FARMS are overestimations compared to the energy reported by the farm's owner. FARMS predictions do not show a specific trend for thermal energy production. The range of differences is 0-34% when default values are used and 3%-24% when actual biogas data from the farm is used. The average difference between the predictions of FARMS with defaults, compared to the heat production reported by the farm owner is 8.7% with a standard deviation of 16.6% and standard error of 5.9%. Similarly, the average difference between the predictions of FARMS with the data from the farm owner, compared to the heat production reported by the farm owner is 2.9% with a standard deviation of 15.0% and standard error of 5.3%.

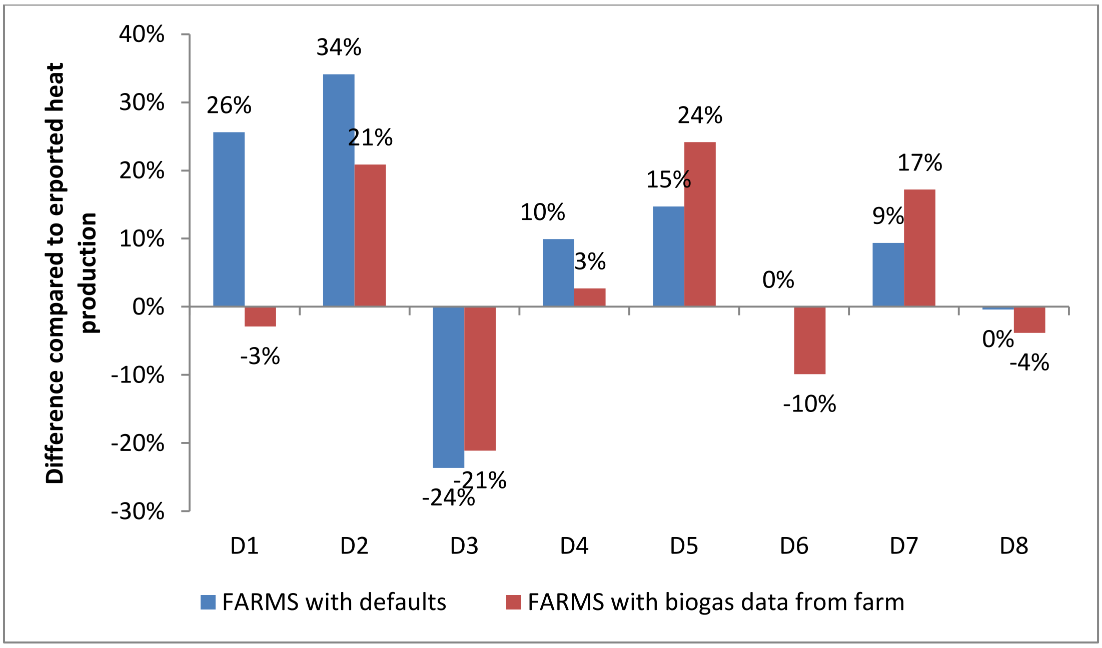

Figure 6.8. Percent difference between FARMS predictions with defaults and with biogas data from the farm, compared to reported heat production

The differences between real energy production compared to the predictions of FARMS are mainly due to:

(a) Differences between waste and biogas estimates compared to actual values that result in differences in predicted and actual energy production.

(b) Default values of characteristics for CHP generator used in FARMS which may differ from the characteristics of the generators used in the AD plant considered.

(c) Assumption of a constant 60% methane content of biogas in FARMS. Actual methane content and conditions in the digester vary throughout the year.

All these factors can be considered in more detail in future development of FARMS. However, the comparisons presented have shown that FARMS can provide predictions of sufficient quality for farmers and policy makers to make informed decisions on the application of AD for a particular case.

6.2.4.4 Prediction of area requirements for the installation of anaerobic digestion

Area requirements for the installation of anaerobic digestion are estimated for two choices provided by FARMS: “cost for the installation and operation of an anaerobic digester” and “optimum scenario for a farm with respect to cost and greenhouse gas emissions”.

The information necessary for the prediction of area requirements for the installation of anaerobic digestion are annual waste production, retention time, height, safety volume and active volume of the digester and the bulk density of the waste. The land area needed for activities compared to the total area necessary for anaerobic digestion (e.g. area needed for the digester and area needed for the control room).

FARMS was ran twice. For the first time with the reported animal population from the farm’s owner and the defaults proposed by FARMS (Table 6.21) were used. The waste production estimated by FARMS using the default waste production per animal (3.09 t pig^{-1}) and the animal population reported, as already presented in section 6.2.4.1 were also used. For the second time, the waste production reported by the farm’s owner was used and the defaults proposed by FARMS (Table 6.21). The waste production used for each time is presented in Table 6.22.

The methodology applied by FARMS to estimate the area requirements is explained in detail in section 4.4.

Table 6.21. FARMS default values used for the prediction of area requirements for the installation of anaerobic digestion

Parameter	Completely Mixed	Anaerobic Lagoon
Retention Time (days)	20	100
Height of digester (m)	6	6
Safety volume of digester	20%	20%
Active volume of digester	75%	75%
Bulk density of waste (t m^{-3})	0.973	0.973

Table 6.21. FARMS default values used for the prediction of area requirements for the installation of anaerobic digestion (continued)

Parameter	Completely Mixed	Anaerobic Lagoon
Contribution of the digester to the total area needed	24%	7%
Contribution of roads, safety area, open space, sludge storage and homogenisation tank to the total area needed	66%	90%
Contribution of control room, biogas scrubbing, generator room and office to the total area needed	10%	3%

Table 6.22. Waste production used for the prediction of area requirements for the installation of anaerobic digestion

Farm	Reported annual waste production (t $year^{-1}$)	Predicted annual waste production by FARMS (t $year^{-1}$)
D1	29505	30940
D2	52500	54145
D3	21000	20730
D4	45500	44863
D5	35000	43316
D6	24500	21658
D7	16100	19802
D8	108500	96533

The data obtained from the farm's owners is presented in Table 6.23Table 6.23 and it includes only information regarding the built areas; i.e. digester and control room (including biogas collection and treatment, and generator), because the digester has been installed in the area of the farm and the other areas are commonly used for the farm and the digester. Therefore the comparison of the data collected from the farm's owners compared to the FARMS' predictions was made only for these two areas and not the total area. Table 6.23 also includes information regarding the type of digester used.

Table 6.23. Built areas and type of digesters used at the eight farms studied

Farm	Type of digester	Digester (m^2)	Control room, biogas scrubbing, generator room and office (m^2)
D1	Completely mixed	500	270
D2	Completely mixed	600	420
D3	Anaerobic lagoon	1500 [a]	280
D4	Completely mixed	800 [b]	200
D5	Completely mixed	400	250
D6	Completely mixed	400	180
D7	Anaerobic lagoon	1200 [c]	300
D8	Completely mixed	1500 [a]	500

[a] Total area of three digesters of 500 m^2 each; [b] Total area of two digesters of 400 m^2 each; [c] Total area of three digesters of 400 m^2 each

The predictions of FARMS regarding area requirements for the eight farms are presented in Table 6.24. It should be noted here that for farms D3 and D7 the FARMS simulation was made with the characteristics of anaerobic lagoons, while for the remaining farms with the characteristics of completely mixed digester so that the results are comparable to the real data.

Table 6.24. Predictions of FARMS regarding area requirements for the eight farms

Farm	Estimated area with reported annual waste production (m^2)		Estimated area with predicted annual waste production by FARMS (m^2)	
	Digester	Control room etc.	Digester	Control room etc.
D1	465	194	443	185
D2	813	339	788	329
D3	1557	667	1577	676
D4	674	281	683	285
D5	650	271	526	219
D6	325	136	368	153
D7	1487	637	1209	518
D8	1450	604	1629	679

The percent difference of the predictions of FARMS compared to real areas is presented in Table 6.25. The size of the digester estimated is for most farms comparable to the actual area with the exception of D5. The results for the control room are also comparable apart from D3 and D7.

Table 6.25. Percent difference of the predictions of FARMS compared to actual areas

Farm	Area estimated with reported annual waste production (m^2)		Area estimated with predicted annual waste production by FARMS (m^2)	
	Digester	Control room etc	Digester	Control room etc
D1	-7%	-28%	-11%	-32%
D2	36%	-19%	31%	-22%
D3	4%	138%	5%	141%
D4	-16%	40%	-15%	42%
D5	63%	8%	31%	-12%
D6	-19%	-25%	-8%	-15%
D7	24%	112%	1%	73%
D8	-3%	21%	9%	36%

The differences between estimations by FARMS and actual data can be attributed to:

(a) Differences between actual data and estimations of waste production by farms.
(b) Land availability and cost: if land around or close to the farm is not readily available or if it is available but the cost is high, the farm's owner will have to find ways to use the land available more effectively.

Overall, it can be concluded that FARMS can provide reasonable estimates of the land requirements for anaerobic digestion. However, a very detailed study will be needed in each case to prepare the necessary layout of the equipment for most efficient use of the available land.

6.2.4.5 Prediction of capital and operating costs for anaerobic digestion

Capital and operating costs for anaerobic digestion can be estimated through two choices provided by FARMS: "cost for the installation and operation of an anaerobic digester" and "optimum scenario for a farm with respect to cost and greenhouse gas emissions".

The information necessary for the prediction of capital and operating costs for anaerobic digestion are annual waste production and the contribution of various activities to the total capital and operating costs (e.g. area of digester and control room).

Simulations were carried out using, a) the reported animal population of the farm and, b) default values in FARMS (Table 6.26). The waste production estimated by FARMS is based on the waste production per animal (3.09 t pig^{-1}) and the animal population as presented in section 6.2.4.1. The waste production used for each farm is presented in Table 6.27.

The methodology applied by FARMS to estimate the capital and operating costs is explained in detail in section 4.5.

Table 6.26. Prediction of capital and operating costs for anaerobic digestion using default values in FARMS

Parameter	Default value
Waste density	0.973 t m^{-3}
Contribution of the cost of the digester to the total capital cost	65%
Contribution of the cost of other expenditure to the total capital cost (Construction, equipment, permitting, consultants, construction)	35%
Contribution of personnel cost to the total operating costs	48%
Contribution of maintenance costs to the total operating costs	47%
Contribution of the cost of other expenditure to the total operating cost (overhead cost, tax on profit, cost of emissions, loan repayment)	5%

Table 6.27. Waste production used for the prediction of capital and operating costs for anaerobic digestion with FARMS

Farm	Predicted annual waste production by FARMS (t $year^{-1}$)
D1	30940
D2	54145
D3	20730
D4	44863
D5	43316
D6	21658
D7	19802
D8	96533

The data from the farm owners was collected for both capital and operating costs. Capital costs, which are presented in Table 6.28, included the cost for the purchase and installation of the digester and other (construction of control room, consulting studies and licenses, miscellaneous expenses). Land cost has been excluded from the reported capital costs.

Table 6.28. Data collected for capital costs for the eight anaerobic digesters studied

Farm	Type of digester	Capital costs (€)			Contribution to total	
		Digester	Other	TOTAL	Digester	Other
D1	CM [a]	500,000	200,000	700,000	71%	29%
D2	CM	800,000	300,000	1,100,000	73%	27%
D3	AL [b]	400,000	120,000	520,000	77%	23%
D4	CM	700,000	150,000	850,000	82%	18%
D5	CM	680,000	300,000	980,000	69%	31%
D6	CM	450,000	180,000	630,000	71%	29%
D7	AL	400,000	200,000	600,000	67%	33%
D8	CM	1,000,000	400,000	1,400,000	71%	29%

[a] CM: Completely mixed; [b] AL: Anaerobic Lagoon

Operating expenditure for the eight anaerobic digesters (Table 6.29) included personnel, maintenance and other (energy, overheads, taxes and miscellaneous expenses). Land rent and loan repayment, have been excluded from the reported operating costs.

Table 6.29. Data collected for operating expenditure for the eight anaerobic digesters studied

Farm	Type of digester	Operational costs (€)				Contribution to total		
		P [c]	M [d]	O [e]	TOTAL	P [c]	M [d]	O [e]
D1	CM [a]	30,000	15,000	2,000	47,000	64%	32%	4%
D2	CM	40,000	20,000	4,000	64,000	63%	31%	6%
D3	AL [b]	20,000	10,000	2,000	32,000	63%	31%	6%
D4	CM	40,000	20,000	5,000	65,000	62%	31%	8%
D5	CM	40,000	20,000	5,000	65,000	62%	31%	8%
D6	CM	25,000	15,000	2,000	42,000	60%	36%	5%
D7	AL	20,000	10,000	2,000	32,000	63%	31%	6%
D8	CM	50,000	30,000	5,000	85,000	59%	35%	6%

[a] CM: Completely mixed; [b] AL: Anaerobic Lagoon; [c] P: Personnel costs; [d] M: Maintenance costs; [e] O: Other costs

The predictions of FARMS regarding capital and operating costs for the eight anaerobic digesters are presented in Table 6.30. For farms D3 and D7 the FARMS run was made with the characteristics of anaerobic lagoons, while for the remaining farms with the characteristics of completely mixed digester for the results to be comparable with the results from the actual digesters.

Moreover, for the operational costs the cost of emissions (which has a default price of €2 t^{-1} CO_2 eq. (Mesimeris, 2013)) was considered as zero, since it is not applicable to Cyprus at present.

Table 6.30. Predictions by FARMS of capital and annual operating costs for the eight anaerobic digesters

Farm	Capital costs estimated with reported waste production (€)			Operating costs estimated with predicted waste production by FARMS (€)			
	Digester	Other	TOTAL	Pers.[a]	Maint.[b]	Other	TOTAL
D1	503,879	176,358	775,198	29,722	29,102	3,096	61,920
D2	787,681	275,688	1,211,816	45,641	44,690	4,754	95,086
D3	282,171	98,760	434,109	21,092	20,653	2,197	43,942
D4	710,105	248,537	1,092,469	39,846	39,016	4,151	83,013
D5	579,508	202,828	891,550	38,809	38,000	4,043	80,852
D6	430,365	150,628	662,101	21,922	21,465	2,283	45,670
D7	222,384	77,834	342,128	20,253	19,831	2,110	42,194
D8	1,187,571	415,650	1,827,033	64,092	62,757	6,676	133,525

[a] Pers. = Personnel; [b] Maint. = Maintenance

The difference between predictions of FARMS and actual capital costs are presented in Figure 6.9. As it can be seen from the chart, FARMS overestimates the cost for five digesters (D1, D2, D4, D5 and D8) and underestimates the cost for the remaining three (D3, D6 and D7). FARMS predictions are very similar to the actual data for D5 and D6 with 7% and 6% respectively. With 46%, D7 has the largest percent difference between the predicted and real data.

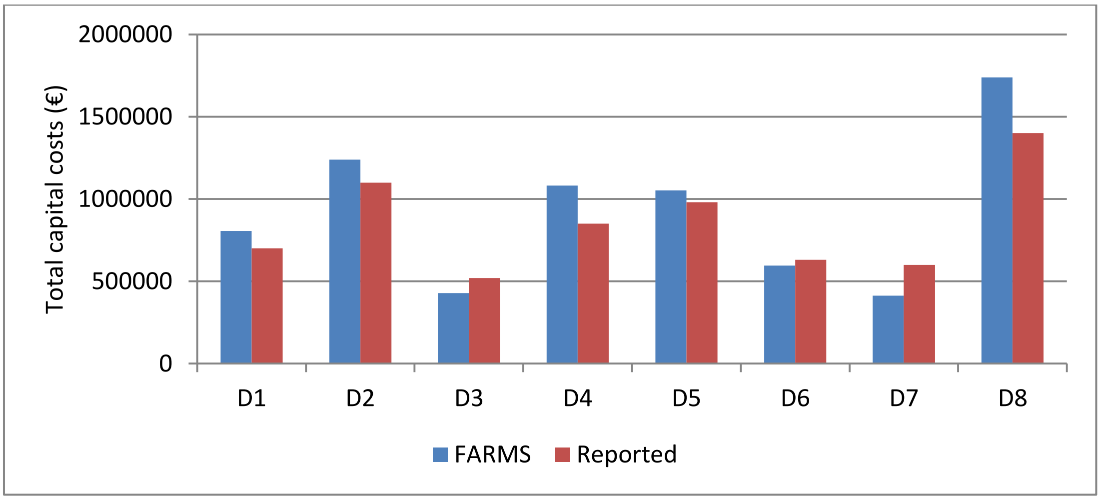

Figure 6.9. Difference of the predictions of FARMS compared to real total capital costs

The difference between the predictions of FARMS and actual operating costs are presented in Figure 6.10. FARMS overestimates the operating costs by between 8% and 36% (D6 and D8 respectively), with differences for most digesters ranging between 20% and 25%.

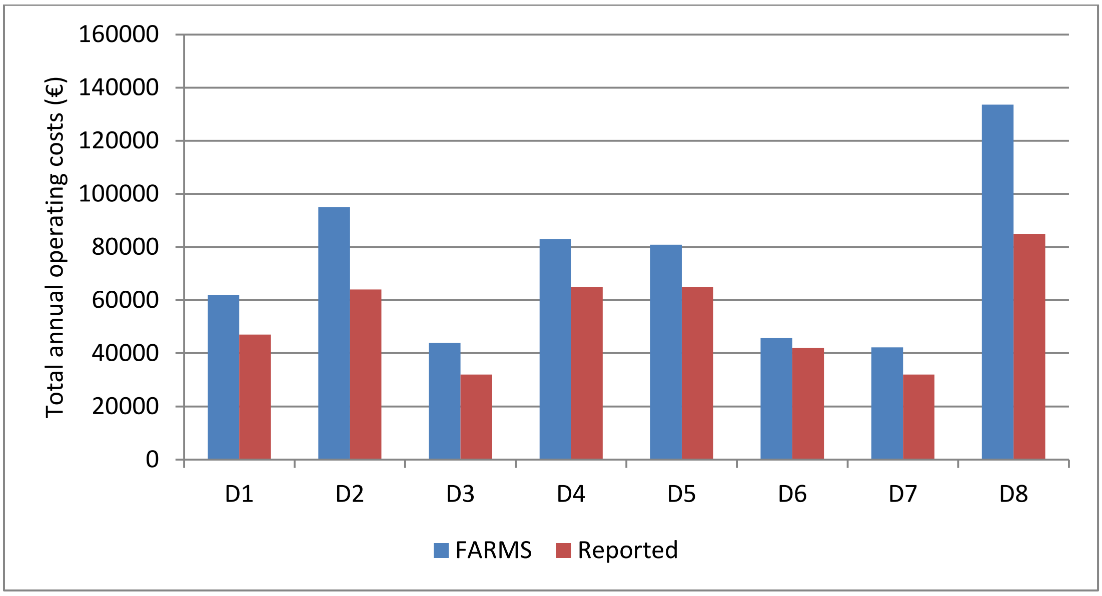

Figure 6.10. Difference between predictions by FARMS and actual annual operating costs

From the results it can be concluded that FARMS can provide good predictions for the capital and operating costs. Moreover, FARMS, with the opportunity provided to change the default values of key parameters, provides flexibility to the user to make the necessary changes in the software to better reflect specific conditions of his farm.

6.2.5 Summary

From the case studies considered it can be concluded that FARMS can

(a) be used to consider the application and economics of AD for the specific conditions of Cyprus,

(b) can be used with limited from specific farms,

(c) can provide reasonable estimates of energy generation potential, area requirements and costs of implementing AD.

6.3 Testing by potential users

Testing by potential users took place after the completion of the software development. A questionnaire was prepared and given with the FARMS installation file and user guide on a compact disc to twenty farmers, of different levels of knowledge and experience twenty public officers involved with environmental and energy issues and five environmental consultants. Twenty one questionnaires were returned completed: eleven farmers, eight public servants and two consultants.

The questionnaire and responses are presented in Appendix E. The questionnaire consisted of eleven sections: identity of the user, user guide, installation, use, animal types, defaults, results, errors, other software, potential users and overall assessment. Most of the questions were closed format questions (multiple choice answers) followed by open format questions to explain the choice made. Three types of answers were used in the closed format questions (Table 6.31). The replies to the closed formal questions were scored according to Table 6.16.

Table 6.31. Options and marking of answers to closed format questions

Type 1 answers		Type 2 answers		Type 3 answers	
Choice	Mark	Choice	Mark	Choice	Mark
Excellent	5	Excellent	5	Yes	2
Very good	4	Very good	4	Maybe	1
Good	3	Good	3	No	0
Not very good	2	Not very good	2		
None/No	1	Not good	1		
		Cannot assess	0		

Identity of the user

As it has already been mentioned, the questionnaire was completed by public officers, farmers and environmental consultants. Their academic background varied considerably ranging from no higher education qualifications to highly educated and trained professionals. The scores on academic background, familiarity with animal waste, anaerobic digestion and environmental terminology of the potential users that complete the questionnaires are presented in Table 6.32. The academic background question was an open question, and the answers were rated with 2 if the background was highly relevant (e.g. environment or energy), with 1 if it was related (e.g. chemical engineer) and with 0 if it was irrelevant (e.g. mathematician or Greek literature). Even though several of the farmers who completed the questionnaire were highly qualified in their field, none of them completed the field on academic background. Most of the potential users answered that they have a good familiarity with the relevant topics.

Table 6.32. Relevance of potential users

Question	Mark
Academic Background	13/42
Familiarity with animal waste	68/105
Familiarity with anaerobic digestion	74/105
Familiarity with environmental terminology	61/105

User guide

Two questions were designed for the user guide: whether the user guide was easy to read and understand and whether there was sufficient explanation in the guide for the options available in FARMS. The potential user could choose an option between Excellent, Very good, Good, Not very good and No. In both questions, the total rating was 89/105. The answers ranged from very good to excellent.

Installation

The questions related to installation were also two: was the installation of FARMS easy and have any problems been encountered during installation. Both questions were closed format questions; the responses could vary from excellent to no for the first question and yes (0 points) or no (1 point) for the second. Both questions received top score from the potential users.

Use

Here the potential user had to answer whether FARMS was a user-friendly software and choose one or more from the reasons provided. All potential users replied yes to the question. The reasoning for their choice is shown in Table 6.33.

Table 6.33. Options chosen to assess user friendliness of FARMS.

Choice	Mark
Easy	19/21
You can see all data used	18/21
The options are clear	18/21
The options are representative of the situation in Cyprus	10/21

Animal types

To the question if other animal types should be included, only three users replied yes. The animal types proposed to be added were sheep, goats, horses and rabbits. The fact however that the remaining 18 users replied no, shows that the FARMS in its current form deals with the most important animal populations in Cyprus.

Defaults

The questions for defaults were two: the potential user was asked to rate the way the default values are presented and if they have used their own data. Both questions were closed format questions; the answers could range from excellent to no for the first question and yes (1 point) or no (0 point) for the second. The replies to the first question were excellent or very good and the resulting score was 88/105 (4 excellent rated with 5 marks and 17 very good rated with 4 marks). 13 of the 21 potential users did replace the default values with their own data (Table 6.34).

Table 6.34. Variables for which default values were changed by potential users

Choice	Mark
Waste production	12/13
Energy consumption	12/13
Financial parameters	10/13
Area parameters	8/13

Results

The questions related to the results were three: rate how realistic are the results of FARMS, rate how results of FARMS are presented and will the results of FARMS assist you in your work. The first two questions were closed format questions; the answers were ranging from excellent to not good, that were rated with a scale from 5 to 0,while for the third question the answers were yes (1 point) or no (0 point). In all questions the potential user was asked to explain the answer given. The marking and the explanations given for the answers are presented in Table 6.35.

Table 6.35. Replies to the questions related to "Results"

Choice	Overall score
How realistic are the results of FARMS?	61/90*
The presentation of the results?	102/105
Do you think the results of FARMS will assist you in your work?	16/21
Yes	(16)
Possibility to install anaerobic digestion	1/16
The model can provide data for Cyprus not readily available	3/16
Assessment of scenarios for a farm	11/16
No	(5)

* three questionnaires did not have an answer to this question therefore the total reduced to 90

Errors

According to the answers provided by the potential users, none encountered errors during working with FARMS.

Other software

None of the potential users had used other software for the same purpose.

Potential Users

In the potential users section, the potential user was given an option to choose from a list of expertise. The results are presented in Table 6.36.

Table 6.36. Potential users of FARMS

Choice	Mark
A farmer with no knowledge on anaerobic digestion	18/21
A farmer with no data	18/21
A student	20/21
A consultant	20/21
A policy maker	18/21
Other: researcher	12/21

Overall assessment

In the last section of the questionnaire, the potential user was requested to choose between yes, maybe and no to answer the questions "Will you use FARMS for your work" and "Will you use FARMS for data reference", with 2 marks given to yes, 1 to maybe and 0 to no. For the last question, "please indicate your overall evaluation of FARMS" the user was given the options of excellent to not good (i.e. rated on a scale from 5 to 0). The scores are presented in Table 6.37.

Table 6.37. Overall assessment of FARMS

Choice	Mark
Will you use FARMS for your work?	37/42
Will you use FARMS for data reference?	41/42
Please indicate your overall evaluation for FARMS	87/105

The potential user was also provided with space to add any other comments on FARMS. The comments made are the following:

- User friendly
- Very useful tool
- Accuracy depends on quality of data input
- There are some mistakes in defaults but user can change the data and receive results that would need many calculations
- Lower limits have to be added
- Additional research needed for area and cost parameters
- Not sure that some of the defaults are correct but user can change all data to more appropriate values
- It is good to have a software for Cyprus
- It is good to have a software and data for Cyprus; there are some mistakes in defaults but user can change the data
- I do not have much data available for my farm and this was very useful to assess things that would cost a lot if were to be done by a consultant
- There are some mistakes in defaults but user can change the data and receive results that would need many calculations

As it can be seen from the list above, two users identified “some mistakes in defaults”. These two users were contacted and their expert opinion was taken into consideration for the finalisation of the defaults. The comment of one user referred to the waste production of pigs, while the other user commented on the assumption made in the determination of the population of poultry.

Summary from the model evaluation by potential users

According to the replies received from the questionnaires, it appears that some people with experience in data for Cyprus have doubted some of the defaults chosen for FARMS. However, this did not prohibit them from obtaining results, since they had the option to change the defaults to more representative values for their case. On the other hand, users with limited knowledge of anaerobic digestion have found the results very helpful as it provided them with the opportunity to assess the potential benefits of application of AD in their farm. Therefore, an important output of the research and the model is raising awareness on the economic and environmental benefits of anaerobic digestion.

6.4 Conclusions

Verification and validation activities constitute the last stage of a software development process. In this chapter, the work carried out to verify and validate the software tool developed to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level, has been presented.

It has been shown that the tool can provide good estimates for potential biogas and energy production, cost and area requirements. It is a simple software tool to be used by both experts and non-experts for the specific conditions of Cyprus and provides results that include plant sizing and financial analysis, as well as impact on greenhouse gas emissions.

Chapter 7 presents the overall conclusions of the research and recommendations for further work.

CHAPTER 7. Conclusions and recommendations for further work

7.1 Introduction

The aim of this work was to study the quantities and distribution of biodegradable waste in Cyprus and develop the necessary methodologies and tools for their estimation and determination of the potential for energy production through anaerobic digestion.

The main objectives were: i) assessment of biodegradable waste in Cyprus; ii) estimation of on-farm energy consumption in agriculture and respective GHG emissions; iii) assessment of application of anaerobic digestion in Cyprus and iv) develop a software tool to assess the potential for energy production and mitigation of GHG emissions from livestock production at farm level.

The current practices for the management of biodegradable wastes have been identified and the potential amount of solid and liquid biomass of the specified waste streams has been estimated. The potential contribution of biodegradable waste has been assessed with regards to GHG emissions and renewable energy production.

Methodologies for the estimation of the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport) and the associated GHG emissions have been developed. These methodologies were then used to estimate on-farm fossil fuel and electricity consumption for livestock production in Cyprus and the GHG emissions caused from on-farm energy consumption.

The potential of biogas production and the respective thermal and electrical energy which could be produced has been estimated. Methodologies have also been developed to estimate the cost and area requirements for anaerobic digestion in Cyprus.

Available models for the estimation of biogas from livestock production have been assessed to examine their functionality and the methodologies and default values of parameters used. A tool has then been developed for Cyprus which includes plant sizing and financial analysis and also considers both the cost and greenhouse gas emissions.

7.2 Main conclusions

The main conclusions of this work are as the following:

- The predominant biodegradable wastes identified in Cyprus are the biodegradable fraction of municipal solid waste (MSW), sewage sludge, solid and liquid agricultural residues and solid and liquid wastes from the food and drinks industries. According to the estimated amount of solid and liquid biomass from these waste streams, there is a great potential in Cyprus to utilise biodegradable waste for the production of energy. This should be further considered by the policy makers of the country, since there is a significant possibility that further GHG emission reduction targets will be imposed by the EU. Policy makers should take into consideration the cost per unit reduction of GHG emissions that could be achieved and identify appropriate support mechanisms. The GHG emissions from both agriculture and waste can be reduced through the introduction of waste to energy technologies.
- It has been estimated that introducing biodegradable waste to energy technologies in Cyprus could contribute 4,200 TJ (minimum of AD) to 60,700 TJ

(thermal treatment) of energy to the energy balance of the country from a renewable energy source. The gross consumption of primary energy in Cyprus during 2011 was 112,000 TJ (Eurostat, 2013). Therefore, the utilisation of biodegradable waste for the production of energy could contribute between 4% and 54% of the total energy demand of the country. Such energy production would contribute considerably towards the achievement of the national renewable energy targets.

- Comparing the two available options for the production of energy from animal wastes; i.e. thermal treatment Vs. anaerobic digestion, anaerobic digestion could be considered more appropriate for Cyprus as, not only it allows farmers to meet the waste disposal obligations, but also provides high quality fertiliser.
- Given the spatial distribution of biodegradable waste production in the country, policy makers should consider the promotion of centralised systems in areas of large biodegradable waste production. Such installations would particularly benefit the farmers financially since (a) more than one farm would have to make the investments for the installation and (b) the transport of waste could take place through pipelines due to the short distances.
- On-farm energy consumption is becoming increasingly important in the context of rising energy costs and concerns over greenhouse gas emissions. It has been identified that there is a lack of systematic research on energy use by agriculture in Cyprus, which makes benchmarking and decisions on investment to improve energy efficiency difficult.
- The methodology developed for the estimation of the on-farm consumption of fossil fuels and electricity for livestock production (excluding transport) is simple and uses internationally accepted emission factors for the estimation of emissions (IPCC, 1996; 2006). The methodology has been applied to the conditions and activity data of Cyprus to estimate the contributions of: (a) livestock production to national energy consumption and, (b) on-farm energy consumption to the total GHG emissions from livestock production.
- Overall, the estimated annual energy consumption per animal was found to be lower than most other countries, due to favourable weather conditions in Cyprus which reduces the energy consumption for heating.
- The results for GHG emissions showed that the emissions from energy use in livestock production contribute 16% to the total agricultural energy emissions.

Even though GHG emissions from direct energy use is small, considerable improvements in energy efficiency can be achieved , including application of renewable energy technologies, to reduce farm-operating costs, improve air quality and reduce GHG emissions. Energy conservation is especially important in Cyprus, where fossil fuels, particularly fuel oil, remain the primary source of electrical generation.

- The information collected and presented concerning AD, confirm the complexity of the process, due to the many microorganisms involved. A small change in the conditions of the digestion or the type of wastes digested can affect considerably the process and result in a reduction of biogas production. Nevertheless, there are general relations that can provide estimates of biogas production from the process. Three methods were developed based on the accepted relations that exist between Chemical Oxygen Demand (COD), volatile solids (VS), waste digested and biogas production. These methods were applied to estimate the potential biogas production from animal waste in Cyprus. Consequently, the amount of potential thermal and electrical energy was estimated assuming that all biogas produced was combusted. The results show that livestock production waste can make a considerable contribution to the renewable energy targets of Cyprus.
- Two important parameters that have to be considered before investment in AD of livestock waste are operational and capital cost, and area requirements. Data has been collected for AD installations in Cyprus and relationships between cost and area have been developed.
- To overcome deficiencies of existing models, a software tool, FARMS has been developed, for the conditions in Cyprus. The tool can be used by any farmer or consultant for the estimation of the potential of biogas production, associated costs, reduction in GHG emissions and comparison of scenarios for waste management. This tool will help accelerate the implementation of AD for both waste management and energy demand reduction for the island.
- Throughout the development of FARMS and after the completion of the software development phase, validation and verification activities have been carrying out. These activities continued when the software development was completed, through comparison of FARMS results with data collected from existing anaerobic digesters in Cyprus, and testing by potential users. The final version of FARMS is included in this thesis in a compact disc. The tool provides good

estimates for potential biogas and energy production, cost and area requirements. The validation demonstrates that the goal to develop a simple software tool for the conditions of Cyprus that provides plant sizing and financial analysis for AD while taking into consideration both the cost and the greenhouse gas emissions has been achieved.

7.3 Recommendations for Further Work

The following areas are recommended for further investigation:

(a) A large scale study can be performed to collect data from farms concerning the amount of waste generated per animal according to the stage of its life, the energy consumption at the farm and the resulting greenhouse gas emissions.

As it has already been mentioned during this thesis, there is a large problem associated with data availability in Cyprus regarding waste production and energy consumption. Even though an estimation has been made through this work for waste generation and energy consumption per animal, data has to be collected at the source and monitored for a period of time to study any fluctuations that exist.

This work could be performed through an official survey of the National Statistical Service or a collaboration of the Department of Environment and the Energy Service with an academic or research institution. Another option for the data collection of waste production is the collaboration of the Department of Environment with the private and public veterinary services that have a continuous and close collaboration with farmers.

(b) The software application has been developed for two anaerobic technologies (complete mixed and anaerobic lagoon). The necessary characteristics could be collected and methodologies could be developed to include additional digester technologies such as anaerobic filters, plug-flow anaerobic digester or upflow anaerobic sludge blanket digestion in the software.

The software application and the underlying methodologies also assume mixing is performed with mechanical means. Similarly, it can be further developed to include the effect of the intensity of mixing or alternative technologies for mixing (e.g. mixing with the biogas produced instead of mechanical mixers),

Additionally, the model can be developed further to include more details for the treatment of the waste before and after anaerobic digestion. For example, include mechanical separation or chemical pre-treatment as a step before the anaerobic digester and aerobic treatment after the digester.

Such improvements of the model will allow more accurate results, especially for cost and area requirements.

(c) The software application can also be developed for more animal species and additional waste streams that are suitable for anaerobic digestion, which will allow its wider use.

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Appendices

Appendix A1: Publications in Journals

Appendix A1: Publications in Journals (decision pending)

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Appendix A2: Publications in Conference proceedings

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Direct energy use in the livestock-breeding sector of Cyprus

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Abstract: Energy consumption for most sectors in Cyprus is not well monitored and therefore their impact on greenhouse gases emissions has never been estimated. Thus, the aim of this study was to estimate the energy consumption in livestock breeding activities in Cyprus, and estimate the respective emissions of greenhouse gases. The energy consumption considered is related to all direct energy uses on a farm except transport. All data available from national sources have been taken into account and the consumption of energy per animal was estimated to be 401 kWh/cow, 624 kWh/sow and 0.618 kWh/chicken. The direct energy consumption in livestock breeding was estimated to be 53 GWh for 2008. The greenhouse gas emissions from this were estimated to be 15.6 kt CO_2 equivalent of which 91% is CO_2. The contribution of livestock breeding to the total agricultural energy consumption has been found to be 10-15%. Comparing the energy consumption per animal to other countries in a sample for which data was available, the consumption for Cyprus has been found for all animal species to be lower, mainly due to the warmer climatic conditions.

Keywords: *Direct energy consumption, Livestock breeding, Cyprus, Greenhouse gases emissions*

1. Introduction

Sustainability, energy and climate change during the recent years are increasingly gaining political attention. The European Union has already set legally regulated targets on climate and energy in June 2009 [1] and has just recently agreed to the new sustainability and financial strategy of the Union, the EU2020 [2] which also includes climate and energy targets. Currently, there are several legal obligations in the European Union at country level and installation level that require baseline data on sectoral energy consumption to be available. Decision 406/2009/EC [3] is among those obligations that requires Member States of the European Union to reduce greenhouse gases emissions from sectors not included in the European emissions trading system, i.e. waste, agriculture, transport, energy use in household and services and agriculture. Cyprus is facing a large deficiency in statistics for several sectors, among which the energy sector. One source of greenhouse gases emissions for which a target has been set by Decision 406/2009/EC [3] is energy use by livestock breeding.

The uses of energy in a farm can be classified into direct and indirect [4]. Direct energy use is associated with the consumption of energy (fuels and electricity) in a farm. Indirect energy use is the energy consumed for the production and transport of materials used in a farm (e.g. feed and machinery). 70% of total energy use on dairy cattle and pig farms is for indirect uses [5].

Traditionally, animal farming in Cyprus was characterized by small; family ran units, spread throughout the island, but the increasing demand in meat and other products, the production of genetic material and the automation introduced in the production, have caused an increase in animal farming, which have caused certain areas of the island to have high animal density. A typical animal farm in Cyprus, as in the rest of the world, consists of one or more buildings distinguished in three types: animal breeding areas, support buildings and waste treatment and storage areas. In most areas in Cyprus, electricity is supplied by the central network of the solely electricity provider, the Electricity Authority of Cyprus (EAC). Electricity in Cyprus is produced predominately by heavy fuel oil (HFO), with only a small amount produced by diesel [6]. It is expected that by 2014, natural gas will also be available for use. The most commonly used fuel in farms in Cyprus is diesel, which is mainly used for heating of the housing areas. During the last years the consumption of Liquid Petroleum Gas (LPG) for heating is rapidly increasing.

Not much data is readily available on energy consumption for livestock breeding in Cyprus. This paper brings together all the available data for stationary uses of energy for cattle, pig and poultry farming in Cyprus. Based on this data, the total energy consumption is estimated for the total population of the three animal species in Cyprus for 2005-2008. For 2008 the greenhouse gases emissions are also estimated and compared to other sources of emissions. Finally, results for both energy consumption and greenhouse gases emissions are compared to international literature.

2. Methodology

The main stages of the methodology applied are presented in Figure 1: (a) estimation of total energy consumption, (b) estimation of energy consumption according to source of energy and (c) estimation of the greenhouse gases emissions.

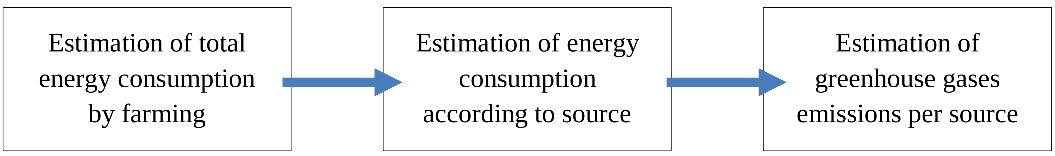


Fig. 1. Methodology implemented for the estimation of greenhouse gases emissions from energy consumption in livestock breeding in Cyprus.

2.1. Estimation of direct energy use from livestock breeding of Cyprus

The main sources of available data in Cyprus is limited to environmental impact assessment reports for animal farms submitted to the Department of Environment according to the Cyprus Law No. 140(I)/2005 on the assessment of environmental impacts from works [7] and annual reports submitted by installations that are above the benchmarks of the Integrated Pollution Prevention (IPPC) Directive [8]. Table 1 summarises the weighted energy consumption per animal in Cyprus as these were reported by the sources presented above; i.e. total amount of energy divided by total number of animals.

Table 1. Annual energy consumption per animal in Cyprus.

	Dairy cattle farms (kWh/cow)	Pig farms (kWh/sow)		Chicken farms (kWh/chicken)	
	178^{*}	763^{+}	1015^{+}	0.741^{+}	0.500^{+}
	908^{*}	1282^{+}	244^{+}	0.498^{+}	0.292^{+}
	610^{*}	918^{+}	1742^{*}	0.578^{+}	0.344^{+}
		892^{+}	64^{*}	0.592^{+}	0.760^{*}
		181^{+}	328^{*}	layer chicken 0.864 [10,11]	
		1087^{+}	111^{*}	broiler chicken 0.644 [10,11]	
		225^{+}	227^{*}		
Weighted Average	401	624		0.618	

+ data submitted by installations that are above the IPPC levels for 2008 [9]
* data submitted for new installations according to the Environmental Impact Assessment report prepared [10]

Using the average annual energy consumption per animal in Cyprus of 401 kWh/cow, 624 kWh/sow and 0.618 kWh/chicken and using the animal population for 2005 - 2008, the total energy consumption for animal breeding of cattle, pigs and chicken in Cyprus for the same period was estimated by multiplying the animal population by the per animal consumption (Table 2). The animal population data used was according to the latest published annual animal population census of the Department of Agriculture [12]. The results of Table 2 were also based on the following assumptions:

(a) Layer chicken and broiler chicken have the same, average energy consumption because not sufficient data was available for the population of each type.
(b) Dairy cows and other cattle were assumed to have the same energy consumption per animal because in Cyprus the animals are in the same farms.
(c) Goats and sheep are not taken into account for the estimation of the total energy consumption by livestock breeding in Cyprus because no data is available yet.
(d) No distinction is made into breeding methods and waste management technologies used.
(e) Energy consumption of waste management technologies is also included in the energy consumption of the farm.
(f) Both gestating and farrowing sows have been considered for the population of sows because the difference in energy consumption is small to be taken into consideration.

Table 2. Animal population and total energy consumption from livestock breeding in Cyprus for 2005 - 2008.

	Animal population (x1000)				Annual energy consumption (GWh)			
	2005	2006	2007	2008	2005	2006	2007	2008
Cattle	57.6	56.1	54.9	55.9	23.1	22.5	22.0	22.4
Sows	61.4	64.7	64.3	46.6	38.3	40.4	40.2	29.1
Chicken	3007	2763	2800	2820	1.9	1.7	1.7	1.7
Total					63.3	64.6	63.9	53.3

2.2. *Estimation of greenhouse gas emissions from direct energy use in livestock breeding of Cyprus*

The distribution of energy consumption according to source (Table 3) was estimated using the average energy breakdown according to the IPPC annual reports for pig and chicken farming [9].

Table 3. Average energy breakdown of energy consumption in Cyprus for chicken and pig farms according to IPPC annual reports [9]

	Electricity	Diesel	LPG
Cattle*	28.5%	44.8%	26.7%
Pigs	28.7%	48.3%	23.0%
Chicken	28.3%	41.3%	30.4%

* cattle farms energy consumption = average of pigs and chicken due to lack of data

Using the emission factors of the greenhouse gases and the fuel densities proposed as default by the IPCC 2006 guidelines [13], the CO_2 emission factors from electricity production based on the weighted average specific emissions of the electricity producing units of Cyprus [6], and the global warming potentials proposed by the 1996 IPCC guidelines [14], the emissions of a specific greenhouse gas by an animal species (GHG_{animal}) were estimated by equation 1 in t CO_2 equiv.

$$GHG_{animal} = (EF_{GHG})_{fuel} \times EC_{fuel} \times GWP_{GHG} \quad (1)$$

where $(EF_{GHG})_{fuel}$= emission factor for a specific gas for a specific energy source (or fuel), t/TJ and GWP_{GHG}= is the global warming potential of a specific gas. The energy consumption of a specific energy source (or fuel), in (EC_{fuel}) was estimated by Eq.2:

$$EC_{fuel} = (\%_{fuel})_{animal} \times EC_{animal} \quad (2)$$

where $(\%_{fuel})_{animal}$ = percent contribution of a specific energy source (or fuel) to the total energy (or fuel) consumption of an animal species, % and EC_{animal} is the total energy (or fuel) consumption of an animal species, TJ. All the data used is presented in Table 4.

Table 4. Parameters used for the estimation of GHG emissions

Parameter in Eq.1	Description	Value
$(EF_{CO2})_{electricity}$	Electricity CO_2 EF*	78.94 t/ TJ [6]
$(EF_{CH4})_{electricity}$	Electricity CH_4 EF	3 kg/ TJ [13]
$(EF_{N2O})_{electricity}$	Electricity N_2O EF	0.6 kg/TJ [13]
$(EF_{CO2})_{diesel}$	Diesel CO_2 EF	74.1 t/ TJ [13]
$(EF_{CH4})_{diesel}$	Diesel CH_4 EF	10 kg/ TJ [13]
$(EF_{N2O})_{diesel}$	Diesel N_2O EF	0.6 kg/TJ [13]
$(EF_{CO2})_{LPG}$	LPG** CO_2 EF	63.1 t/ TJ [13]
$(EF_{CH4})_{LPG}$	LPG CH_4 EF	5 kg/ TJ [13]
$(EF_{N2O})_{LPG}$	LPG N_2O EF	0.1 kg/TJ [13]
GWP_{CO2}	GWP*** of CO_2	1 [14]
GWP_{CH4}	GWP of CH_4	1 t CH_4 = 21 t CO_2 eq. [14]
GWP_{N2O}	GWP of N_2O	1 t N_2O = 296 t CO_2 eq. [14]
	Energy conversion	3600 kJ/kWh [13]
	Diesel Energy content	43 TJ/ Gg [13]
	Diesel Density	0.85 kg/l [13]
	LPG Energy content	47.3 TJ/ Gg [13]
	Butane liquid density	0.57-0.58 kg/l [13]
	Propane liquid density	0.50-0.51 kg/l [13]

* EF = emission factor, ** LPG = liquid petroleum gas, *** GWP = global warming potential

3. Results and Discussion

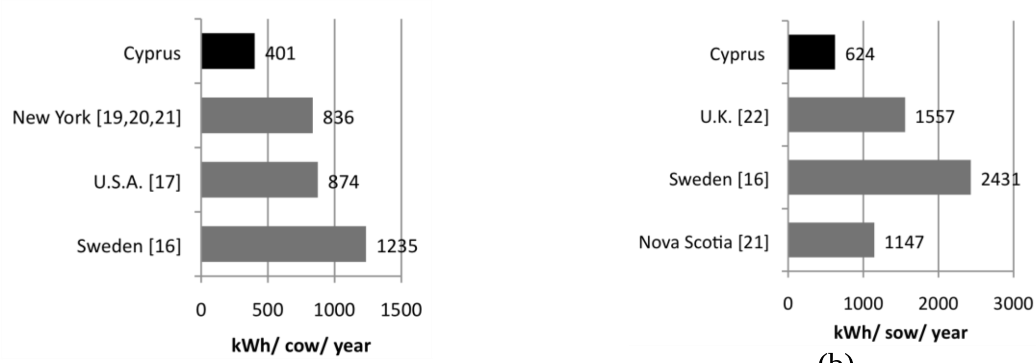
Data collected from the available studies and reports in Cyprus, have shown that energy consumption per animal varies considerably among farms. The available data has a very large range for all animal species, i.e. 178 - 908 kWh/cow, 64 - 1742 kWh/sow, 0.292 – 0.760 kWh/chicken. Nevertheless, the average of the results are reasonable when compared to other countries and the total contribution of the sector to energy consumption by agriculture.

3.1. Contribution of livestock breeding to agricultural energy uses

Comparing the results obtained for livestock breeding energy consumption (Table 2) to the total energy consumption by agriculture [15], the contribution of direct energy use in livestock breeding to the total energy consumption by agriculture has been found to decrease from 14% in 2005 to 11% in 2008. The energy consumption by livestock breeding has reduced considerably from 63 GWh in 2005 to 53 GWh in 2008, due to a decrease in the animal population, which is probably due to the increase in imports of meat. The total energy consumption of the sector has increased from 439 GWh in 2005 to 504 GWh in 2008, probably due to the change in climate conditions. The years of 2006 to 2008 were years with extensive droughts in Cyprus. This has caused the cultivations to require more artificial irrigation since natural precipitation was very limited. Consequently, the energy demand for the irrigation systems was larger. Additionally, the number of small desalination plants installed for agricultural use in coastal areas where saline intrusion takes place has been increasing during the last few years. This has been again caused by the reduction in precipitation and the need for farmers to use their already exhausted water extracting boreholes.

3.2. Comparison of direct energy consumption in livestock breeding in Cyprus to other countries

Cattle in most farms throughout the world are field-grazing most of the time of the year. When the cows are collected indoors due to weather conditions, the housing areas are closed. Therefore energy for ventilation and lighting is needed. In the case of Cyprus cattle is kept in the open but restricted areas instead of fields. With no lighting and ventilation used, energy per animal is considerably less. The comparison is presented in Fig. 2(a).



(a) (b)

Fig. 2. Annual energy consumption for various countries compared to energy consumption in Cyprus (a) per dairy cow found and (b) per sow for farrow to finish.

Figure 2(b) presents the Nova Scotia [18], U.K. [19] and Sweden [16] consumption per sow compared to Cyprus. Cyprus has the smallest consumption among the four areas. This is due to the reason that in pig farming most of the energy demands is for heating. Therefore, in Cyprus, where heating days are significantly less than Nova Scotia [18], U.K. [19] and Sweden [16], the energy demand is also significantly less compared to the same countries.

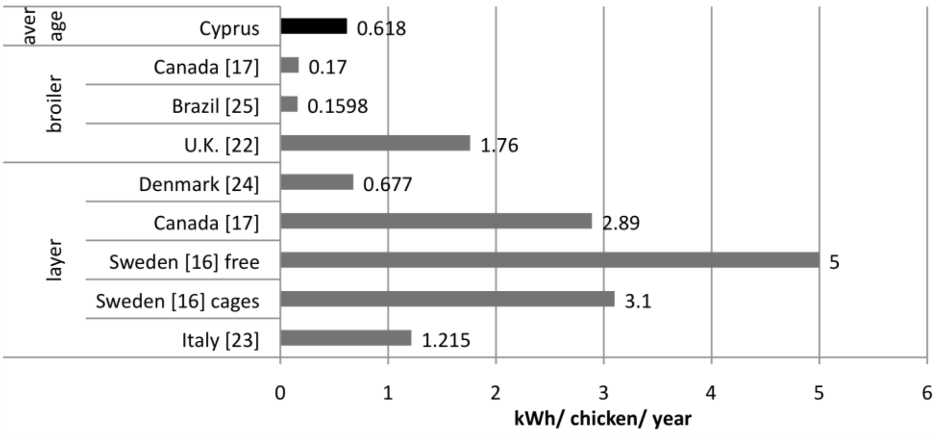


Fig. 3. Annual energy consumption per chicken for various countries compared to energy consumption in Cyprus for layer and broiler chicken.

The energy consumption estimated for chicken farming (Fig. 3) appears not very dissimilar to other countries. Most of the energy consumption is expected to be during summer for ventilation purposes as in Italy [20]. The per-chicken consumption of Denmark [21], Brazil [22] and Canada [17] is smaller than Cyprus. A probable reason for this is that Denmark has well-developed technologies and therefore higher efficiency in energy consumption than Cyprus. For Brazil and Canada the smaller energy consumption could be due to differences in the methods of breeding.

3.3. Greenhouse gas emissions from energy consumption in livestock breeding

The total GHG emissions from energy consumption in livestock breeding have been estimated to be 15.26 kt CO_2e for 2008 of which 91% is CO_2. For the same year other agricultural greenhouse gas emissions according to the Greenhouse Gas Inventory of the country were 348 kt CO_2e [24]. The emissions according to gas and energy sources are presented in Table 5. The larger emissions are CO_2 emissions from diesel consumption in cattle and pig farming, which correspond to 21% and 29% of the total emissions respectively. Energy related emissions contribute approximately 3% to the total for cattle, 2% for pigs and 1.4% for poultry. Comparing the results to emissions from total agricultural use of energy, energy use in livestock breeding contributes 4% to the total agricultural emissions and 13% to the total agricultural energy emissions. This result is supported by the estimations of "Compassion in world farming" [23] where energy contributes 2% to the total livestock emissions.

Table 5. GHG emissions from direct energy consumption in livestock breeding in Cyprus according to gas and energy source, 2008.

	Cattle	Pigs	Poultry	TOTAL
CO_2 from Electricity, t	1,816	2,375	140	4,331
CO_2 from Diesel, t	2,679	3,752	192	6,624
CO_2 from LPG, t	1,360	1,521	120	3,002
Total CO2, t	5,855	7,649	453	13,956
CH_4 from Electricity, kg	69	90	5	165
CH_4 from Diesel, kg	362	506	26	894
CH_4 from LPG, kg	108	121	10	238
Total CH_4, kg	538	717	41	1,296
N_2O from Electricity, kg	14	18	1	33
N_2O from Diesel, kg	1,608	2,251	115	3,974
N_2O from LPG, kg	136	152	12	300
Total N_2O, kg	1,757	2,421	128	4,307
Total GHG from Electricity, kt CO_2 equiv.	1.82	2.38	0.14	4.34
Total GHG from Diesel, kt CO_2 equiv.	3.16	4.43	0.23	7.82
Total GHG from LPG, kt CO_2 equiv.	1.40	1.57	0.12	3.10
TOTAL GHG, kt CO_2 equiv.	6.39	8.38	0.49	15.26

4. Conclusions

In Cyprus, the annual consumption per animal was estimated to be 401 kWh/cow, 624 kWh/sow and 0.618 kWh/chicken. The estimates were based on available data for Cyprus. According to these figure, the direct energy consumption in livestock breeding of cattle, pigs and poultry is estimated at 53 GWh for 2008, which corresponds to 10-15% of the total agricultural energy consumption. Comparing the energy consumption per animal to other countries in the sample used in the study it was found that energy consumption per animal for Cyprus was, on average, lower. Energy consumption for cows was much lower than the countries for which data was available (Canada, Nova Scotia, U.K., Sweden) mainly because the majority of energy consumption in these countries is for heating which is not needed in Cyprus due to the relatively warm weather conditions. For chicken farming, the results are comparable to Italy, since a large portion of the country has similar climatic conditions to Cyprus (hot and dry).

Using the emission factor of each greenhouse gas according to fuel type proposed by the IPCC 2006 guidelines [13] and for electricity as proposed by national specific data by the Electricity Authority of Cyprus [6], the greenhouse gas emissions for each animal species and energy source were estimated. Comparing these to emissions from total agricultural use of energy, the results show that the emissions from energy use in livestock breeding contribute approximately 4% to the total agricultural emissions and 13% to the total agricultural energy emissions.

These results can be used by relevant Cyprus authorities for the assessment of the impact of measures for the reduction of energy consumption and greenhouse gases emissions.

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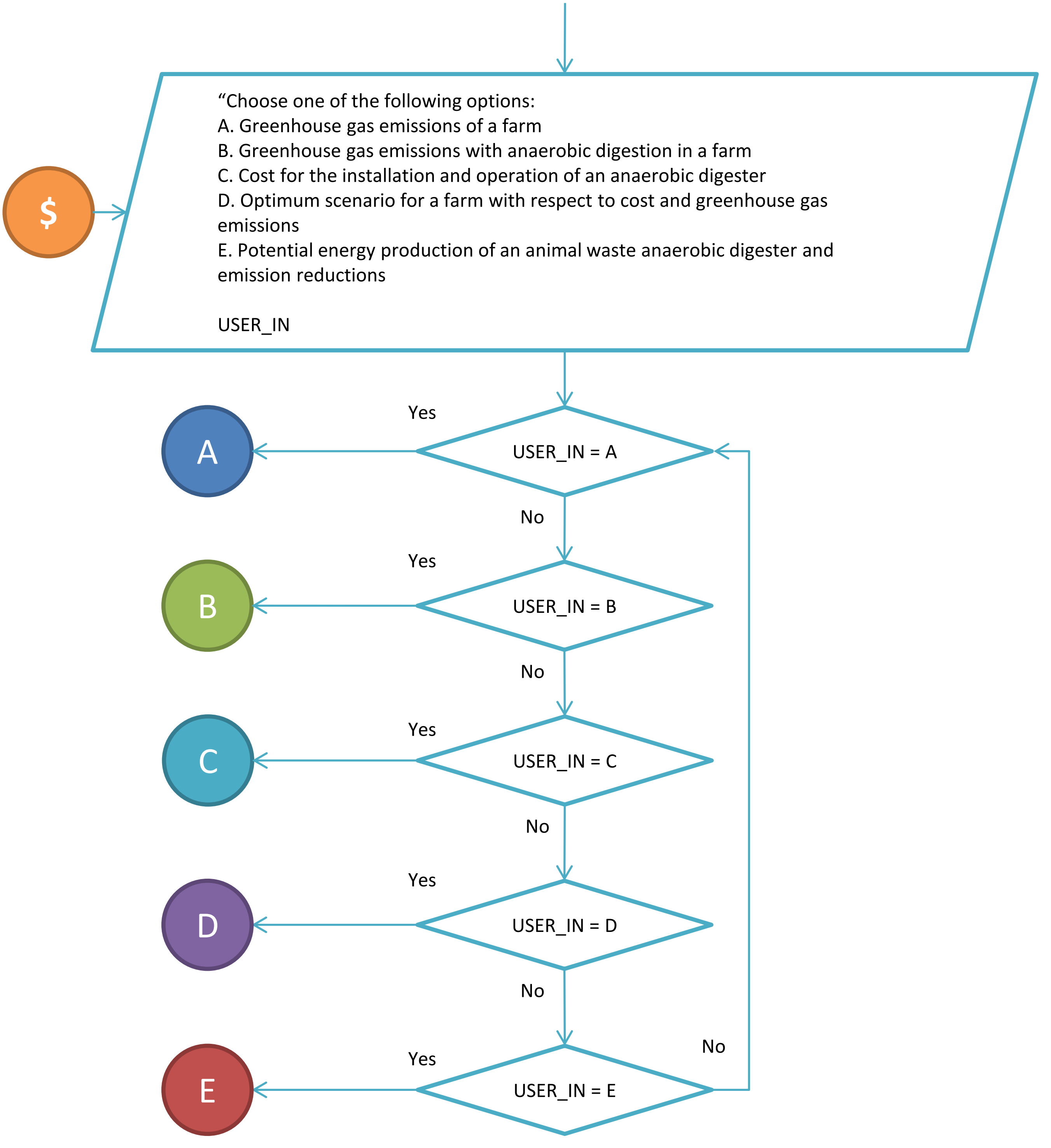
Appendix B: Flow chart for the software development of FARMS

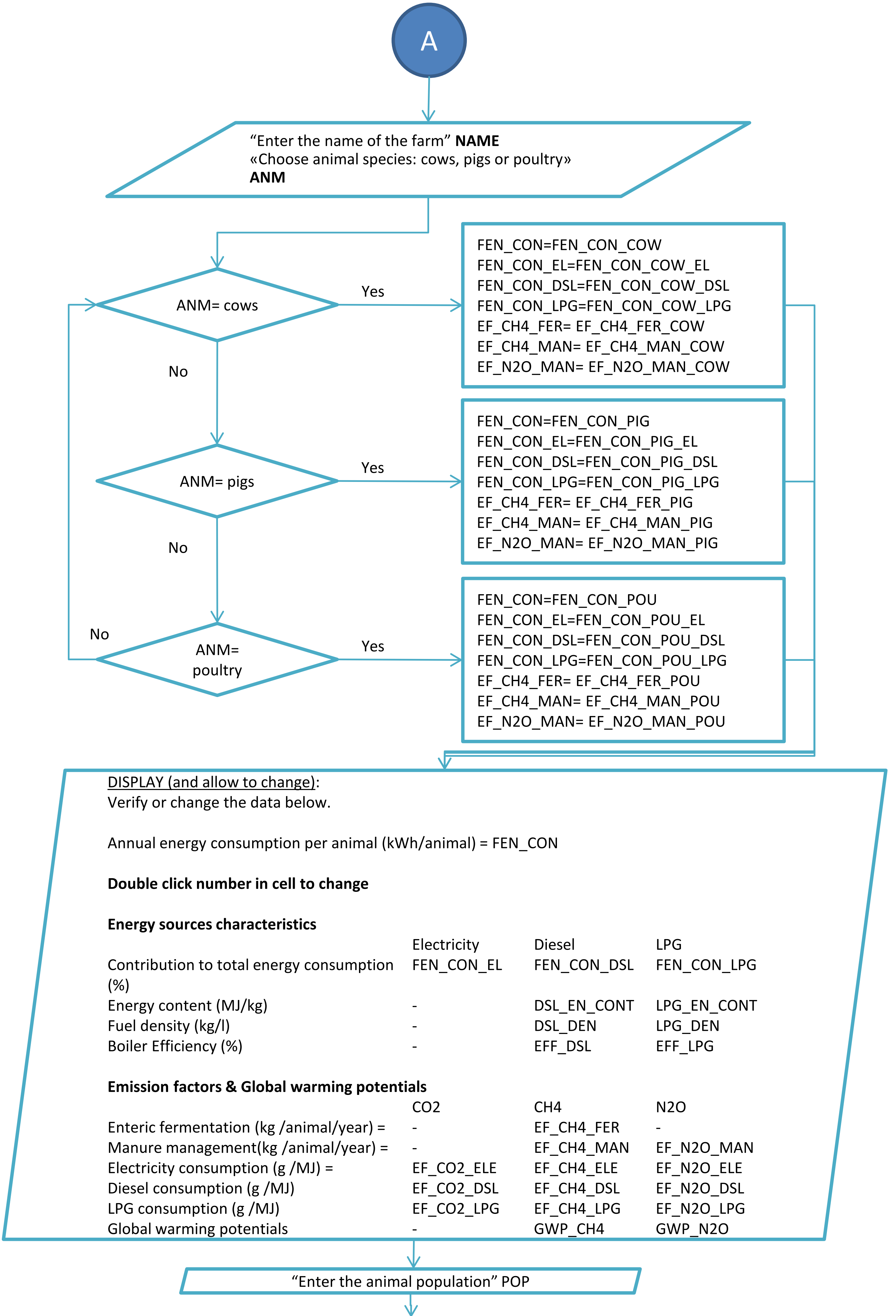
Start

BG_CH4=60
BG_CO2=40
CH4_DEN=0.668
CH4_EN=9.8
CO2_DEN=1.842
DE=95
DEF_ACT_VOL_CM=75
DEF_ACT_VOL_LAG=75
DEF_AD_HEIGHT=6
DEF_AREA_CM=24
DEF_AREA_LAG=7
DEF_CAP_COST_DIG=65
DEF_CAP_COST_OTHER=35
DEF_CH4_TRANS=0.08
DEF_CHP_MAINT_COST=0.011
DEF_CO2_TRANS=774
DEF_COST_TRANS=100
DEF_CTRL_CM=10
DEF_CTRL_LAG=3
DEF_DSL_BPRICE=1.419
DEF_EL_BPRICE=0.16953
DEF_EL_PRICE=0.135
DEF_GEN_MAINT_COST=200
DEF_GF=100
DEF_GHG_COST=2
DEF_IR=1.83
DEF_LAND_PRICE=80
DEF_LAND_RENT=10
DEF_LIFE=20
DEF_LOR_CAP=15
DEF_LPG_BPRICE=0.68
DEF_MAINT_COST=47
DEF_MDR=6.5
DEF_N2O_TRANS=0.30
DEF_OPER_OTHER_COST=5
DEF_OTHAREA_CM=66
DEF_OTHAREA_LAG=90
DEF_OVER=17.5
DEF_PENALTY = 2000
DEF_PER_COST=48
DEF_PER=10
DEF_RATE=10
DEF_RT_CM=20
DEF_RT_LAG=100
DEF_SAF_VOL=25
DEF_TAX=5
DEF_WST_MNG_COST=120
DSL_DEN=0.85
DSL_EN_CONT=43
EF_CH4_DSL=0.01
EF_CH4_ELE=0.003
EF_CH4_FER_COW=79
EF_CH4_FER_PIG=1.5
EF_CH4_FER_POU= 0.03
EF_CH4_LPG=0.005
EF_CH4_MAN_COW=16
EF_CH4_MAN_PIG=10
EF_CH4_MAN_POU=0.117

EF_CO2_DSL=74.1
EF_CO2_ELE=78.94
EF_CO2_LPG=63.1
EF_N2O_DSL=0.0006
EF_N2O_ELE=0.0006
EF_N2O_LPG=0.0001
EF_N2O_MAN_COW=2.357
EF_N2O_MAN_PIG=0.2514
EF_N2O_MAN_POU=0.0188
EFF_DSL=85
EFF_LPG=85
FAD_EN_CON=469
FBG_COD=0.55
FBG_VS=0.867
FBG_WST_COW=20
FBG_WST_PIG=25
FBG_WST_POU=40
FEN_CON_COW_DSL=44.8
FEN_CON_COW_EL=28.5
FEN_CON_COW_LPG=26.7
FEN_CON_COW=565
FEN_CON_PIG_DSL=48.3
FEN_CON_PIG_EL=28.7
FEN_CON_PIG_LPG=23
FEN_CON_PIG=60.6
FEN_CON_POU_DSL=41.3
FEN_CON_POU_EL=28.3
FEN_CON_POU_LPG=30.4
FEN_CON_POU=0.777
FWST_PROD_COW=2.68
FWST_PROD_PIG=3.094
FWST_PROD_POUL=0.01254
GEN_EFF_EL=35
GEN_EFF_TH=50
GWP_CH4=21
GWP_N2O=310
LPG_DEN=0.54
LPG_EN_CONT=47.3
WST_BULK_COW=1.55
WST_BULK_PIG=0.973
WST_BULK_POU=0.546
WST_COD_COW=191
WST_COD_PIG=40
WST_COD_POU=190
WST_TS_COW=14
WST_TS_PIG=5
WST_TS_POU=39
WST_VS_COW=65
WST_VS_PIG=70
WST_VS_POU=63

FARMS
a software developed by N. Kythreotou and A. G. Florides
for the estimation of greenhouse gases by the installation of anaerobic digestion for the treatment of animal waste


"Choose one of the following options:
A. Greenhouse gas emissions of a farm
B. Greenhouse gas emissions with anaerobic digestion in a farm
C. Cost for the installation and operation of an anaerobic digester
D. Optimum scenario for a farm with respect to cost and greenhouse gas emissions
E. Potential energy production of an animal waste anaerobic digester and emission reductions
USER_IN
$
USER_IN = A
USER_IN = B
USER_IN = C
USER_IN = D
USER_IN = E
Yes
No
A
B
C
D
E


A
"Enter the name of the farm" NAME
«Choose animal species: cows, pigs or poultry»
ANM
ANM= cows
Yes
No
FEN_CON=FEN_CON_COW
FEN_CON_EL=FEN_CON_COW_EL
FEN_CON_DSL=FEN_CON_COW_DSL
FEN_CON_LPG=FEN_CON_COW_LPG
EF_CH4_FER= EF_CH4_FER_COW
EF_CH4_MAN= EF_CH4_MAN_COW
EF_N2O_MAN= EF_N2O_MAN_COW
ANM= pigs
Yes
No
FEN_CON=FEN_CON_PIG
FEN_CON_EL=FEN_CON_PIG_EL
FEN_CON_DSL=FEN_CON_PIG_DSL
FEN_CON_LPG=FEN_CON_PIG_LPG
EF_CH4_FER= EF_CH4_FER_PIG
EF_CH4_MAN= EF_CH4_MAN_PIG
EF_N2O_MAN= EF_N2O_MAN_PIG
No
ANM= poultry
Yes
FEN_CON=FEN_CON_POU
FEN_CON_EL=FEN_CON_POU_EL
FEN_CON_DSL=FEN_CON_POU_DSL
FEN_CON_LPG=FEN_CON_POU_LPG
EF_CH4_FER= EF_CH4_FER_POU
EF_CH4_MAN= EF_CH4_MAN_POU
EF_N2O_MAN= EF_N2O_MAN_POU
DISPLAY (and allow to change):
Verify or change the data below.
Annual energy consumption per animal (kWh/animal) = FEN_CON
Double click number in cell to change
Energy sources characteristics
Electricity Diesel LPG
Contribution to total energy consumption (%) FEN_CON_EL FEN_CON_DSL FEN_CON_LPG
Energy content (MJ/kg) - DSL_EN_CONT LPG_EN_CONT
Fuel density (kg/l) - DSL_DEN LPG_DEN
Boiler Efficiency (%) - EFF_DSL EFF_LPG
Emission factors & Global warming potentials
CO2 CH4 N2O
Enteric fermentation (kg /animal/year) = - EF_CH4_FER -
Manure management(kg /animal/year) = - EF_CH4_MAN EF_N2O_MAN
Electricity consumption (g /MJ) = EF_CO2_ELE EF_CH4_ELE EF_N2O_ELE
Diesel consumption (g /MJ) EF_CO2_DSL EF_CH4_DSL EF_N2O_DSL
LPG consumption (g /MJ) EF_CO2_LPG EF_CH4_LPG EF_N2O_LPG
Global warming potentials - GWP_CH4 GWP_N2O
"Enter the animal population" POP

EN_CON=FEN_CON*POP

DISPLAY and allow to change:
Verify or change the data below.
Total annual energy consumption (kWh) = EN_CON

EN_CON_DSL=FEN_CON_DSL*EN_CON*3.6/DSL_EN_CONT/DSL_DEN/EFF_DSL
EN_CON_EL=FEN_CON_EL/100 *EN_CON
EN_CON_LPG=FEN_CON_LPG*EN_CON*3.6/LPG_EN_CONT/LPG_DEN/EFF_LPG

Annual consumption of electricity (kWh)	EN_CON_EL
Annual consumption of diesel (litres)	EN_CON_DSL
Annual consumption of LPG (litres)	EN_CON_LPG

"A word document will be generated with the results and you will return to the main menu"

CO2_EN_DSL=EF_CO2_DSL*EN_CON_DSL*DSL_EN_CONT*DSL_DEN/1000
CH4_EN_DSL=EF_CH4_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
N2O_EN_DSL=EF_N2O_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
CO2_EN_ELE=EF_CO2_ELE*EN_CON_EL*3.6/1000
CH4_EN_ELE=EF_CH4_ELE*EN_CON_EL*3.6/1000
N2O_EN_ELE=EF_N2O_ELE*EN_CON_EL*3.6/1000
CO2_EN_LPG=EF_CO2_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
CH4_EN_LPG=EF_CH4_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
N2O_EN_LPG=EF_N2O_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
GHG_CH4_EN_DSL=CH4_EN_DSL*GWP_CH4/1000
GHG_N2O_EN_DSL=N2O_EN_DSL*GWP_N2O/1000
GHG_CH4_EN_ELE=CH4_EN_ELE*GWP_CH4/1000
GHG_N2O_EN_ELE=N2O_EN_ELE*GWP_N2O/1000
GHG_CH4_EN_LPG=CH4_EN_LPG*GWP_CH4/1000
GHG_N2O_EN_LPG=N2O_EN_LPG*GWP_N2O/1000
GHG_EN_DSL=CO2_EN_DSL/1000+GHG_CH4_EN_DSL+GHG_N2O_EN_DSL
GHG_EN_ELE=CO2_EN_ELE/1000+GHG_CH4_EN_ELE+GHG_N2O_EN_ELE
GHG_EN_LPG=CO2_EN_LPG/1000+GHG_CH4_EN_LPG+GHG_N2O_EN_LPG

GHG_EN=GHG_EN_DSL+GHG_EN_ELE+GHG_EN_LPG

EN_CO2=(CO2_EN_DSL+CO2_EN_ELE+CO2_EN_LPG)/1000
EN_CH4=(CH4_EN_DSL+CH4_EN_ELE+CH4_EN_LPG)/1000
EN_CH4_GHG=EN_CH4*GWP_CH4
EN_N2O=(N2O_EN_DSL+N2O_EN_ELE+N2O_EN_LPG)/1000
EN_N2O_GHG=EN_N2O*GWP_N20

CH4_FER=EF_CH4_FER*POP
GHG_CH4_FER=CH4_FER*GWP_CH4/1000

CH4_MAN=EF_CH4_MAN*POP
GHG_CH4_MAN=CH4_MAN*GWP_CH4/1000
N2O_MAN=EF_N2O_MAN*POP
GHG_N2O_MAN=N2O_MAN*GWP_N2O/1000
GHG_MAN=GHG_CH4_MAN+GHG_N2O_MAN

GHG_TOT=GHG_EN+GHG_MAN+GHG_CH4_FER

CO2_TOT=EN_CO2
CH4_TOT=EN_CH4+(CH4_FER+CH4_MAN)/1000
CH4_TOT_GHG= EN_CH4_GHG+GHG_CH4_FER+GHG_CH4_MAN
N2O_TOT=EN_N2O+N2O_MAN/1000
N2O_TOT _GHG = EN_N2O_GHG+ GHG_N2O_MAN

OUTPUT IN DOC. FILE

ESTIMATION OF ANNUAL EMISSIONS OF GREENHOUSE GASES FOR THE FARM NAME

Animal type: ANM
Animal population: POP

Annual Energy consumption

	Consumption
Electricity	EN_CON_ELE kWh
Diesel	EN_CON_DSL litres
LPG	EN_CON_LPG litres
TOTAL	EN_CON kWh

Annual Emissions from energy consumption (kg)

	CO_2	CH_4	N_2O
Electricity	CO2_EN_ELE	CH4_EN_ELE	N2O_EN_ELE
Diesel	CO2_EN_DSL	CH4_EN_DSL	N2O_EN_DSL
LPG	CO2_EN_LPG	CH4_EN_LPG	N2O_EN_LPG

Annual Emissions from energy consumption (t CO_2 eq.)

	CO_2	CH_4	N_2O	TOTAL
Electricity	CO2_EN_ELE/1000	GHG_CH4_EN_ELE	GHG_N2O_EN_ELE	GHG_EN_ELE
Diesel	CO2_EN_DSL/1000	GHG_CH4_EN_DSL	GHG_N2O_EN_DSL	GHG_EN_DSL
LPG	CO2_EN_LPG/1000	GHG_CH4_EN_LPG	GHG_N2O_EN_LPG	GHG_EN_LPG
TOTAL	EN_CO2	EN_CH4_GHG	EN_N2O_GHG	GHG_EN

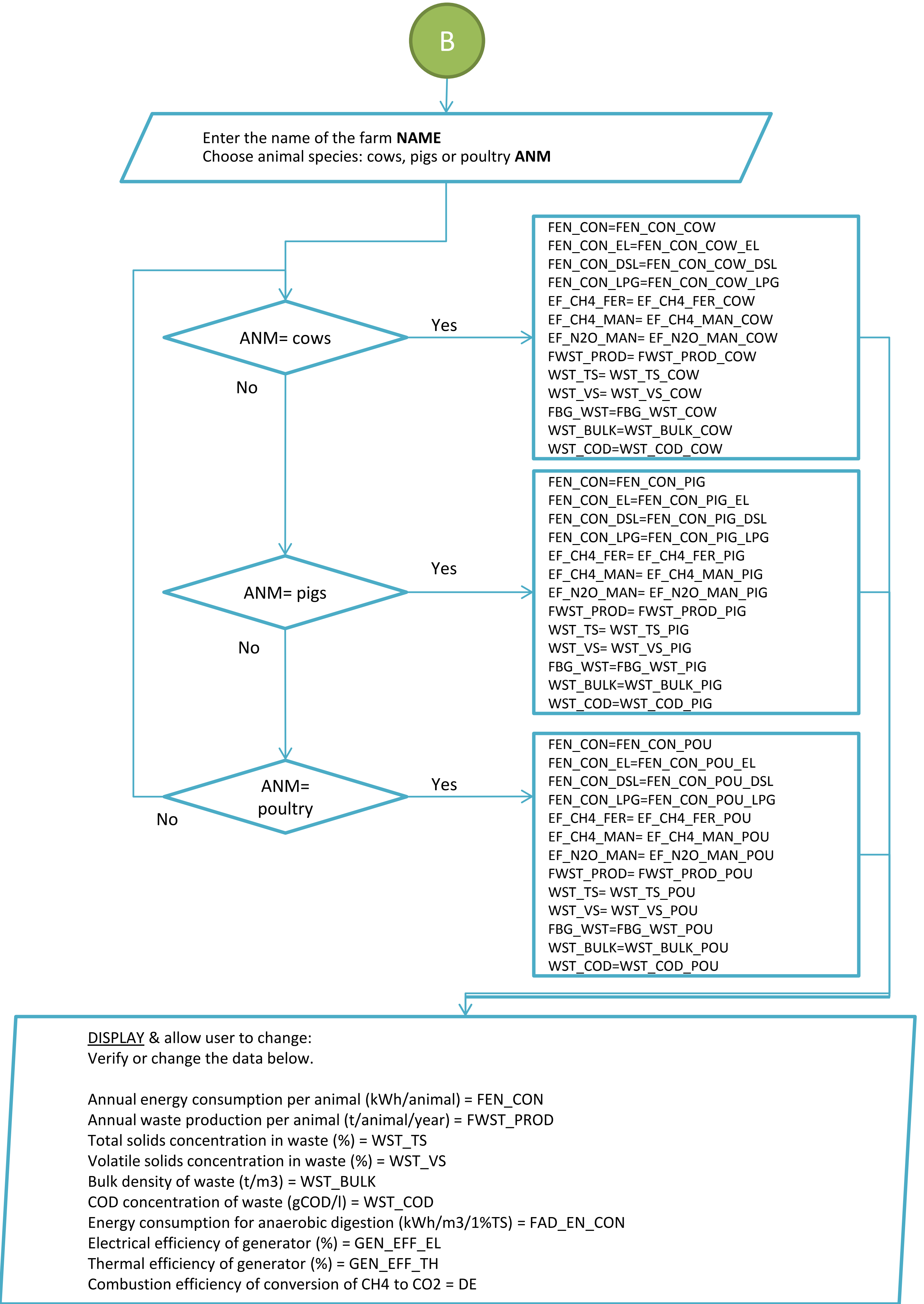
Total annual emissions of greenhouse gases (t)

	Fermentation	Manure management	Energy	TOTAL
CO_2	-	-	EN_CO2	CO2_TOT
CH_4	CH4_FER/1000	CH4_MAN/1000	EN_CH4	CH4_TOT
N_2O	-	N2O_MAN/1000	EN_N2O	N2O_TOT

Total annual emissions of greenhouse gases (t CO_2 eq.)

	Fermentation	Manure management	Energy	TOTAL
CO_2	-	-	EN_CO2	CO2_TOT
CH_4	GHG_CH4_FER	GHG_CH4_MAN	EN_CH4_GHG	CH4_TOT_GHG
N_2O	-	GHG_N2O_MAN	EN_N2O_GHG	N2O_TOT_GHG
TOTAL	GHG_CH4_FER	GHG_MAN	GHG_EN	GHG_TOT

$


B
Enter the name of the farm NAME
Choose animal species: cows, pigs or poultry ANM
ANM= cows
Yes
No
FEN_CON=FEN_CON_COW
FEN_CON_EL=FEN_CON_COW_EL
FEN_CON_DSL=FEN_CON_COW_DSL
FEN_CON_LPG=FEN_CON_COW_LPG
EF_CH4_FER= EF_CH4_FER_COW
EF_CH4_MAN= EF_CH4_MAN_COW
EF_N2O_MAN= EF_N2O_MAN_COW
FWST_PROD= FWST_PROD_COW
WST_TS= WST_TS_COW
WST_VS= WST_VS_COW
FBG_WST=FBG_WST_COW
WST_BULK=WST_BULK_COW
WST_COD=WST_COD_COW
ANM= pigs
Yes
No
FEN_CON=FEN_CON_PIG
FEN_CON_EL=FEN_CON_PIG_EL
FEN_CON_DSL=FEN_CON_PIG_DSL
FEN_CON_LPG=FEN_CON_PIG_LPG
EF_CH4_FER= EF_CH4_FER_PIG
EF_CH4_MAN= EF_CH4_MAN_PIG
EF_N2O_MAN= EF_N2O_MAN_PIG
FWST_PROD= FWST_PROD_PIG
WST_TS= WST_TS_PIG
WST_VS= WST_VS_PIG
FBG_WST=FBG_WST_PIG
WST_BULK=WST_BULK_PIG
WST_COD=WST_COD_PIG
ANM= poultry
Yes
No
FEN_CON=FEN_CON_POU
FEN_CON_EL=FEN_CON_POU_EL
FEN_CON_DSL=FEN_CON_POU_DSL
FEN_CON_LPG=FEN_CON_POU_LPG
EF_CH4_FER= EF_CH4_FER_POU
EF_CH4_MAN= EF_CH4_MAN_POU
EF_N2O_MAN= EF_N2O_MAN_POU
FWST_PROD= FWST_PROD_POU
WST_TS= WST_TS_POU
WST_VS= WST_VS_POU
FBG_WST=FBG_WST_POU
WST_BULK=WST_BULK_POU
WST_COD=WST_COD_POU
DISPLAY & allow user to change:
Verify or change the data below.
Annual energy consumption per animal (kWh/animal) = FEN_CON
Annual waste production per animal (t/animal/year) = FWST_PROD
Total solids concentration in waste (%) = WST_TS
Volatile solids concentration in waste (%) = WST_VS
Bulk density of waste (t/m3) = WST_BULK
COD concentration of waste (gCOD/l) = WST_COD
Energy consumption for anaerobic digestion (kWh/m3/1%TS) = FAD_EN_CON
Electrical efficiency of generator (%) = GEN_EFF_EL
Thermal efficiency of generator (%) = GEN_EFF_TH
Combustion efficiency of conversion of CH4 to CO2 = DE

Double click number in cell to change

Energy sources characteristics	Electricity	Diesel	LPG
Contribution to total energy consumption (%)	FEN_CON_EL	FEN_CON_DSL	FEN_CON_LPG
Energy content (MJ/kg)	-	DSL_EN_CONT	LPG_EN_CONT
Fuel density (kg/l)	-	DSL_DEN	LPG_DEN
Boiler Efficiency (%)	-	EFF_DSL	EFF_LPG

Emission factors, global warming potentials, biogas characteristics

	CO2	CH4	N2O
Enteric fermentation (kg /animal/year)	-	EF_CH4_FER	-
Manure management(kg /animal/year)	-	EF_CH4_MAN	EF_N2O_MAN
Electricity consumption (g /MJ)	EF_CO2_ELE	EF_CH4_ELE	EF_N2O_ELE
Diesel consumption (g /MJ)	EF_CO2_DSL	EF_CH4_DSL	EF_N2O_DSL
LPG consumption (g /MJ)	EF_CO2_LPG	EF_CH4_LPG	EF_N2O_LPG
Global warming potentials	-	GWP_CH4	GWP_N2O
Content in biogas (%)	BG_CO2	BG_CH4	-
Energy content at 100% combustion (kWh/m3)	-	CH4_EN	
Density (kg/m3)	CO2_DEN	CH4_DEN	-

	per tonne waste (m3/t)	per kg VS destroyed (m3/kg VS)	per kg COD consumed (m3/kg COD)
Biogas production coefficients	FBG_WST	FBG_VS	FBG_COD

↓

"Enter the animal population" POP

↓

EN_CON=FEN_CON*POP
WST_PROD=FWST_PROD*POP
AD_EN_CON=FAD_EN_CON*WST_PROD/WST_BULK*(WST_TS/100)
EN_TH=(FEN_CON_DSL/100+FEN_CON_LPG/100)*EN_CON

↓

DISPLAY and allow to change:
Verify or change the data below.
Annual animal waste production (t)=WST_PROD
Total annual energy consumption (kWh) = EN_CON

↓

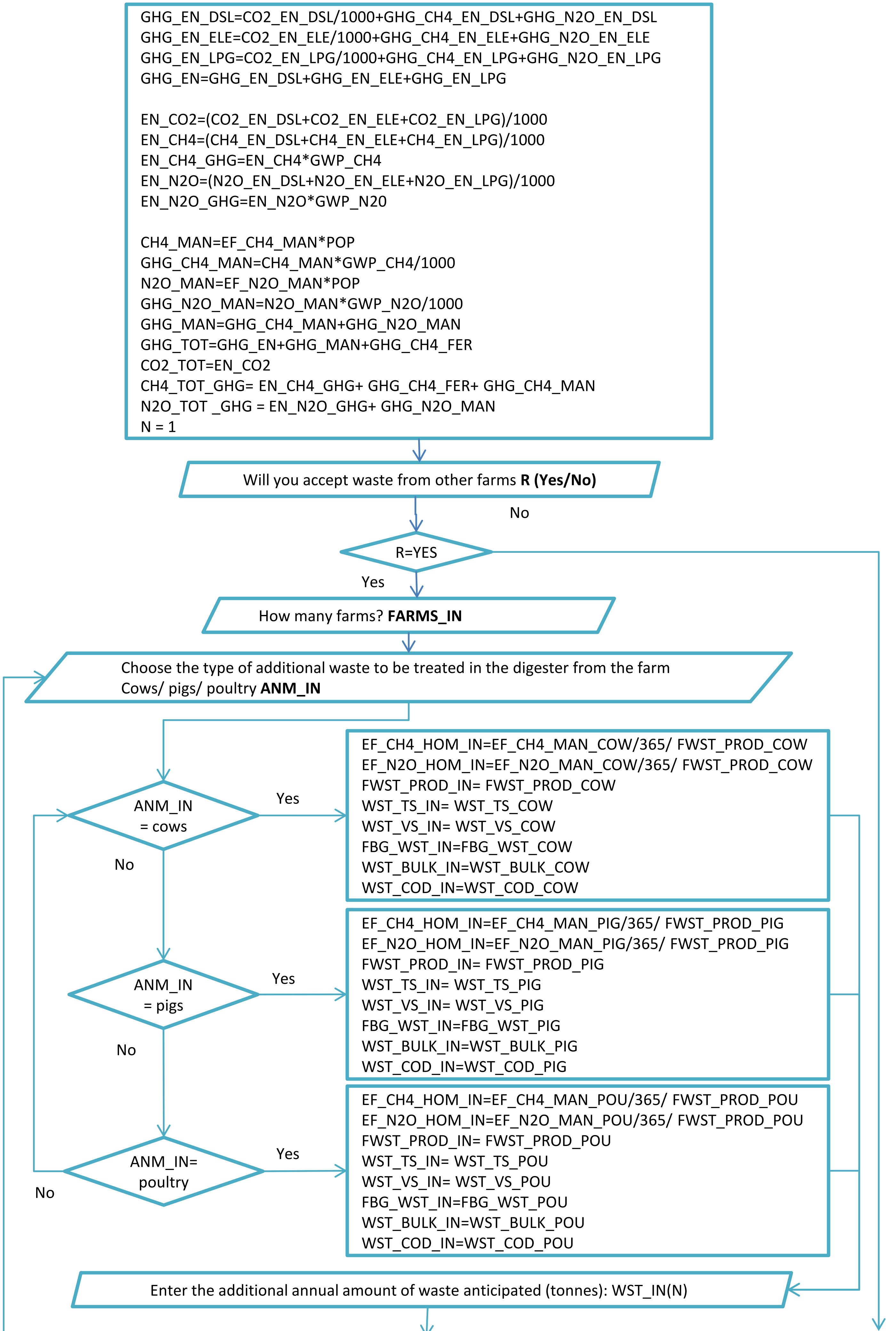
EN_CON_DSL=FEN_CON_DSL*EN_CON*3.6/DSL_EN_CONT/DSL_DEN/EFF_DSL
EN_CON_EL=FEN_CON_EL/100 *EN_CON
EN_CON_LPG=FEN_CON_LPG*EN_CON*3.6/LPG_EN_CONT/LPG_DEN/EFF_LPG

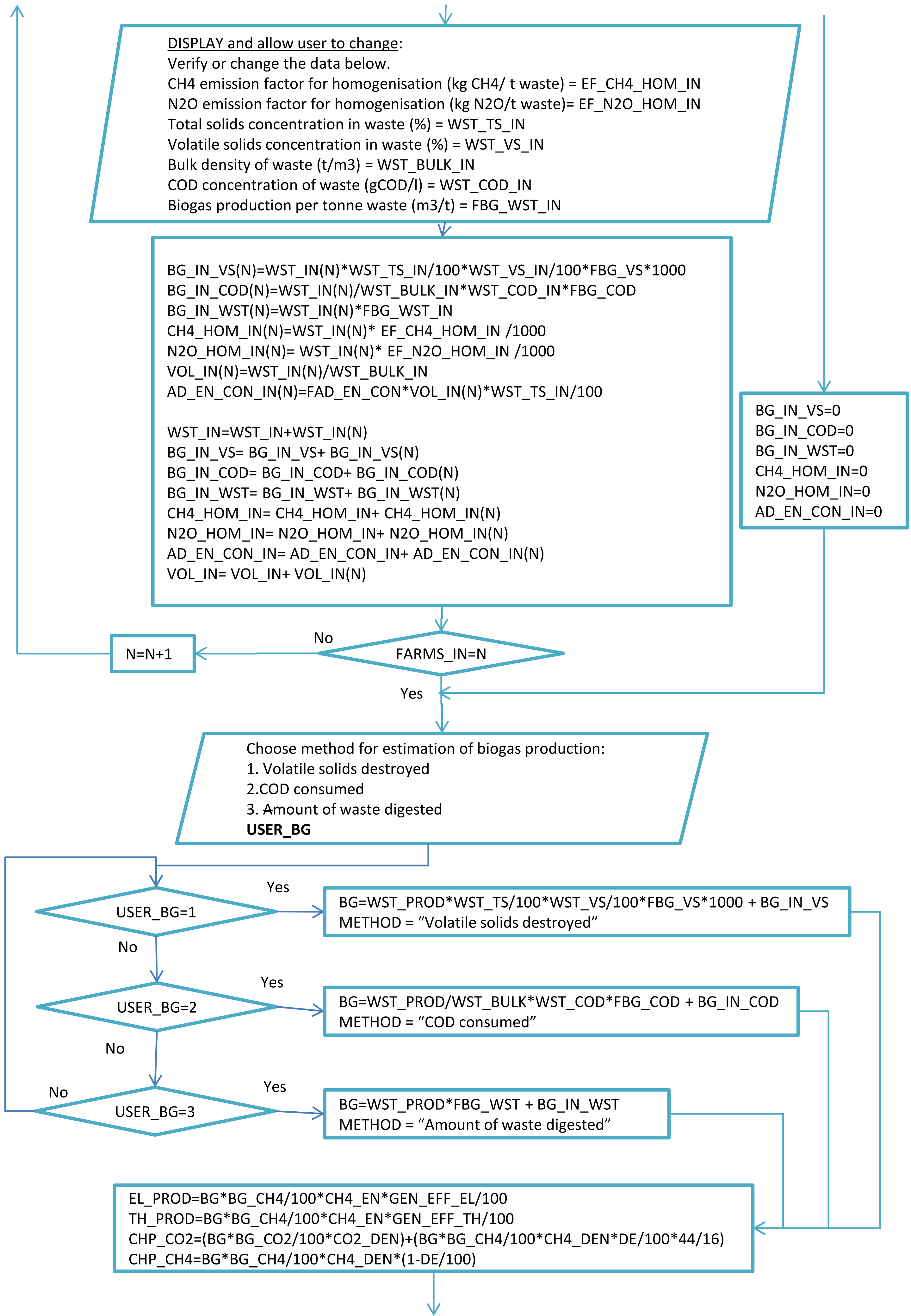
↓

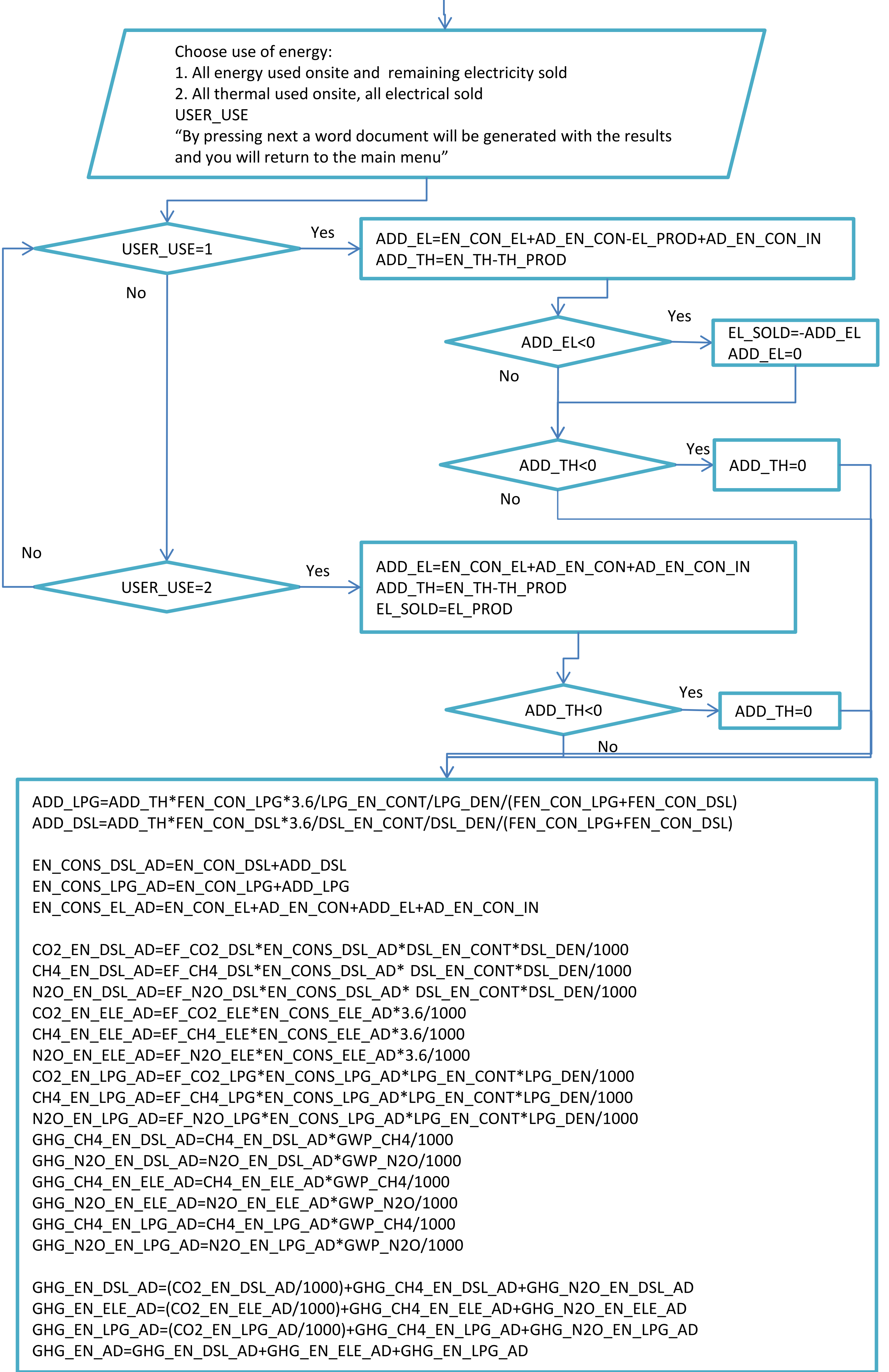
Annual consumption of electricity (kWh) EN_CON_EL
Annual consumption of diesel (litres) EN_CON_DSL
Annual consumption of LPG (litres) EN_CON_LPG
"A word document will be generated with the results and you will return to the main menu"

↓

CO2_EN_DSL=EF_CO2_DSL*EN_CON_DSL*DSL_EN_CONT*DSL_DEN/1000
CH4_EN_DSL=EF_CH4_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
N2O_EN_DSL=EF_N2O_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
CO2_EN_ELE=EF_CO2_ELE*EN_CON_EL*3.6/1000
CH4_EN_ELE=EF_CH4_ELE*EN_CON_EL*3.6/1000
N2O_EN_ELE=EF_N2O_ELE*EN_CON_EL*3.6/1000
CO2_EN_LPG=EF_CO2_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
CH4_EN_LPG=EF_CH4_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
N2O_EN_LPG=EF_N2O_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
GHG_CH4_EN_DSL=CH4_EN_DSL*GWP_CH4/1000
GHG_N2O_EN_DSL=N2O_EN_DSL*GWP_N2O/1000
GHG_CH4_EN_ELE=CH4_EN_ELE*GWP_CH4/1000
GHG_N2O_EN_ELE=N2O_EN_ELE*GWP_N2O/1000
GHG_CH4_EN_LPG=CH4_EN_LPG*GWP_CH4/1000
GHG_N2O_EN_LPG=N2O_EN_LPG*GWP_N2O/1000


GHG_EN_DSL=CO2_EN_DSL/1000+GHG_CH4_EN_DSL+GHG_N2O_EN_DSL
GHG_EN_ELE=CO2_EN_ELE/1000+GHG_CH4_EN_ELE+GHG_N2O_EN_ELE
GHG_EN_LPG=CO2_EN_LPG/1000+GHG_CH4_EN_LPG+GHG_N2O_EN_LPG
GHG_EN=GHG_EN_DSL+GHG_EN_ELE+GHG_EN_LPG
EN_CO2=(CO2_EN_DSL+CO2_EN_ELE+CO2_EN_LPG)/1000
EN_CH4=(CH4_EN_DSL+CH4_EN_ELE+CH4_EN_LPG)/1000
EN_CH4_GHG=EN_CH4*GWP_CH4
EN_N2O=(N2O_EN_DSL+N2O_EN_ELE+N2O_EN_LPG)/1000
EN_N2O_GHG=EN_N2O*GWP_N20
CH4_MAN=EF_CH4_MAN*POP
GHG_CH4_MAN=CH4_MAN*GWP_CH4/1000
N2O_MAN=EF_N2O_MAN*POP
GHG_N2O_MAN=N2O_MAN*GWP_N2O/1000
GHG_MAN=GHG_CH4_MAN+GHG_N2O_MAN
GHG_TOT=GHG_EN+GHG_MAN+GHG_CH4_FER
CO2_TOT=EN_CO2
CH4_TOT_GHG= EN_CH4_GHG+ GHG_CH4_FER+ GHG_CH4_MAN
N2O_TOT _GHG = EN_N2O_GHG+ GHG_N2O_MAN
N = 1
Will you accept waste from other farms **R (Yes/No)**
No
R=YES
Yes
How many farms? **FARMS_IN**
Choose the type of additional waste to be treated in the digester from the farm
Cows/ pigs/ poultry **ANM_IN**
ANM_IN
= cows
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_COW/365/ FWST_PROD_COW
EF_N2O_HOM_IN=EF_N2O_MAN_COW/365/ FWST_PROD_COW
FWST_PROD_IN= FWST_PROD_COW
WST_TS_IN= WST_TS_COW
WST_VS_IN= WST_VS_COW
FBG_WST_IN=FBG_WST_COW
WST_BULK_IN=WST_BULK_COW
WST_COD_IN=WST_COD_COW
ANM_IN
= pigs
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_PIG/365/ FWST_PROD_PIG
EF_N2O_HOM_IN=EF_N2O_MAN_PIG/365/ FWST_PROD_PIG
FWST_PROD_IN= FWST_PROD_PIG
WST_TS_IN= WST_TS_PIG
WST_VS_IN= WST_VS_PIG
FBG_WST_IN=FBG_WST_PIG
WST_BULK_IN=WST_BULK_PIG
WST_COD_IN=WST_COD_PIG
ANM_IN=
poultry
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_POU/365/ FWST_PROD_POU
EF_N2O_HOM_IN=EF_N2O_MAN_POU/365/ FWST_PROD_POU
FWST_PROD_IN= FWST_PROD_POU
WST_TS_IN= WST_TS_POU
WST_VS_IN= WST_VS_POU
FBG_WST_IN=FBG_WST_POU
WST_BULK_IN=WST_BULK_POU
WST_COD_IN=WST_COD_POU
Enter the additional annual amount of waste anticipated (tonnes): WST_IN(N)


DISPLAY and allow user to change:
Verify or change the data below.
CH4 emission factor for homogenisation (kg CH4/ t waste) = EF_CH4_HOM_IN
N2O emission factor for homogenisation (kg N2O/t waste)= EF_N2O_HOM_IN
Total solids concentration in waste (%) = WST_TS_IN
Volatile solids concentration in waste (%) = WST_VS_IN
Bulk density of waste (t/m3) = WST_BULK_IN
COD concentration of waste (gCOD/l) = WST_COD_IN
Biogas production per tonne waste (m3/t) = FBG_WST_IN
BG_IN_VS(N)=WST_IN(N)*WST_TS_IN/100*WST_VS_IN/100*FBG_VS*1000
BG_IN_COD(N)=WST_IN(N)/WST_BULK_IN*WST_COD_IN*FBG_COD
BG_IN_WST(N)=WST_IN(N)*FBG_WST_IN
CH4_HOM_IN(N)=WST_IN(N)* EF_CH4_HOM_IN /1000
N2O_HOM_IN(N)= WST_IN(N)* EF_N2O_HOM_IN /1000
VOL_IN(N)=WST_IN(N)/WST_BULK_IN
AD_EN_CON_IN(N)=FAD_EN_CON*VOL_IN(N)*WST_TS_IN/100
WST_IN=WST_IN+WST_IN(N)
BG_IN_VS= BG_IN_VS+ BG_IN_VS(N)
BG_IN_COD= BG_IN_COD+ BG_IN_COD(N)
BG_IN_WST= BG_IN_WST+ BG_IN_WST(N)
CH4_HOM_IN= CH4_HOM_IN+ CH4_HOM_IN(N)
N2O_HOM_IN= N2O_HOM_IN+ N2O_HOM_IN(N)
AD_EN_CON_IN= AD_EN_CON_IN+ AD_EN_CON_IN(N)
VOL_IN= VOL_IN+ VOL_IN(N)
BG_IN_VS=0
BG_IN_COD=0
BG_IN_WST=0
CH4_HOM_IN=0
N2O_HOM_IN=0
AD_EN_CON_IN=0
No
N=N+1
FARMS_IN=N
Yes
Choose method for estimation of biogas production:
1. Volatile solids destroyed
2.COD consumed
3. Amount of waste digested
USER_BG
USER_BG=1
Yes
BG=WST_PROD*WST_TS/100*WST_VS/100*FBG_VS*1000 + BG_IN_VS
METHOD = “Volatile solids destroyed”
No
USER_BG=2
Yes
BG=WST_PROD/WST_BULK*WST_COD*FBG_COD + BG_IN_COD
METHOD = “COD consumed”
No
No
USER_BG=3
Yes
BG=WST_PROD*FBG_WST + BG_IN_WST
METHOD = “Amount of waste digested”
EL_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_EL/100
TH_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_TH/100
CHP_CO2=(BG*BG_CO2/100*CO2_DEN)+(BG*BG_CH4/100*CH4_DEN*DE/100*44/16)
CHP_CH4=BG*BG_CH4/100*CH4_DEN*(1-DE/100)



Choose use of energy:
1. All energy used onsite and remaining electricity sold
2. All thermal used onsite, all electrical sold
USER_USE
"By pressing next a word document will be generated with the results and you will return to the main menu"
USER_USE=1
Yes
No
ADD_EL=EN_CON_EL+AD_EN_CON-EL_PROD+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
ADD_EL<0
Yes
No
EL_SOLD=-ADD_EL
ADD_EL=0
ADD_TH<0
Yes
No
ADD_TH=0
No
USER_USE=2
Yes
ADD_EL=EN_CON_EL+AD_EN_CON+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
EL_SOLD=EL_PROD
ADD_TH<0
Yes
No
ADD_TH=0
ADD_LPG=ADD_TH*FEN_CON_LPG*3.6/LPG_EN_CONT/LPG_DEN/(FEN_CON_LPG+FEN_CON_DSL)
ADD_DSL=ADD_TH*FEN_CON_DSL*3.6/DSL_EN_CONT/DSL_DEN/(FEN_CON_LPG+FEN_CON_DSL)
EN_CONS_DSL_AD=EN_CON_DSL+ADD_DSL
EN_CONS_LPG_AD=EN_CON_LPG+ADD_LPG
EN_CONS_EL_AD=EN_CON_EL+AD_EN_CON+ADD_EL+AD_EN_CON_IN
CO2_EN_DSL_AD=EF_CO2_DSL*EN_CONS_DSL_AD*DSL_EN_CONT*DSL_DEN/1000
CH4_EN_DSL_AD=EF_CH4_DSL*EN_CONS_DSL_AD* DSL_EN_CONT*DSL_DEN/1000
N2O_EN_DSL_AD=EF_N2O_DSL*EN_CONS_DSL_AD* DSL_EN_CONT*DSL_DEN/1000
CO2_EN_ELE_AD=EF_CO2_ELE*EN_CONS_ELE_AD*3.6/1000
CH4_EN_ELE_AD=EF_CH4_ELE*EN_CONS_ELE_AD*3.6/1000
N2O_EN_ELE_AD=EF_N2O_ELE*EN_CONS_ELE_AD*3.6/1000
CO2_EN_LPG_AD=EF_CO2_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000
CH4_EN_LPG_AD=EF_CH4_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000
N2O_EN_LPG_AD=EF_N2O_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000
GHG_CH4_EN_DSL_AD=CH4_EN_DSL_AD*GWP_CH4/1000
GHG_N2O_EN_DSL_AD=N2O_EN_DSL_AD*GWP_N2O/1000
GHG_CH4_EN_ELE_AD=CH4_EN_ELE_AD*GWP_CH4/1000
GHG_N2O_EN_ELE_AD=N2O_EN_ELE_AD*GWP_N2O/1000
GHG_CH4_EN_LPG_AD=CH4_EN_LPG_AD*GWP_CH4/1000
GHG_N2O_EN_LPG_AD=N2O_EN_LPG_AD*GWP_N2O/1000
GHG_EN_DSL_AD=(CO2_EN_DSL_AD/1000)+GHG_CH4_EN_DSL_AD+GHG_N2O_EN_DSL_AD
GHG_EN_ELE_AD=(CO2_EN_ELE_AD/1000)+GHG_CH4_EN_ELE_AD+GHG_N2O_EN_ELE_AD
GHG_EN_LPG_AD=(CO2_EN_LPG_AD/1000)+GHG_CH4_EN_LPG_AD+GHG_N2O_EN_LPG_AD
GHG_EN_AD=GHG_EN_DSL_AD+GHG_EN_ELE_AD+GHG_EN_LPG_AD

```
EN_CO2_AD=(CO2_EN_DSL_AD+CO2_EN_ELE_AD+CO2_EN_LPG_AD)/1000
EN_CH4_AD=(CH4_EN_DSL_AD+CH4_EN_ELE_AD+CH4_EN_LPG_AD)/1000
EN_CH4_GHG_AD=EN_CH4_AD*GWP_CH4
EN_N2O_AD=(N2O_EN_DSL_AD+N2O_EN_ELE_AD+N2O_EN_LPG_AD)/1000
EN_N2O_GHG_AD=EN_N2O_AD*GWP_N20

CH4_FER=EF_CH4_FER*POP
GHG_CH4_FER=CH4_FER*GWP_CH4/1000

CH4_HOM=EF_CH4_MAN*POP/365/1000 + CH4_HOM_IN
GHG_CH4_HOM=CH4_HOM*GWP_CH4
N2O_HOM=EF_N2O_MAN*POP/365/1000 + N2O_HOM_IN
GHG_N2O_HOM=N2O_HOM*GWP_N2O
GHG_HOM=GHG_CH4_HOM+GHG_N2O_HOM

CHP_TOT=(CHP_CO2+CHP_CH4*GWP_CH4)/1000

GHG_TOT_AD=GHG_EN_AD+GHG_HOM+GHG_CH4_FER+CHP_TOT
CO2_TOT_AD=EN_CO2_AD+(CHP_CO2/1000)
CH4_TOT_GHG_AD=EN_CH4_GHG_AD+GHG_CH4_FER+GHG_CH4_HOM+CHP_CH4/1000*GWP_CH4
N2O_TOT_AD=EN_N2O_AD+N2O_HOM
N2O_TOT_GHG_AD=N2O_TOT_AD*GWP_N2O

GHG_EN_DIF=GHG_EN_AD-GHG_EN
EN_CO2_DIF=EN_CO2_AD-EN_CO2
EN_CH4_GHG_DIF=EN_CH4_GHG_AD-EN_CH4_GHG
EN_N2O_GHG_DIF=EN_N2O_GHG_AD-EN_N2O_GHG

GHG_TOT_DIF=GHG_TOT_AD-GHG_TOT
CO2_TOT_DIF=CO2_TOT_AD-CO2_TOT
GHG_CH4_TOT_DIF=CH4_TOT_GHG_AD-CH4_TOT_GHG
GHG_N2O_TOT_DIF=N2O_TOT_GHG_AD-N2O_TOT_GHG
```

OUTPUT IN DOC. FILE

OUTPUT IN DOC. FILE

Annual emission of greenhouse gases with and without anaerobic digestion in farm NAME

Animal type:	ANM
Animal population:	POP
Additional waste from other farms (m3)	VOL_IN
Potential annual biogas production (m3):	BG
Biogas estimation based on :	METHOD
Annual energy produced by anaerobic digestion (kWh)	
Electrical	EL_PROD
Thermal	TH_PROD
Electrical energy sold annually (kWh)	EL_SOLD

Comparison of energy bought for the farm with and without anaerobic digestion annually

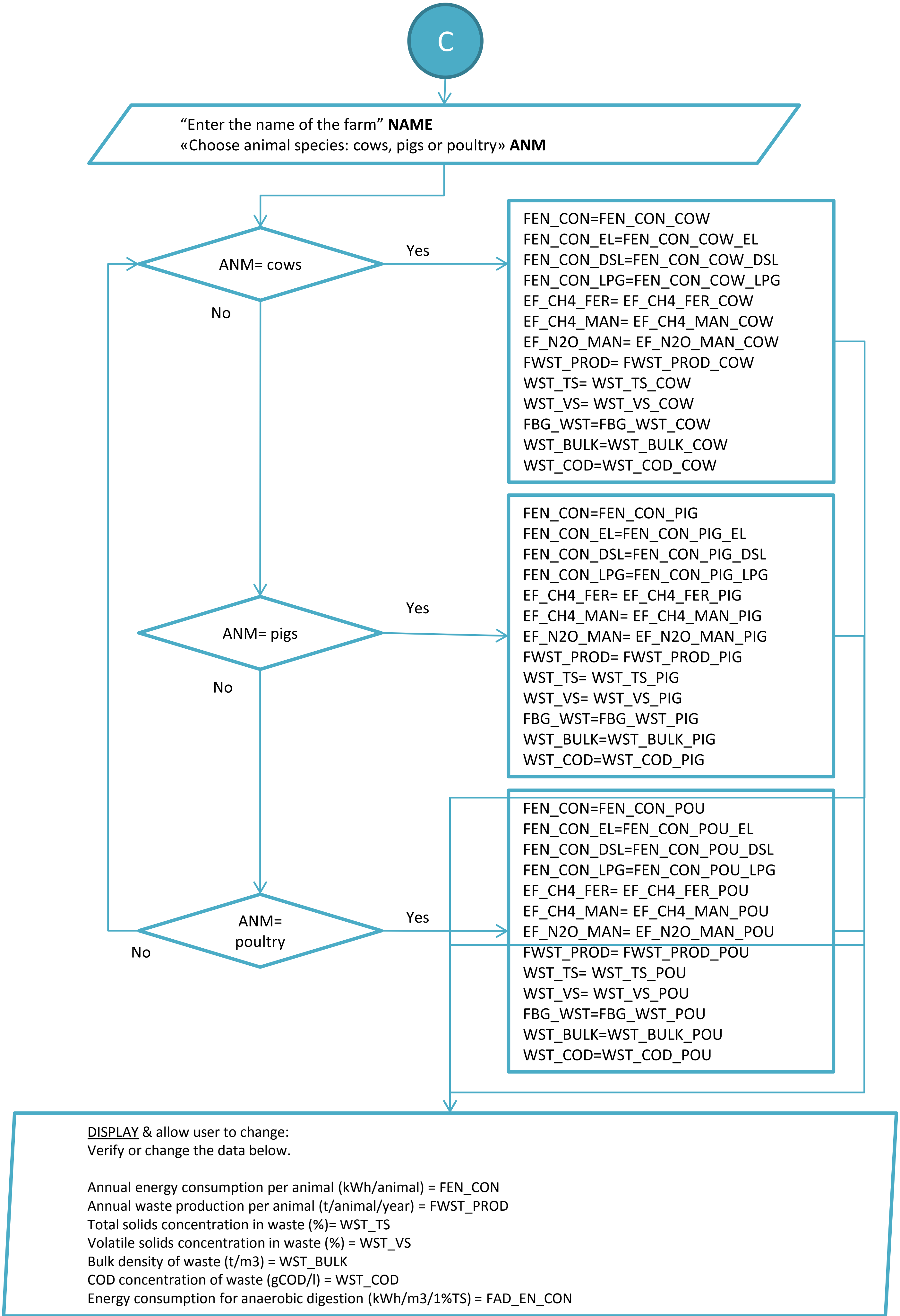
	with anaerobic digestion	without anaerobic digestion
Electricity (kWh)	EN_CONS_EL_AD	EN_CONS_EL
Diesel (l)	EN_CONS_DSL_AD	EN_CONS_DSL
LPG (l)	EN_CONS_LPG_AD	EN_CONS_LPG

Comparison of annual emissions of the farm with and without anaerobic digestion

	with anaerobic digestion	without anaerobic digestion	difference
Energy (t CO2 eq.)	GHG_EN_AD	GHG_EN	GHG_EN_DIF
CO2 (t)	EN_CO2_AD	EN_CO2	EN_CO2_DIF
CH4 (t CO2 eq.)	EN_CH4_GHG_AD	EN_CH4_GHG	EN_CH4_GHG_DIF
N2O (t CO2 eq.)	EN_N2O_GHG_AD	EN_N2O_GHG	EN_N2O_GHG_DIF
CH4 emissions from enteric fermentation (t CO2 eq.)	GHG_CH4_FER	GHG_CH4_FER	0
Manure management		GHG_MAN	-GHG_MAN
CH4 (t CO2 eq.)		GHG_CH4_MAN	-GHG_CH4_MAN
N2O (t CO2 eq.)		GHG_N2O_MAN	-GHG_N2O_MAN
Waste homogenisation	GHG_HOM		GHG_HOM
CH4 (t CO2 eq.)	GHG_CH4_HOM		GHG_CH4_HOM
N2O (t CO2 eq.)	GHG_N2O_HOM		GHG_N2O_HOM
Combustion of biogas	CHP_TOT		CHP_TOT
CO2 (t)	CHP_CO2/1000		CHP_CO2/1000
CH4 (t CO2 eq.)	CHP_CH4/1000*GWP_CH4		CHP_CH4/1000*GWP_CH4
TOTAL EMISSIONS OF THE FARM (t CO2 eq.)	GHG_TOT_AD	GHG_TOT	GHG_TOT_DIF
CO2 (t)	CO2_TOT_AD	CO2_TOT	CO2_TOT_DIF
CH4 (t CO2 eq.)	CH4_TOT_GHG_AD	CH4_TOT_GHG	GHG_CH4_TOT_DIF
N2O (t CO2 eq.)	N2O_TOT_GHG_AD	N2O_TOT_GHG	GHG_N2O_TOT_DIF

Note

1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.
2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.


C
“Enter the name of the farm” NAME
«Choose animal species: cows, pigs or poultry» ANM
ANM= cows
Yes
No
FEN_CON=FEN_CON_COW
FEN_CON_EL=FEN_CON_COW_EL
FEN_CON_DSL=FEN_CON_COW_DSL
FEN_CON_LPG=FEN_CON_COW_LPG
EF_CH4_FER= EF_CH4_FER_COW
EF_CH4_MAN= EF_CH4_MAN_COW
EF_N2O_MAN= EF_N2O_MAN_COW
FWST_PROD= FWST_PROD_COW
WST_TS= WST_TS_COW
WST_VS= WST_VS_COW
FBG_WST=FBG_WST_COW
WST_BULK=WST_BULK_COW
WST_COD=WST_COD_COW
ANM= pigs
Yes
No
FEN_CON=FEN_CON_PIG
FEN_CON_EL=FEN_CON_PIG_EL
FEN_CON_DSL=FEN_CON_PIG_DSL
FEN_CON_LPG=FEN_CON_PIG_LPG
EF_CH4_FER= EF_CH4_FER_PIG
EF_CH4_MAN= EF_CH4_MAN_PIG
EF_N2O_MAN= EF_N2O_MAN_PIG
FWST_PROD= FWST_PROD_PIG
WST_TS= WST_TS_PIG
WST_VS= WST_VS_PIG
FBG_WST=FBG_WST_PIG
WST_BULK=WST_BULK_PIG
WST_COD=WST_COD_PIG
ANM= poultry
Yes
No
FEN_CON=FEN_CON_POU
FEN_CON_EL=FEN_CON_POU_EL
FEN_CON_DSL=FEN_CON_POU_DSL
FEN_CON_LPG=FEN_CON_POU_LPG
EF_CH4_FER= EF_CH4_FER_POU
EF_CH4_MAN= EF_CH4_MAN_POU
EF_N2O_MAN= EF_N2O_MAN_POU
FWST_PROD= FWST_PROD_POU
WST_TS= WST_TS_POU
WST_VS= WST_VS_POU
FBG_WST=FBG_WST_POU
WST_BULK=WST_BULK_POU
WST_COD=WST_COD_POU
DISPLAY & allow user to change:
Verify or change the data below.
Annual energy consumption per animal (kWh/animal) = FEN_CON
Annual waste production per animal (t/animal/year) = FWST_PROD
Total solids concentration in waste (%)= WST_TS
Volatile solids concentration in waste (%) = WST_VS
Bulk density of waste (t/m3) = WST_BULK
COD concentration of waste (gCOD/l) = WST_COD
Energy consumption for anaerobic digestion (kWh/m3/1%TS) = FAD_EN_CON

Electrical efficiency of generator (%) = GEN_EFF_EL
Thermal efficiency of generator (%) = GEN_EFF_TH
Combustion efficiency of conversion of CH4 to CO2 (%)= DE

Financial parameters

Loan interest rate (%)=DEF_RATE
Loan repayment period (years)=DEF_PER
Inflation rate (%) =DEF_IR
Annual market discount rate (%) =DEF_MDR
Electricity buying price for electricity from biomass (€/kWh)=DEF_EL_PRICE
Gate fee for input waste (€/m3)=DEF_GF
Price for renting land (€/m2)=DEF_LAND_RENT
Price for land purchase (€/m2)=DEF_LAND_PRICE
Income tax on profit (%) =DEF_TAX
Cost of emission allowances (€/ t CO2 eq.) = DEF_GHG_COST
Annual boiler maintenance cost (€) = DEF_GEN_MAINT_COST
Maintenance cost for the CHP generator per unit electrical energy produced (€/kWh)=DEF_CHP_MAINT_COST
Overheads (salary management, insurance, accountants) (%) = DEF_OVER

Contribution of digester and its installation to total capital costs (%) = DEF_CAP_COST_DIG
Contribution of other capital costs to total capital costs (%) = DEF_CAP_COST_OTHER

Contribution of annual personnel cost to total annual operational costs (%) = DEF_PER_COST
Contribution of maintenance cost to total annual operational costs (%) =DEF_MAINT_COST
Contribution of other costs to total annual operational costs (%) = DEF_OPER_OTHER_COST

Double click number in cell to change

Energy sources characteristics	Electricity	Diesel	LPG
Contribution to total energy consumption (%)	FEN_CON_EL	FEN_CON_DSL	FEN_CON_LPG
Energy content (MJ/kg)	-	DSL_EN_CONT	LPG_EN_CONT
Fuel density (kg/l)	-	DSL_DEN	LPG_DEN
Boiler Efficiency (%)	-	EFF_DSL	EFF_LPG
Market price	EL_BPRICE €/kWh	DSL_BPRICE €/l	LPG_BPRICE €/l

Emission factors, global warming potentials, biogas characteristics

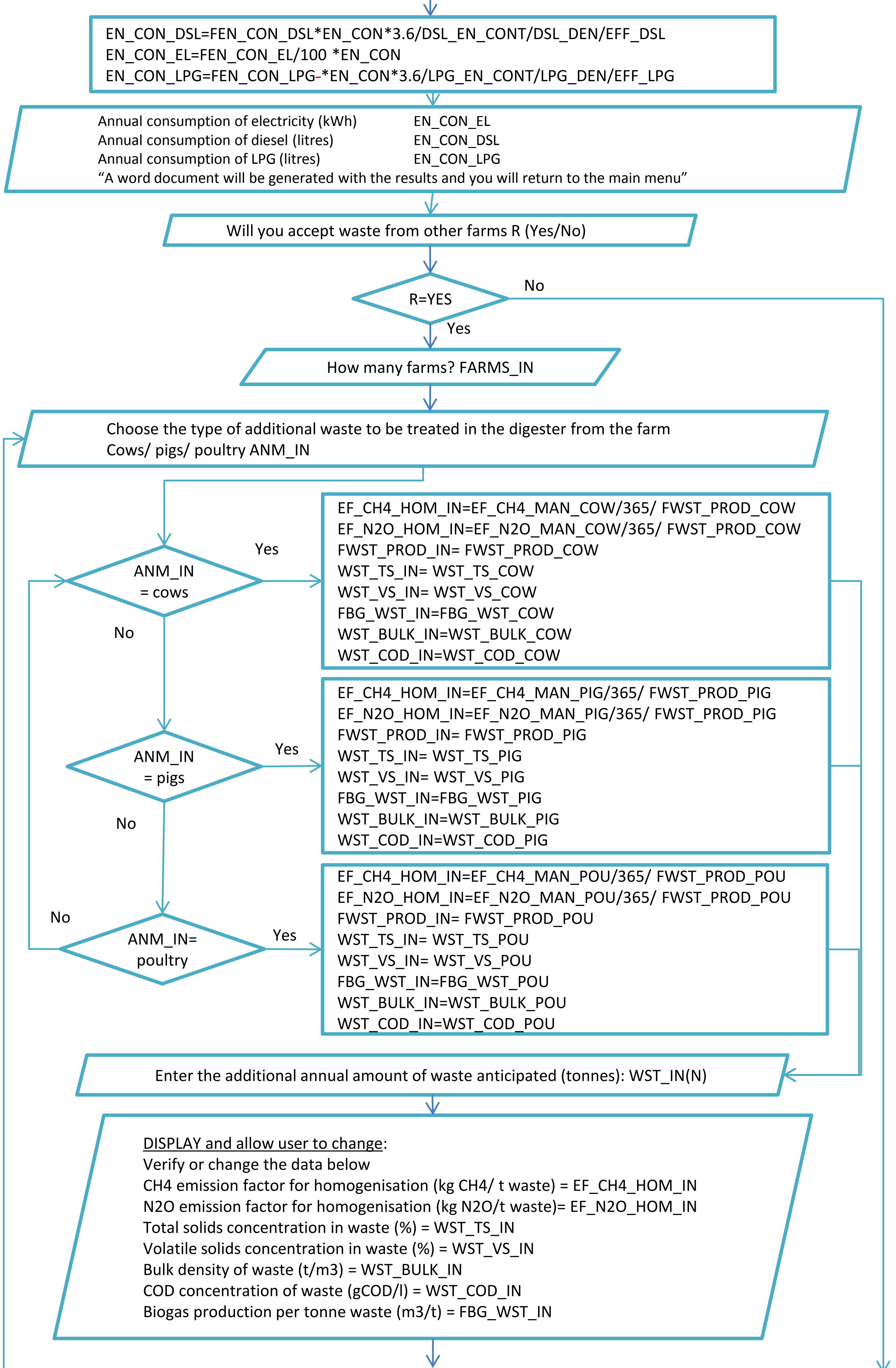
	CO2	CH4	N2O
Enteric fermentation (kg /animal/year)	-	EF_CH4_FER	-
Homogenisation tank (kg /animal/year)	-	EF_CH4_MAN/365	EF_N2O_MAN/365
Electricity consumption (g /MJ) =	EF_CO2_ELE	EF_CH4_ELE	EF_N2O_ELE
Diesel consumption (g /MJ)	EF_CO2_DSL	EF_CH4_DSL	EF_N2O_DSL
LPG consumption (g /MJ)	EF_CO2_LPG	EF_CH4_LPG	EF_N2O_LPG
Global warming potentials	-	GWP_CH4	GWP_N2O
Content in biogas (%)	BG_CO2	BG_CH4	-
Energy content at 100% combustion (kWh/m3)	-	CH4_EN	
Density (kg/m3)	CO2_DEN	CH4_DEN	-

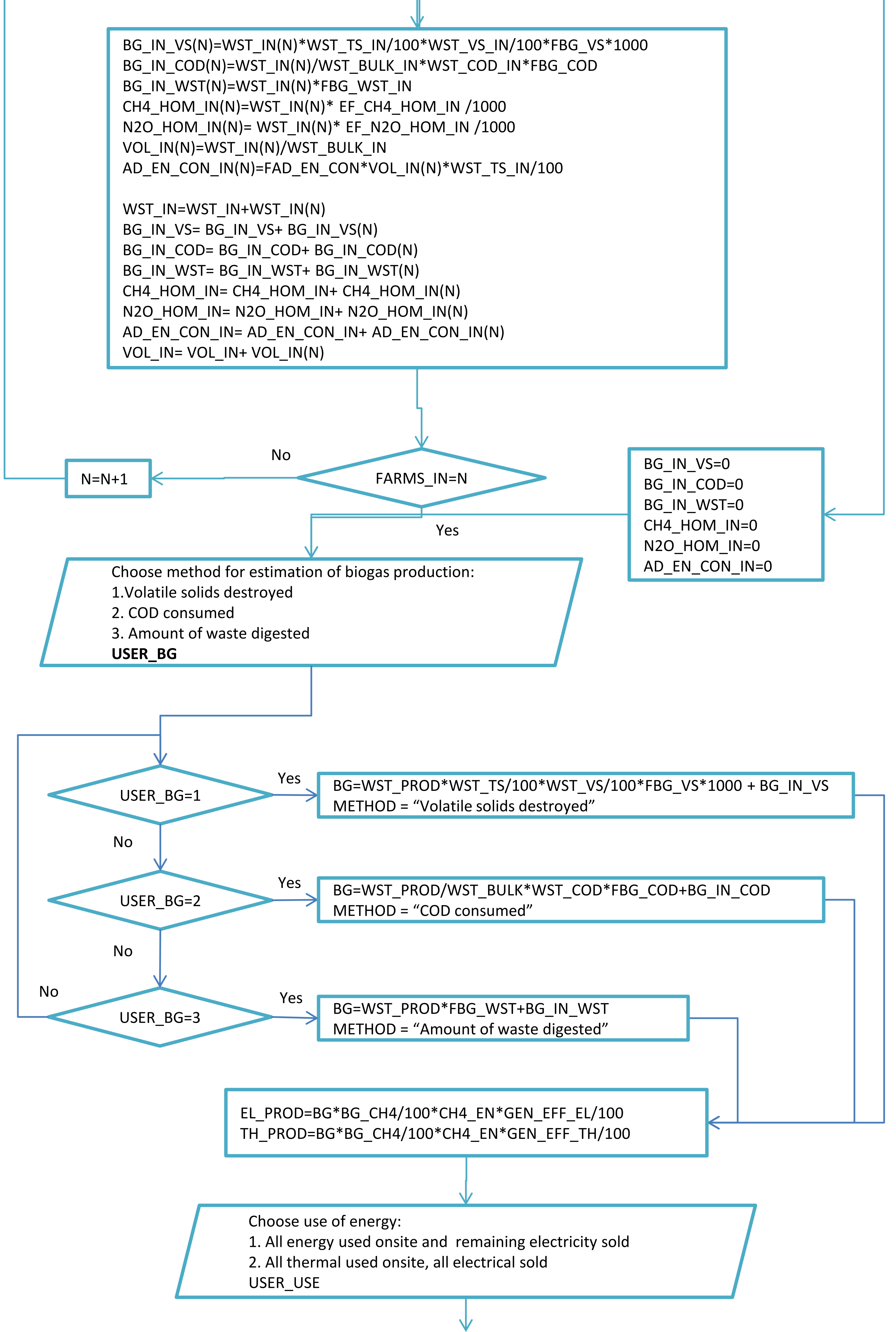
	per tonne waste (m3/t)	per kg VS destroyed (m3/kg VS)	per kg COD consumed (m3/kg COD)
Biogas production coefficients	FBG_WSTF	BG_VS	FBG_COD

"Enter the animal population" POP

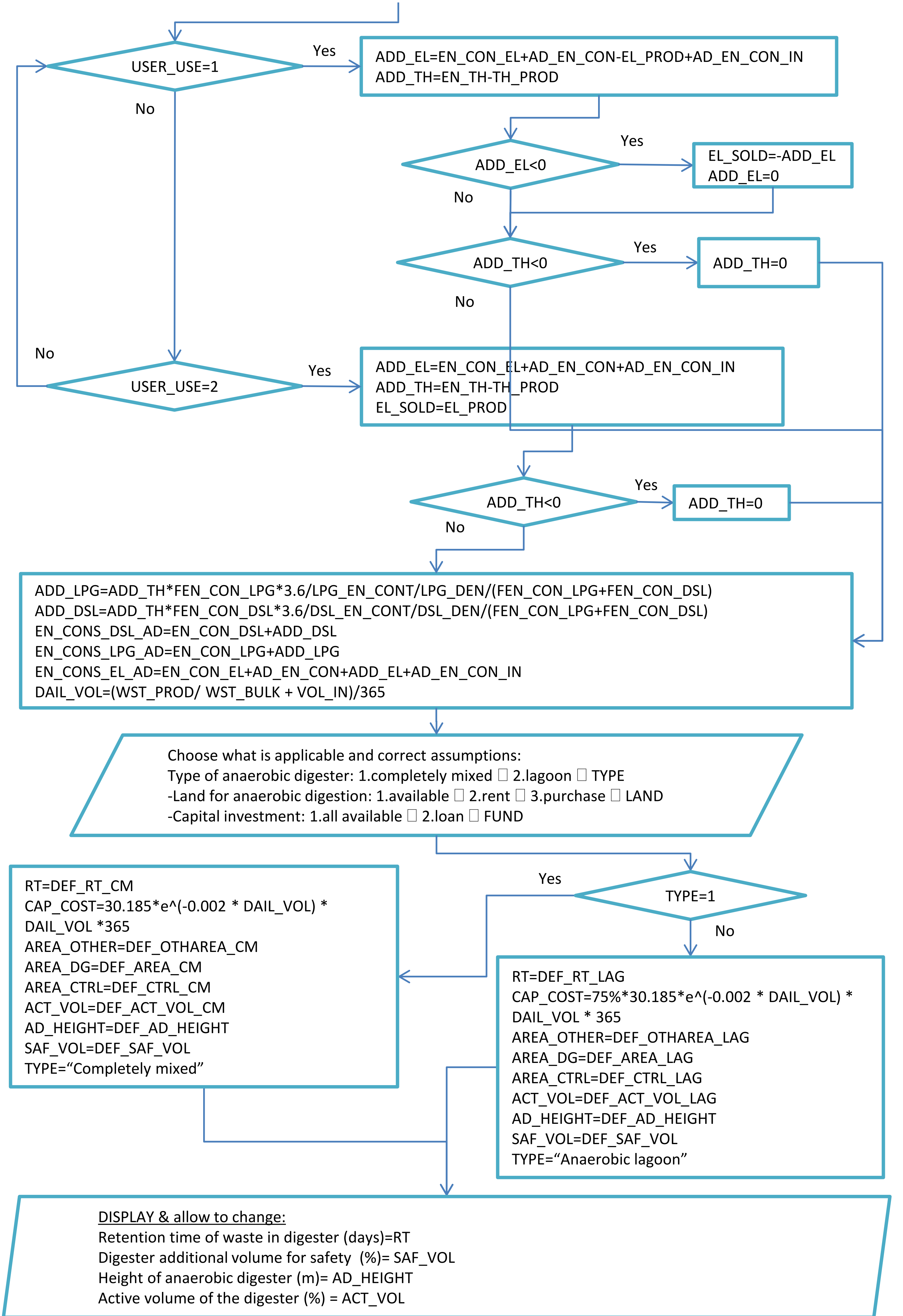
EN_CON=FEN_CON*POP
WST_PROD=FWST_PROD*POP
AD_EN_CON=FAD_EN_CON*WST_PROD/WST_BULK*WST_TS/100
EN_TH=(FEN_CON_DSL/100+FEN_CON_LPG/100)*EN_CON
N = 1
GF=DEF_GF

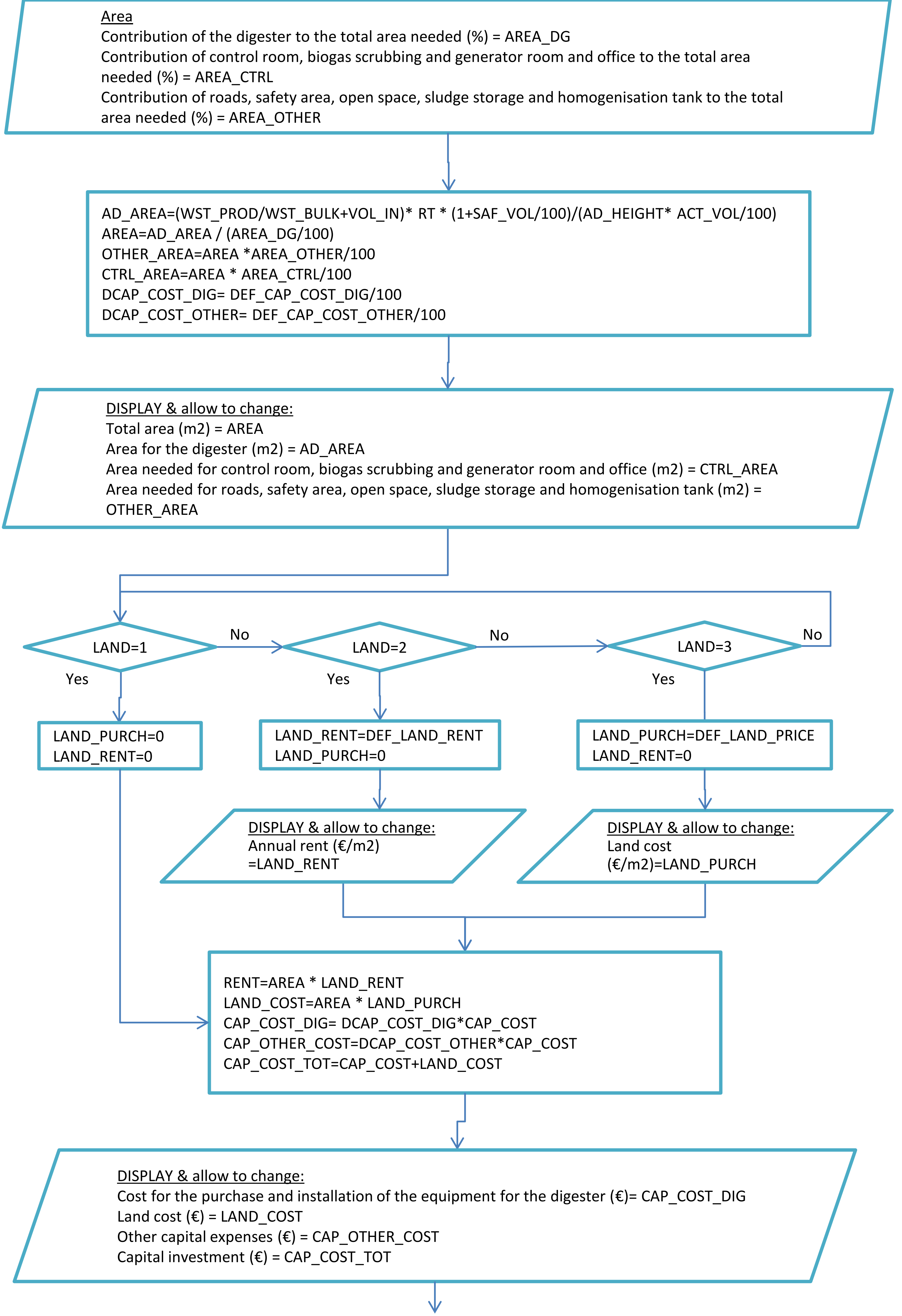
DISPLAY and allow to change:
Verify or change the data below.
Annual animal waste production (t)=WST_PROD
Total annual energy consumption (kWh) = EN_CON

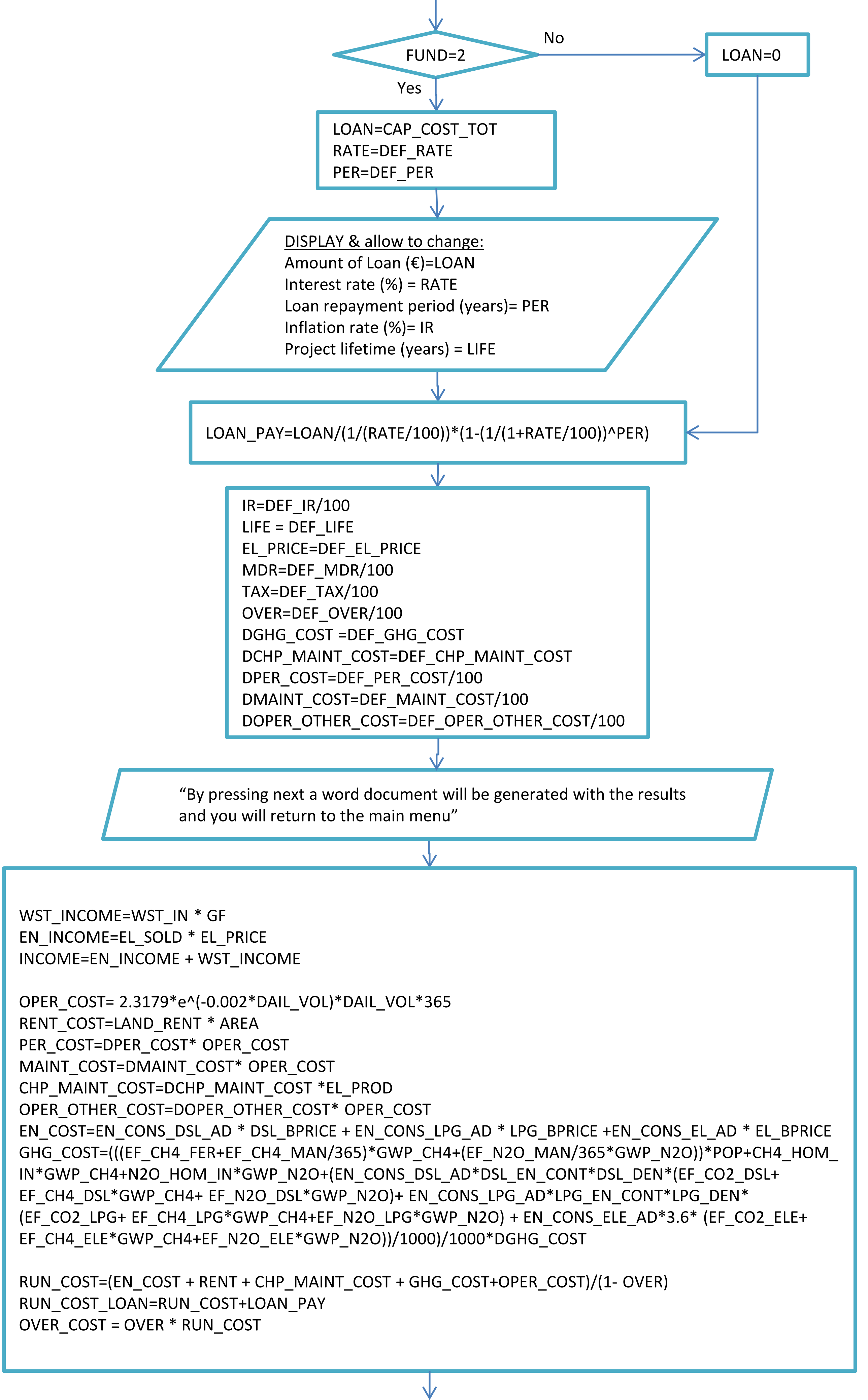

EN_CON_DSL=FEN_CON_DSL*EN_CON*3.6/DSL_EN_CONT/DSL_DEN/EFF_DSL
EN_CON_EL=FEN_CON_EL/100 *EN_CON
EN_CON_LPG=FEN_CON_LPG-*EN_CON*3.6/LPG_EN_CONT/LPG_DEN/EFF_LPG
Annual consumption of electricity (kWh) EN_CON_EL
Annual consumption of diesel (litres) EN_CON_DSL
Annual consumption of LPG (litres) EN_CON_LPG
“A word document will be generated with the results and you will return to the main menu”
Will you accept waste from other farms R (Yes/No)
R=YES
No
Yes
How many farms? FARMS_IN
Choose the type of additional waste to be treated in the digester from the farm
Cows/ pigs/ poultry ANM_IN
ANM_IN = cows
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_COW/365/ FWST_PROD_COW
EF_N2O_HOM_IN=EF_N2O_MAN_COW/365/ FWST_PROD_COW
FWST_PROD_IN= FWST_PROD_COW
WST_TS_IN= WST_TS_COW
WST_VS_IN= WST_VS_COW
FBG_WST_IN=FBG_WST_COW
WST_BULK_IN=WST_BULK_COW
WST_COD_IN=WST_COD_COW
ANM_IN = pigs
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_PIG/365/ FWST_PROD_PIG
EF_N2O_HOM_IN=EF_N2O_MAN_PIG/365/ FWST_PROD_PIG
FWST_PROD_IN= FWST_PROD_PIG
WST_TS_IN= WST_TS_PIG
WST_VS_IN= WST_VS_PIG
FBG_WST_IN=FBG_WST_PIG
WST_BULK_IN=WST_BULK_PIG
WST_COD_IN=WST_COD_PIG
No
ANM_IN= poultry
Yes
EF_CH4_HOM_IN=EF_CH4_MAN_POU/365/ FWST_PROD_POU
EF_N2O_HOM_IN=EF_N2O_MAN_POU/365/ FWST_PROD_POU
FWST_PROD_IN= FWST_PROD_POU
WST_TS_IN= WST_TS_POU
WST_VS_IN= WST_VS_POU
FBG_WST_IN=FBG_WST_POU
WST_BULK_IN=WST_BULK_POU
WST_COD_IN=WST_COD_POU
Enter the additional annual amount of waste anticipated (tonnes): WST_IN(N)
DISPLAY and allow user to change:
Verify or change the data below
CH4 emission factor for homogenisation (kg CH4/ t waste) = EF_CH4_HOM_IN
N2O emission factor for homogenisation (kg N2O/t waste)= EF_N2O_HOM_IN
Total solids concentration in waste (%) = WST_TS_IN
Volatile solids concentration in waste (%) = WST_VS_IN
Bulk density of waste (t/m3) = WST_BULK_IN
COD concentration of waste (gCOD/l) = WST_COD_IN
Biogas production per tonne waste (m3/t) = FBG_WST_IN

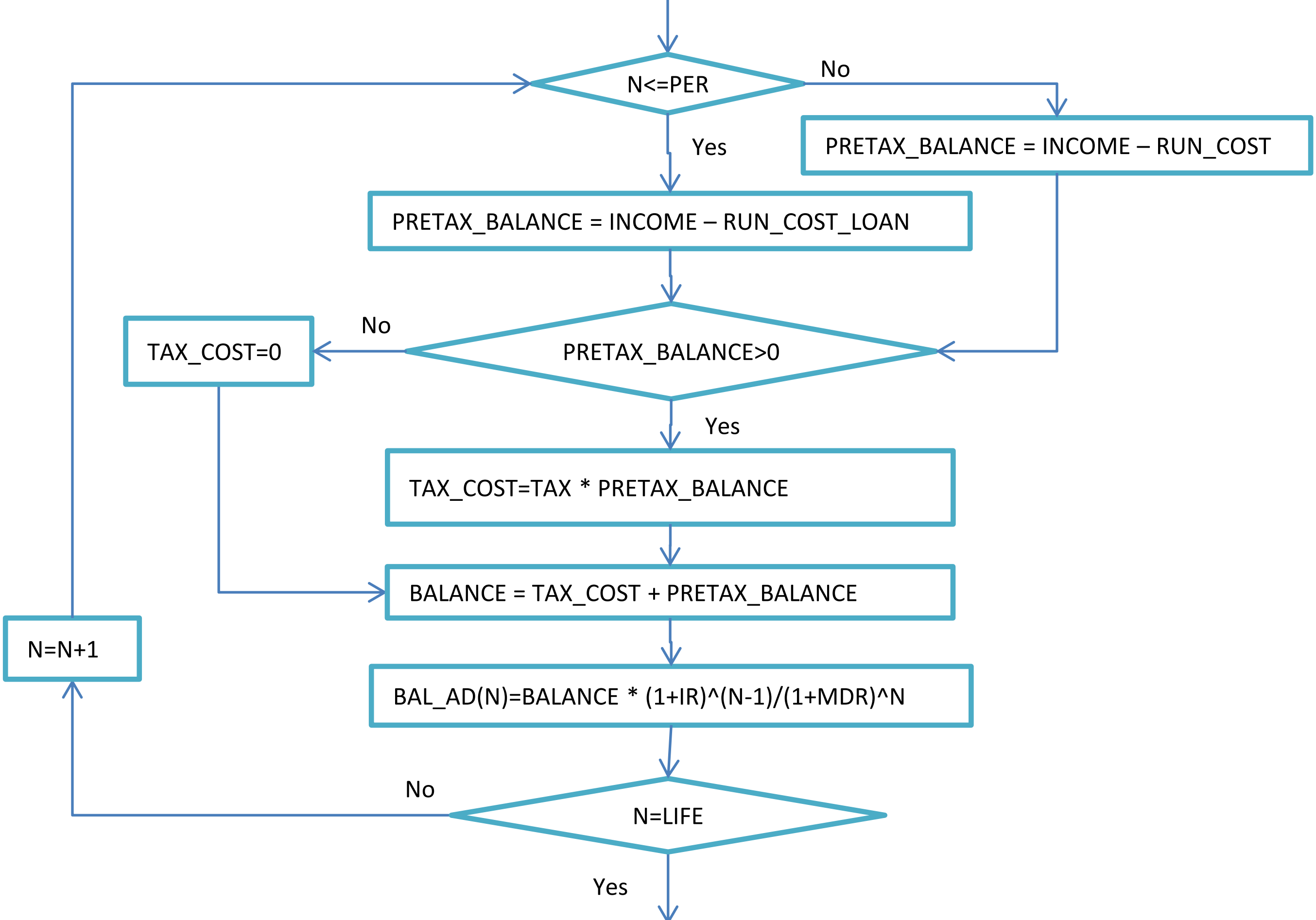


BG_IN_VS(N)=WST_IN(N)*WST_TS_IN/100*WST_VS_IN/100*FBG_VS*1000
BG_IN_COD(N)=WST_IN(N)/WST_BULK_IN*WST_COD_IN*FBG_COD
BG_IN_WST(N)=WST_IN(N)*FBG_WST_IN
CH4_HOM_IN(N)=WST_IN(N)* EF_CH4_HOM_IN /1000
N2O_HOM_IN(N)= WST_IN(N)* EF_N2O_HOM_IN /1000
VOL_IN(N)=WST_IN(N)/WST_BULK_IN
AD_EN_CON_IN(N)=FAD_EN_CON*VOL_IN(N)*WST_TS_IN/100
WST_IN=WST_IN+WST_IN(N)
BG_IN_VS= BG_IN_VS+ BG_IN_VS(N)
BG_IN_COD= BG_IN_COD+ BG_IN_COD(N)
BG_IN_WST= BG_IN_WST+ BG_IN_WST(N)
CH4_HOM_IN= CH4_HOM_IN+ CH4_HOM_IN(N)
N2O_HOM_IN= N2O_HOM_IN+ N2O_HOM_IN(N)
AD_EN_CON_IN= AD_EN_CON_IN+ AD_EN_CON_IN(N)
VOL_IN= VOL_IN+ VOL_IN(N)
No
N=N+1
FARMS_IN=N
Yes
BG_IN_VS=0
BG_IN_COD=0
BG_IN_WST=0
CH4_HOM_IN=0
N2O_HOM_IN=0
AD_EN_CON_IN=0
Choose method for estimation of biogas production:
1.Volatile solids destroyed
2. COD consumed
3. Amount of waste digested
USER_BG
USER_BG=1
Yes
BG=WST_PROD*WST_TS/100*WST_VS/100*FBG_VS*1000 + BG_IN_VS
METHOD = "Volatile solids destroyed"
No
USER_BG=2
Yes
BG=WST_PROD/WST_BULK*WST_COD*FBG_COD+BG_IN_COD
METHOD = "COD consumed"
No
No
USER_BG=3
Yes
BG=WST_PROD*FBG_WST+BG_IN_WST
METHOD = "Amount of waste digested"
EL_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_EL/100
TH_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_TH/100
Choose use of energy:
1. All energy used onsite and remaining electricity sold
2. All thermal used onsite, all electrical sold
USER_USE


USER_USE=1
Yes
No
ADD_EL=EN_CON_EL+AD_EN_CON-EL_PROD+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
ADD_EL<0
Yes
No
EL_SOLD=-ADD_EL
ADD_EL=0
ADD_TH<0
Yes
No
ADD_TH=0
No
USER_USE=2
Yes
ADD_EL=EN_CON_EL+AD_EN_CON+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
EL_SOLD=EL_PROD
ADD_TH<0
Yes
No
ADD_TH=0
ADD_LPG=ADD_TH*FEN_CON_LPG*3.6/LPG_EN_CONT/LPG_DEN/(FEN_CON_LPG+FEN_CON_DSL)
ADD_DSL=ADD_TH*FEN_CON_DSL*3.6/DSL_EN_CONT/DSL_DEN/(FEN_CON_LPG+FEN_CON_DSL)
EN_CONS_DSL_AD=EN_CON_DSL+ADD_DSL
EN_CONS_LPG_AD=EN_CON_LPG+ADD_LPG
EN_CONS_EL_AD=EN_CON_EL+AD_EN_CON+ADD_EL+AD_EN_CON_IN
DAIL_VOL=(WST_PROD/ WST_BULK + VOL_IN)/365
Choose what is applicable and correct assumptions:
Type of anaerobic digester: 1.completely mixed □ 2.lagoon □ TYPE
-Land for anaerobic digestion: 1.available □ 2.rent □ 3.purchase □ LAND
-Capital investment: 1.all available □ 2.loan □ FUND
TYPE=1
Yes
No
RT=DEF_RT_CM
CAP_COST=30.185*e^(-0.002 * DAIL_VOL) *
DAIL_VOL *365
AREA_OTHER=DEF_OTHAREA_CM
AREA_DG=DEF_AREA_CM
AREA_CTRL=DEF_CTRL_CM
ACT_VOL=DEF_ACT_VOL_CM
AD_HEIGHT=DEF_AD_HEIGHT
SAF_VOL=DEF_SAF_VOL
TYPE="Completely mixed"
RT=DEF_RT_LAG
CAP_COST=75%*30.185*e^(-0.002 * DAIL_VOL) *
DAIL_VOL * 365
AREA_OTHER=DEF_OTHAREA_LAG
AREA_DG=DEF_AREA_LAG
AREA_CTRL=DEF_CTRL_LAG
ACT_VOL=DEF_ACT_VOL_LAG
AD_HEIGHT=DEF_AD_HEIGHT
SAF_VOL=DEF_SAF_VOL
TYPE="Anaerobic lagoon"
DISPLAY & allow to change:
Retention time of waste in digester (days)=RT
Digester additional volume for safety (%)= SAF_VOL
Height of anaerobic digester (m)= AD_HEIGHT
Active volume of the digester (%) = ACT_VOL


Area
Contribution of the digester to the total area needed (%) = AREA_DG
Contribution of control room, biogas scrubbing and generator room and office to the total area needed (%) = AREA_CTRL
Contribution of roads, safety area, open space, sludge storage and homogenisation tank to the total area needed (%) = AREA_OTHER
AD_AREA=(WST_PROD/WST_BULK+VOL_IN)* RT * (1+SAF_VOL/100)/(AD_HEIGHT* ACT_VOL/100)
AREA=AD_AREA / (AREA_DG/100)
OTHER_AREA=AREA *AREA_OTHER/100
CTRL_AREA=AREA * AREA_CTRL/100
DCAP_COST_DIG= DEF_CAP_COST_DIG/100
DCAP_COST_OTHER= DEF_CAP_COST_OTHER/100
DISPLAY & allow to change:
Total area (m2) = AREA
Area for the digester (m2) = AD_AREA
Area needed for control room, biogas scrubbing and generator room and office (m2) = CTRL_AREA
Area needed for roads, safety area, open space, sludge storage and homogenisation tank (m2) = OTHER_AREA
LAND=1
No
LAND=2
No
LAND=3
No
Yes
Yes
Yes
LAND_PURCH=0
LAND_RENT=0
LAND_RENT=DEF_LAND_RENT
LAND_PURCH=0
LAND_PURCH=DEF_LAND_PRICE
LAND_RENT=0
DISPLAY & allow to change:
Annual rent (€/m2) =LAND_RENT
DISPLAY & allow to change:
Land cost (€/m2)=LAND_PURCH
RENT=AREA * LAND_RENT
LAND_COST=AREA * LAND_PURCH
CAP_COST_DIG= DCAP_COST_DIG*CAP_COST
CAP_OTHER_COST=DCAP_COST_OTHER*CAP_COST
CAP_COST_TOT=CAP_COST+LAND_COST
DISPLAY & allow to change:
Cost for the purchase and installation of the equipment for the digester (€)= CAP_COST_DIG
Land cost (€) = LAND_COST
Other capital expenses (€) = CAP_OTHER_COST
Capital investment (€) = CAP_COST_TOT


FUND=2
No
LOAN=0
Yes
LOAN=CAP_COST_TOT
RATE=DEF_RATE
PER=DEF_PER
DISPLAY & allow to change:
Amount of Loan (€)=LOAN
Interest rate (%) = RATE
Loan repayment period (years)= PER
Inflation rate (%)= IR
Project lifetime (years) = LIFE
LOAN_PAY=LOAN/(1/(RATE/100))*(1-(1/(1+RATE/100))^PER)
IR=DEF_IR/100
LIFE = DEF_LIFE
EL_PRICE=DEF_EL_PRICE
MDR=DEF_MDR/100
TAX=DEF_TAX/100
OVER=DEF_OVER/100
DGHG_COST =DEF_GHG_COST
DCHP_MAINT_COST=DEF_CHP_MAINT_COST
DPER_COST=DEF_PER_COST/100
DMAINT_COST=DEF_MAINT_COST/100
DOPER_OTHER_COST=DEF_OPER_OTHER_COST/100
“By pressing next a word document will be generated with the results
and you will return to the main menu”
WST_INCOME=WST_IN * GF
EN_INCOME=EL_SOLD * EL_PRICE
INCOME=EN_INCOME + WST_INCOME
OPER_COST= 2.3179*e^(-0.002*DAIL_VOL)*DAIL_VOL*365
RENT_COST=LAND_RENT * AREA
PER_COST=DPER_COST* OPER_COST
MAINT_COST=DMAINT_COST* OPER_COST
CHP_MAINT_COST=DCHP_MAINT_COST *EL_PROD
OPER_OTHER_COST=DOPER_OTHER_COST* OPER_COST
EN_COST=EN_CONS_DSL_AD * DSL_BPRICE + EN_CONS_LPG_AD * LPG_BPRICE +EN_CONS_EL_AD * EL_BPRICE
GHG_COST=(((EF_CH4_FER+EF_CH4_MAN/365)*GWP_CH4+(EF_N2O_MAN/365*GWP_N2O))*POP+CH4_HOM_
IN*GWP_CH4+N2O_HOM_IN*GWP_N2O+(EN_CONS_DSL_AD*DSL_EN_CONT*DSL_DEN*(EF_CO2_DSL+
EF_CH4_DSL*GWP_CH4+ EF_N2O_DSL*GWP_N2O)+ EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN*
(EF_CO2_LPG+ EF_CH4_LPG*GWP_CH4+EF_N2O_LPG*GWP_N2O) + EN_CONS_ELE_AD*3.6* (EF_CO2_ELE+
EF_CH4_ELE*GWP_CH4+EF_N2O_ELE*GWP_N2O))/1000)/1000*DGHG_COST
RUN_COST=(EN_COST + RENT + CHP_MAINT_COST + GHG_COST+OPER_COST)/(1- OVER)
RUN_COST_LOAN=RUN_COST+LOAN_PAY
OVER_COST = OVER * RUN_COST



<u>OUTPUT in DOC file (1st page)</u>

Assessment of investment for the installation of an anaerobic digester in farm NAME
Type of animal: ANM
Animal Population: POP
Type of Digester: TYPE
Additional waste from other farms (m3/year): VOL_IN
Total waste treated by the digester (m3/year): WST_PROD/WST_BULK+VOL_IN
Potential annual biogas production (m3): BG
Biogas estimation based on : METHOD

Annual electrical energy produced (kWh): EL_PROD
Annual thermal energy produced (kWh): TH_PROD
Electrical energy sold annually (kWh): EL_SOLD

<u>Area</u>
Area for the digester (m2) = AD_AREA
Area needed for control room, biogas scrubbing and generator room and office (m2)= CTRL_AREA
Area needed for roads, safety area, open space, sludge storage and homogenisation tank (m2) = OTHER_AREA
Total area (m2) = AREA

<u>Capital costs</u>
Equipment and installation (€): CAP_COST_DIG
Landscaping, construction, permitting, consultants and other (€): CAP_OTHER_COST
Cost for purchase of land (€): LAND_COST
Total initial Investment (€): **CAP_COST_TOT**

<u>Annual expenses</u>
Loan repayment (€): LOAN_PAY (for PER years)
Renting cost for land (€): RENT
Personnel cost (€): PER_COST
Maintenance cost (€): MAINT_COST
Maintenance cost of the generator (€): CHP_MAINT_COST
Other operational costs (€): OPER_OTHER_COST

Energy cost (€): EN_COST
Cost for emissions allowances (€): GHG_COST
Overheads (salary management, insurance, accountants) (€) = OVER_COST
Tax on profit (€): TAX_COST

Annual incomes
Treatment of additional waste (€): WST_INCOME
Sales of electricity (€): EN_INCOME
Total (€)=INCOME

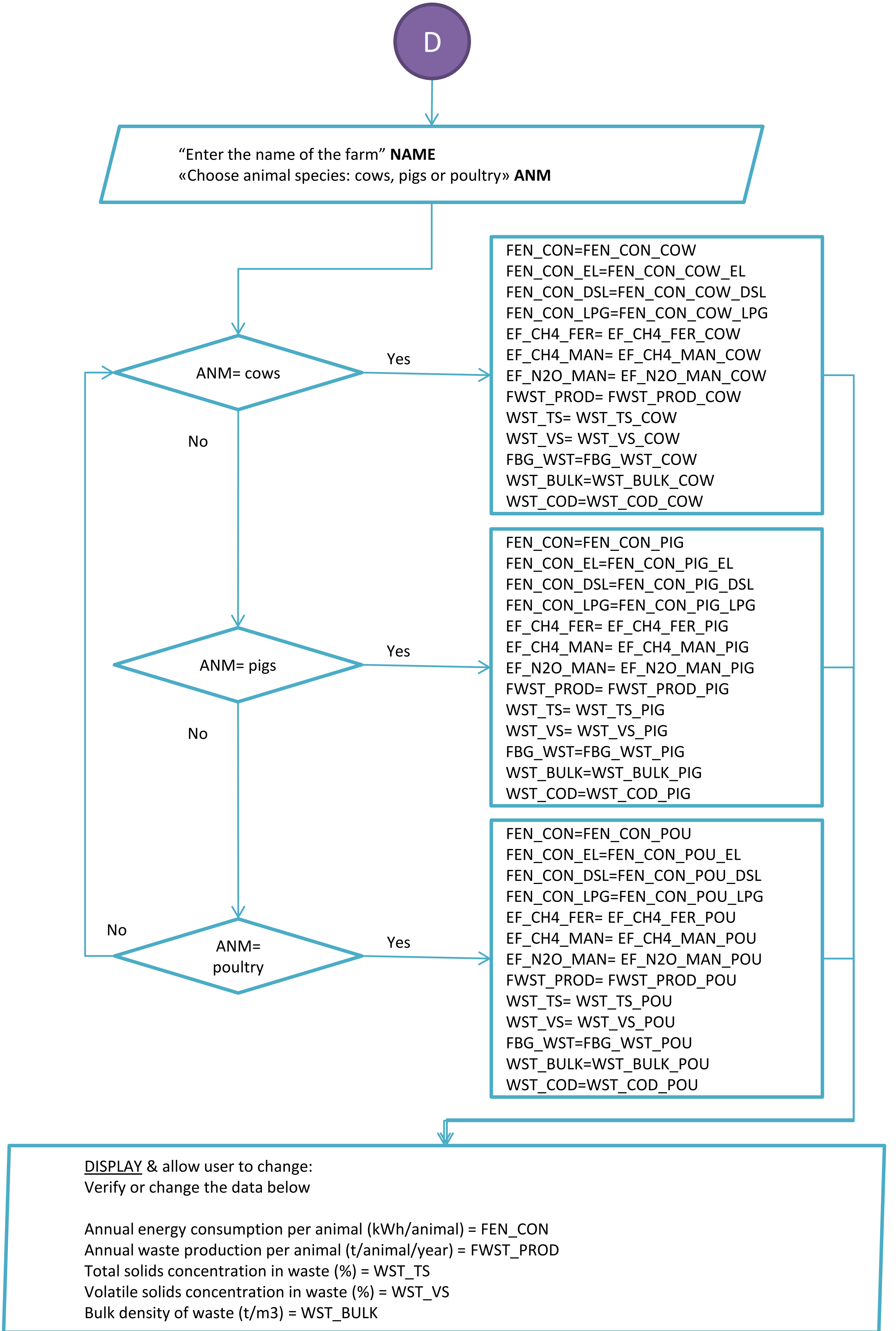
OUTPUT in DOC file (2nd page)

Annual balance for lifetime of project

Year	Loan payment(€)	Expenses (€)	Tax (€)	Incomes (€)	Balance (€)	Discounted balance (€)
N	LOAN_PAY	RUN_COST	TAX_COST	INCOME	BALANCE	BAL_AD(N)

Note
1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.
2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

$


D
“Enter the name of the farm” NAME
«Choose animal species: cows, pigs or poultry» ANM
ANM= cows
Yes
No
FEN_CON=FEN_CON_COW
FEN_CON_EL=FEN_CON_COW_EL
FEN_CON_DSL=FEN_CON_COW_DSL
FEN_CON_LPG=FEN_CON_COW_LPG
EF_CH4_FER= EF_CH4_FER_COW
EF_CH4_MAN= EF_CH4_MAN_COW
EF_N2O_MAN= EF_N2O_MAN_COW
FWST_PROD= FWST_PROD_COW
WST_TS= WST_TS_COW
WST_VS= WST_VS_COW
FBG_WST=FBG_WST_COW
WST_BULK=WST_BULK_COW
WST_COD=WST_COD_COW
ANM= pigs
Yes
No
FEN_CON=FEN_CON_PIG
FEN_CON_EL=FEN_CON_PIG_EL
FEN_CON_DSL=FEN_CON_PIG_DSL
FEN_CON_LPG=FEN_CON_PIG_LPG
EF_CH4_FER= EF_CH4_FER_PIG
EF_CH4_MAN= EF_CH4_MAN_PIG
EF_N2O_MAN= EF_N2O_MAN_PIG
FWST_PROD= FWST_PROD_PIG
WST_TS= WST_TS_PIG
WST_VS= WST_VS_PIG
FBG_WST=FBG_WST_PIG
WST_BULK=WST_BULK_PIG
WST_COD=WST_COD_PIG
No
ANM= poultry
Yes
FEN_CON=FEN_CON_POU
FEN_CON_EL=FEN_CON_POU_EL
FEN_CON_DSL=FEN_CON_POU_DSL
FEN_CON_LPG=FEN_CON_POU_LPG
EF_CH4_FER= EF_CH4_FER_POU
EF_CH4_MAN= EF_CH4_MAN_POU
EF_N2O_MAN= EF_N2O_MAN_POU
FWST_PROD= FWST_PROD_POU
WST_TS= WST_TS_POU
WST_VS= WST_VS_POU
FBG_WST=FBG_WST_POU
WST_BULK=WST_BULK_POU
WST_COD=WST_COD_POU
DISPLAY & allow user to change:
Verify or change the data below
Annual energy consumption per animal (kWh/animal) = FEN_CON
Annual waste production per animal (t/animal/year) = FWST_PROD
Total solids concentration in waste (%) = WST_TS
Volatile solids concentration in waste (%) = WST_VS
Bulk density of waste (t/m3) = WST_BULK

COD concentration of waste (gCOD/l) = WST_COD
Energy consumption for anaerobic digestion (kWh/m3/1%TS) = FAD_EN_CON
Electrical efficiency of generator (%) = GEN_EFF_EL
Thermal efficiency of generator (%) = GEN_EFF_TH
Combustion efficiency of conversion of CH4 to CO2 (%)= DE
Capacity of lorries transporting the waste to the offsite digester (m3)=DEF_LOR_CAP

<u>Financial parameters</u>
Loan interest rate (%)=DEF_RATE
Loan repayment period (years)=DEF_PER
Inflation rate (%)=DEF_IR
Annual market discount rate (%)=DEF_MDR
Electricity buying price for electricity from biomass (€/kWh)=DEF_EL_PRICE
Gate fee for input waste (€/m3)=DEF_GF
Price for renting land (€/m2)=DEF_LAND_RENT
Price for land purchase (€/m2)=DEF_LAND_PRICE
Income tax on profit (%)=DEF_TAX
Waste management cost (€/m3)=DEF_WST_MNG_COST
Transport cost (€/km~~m3~~)=DEF_COST_TRANS
Annual penalty for improper treatment of waste (€) = DEF_PENALTY
Cost of emission allowances (€/ t CO2 eq.) = DEF_GHG_COST
Annual boiler maintenance cost (€) = DEF_GEN_MAINT_COST
Maintenance cost for the CHP generator per unit electrical energy produced (€/kWh) = DEF_CHP_MAINT_COST
Overheads (salary management, insurance, accountants) (%) = DEF_OVER

Contribution of digester and its installation to total capital costs (%) = DEF_CAP_COST_DIG
Contribution of other capital costs to total capital costs (%) = DEF_CAP_COST_OTHER

Contribution of annual personnel cost to total annual operational costs (%) = DEF_PER_COST
Contribution of maintenance cost to total annual operational costs (%) =DEF_MAINT_COST
Contribution of other costs to total annual operational costs (%) = DEF_OPER_OTHER_COST

Double click number in cell to change

Energy sources characteristics	Electricity	Diesel	LPG
Contribution to total energy consumption (%)	FEN_CON_EL	FEN_CON_DSL	FEN_CON_LPG
Energy content (MJ/kg)	-	DSL_EN_CONT	LPG_EN_CONT
Fuel density (kg/l)	-	DSL_DEN	LPG_DEN
Boiler Efficiency (%)		EFF_DSL	EFF_LPG
Market price (€ /kWh, € /l)	DEF_EL_BPRICE	DEF_DSL_BPRICE	DEF_LPG_BPRICE

Emission factors, global warming potentials, biogas characteristics

	CO2	CH4	N2O
Enteric fermentation (kg /animal) =	-	EF_CH4_FER	-
Manure management(kg /animal) =	-	EF_CH4_MAN	EF_N2O_MAN
Homogenisation tank (kg /animal) =	-	EF_CH4_MAN/365	EF_N2O_MAN/365
Electricity consumption (g /MJ) =	EF_CO2_ELE	EF_CH4_ELE	EF_N2O_ELE
Diesel consumption (g /MJ)	EF_CO2_DSL	EF_CH4_DSL	EF_N2O_DSL
LPG consumption (g /MJ)	EF_CO2_LPG	EF_CH4_LPG	EF_N2O_LPG
Global warming potentials	-	GWP_CH4	GWP_N2O
Transport (g/km)	DEF_CO2_TRANS	DEF_CH4_TRANS	DEF_N2O_TRANS
Content in biogas (%)	BG_CO2	BG_CH4	-
Energy content at 100% combustion (kWh/m3)	-	CH4_EN	
Density (kg/m3)	CO2_DEN	CH4_DEN	-

	per tonne waste (m3/t)	per kg VS destroyed (m3/kg VS)	per kg COD consumed (m3/kg COD)
Biogas production coefficients	FBG_WST	FBG_VS	FBG_COD

"Enter the animal population" POP

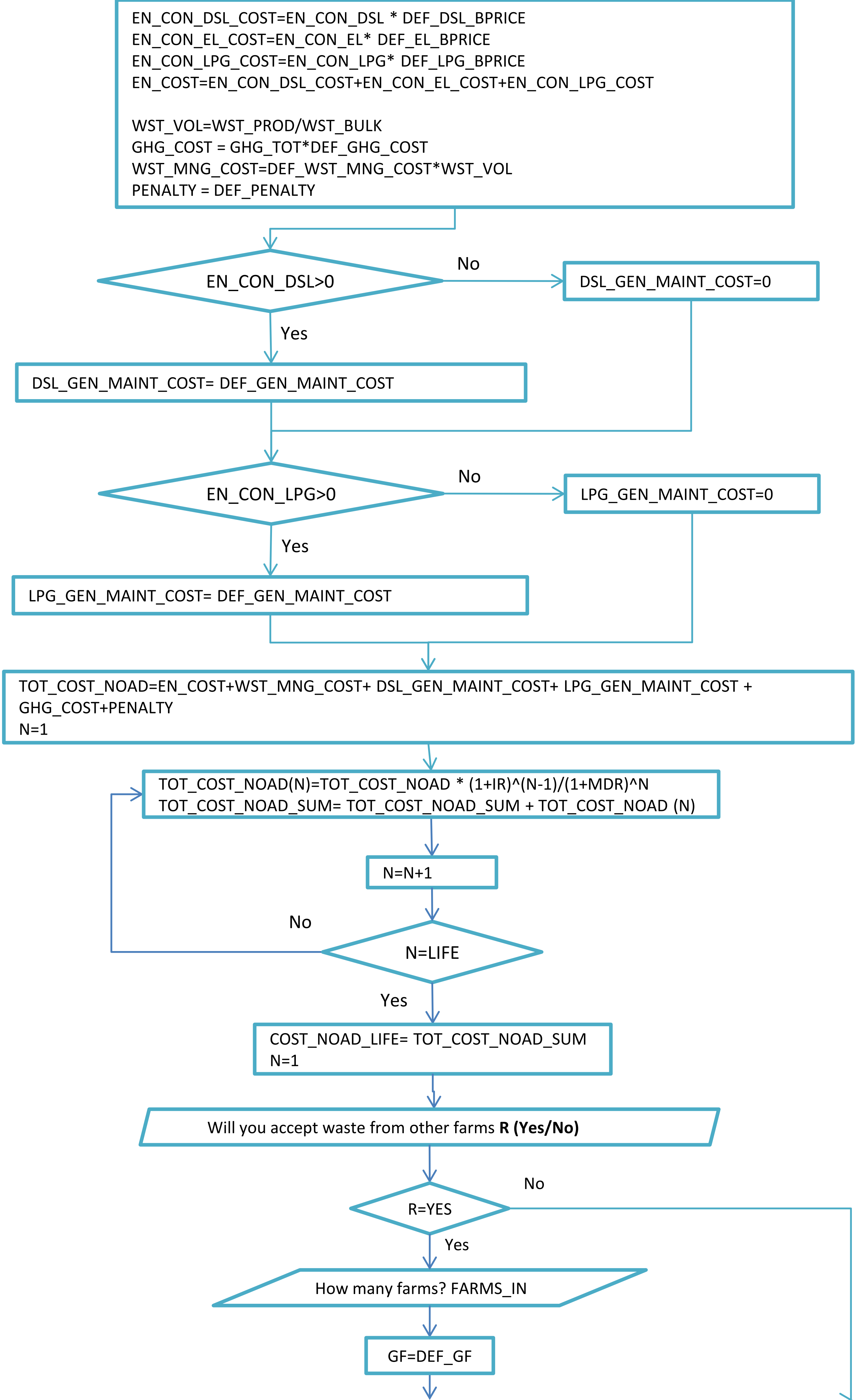
EN_CON=FEN_CON*POP
WST_PROD=FWST_PROD*POP
AD_EN_CON=FAD_EN_CON*WST_PROD/WST_BULK*WST_TS/100
LIFE=DEF_LIFE

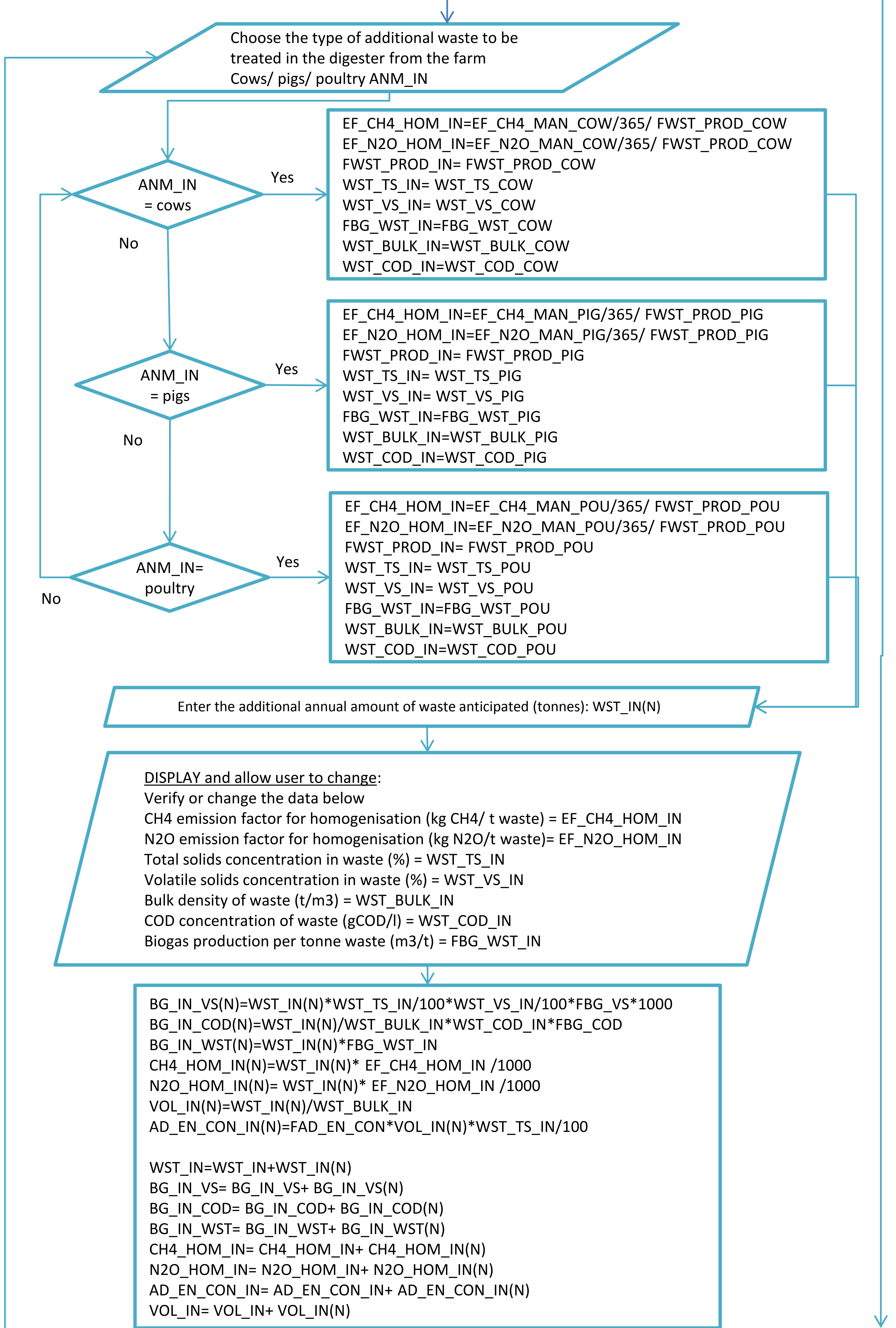
DISPLAY and allow to change:
Verify or change the data below.
Annual animal waste production (t)=WST_PROD
Total annual energy consumption (kWh) = EN_CON

```
EN_CON_DSL=FEN_CON_DSL*EN_CON*3.6/DSL_EN_CONT/DSL_DEN/EFF_DSL
EN_CON_EL=FEN_CON_EL/100 *EN_CON
EN_CON_LPG=FEN_CON_LPG*EN_CON*3.6/LPG_EN_CONT/LPG_DEN/EFF_LPG
```

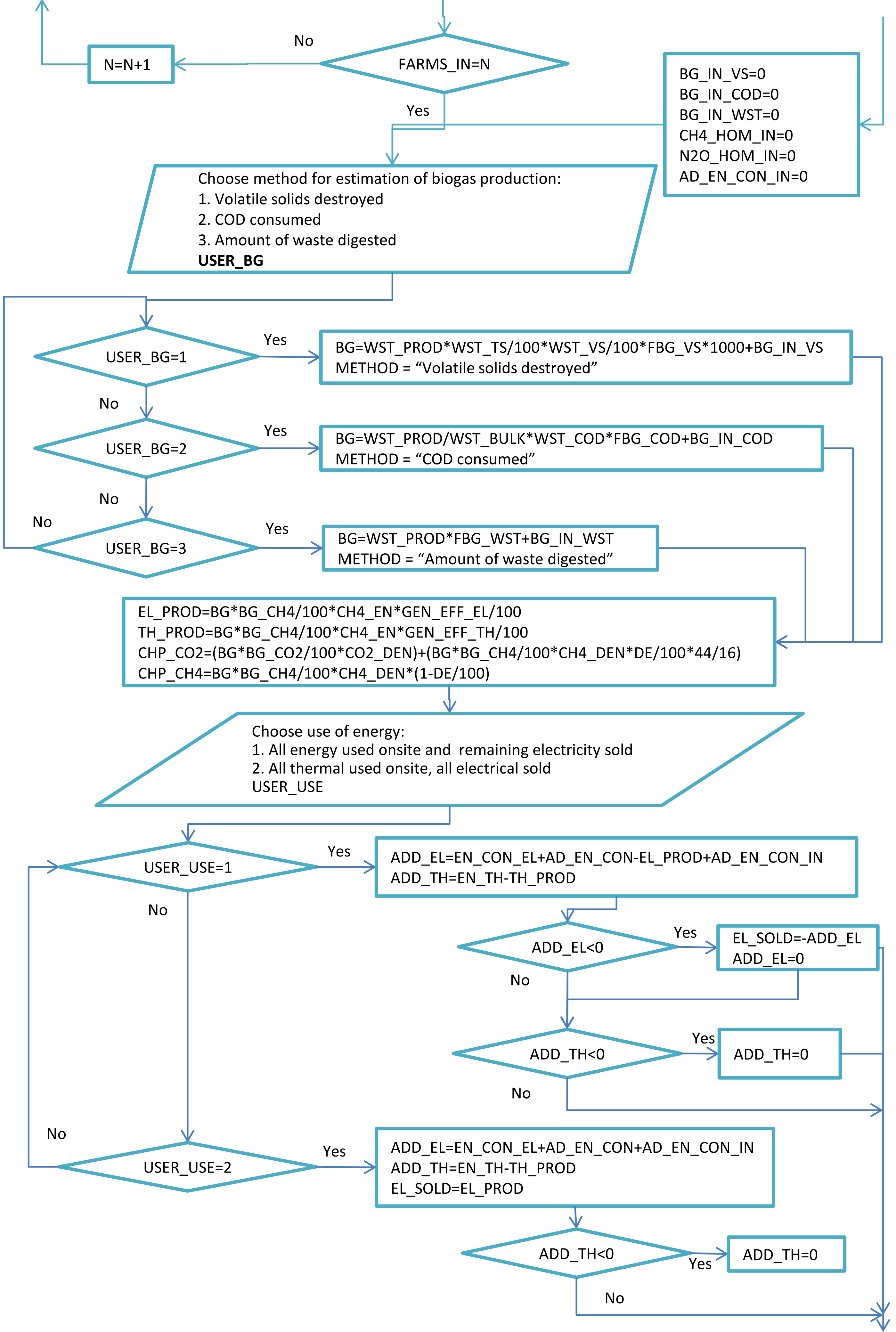
Annual consumption of electricity (kWh) EN_CON_EL
Annual consumption of diesel (litres) EN_CON_DSL
Annual consumption of LPG (litres) EN_CON_LPG
“A word document will be generated with the results and you will return to the main menu”

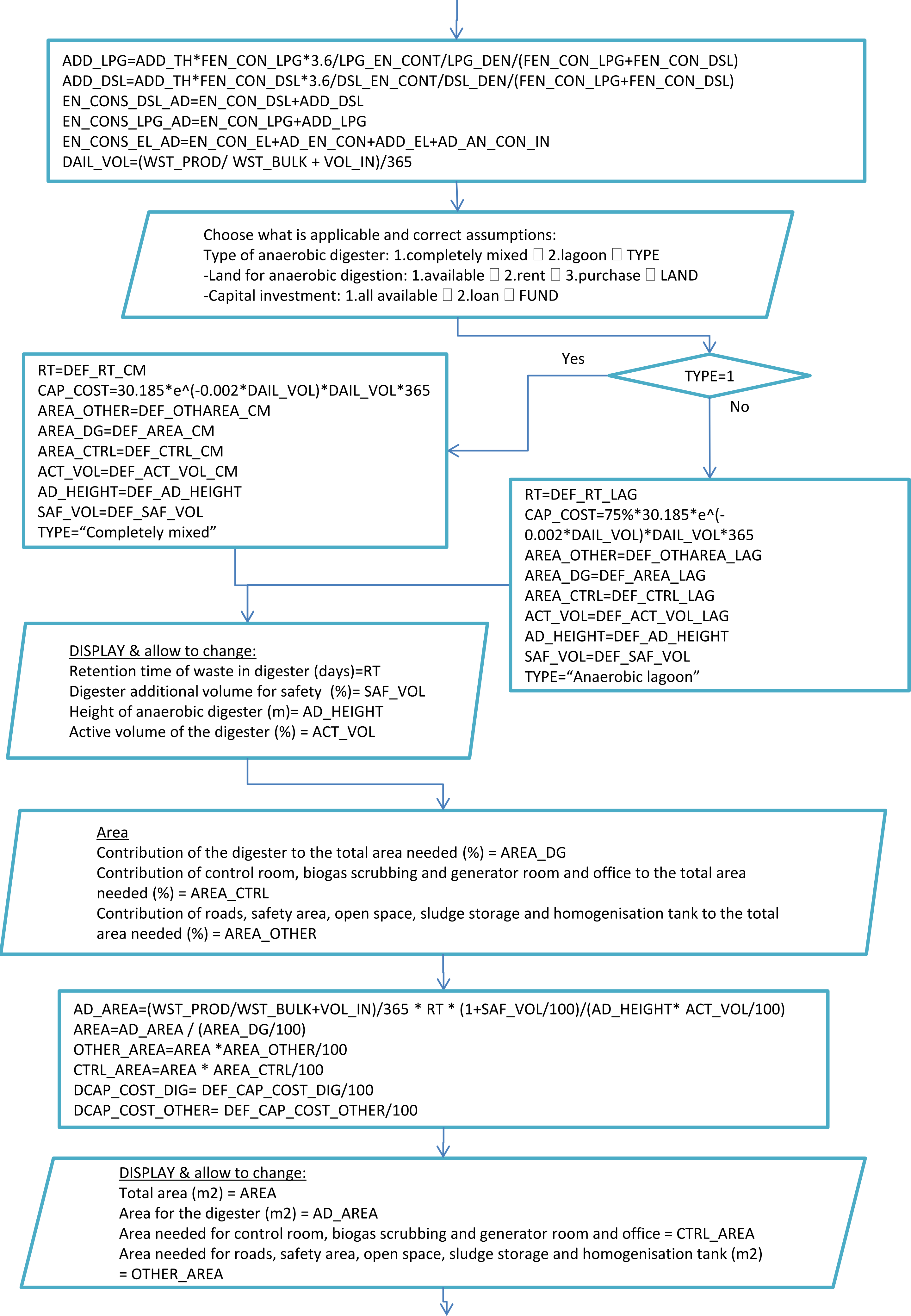
```
CO2_EN_DSL=EF_CO2_DSL*EN_CON_DSL*DSL_EN_CONT*DSL_DEN/1000
CH4_EN_DSL=EF_CH4_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
N2O_EN_DSL=EF_N2O_DSL*EN_CON_DSL* DSL_EN_CONT*DSL_DEN/1000
CO2_EN_ELE=EF_CO2_ELE*EN_CON_EL*3.6/1000
CH4_EN_ELE=EF_CH4_ELE*EN_CON_EL*3.6/1000
N2O_EN_ELE=EF_N2O_ELE*EN_CON_EL*3.6/1000
CO2_EN_LPG=EF_CO2_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
CH4_EN_LPG=EF_CH4_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
N2O_EN_LPG=EF_N2O_LPG*EN_CON_LPG* LPG_EN_CONT*LPG_DEN/1000
GHG_CH4_EN_DSL=CH4_EN_DSL*GWP_CH4/1000
GHG_N2O_EN_DSL=N2O_EN_DSL*GWP_N2O/1000
GHG_CH4_EN_ELE=CH4_EN_ELE*GWP_CH4/1000
GHG_N2O_EN_ELE=N2O_EN_ELE*GWP_N2O/1000
GHG_CH4_EN_LPG=CH4_EN_LPG*GWP_CH4/1000
GHG_N2O_EN_LPG=N2O_EN_LPG*GWP_N2O/1000

GHG_EN_DSL=CO2_EN_DSL/1000+GHG_CH4_EN_DSL+GHG_N2O_EN_DSL
GHG_EN_ELE=CO2_EN_ELE/1000+GHG_CH4_EN_ELE+GHG_N2O_EN_ELE
GHG_EN_LPG=CO2_EN_LPG/1000+GHG_CH4_EN_LPG+GHG_N2O_EN_LPG

GHG_EN=GHG_EN_DSL+GHG_EN_ELE+GHG_EN_LPG

EN_CO2=(CO2_EN_DSL+CO2_EN_ELE+CO2_EN_LPG)/1000
EN_CH4=(CH4_EN_DSL+CH4_EN_ELE+CH4_EN_LPG)/1000
EN_CH4_GHG=EN_CH4*GWP_CH4
EN_N2O=(N2O_EN_DSL+N2O_EN_ELE+N2O_EN_LPG)/1000
EN_N2O_GHG=EN_N2O*GWP_N20

CH4_FER=EF_CH4_FER*POP
GHG_CH4_FER=CH4_FER*GWP_CH4/1000

CH4_MAN=EF_CH4_MAN*POP
GHG_CH4_MAN=CH4_MAN*GWP_CH4/1000
N2O_MAN=EF_N2O_MAN*POP

GHG_N2O_MAN=N2O_MAN*GWP_N2O/1000
GHG_MAN=GHG_CH4_MAN+GHG_N2O_MAN

GHG_TOT=GHG_EN+GHG_MAN+GHG_CH4_FER
GHG_TOT_LIFE=GHG_TOT*LIFE


CO2_TOT=EN_CO2
CH4_TOT_GHG= EN_CH4_GHG+ GHG_CH4_FER+ GHG_CH4_MAN
N2O_TOT _GHG = EN_N2O_GHG+ GHG_N2O_MAN
```

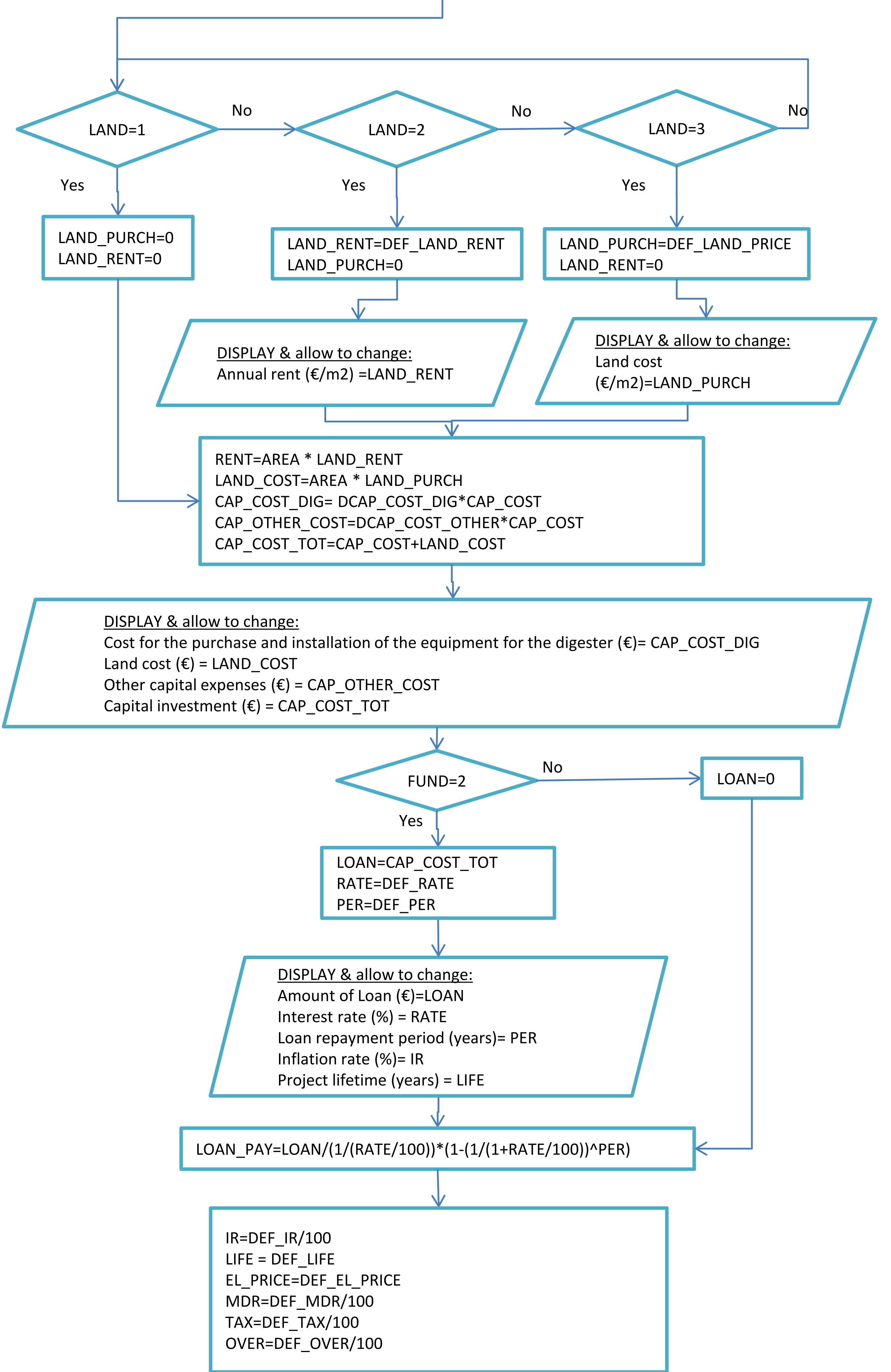

EN_CON_DSL_COST=EN_CON_DSL * DEF_DSL_BPRICE
EN_CON_EL_COST=EN_CON_EL* DEF_EL_BPRICE
EN_CON_LPG_COST=EN_CON_LPG* DEF_LPG_BPRICE
EN_COST=EN_CON_DSL_COST+EN_CON_EL_COST+EN_CON_LPG_COST
WST_VOL=WST_PROD/WST_BULK
GHG_COST = GHG_TOT*DEF_GHG_COST
WST_MNG_COST=DEF_WST_MNG_COST*WST_VOL
PENALTY = DEF_PENALTY
EN_CON_DSL>0
No
DSL_GEN_MAINT_COST=0
Yes
DSL_GEN_MAINT_COST= DEF_GEN_MAINT_COST
EN_CON_LPG>0
No
LPG_GEN_MAINT_COST=0
Yes
LPG_GEN_MAINT_COST= DEF_GEN_MAINT_COST
TOT_COST_NOAD=EN_COST+WST_MNG_COST+ DSL_GEN_MAINT_COST+ LPG_GEN_MAINT_COST + GHG_COST+PENALTY
N=1
TOT_COST_NOAD(N)=TOT_COST_NOAD * (1+IR)^(N-1)/(1+MDR)^N
TOT_COST_NOAD_SUM= TOT_COST_NOAD_SUM + TOT_COST_NOAD (N)
N=N+1
No
N=LIFE
Yes
COST_NOAD_LIFE= TOT_COST_NOAD_SUM
N=1
Will you accept waste from other farms R (Yes/No)
No
R=YES
Yes
How many farms? FARMS_IN
GF=DEF_GF



Choose the type of additional waste to be treated in the digester from the farm
Cows/ pigs/ poultry ANM_IN
ANM_IN = cows
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_COW/365/ FWST_PROD_COW
EF_N2O_HOM_IN=EF_N2O_MAN_COW/365/ FWST_PROD_COW
FWST_PROD_IN= FWST_PROD_COW
WST_TS_IN= WST_TS_COW
WST_VS_IN= WST_VS_COW
FBG_WST_IN=FBG_WST_COW
WST_BULK_IN=WST_BULK_COW
WST_COD_IN=WST_COD_COW
ANM_IN = pigs
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_PIG/365/ FWST_PROD_PIG
EF_N2O_HOM_IN=EF_N2O_MAN_PIG/365/ FWST_PROD_PIG
FWST_PROD_IN= FWST_PROD_PIG
WST_TS_IN= WST_TS_PIG
WST_VS_IN= WST_VS_PIG
FBG_WST_IN=FBG_WST_PIG
WST_BULK_IN=WST_BULK_PIG
WST_COD_IN=WST_COD_PIG
ANM_IN= poultry
Yes
No
EF_CH4_HOM_IN=EF_CH4_MAN_POU/365/ FWST_PROD_POU
EF_N2O_HOM_IN=EF_N2O_MAN_POU/365/ FWST_PROD_POU
FWST_PROD_IN= FWST_PROD_POU
WST_TS_IN= WST_TS_POU
WST_VS_IN= WST_VS_POU
FBG_WST_IN=FBG_WST_POU
WST_BULK_IN=WST_BULK_POU
WST_COD_IN=WST_COD_POU
Enter the additional annual amount of waste anticipated (tonnes): WST_IN(N)
DISPLAY and allow user to change:
Verify or change the data below
CH4 emission factor for homogenisation (kg CH4/ t waste) = EF_CH4_HOM_IN
N2O emission factor for homogenisation (kg N2O/t waste)= EF_N2O_HOM_IN
Total solids concentration in waste (%) = WST_TS_IN
Volatile solids concentration in waste (%) = WST_VS_IN
Bulk density of waste (t/m3) = WST_BULK_IN
COD concentration of waste (gCOD/l) = WST_COD_IN
Biogas production per tonne waste (m3/t) = FBG_WST_IN
BG_IN_VS(N)=WST_IN(N)*WST_TS_IN/100*WST_VS_IN/100*FBG_VS*1000
BG_IN_COD(N)=WST_IN(N)/WST_BULK_IN*WST_COD_IN*FBG_COD
BG_IN_WST(N)=WST_IN(N)*FBG_WST_IN
CH4_HOM_IN(N)=WST_IN(N)* EF_CH4_HOM_IN /1000
N2O_HOM_IN(N)= WST_IN(N)* EF_N2O_HOM_IN /1000
VOL_IN(N)=WST_IN(N)/WST_BULK_IN
AD_EN_CON_IN(N)=FAD_EN_CON*VOL_IN(N)*WST_TS_IN/100
WST_IN=WST_IN+WST_IN(N)
BG_IN_VS= BG_IN_VS+ BG_IN_VS(N)
BG_IN_COD= BG_IN_COD+ BG_IN_COD(N)
BG_IN_WST= BG_IN_WST+ BG_IN_WST(N)
CH4_HOM_IN= CH4_HOM_IN+ CH4_HOM_IN(N)
N2O_HOM_IN= N2O_HOM_IN+ N2O_HOM_IN(N)
AD_EN_CON_IN= AD_EN_CON_IN+ AD_EN_CON_IN(N)
VOL_IN= VOL_IN+ VOL_IN(N)


No
N=N+1
FARMS_IN=N
Yes
BG_IN_VS=0
BG_IN_COD=0
BG_IN_WST=0
CH4_HOM_IN=0
N2O_HOM_IN=0
AD_EN_CON_IN=0
Choose method for estimation of biogas production:
1. Volatile solids destroyed
2. COD consumed
3. Amount of waste digested
USER_BG
USER_BG=1
Yes
BG=WST_PROD*WST_TS/100*WST_VS/100*FBG_VS*1000+BG_IN_VS
METHOD = "Volatile solids destroyed"
No
USER_BG=2
Yes
BG=WST_PROD/WST_BULK*WST_COD*FBG_COD+BG_IN_COD
METHOD = "COD consumed"
No
No
USER_BG=3
Yes
BG=WST_PROD*FBG_WST+BG_IN_WST
METHOD = "Amount of waste digested"
EL_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_EL/100
TH_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_TH/100
CHP_CO2=(BG*BG_CO2/100*CO2_DEN)+(BG*BG_CH4/100*CH4_DEN*DE/100*44/16)
CHP_CH4=BG*BG_CH4/100*CH4_DEN*(1-DE/100)
Choose use of energy:
1. All energy used onsite and remaining electricity sold
2. All thermal used onsite, all electrical sold
USER_USE
USER_USE=1
Yes
ADD_EL=EN_CON_EL+AD_EN_CON-EL_PROD+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
No
ADD_EL<0
Yes
EL_SOLD=-ADD_EL
ADD_EL=0
No
ADD_TH<0
Yes
ADD_TH=0
No
No
USER_USE=2
Yes
ADD_EL=EN_CON_EL+AD_EN_CON+AD_EN_CON_IN
ADD_TH=EN_TH-TH_PROD
EL_SOLD=EL_PROD
ADD_TH<0
Yes
ADD_TH=0
No


ADD_LPG=ADD_TH*FEN_CON_LPG*3.6/LPG_EN_CONT/LPG_DEN/(FEN_CON_LPG+FEN_CON_DSL)
ADD_DSL=ADD_TH*FEN_CON_DSL*3.6/DSL_EN_CONT/DSL_DEN/(FEN_CON_LPG+FEN_CON_DSL)
EN_CONS_DSL_AD=EN_CON_DSL+ADD_DSL
EN_CONS_LPG_AD=EN_CON_LPG+ADD_LPG
EN_CONS_EL_AD=EN_CON_EL+AD_EN_CON+ADD_EL+AD_AN_CON_IN
DAIL_VOL=(WST_PROD/ WST_BULK + VOL_IN)/365
Choose what is applicable and correct assumptions:
Type of anaerobic digester: 1.completely mixed □ 2.lagoon □ TYPE
-Land for anaerobic digestion: 1.available □ 2.rent □ 3.purchase □ LAND
-Capital investment: 1.all available □ 2.loan □ FUND
Yes
TYPE=1
No
RT=DEF_RT_CM
CAP_COST=30.185*e^(-0.002*DAIL_VOL)*DAIL_VOL*365
AREA_OTHER=DEF_OTHAREA_CM
AREA_DG=DEF_AREA_CM
AREA_CTRL=DEF_CTRL_CM
ACT_VOL=DEF_ACT_VOL_CM
AD_HEIGHT=DEF_AD_HEIGHT
SAF_VOL=DEF_SAF_VOL
TYPE="Completely mixed"
RT=DEF_RT_LAG
CAP_COST=75%*30.185*e^(-0.002*DAIL_VOL)*DAIL_VOL*365
AREA_OTHER=DEF_OTHAREA_LAG
AREA_DG=DEF_AREA_LAG
AREA_CTRL=DEF_CTRL_LAG
ACT_VOL=DEF_ACT_VOL_LAG
AD_HEIGHT=DEF_AD_HEIGHT
SAF_VOL=DEF_SAF_VOL
TYPE="Anaerobic lagoon"
DISPLAY & allow to change:
Retention time of waste in digester (days)=RT
Digester additional volume for safety (%)= SAF_VOL
Height of anaerobic digester (m)= AD_HEIGHT
Active volume of the digester (%) = ACT_VOL
Area
Contribution of the digester to the total area needed (%) = AREA_DG
Contribution of control room, biogas scrubbing and generator room and office to the total area needed (%) = AREA_CTRL
Contribution of roads, safety area, open space, sludge storage and homogenisation tank to the total area needed (%) = AREA_OTHER
AD_AREA=(WST_PROD/WST_BULK+VOL_IN)/365 * RT * (1+SAF_VOL/100)/(AD_HEIGHT* ACT_VOL/100)
AREA=AD_AREA / (AREA_DG/100)
OTHER_AREA=AREA *AREA_OTHER/100
CTRL_AREA=AREA * AREA_CTRL/100
DCAP_COST_DIG= DEF_CAP_COST_DIG/100
DCAP_COST_OTHER= DEF_CAP_COST_OTHER/100
DISPLAY & allow to change:
Total area (m2) = AREA
Area for the digester (m2) = AD_AREA
Area needed for control room, biogas scrubbing and generator room and office = CTRL_AREA
Area needed for roads, safety area, open space, sludge storage and homogenisation tank (m2) = OTHER_AREA


LAND=1
No
LAND=2
No
LAND=3
No
Yes
Yes
Yes
LAND_PURCH=0
LAND_RENT=0
LAND_RENT=DEF_LAND_RENT
LAND_PURCH=0
LAND_PURCH=DEF_LAND_PRICE
LAND_RENT=0
DISPLAY & allow to change:
Annual rent (€/m2) =LAND_RENT
DISPLAY & allow to change:
Land cost
(€/m2)=LAND_PURCH
RENT=AREA * LAND_RENT
LAND_COST=AREA * LAND_PURCH
CAP_COST_DIG= DCAP_COST_DIG*CAP_COST
CAP_OTHER_COST=DCAP_COST_OTHER*CAP_COST
CAP_COST_TOT=CAP_COST+LAND_COST
DISPLAY & allow to change:
Cost for the purchase and installation of the equipment for the digester (€)= CAP_COST_DIG
Land cost (€) = LAND_COST
Other capital expenses (€) = CAP_OTHER_COST
Capital investment (€) = CAP_COST_TOT
FUND=2
No
LOAN=0
Yes
LOAN=CAP_COST_TOT
RATE=DEF_RATE
PER=DEF_PER
DISPLAY & allow to change:
Amount of Loan (€)=LOAN
Interest rate (%) = RATE
Loan repayment period (years)= PER
Inflation rate (%)= IR
Project lifetime (years) = LIFE
LOAN_PAY=LOAN/(1/(RATE/100))*(1-(1/(1+RATE/100))^PER)
IR=DEF_IR/100
LIFE = DEF_LIFE
EL_PRICE=DEF_EL_PRICE
MDR=DEF_MDR/100
TAX=DEF_TAX/100
OVER=DEF_OVER/100

DGHG_COST =DEF_GHG_COST
DCHP_MAINT_COST=DEF_CHP_MAINT_COST
DPER_COST=DEF_PER_COST/100
DMAINT_COST=DEF_MAINT_COST/100
DOPER_OTHER_COST=DEF_OPER_OTHER_COST/100

CO2_EN_DSL_AD=EF_CO2_DSL*EN_CONS_DSL_AD*DSL_EN_CONT*DSL_DEN/1000
CH4_EN_DSL_AD=EF_CH4_DSL*EN_CONS_DSL_AD* DSL_EN_CONT*DSL_DEN/1000
N2O_EN_DSL_AD=EF_N2O_DSL*EN_CONS_DSL_AD* DSL_EN_CONT*DSL_DEN/1000
CO2_EN_ELE_AD=EF_CO2_ELE*EN_CONS_ELE_AD*3.6/1000
CH4_EN_ELE_AD=EF_CH4_ELE*EN_CONS_ELE_AD*3.6/1000
N2O_EN_ELE_AD=EF_N2O_ELE*EN_CONS_ELE_AD*3.6/1000
CO2_EN_LPG_AD=EF_CO2_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000

CH4_EN_LPG_AD=EF_CH4_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000
N2O_EN_LPG_AD=EF_N2O_LPG*EN_CONS_LPG_AD*LPG_EN_CONT*LPG_DEN/1000
GHG_CH4_EN_DSL_AD=CH4_EN_DSL_AD*GWP_CH4/1000
GHG_N2O_EN_DSL_AD=N2O_EN_DSL_AD*GWP_N2O/1000
GHG_CH4_EN_ELE_AD=CH4_EN_ELE_AD*GWP_CH4/1000
GHG_N2O_EN_ELE_AD=N2O_EN_ELE_AD*GWP_N2O/1000
GHG_CH4_EN_LPG_AD=CH4_EN_LPG_AD*GWP_CH4/1000
GHG_N2O_EN_LPG_AD=N2O_EN_LPG_AD*GWP_N2O/1000

GHG_EN_DSL_AD=(CO2_EN_DSL_AD/1000)+GHG_CH4_EN_DSL_AD+GHG_N2O_EN_DSL_AD
GHG_EN_ELE_AD=(CO2_EN_ELE_AD/1000)+GHG_CH4_EN_ELE_AD+GHG_N2O_EN_ELE_AD
GHG_EN_LPG_AD=(CO2_EN_LPG_AD/1000)+GHG_CH4_EN_LPG_AD+GHG_N2O_EN_LPG_AD
GHG_EN_AD=GHG_EN_DSL_AD+GHG_EN_ELE_AD+GHG_EN_LPG_AD

EN_CO2_AD=(CO2_EN_DSL_AD+CO2_EN_ELE_AD+CO2_EN_LPG_AD)/1000
EN_CH4_AD=(CH4_EN_DSL_AD+CH4_EN_ELE_AD+CH4_EN_LPG_AD)/1000
EN_CH4_GHG_AD=EN_CH4_AD*GWP_CH4
EN_N2O_AD=(N2O_EN_DSL_AD+N2O_EN_ELE_AD+N2O_EN_LPG_AD)/1000
EN_N2O_GHG_AD=EN_N2O_AD*GWP_N20

CH4_FER=EF_CH4_FER*POP/1000
GHG_CH4_FER=CH4_FER*GWP_CH4

CH4_HOM=EF_CH4_MAN*POP/365/1000
GHG_CH4_HOM=(CH4_HOM+CH4_HOM_IN)*GWP_CH4
N2O_HOM=EF_N2O_MAN*POP/365/1000
GHG_N2O_HOM=(N2O_HOM+N2O_HOM_IN)*GWP_N2O
GHG_HOM=GHG_CH4_HOM+GHG_N2O_HOM

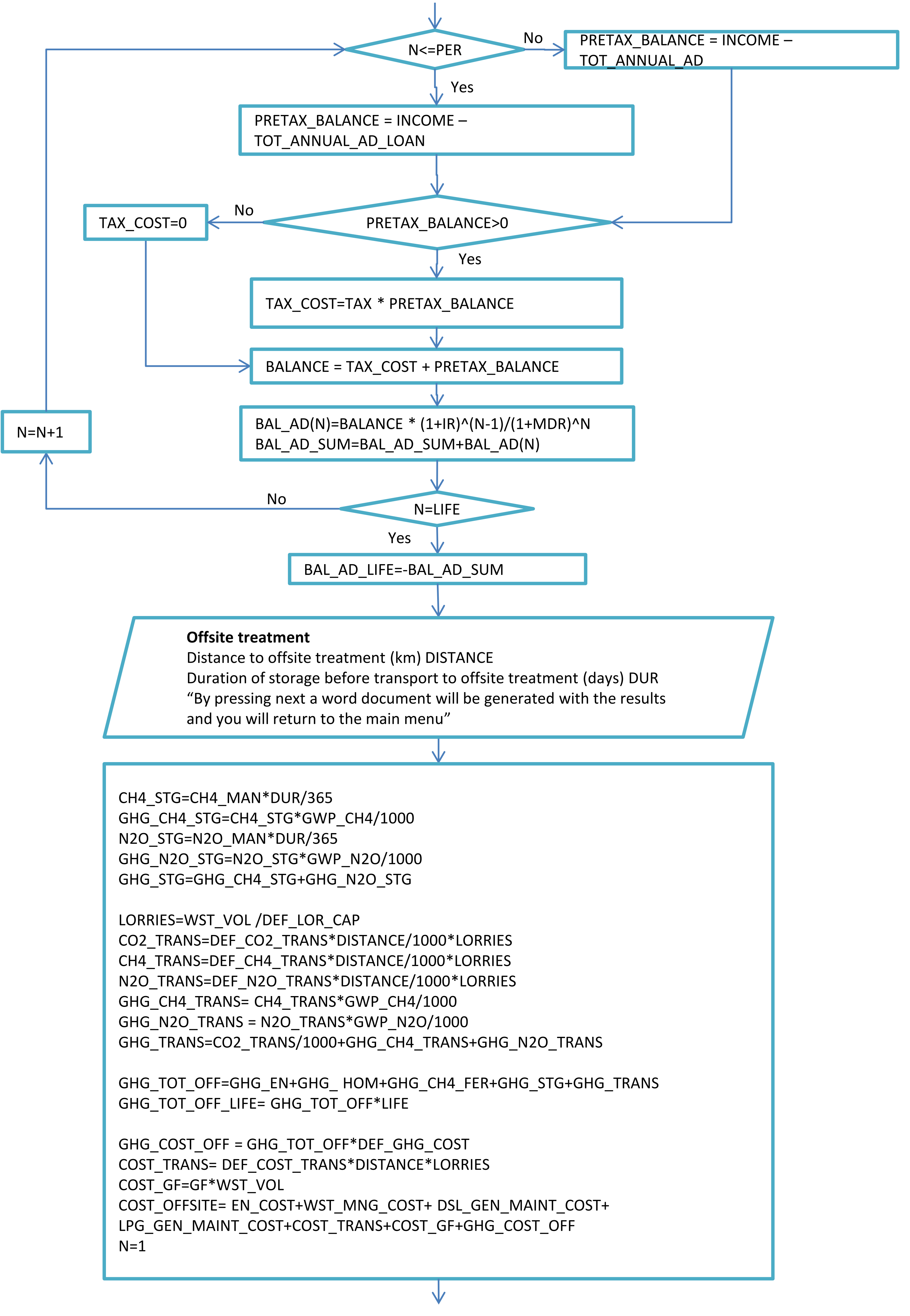
GHG_TOT_AD=GHG_EN_AD+GHG_HOM+GHG_CH4_FER+(CHP_CO2/1000) +CHP_CH4*GWP_CH4/1000

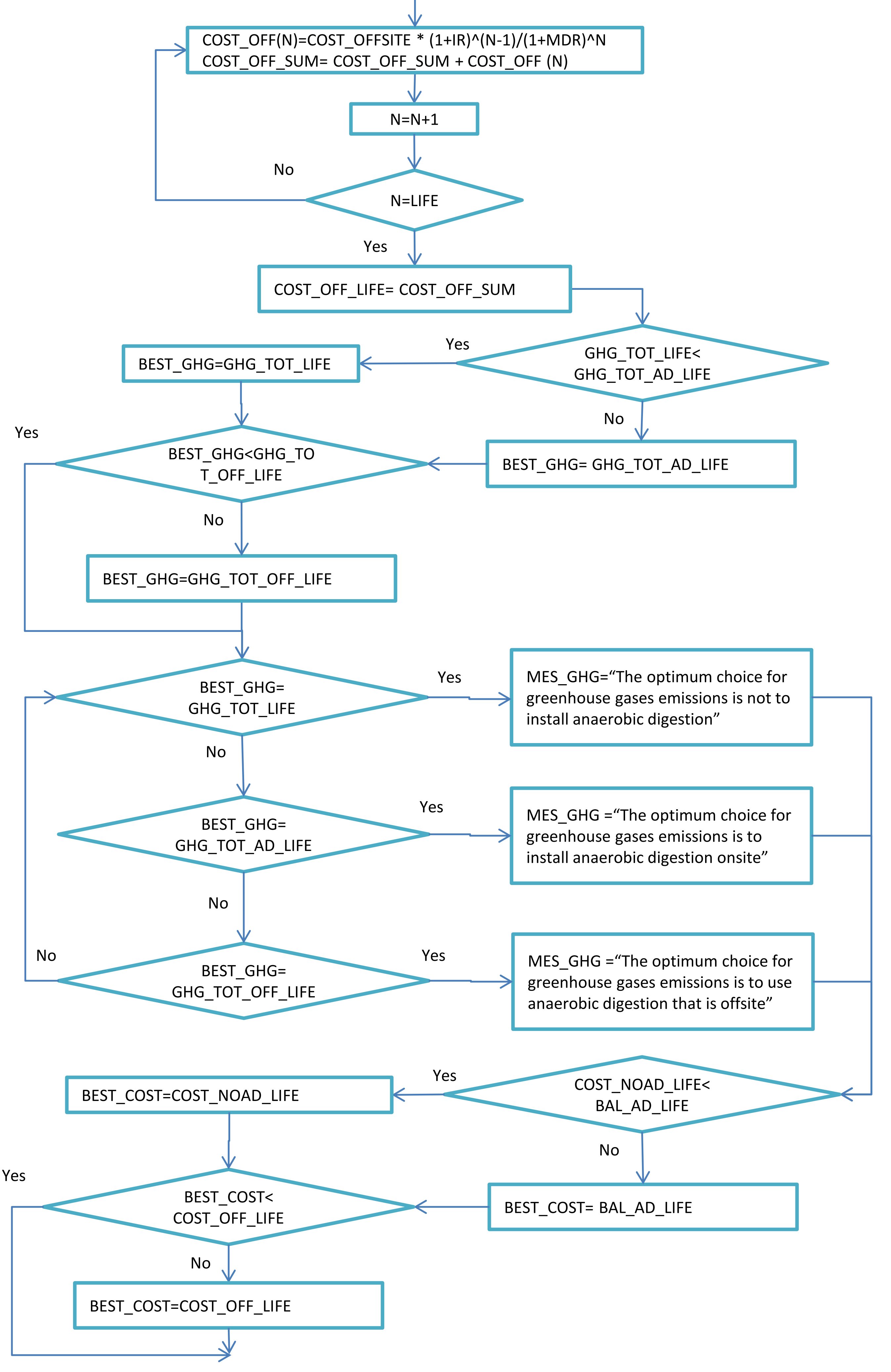
GHG_TOT_AD_LIFE= GHG_TOT_AD*LIFE

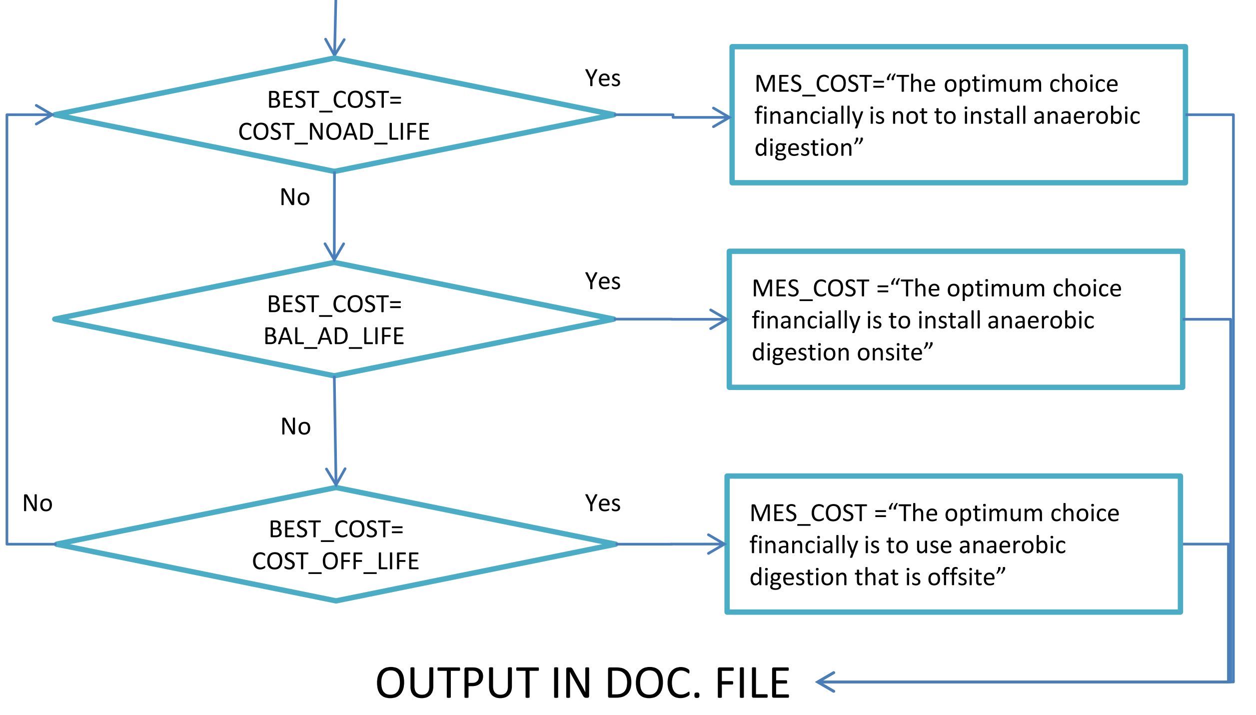
WST_INCOME=WST_IN * GF
EN_INCOME=EL_SOLD * EL_PRICE
INCOME=EN_INCOME + WST_INCOME

OPER_COST= 2.3179*e^(-0.002*DAIL_VOL)*DAIL_VOL*365
RENT_COST=LAND_RENT * AREA
PER_COST=DPER_COST* OPER_COST
MAINT_COST=DMAINT_COST* OPER_COST
CHP_MAINT_COST=DCHP_MAINT_COST*EL_PROD
OPER_OTHER_COST=DOPER_OTHER_COST* OPER_COST
EN_COST_AD=EN_CONS_DSL_AD * DSL_BPRICE + EN_CONS_LPG_AD * LPG_BPRICE +EN_CONS_EL_AD * EL_BPRICE

GHG_COST_AD= GHG_TOT_AD*DEF_GHG_COST
RUN_COST=(EN_COST_AD + RENT + CHP_MAINT_COST + GHG_COST+ OPER_COST) /(1- OVER)
TOT_ANNUAL_AD=RUN_COST+LPG_GEN_MAINT_COST+DSL_GEN_MAINT_COST
TOT_ANNUAL_AD_LOAN=RUN_COST+LPG_GEN_MAINT_COST+DSL_GEN_MAINT_COST+LOAN_PAY
OVER_COST = OVER * RUN_COST
BAL_AD_SUM=0


N<=PER
No
PRETAX_BALANCE = INCOME – TOT_ANNUAL_AD
Yes
PRETAX_BALANCE = INCOME – TOT_ANNUAL_AD_LOAN
TAX_COST=0
No
PRETAX_BALANCE>0
Yes
TAX_COST=TAX * PRETAX_BALANCE
BALANCE = TAX_COST + PRETAX_BALANCE
N=N+1
BAL_AD(N)=BALANCE * (1+IR)^(N-1)/(1+MDR)^N
BAL_AD_SUM=BAL_AD_SUM+BAL_AD(N)
No
N=LIFE
Yes
BAL_AD_LIFE=-BAL_AD_SUM
Offsite treatment
Distance to offsite treatment (km) DISTANCE
Duration of storage before transport to offsite treatment (days) DUR
“By pressing next a word document will be generated with the results
and you will return to the main menu”
CH4_STG=CH4_MAN*DUR/365
GHG_CH4_STG=CH4_STG*GWP_CH4/1000
N2O_STG=N2O_MAN*DUR/365
GHG_N2O_STG=N2O_STG*GWP_N2O/1000
GHG_STG=GHG_CH4_STG+GHG_N2O_STG
LORRIES=WST_VOL /DEF_LOR_CAP
CO2_TRANS=DEF_CO2_TRANS*DISTANCE/1000*LORRIES
CH4_TRANS=DEF_CH4_TRANS*DISTANCE/1000*LORRIES
N2O_TRANS=DEF_N2O_TRANS*DISTANCE/1000*LORRIES
GHG_CH4_TRANS= CH4_TRANS*GWP_CH4/1000
GHG_N2O_TRANS = N2O_TRANS*GWP_N2O/1000
GHG_TRANS=CO2_TRANS/1000+GHG_CH4_TRANS+GHG_N2O_TRANS
GHG_TOT_OFF=GHG_EN+GHG_ HOM+GHG_CH4_FER+GHG_STG+GHG_TRANS
GHG_TOT_OFF_LIFE= GHG_TOT_OFF*LIFE
GHG_COST_OFF = GHG_TOT_OFF*DEF_GHG_COST
COST_TRANS= DEF_COST_TRANS*DISTANCE*LORRIES
COST_GF=GF*WST_VOL
COST_OFFSITE= EN_COST+WST_MNG_COST+ DSL_GEN_MAINT_COST+
LPG_GEN_MAINT_COST+COST_TRANS+COST_GF+GHG_COST_OFF
N=1


COST_OFF(N)=COST_OFFSITE * (1+IR)^(N-1)/(1+MDR)^N
COST_OFF_SUM= COST_OFF_SUM + COST_OFF (N)
N=N+1
No
N=LIFE
Yes
COST_OFF_LIFE= COST_OFF_SUM
Yes
BEST_GHG=GHG_TOT_LIFE
GHG_TOT_LIFE< GHG_TOT_AD_LIFE
No
Yes
BEST_GHG<GHG_TO T_OFF_LIFE
BEST_GHG= GHG_TOT_AD_LIFE
No
BEST_GHG=GHG_TOT_OFF_LIFE
BEST_GHG= GHG_TOT_LIFE
Yes
MES_GHG="The optimum choice for greenhouse gases emissions is not to install anaerobic digestion"
No
BEST_GHG= GHG_TOT_AD_LIFE
Yes
MES_GHG ="The optimum choice for greenhouse gases emissions is to install anaerobic digestion onsite"
No
No
BEST_GHG= GHG_TOT_OFF_LIFE
Yes
MES_GHG ="The optimum choice for greenhouse gases emissions is to use anaerobic digestion that is offsite"
Yes
BEST_COST=COST_NOAD_LIFE
COST_NOAD_LIFE< BAL_AD_LIFE
No
Yes
BEST_COST< COST_OFF_LIFE
BEST_COST= BAL_AD_LIFE
No
BEST_COST=COST_OFF_LIFE


BEST_COST=
COST_NOAD_LIFE
Yes
MES_COST="The optimum choice financially is not to install anaerobic digestion"
No
BEST_COST=
BAL_AD_LIFE
Yes
MES_COST ="The optimum choice financially is to install anaerobic digestion onsite"
No
No
BEST_COST=
COST_OFF_LIFE
Yes
MES_COST ="The optimum choice financially is to use anaerobic digestion that is offsite"
OUTPUT IN DOC. FILE

OUTPUT IN DOC. FILE

OUTPUT in DOC file

Cost analysis for farm NAME with anaerobic digestion
Animal type: ANM
Animal population: POP
Biogas estimation based on : METHOD

MES_GHG
Total lifetime emissions using an offsite anaerobic digester (t CO2 eq.) : GHG_TOT_OFF_LIFE
Total lifetime emissions with anaerobic digestion onsite (t CO2 eq.): GHG_TOT_AD_LIFE
Total lifetime emissions without anaerobic digestion (t CO2 eq.): GHG_TOT_LIFE

MES_COST
Total lifetime balance to install anaerobic digestion onsite (€): BAL_AD_LIFE
Total lifetime cost without anaerobic digestion (€): COST_NOAD_LIFE
Total lifetime cost to use an offsite anaerobic digester (€): COST_OFF_LIFE

	Comparison of lifetime cost (€)	Comparison of lifetime emissions (t CO2 eq.)
Without anaerobic digestion	COST_NOAD_LIFE	GHG_TOT_LIFE
With anaerobic digestion	BAL_AD_LIFE	GHG_TOT_AD_LIFE
Anaerobic digestion offsite	COST_OFF_LIFE	GHG_TOT_OFF_LIFE

NOTE: Negative BALANCE corresponds to income

OUTPUT in DOC file 2nd PAGE

Detailed results	Without anaerobic digestion	With anaerobic digestion	Anaerobic digestion offsite
Energy			
Annual energy consumption (kWh)	EN_CON	EN_CON+AD_EN_CON+AD_EN_CON_IN	EN_CON
Annual electricity production (kWh)		EL_PROD	
Annual thermal energy production (kWh)		TH_PROD	
Annual energy needed in addition to energy produced (kWh) - electrical		ADD_EL	
Annual energy needed in addition to energy produced (kWh) - thermal		ADD_TH	
Electricity sold (kWh)		EL_SOLD	
Digester			
Type of digester		TYPE	
Annual waste production (m3/year)		WST_PROD/WST_BULK	
Additional waste from other farms (m3/year)		VOL_IN	
Potential annual biogas production (m^3)		BG	
Area			
Digester (m^2)		AD_AREA	
Control room etc. (m^2)		CTRL_AREA	
Other (m^2)		OTHER_AREA	
Total (m^2)		AREA	

Duration of storage before treatment (days)			DUR
Times of transport to digester per year			LORRIES
Annual emissions			
Energy consumption (t CO_2 eq.)	GHG_EN	GHG_EN_AD	GHG_EN
Enteric fermentation (t CO_2 eq.)	GHG_CH4_FER	GHG_CH4_FER	GHG_CH4_FER
Manure management (t CO_2 eq.)	GHG_MAN		
Homogenization tank (t CO_2 eq.)		GHG_HOM	GHG_HOM
CHP generator (t CO_2 eq.)		(CHP_CO2+CHP_CH4*GWP_CH4)/1000	
Storage before treatment (t CO_2 eq.)			GHG_STG
Transport (t CO_2 eq.)			GHG_TRANS
TOTAL (t CO_2 eq.)	GHG_TOT	GHG_TOT_AD	GHG_TOT_OFF
Total lifetime emissions (t CO_2 eq.)	GHG_TOT_LIFE	GHG_TOT_AD_LIFE	GHG_TOT_OFF_LIFE
Annual expenses			
Energy consumed (€)	EN_COST	EN_COST_AD	EN_COST
Emissions (€)	GHG_COST	GHG_COST_AD	GHG_COST_OFF
Waste management cost (€)	WST_MNG_COST		COST_GF
Penalty fine (€)	PENALTY		
Transport of waste to digester (€)			COST_TRANS
Generator maintenance (€)	LPG_GEN_MAINT_COST+DSL_GEN_MAINT_COST	LPG_GEN_MAINT_COST+DSL_GEN_MAINT_COST	LPG_GEN_MAINT_COST+DSL_GEN_MAINT_COST
Digester			
Loan payment (€)		LOAN_PAY	
Land rent (€)		RENT	
Personnel (€)		PER_COST	
Digester maintenance (€)		MAINT_COST	
CHP maintenance (€)		CHP_MAINT_COST	
Other expenses (€)		OPER_OTHER_COST	
Overheads (€)		OVER_COST	
TOTAL (€)	TOT_COST_NOAD		COST_OFFSITE
Total lifetime cost (€)	COST_NOAD_LIFE	BAL_AD_LIFE	COST_OFF_LIFE
Capital investment			
Purchase and installation of digester (€)		CAP_COST_DIG	
Land (€)		LAND_COST	
Other capital expenses (€)		CAP_OTHER_COST	
TOTAL (€)		CAP_COST_TOT	
Annual income			
Accepting waste from other farms (€)		WST_INCOME	
Electricity sales (€)		EN_INCOME	
TOTAL (€)		INCOME	

<u>Note</u>

1. The above results have been estimated using a <u>theoretical</u> general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.
2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

$

E

Enter the expected annual amount of waste according animal type in tonnes *(table format)*

Cow	(COW_IN)
Pig	(PIG_IN)
Poultry	(POU_IN)

DISPLAY and allow user to change:

Verify or change the data below

Energy consumption for anaerobic digestion (kWh/m3/1%TS)	FAD_EN_CON
Electrical efficiency of generator (%)	GEN_EFF_EL
Thermal efficiency of generator (%)	GEN_EFF_TH
Combustion efficiency of conversion of CH4 to CO2 (%)	DE

Double click number in cell to change

Waste characteristics

	COWS	PIGS	POULTRY
Annual waste production per animal (t/animal/year)	FWST_PROD_COW	FWST_PROD_PIG	FWST_PROD_POU
Total solids concentration in waste (%)	WST_TS_COW	WST_TS_PIG	WST_TS_POU
Volatile solids concentration in waste (%)	WST_VS_COW	WST_VS_PIG	WST_VS_POU
Bulk density of waste (t/m3)	WST_BULK_COW	WST_BULK_PIG	WST_BULK_POU
COD concentration of waste (gCOD/l)	WST_COD_COW	WST_COD_PIG	WST_COD_POU
Biogas production per tonne waste (m3/t)	FBG_WST_COW	FBG_WST_PIG	FBG_WST_POU

Emission factors, global warming potentials, biogas characteristics

	CO2	CH4	N2O
Manure management emission factor (kg /cow)	-	EF_CH4_MAN_COW	EF_N2O_MAN_COW
Manure management emission factor (kg /pig)	-	EF_CH4_MAN_PIG	EF_N2O_MAN_PIG
Manure management emission factor (kg /bird)	-	EF_CH4_MAN_POU	EF_N2O_MAN_POU
Global warming potentials	-	GWP_CH4	GWP_N2O
Content in biogas (%)	BG_CO2	BG_CH4	-
Energy content at 100% combustion (kWh/m3)	-	CH4_EN	
Density (kg/m3)	CO2_DEN	CH4_DEN	-

	per kg VS destroyed (m3/kg VS)	per kg COD consumed (m3/kg COD)
Biogas production coefficients	FBG_VS	FBG_COD

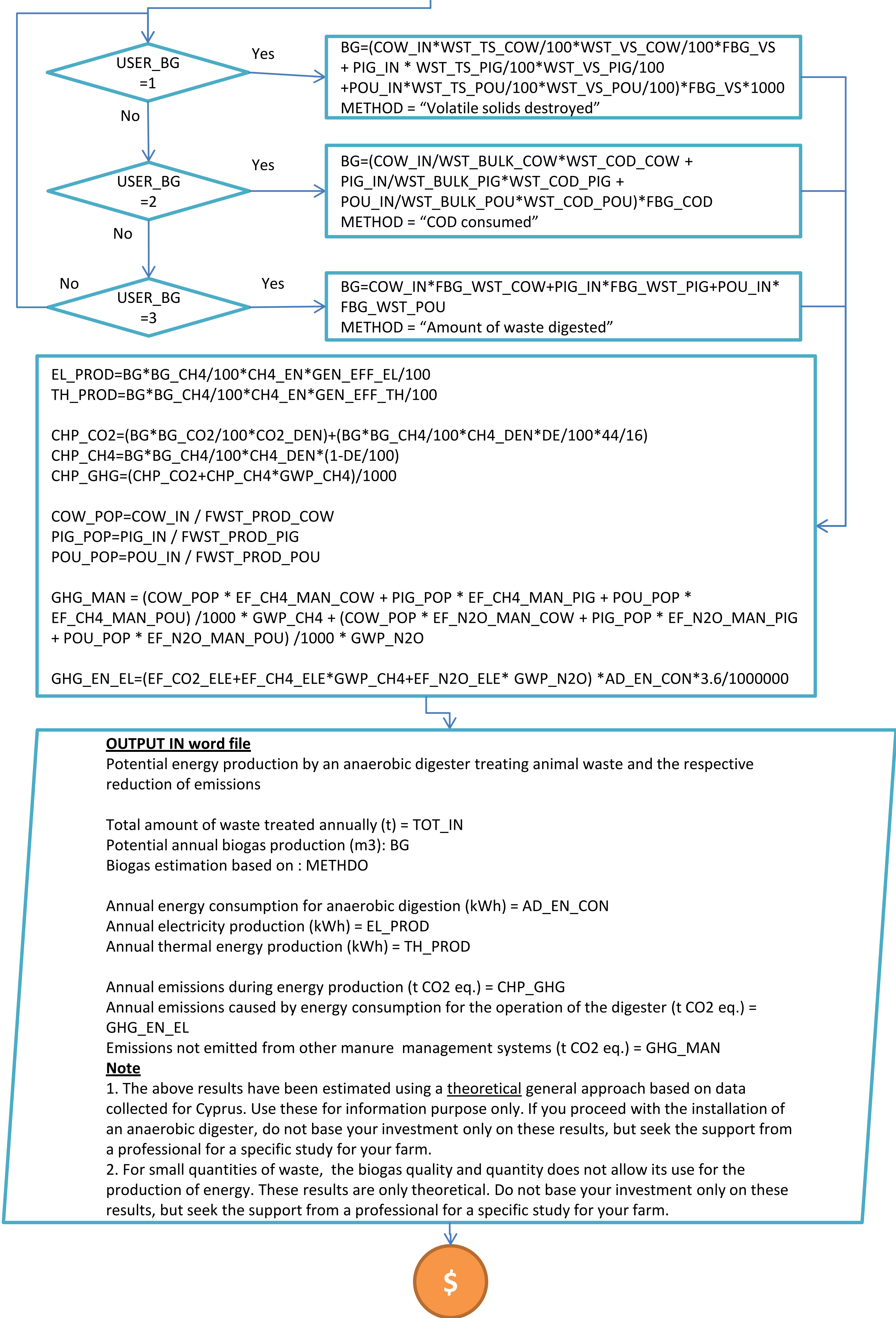
TOT_VOL=COW_IN/WST_BULK_COW+PIG_IN/WST_BULK_PIG+POU_IN/WST_BULK_POU
AD_EN_CON=FAD_EN_CON * (COW_IN / WST_BULK_COW * WST_TS_COW/100 + PIG_IN / WST_BULK_PIG * WST_TS_PIG/100 + POU_IN / WST_BULK_POU * WST_TS_POU/100)

Choose method for estimation of biogas production:

1. Volatile solids destroyed
2. COD consumed
3. Amount of waste digested

USER_BG

By pressing next a word document will be generated with the results and you will return to the main menu


USER_BG =1
Yes
No
BG=(COW_IN*WST_TS_COW/100*WST_VS_COW/100*FBG_VS + PIG_IN * WST_TS_PIG/100*WST_VS_PIG/100 +POU_IN*WST_TS_POU/100*WST_VS_POU/100)*FBG_VS*1000
METHOD = “Volatile solids destroyed”
USER_BG =2
Yes
No
BG=(COW_IN/WST_BULK_COW*WST_COD_COW + PIG_IN/WST_BULK_PIG*WST_COD_PIG + POU_IN/WST_BULK_POU*WST_COD_POU)*FBG_COD
METHOD = “COD consumed”
USER_BG =3
No
Yes
BG=COW_IN*FBG_WST_COW+PIG_IN*FBG_WST_PIG+POU_IN* FBG_WST_POU
METHOD = “Amount of waste digested”
EL_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_EL/100
TH_PROD=BG*BG_CH4/100*CH4_EN*GEN_EFF_TH/100
CHP_CO2=(BG*BG_CO2/100*CO2_DEN)+(BG*BG_CH4/100*CH4_DEN*DE/100*44/16)
CHP_CH4=BG*BG_CH4/100*CH4_DEN*(1-DE/100)
CHP_GHG=(CHP_CO2+CHP_CH4*GWP_CH4)/1000
COW_POP=COW_IN / FWST_PROD_COW
PIG_POP=PIG_IN / FWST_PROD_PIG
POU_POP=POU_IN / FWST_PROD_POU
GHG_MAN = (COW_POP * EF_CH4_MAN_COW + PIG_POP * EF_CH4_MAN_PIG + POU_POP * EF_CH4_MAN_POU) /1000 * GWP_CH4 + (COW_POP * EF_N2O_MAN_COW + PIG_POP * EF_N2O_MAN_PIG + POU_POP * EF_N2O_MAN_POU) /1000 * GWP_N2O
GHG_EN_EL=(EF_CO2_ELE+EF_CH4_ELE*GWP_CH4+EF_N2O_ELE* GWP_N2O) *AD_EN_CON*3.6/1000000
OUTPUT IN word file
Potential energy production by an anaerobic digester treating animal waste and the respective reduction of emissions
Total amount of waste treated annually (t) = TOT_IN
Potential annual biogas production (m3): BG
Biogas estimation based on : METHDO
Annual energy consumption for anaerobic digestion (kWh) = AD_EN_CON
Annual electricity production (kWh) = EL_PROD
Annual thermal energy production (kWh) = TH_PROD
Annual emissions during energy production (t CO2 eq.) = CHP_GHG
Annual emissions caused by energy consumption for the operation of the digester (t CO2 eq.) = GHG_EN_EL
Emissions not emitted from other manure management systems (t CO2 eq.) = GHG_MAN
Note
1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.
2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.
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Appendix C: User guide for the software FARMS

FARMS Software v1.0 User Guide

July 2013

Disclaimer

The results of FARMS are estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. The results of FARMS are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

Software developers

N. Kythreotou and A.G. Florides, 2011-2013

Contents

Overview

About this guide

The guide is intended for novice and experienced users who use FARMS v1.0 for the assessment of greenhouse gas mitigation and renewable energy production from anaerobic digestion. It uses terminology that assumes a working knowledge of the Microsoft® Windows® operating system.

Purpose of the software

The purpose of FARMS is to estimate the reduction of greenhouse gases by the installation of anaerobic digestion for the treatment of animal waste. Potential results also include scenarios for a farm without anaerobic digestion and a farm with uses an offsite anaerobic digester.

Features

FARMS can:

- Estimate the greenhouse gas emissions of a farm
- Estimate the reduction of greenhouse gas emissions with anaerobic digestion in a farm
- Estimate the cost for the installation and operation of an anaerobic digester
- Provide the optimum scenario for a farm with respect to cost and greenhouse gas emissions
- Estimate potential energy production by an anaerobic digester treating animal waste and the respective reduction of emissions

About the methodology

FARMS was developed according to the methodology proposed by the PhD thesis of N. Kythreotou for the assess greenhouse gas mitigation and renewable energy production from anaerobic digestion for the conditions of Cyprus (2013). Detailed analysis of the methodology and algorithm used are presented in the thesis.

Getting started

Operating system requirements

- Windows XP or superior
- 10 MB available in the hard disk
- Microsoft .NET Framework 3.5 or higher
- Microsoft Office 2003 or higher

Installation

Once you have the .rar file with FARMS available:

1. Double click on the file. “WinRAR” should automatically start. If you have the evaluation copy, a message will appear to purchase a WinRAR license. Click close.

2. Click once on the folder FARMS and click the “extract to” or “unzip” button (depends on the software you are using to open the file). Choose your desired location to save the folder in the right hand box with the images and click OK. *<u>Note</u>: where you save the folder is the location that the software will be installed*.

3. While in the folder FARMS, double click on setup setup . The setup of the program will run and subsequently FARM will start.

In case you receive an update, make sure that you install it at the same location as the previous version or uninstall the older version first and then install the new version at the desired location.

<u>Errors</u>

1. If you receive the “Program compatibility assistant” window (Windows 7), click on cancel.

2. If you receive the “Application install – Security warning” window (Windows 7), click on Install.

Necessary data

Before starting FARMS you should have the following data to be able to proceed with the program:

- Type of animal housed in the farm
- Total animal population of the farm
- For standalone AD: annual amounts of waste going to the digester

Using FARMS

Launching FARMS

To launch FARMS,

- select Start > All programs > eac > Farms.
- <u>or</u> Start > type FARMS in *search programs and files*
- <u>or</u> double click the shortcut on the desktop

Upon launch of the program, the following welcome screen will appear (Fig.1)

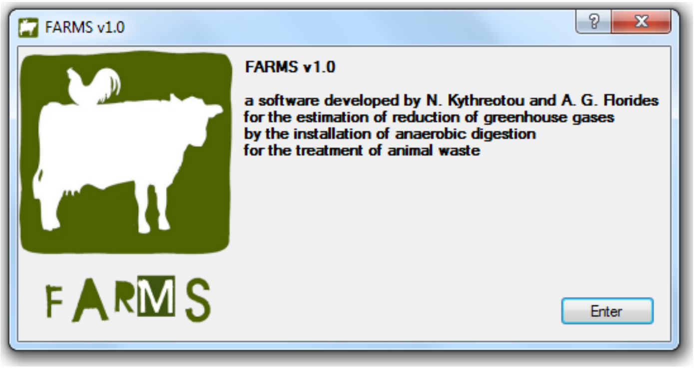
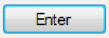


Fig.1

Click on the  button to enter the program.

At any moment you can exit the program by clicking the button , on the top right corner. You can go back to a previous window by clicking the button  at the lower left corner.

Main menu

The main menu of FARMS will then appear (Fig.2)

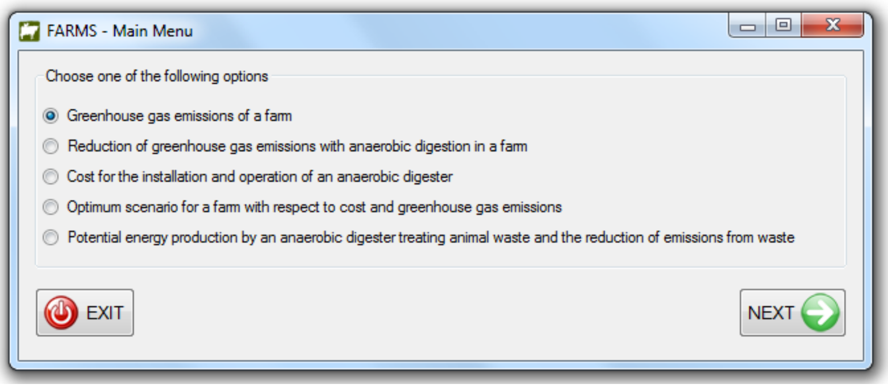


Fig.2

Click on the circle to the left of the choice you want to run:

- Greenhouse gas emissions of a farm – choose this option if you want to estimate the greenhouse gas emissions (GHG). The activities causing the GHG are energy consumption, enteric fermentation and manure management. Data that has to be available: animal type and animal population.

- Reduction of greenhouse gas emissions with anaerobic digestion in a farm – choose this option if you would like to estimate the impact that an anaerobic digester (AD) will have on the GHG and energy consumption of a farm. Data that has to be available: animal type and animal population. If waste from other farms is going to be input in the AD, the annual amount of waste anticipated in tonnes, and the animal type of each farm.

- Cost for the installation and operation of an anaerobic digester – choose this option if you would like to estimate the capital and annual costs for the installation and operation of an AD at a farm. Data that has to be available: animal type and animal population. If waste from other farms is going to be input in the AD, the annual amount of waste anticipated in tonnes, and the animal type of each farm.

- Optimum scenario for a farm with respect to cost and greenhouse gas emissions – three scenarios are assessed for a farm: without AD, with AD and using an offsite AD. Data that has to be available: animal type, animal population and distance between the AD and the farm. If waste from other farms is going to be input in the AD of the farm, the annual amount of waste anticipated in tonnes, and the animal type of each farm.

- Potential energy production by an anaerobic digester treating animal waste and the reduction of waste emissions – choose this option to assess an independent AD. Data that has to be available: annual waste input to the AD per animal type.

You can exit the program by clicking on 

located on the left bottom corner.

Option 1 Greenhouse gas emissions of a farm

Step 1.1. At the main menu window, click on the first circle on the left of the option “Greenhouse gas emissions of a farm” (Fig.3).

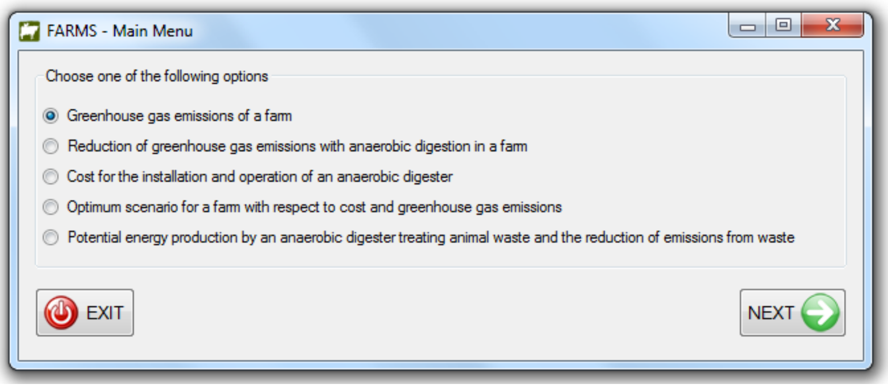


Fig.3

Step 1.2. The window that appears requests the user to enter details for the farm (Fig.4).

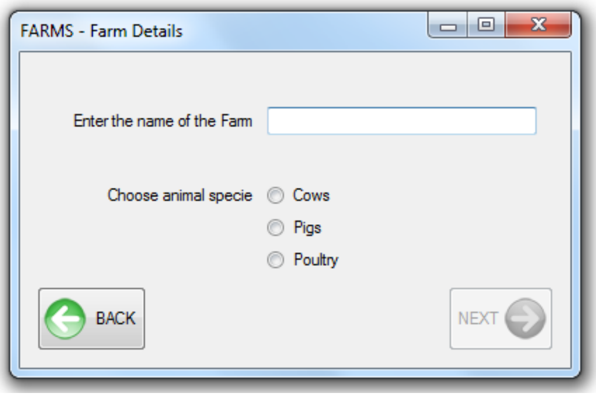


Fig.4

Enter the name of the farm in the white field and choose one of the animal species (cows, pigs and poultry) of the farm by clicking on the circle on the left. If your farm is housing more than one species, an option will be available to enter other species at a later stage.

Step 1.3. Click the 

button. The button will not be activated until all the necessary data is entered or chosen.

Step 1.4. The new window that opens (Fig.5), displays the default values for the parameters that are necessary for the calculations.

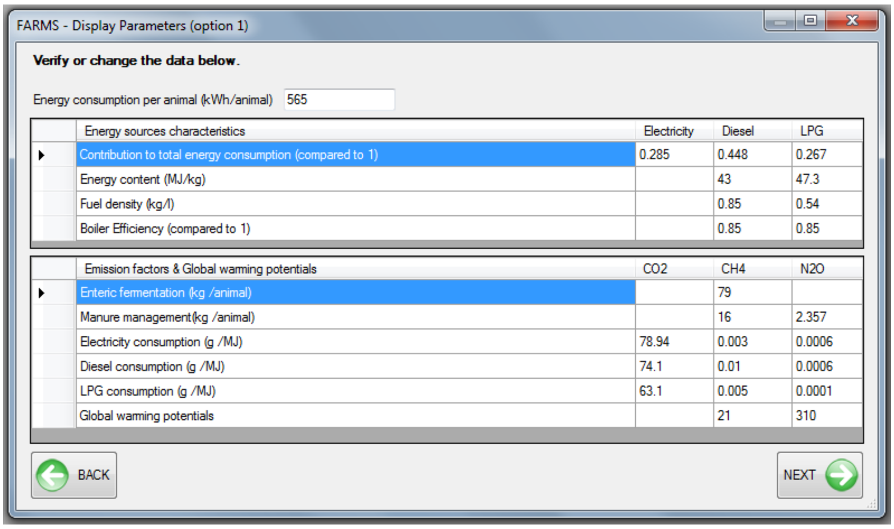


Fig.5

If you have available data you can enter your data. Data cannot be entered in the cells that are empty. A list of all the default values is given at the end of this guidebook. Click the 

button.

Step 1.5. (Fig.6) Enter the animal population in the white field of the new window.

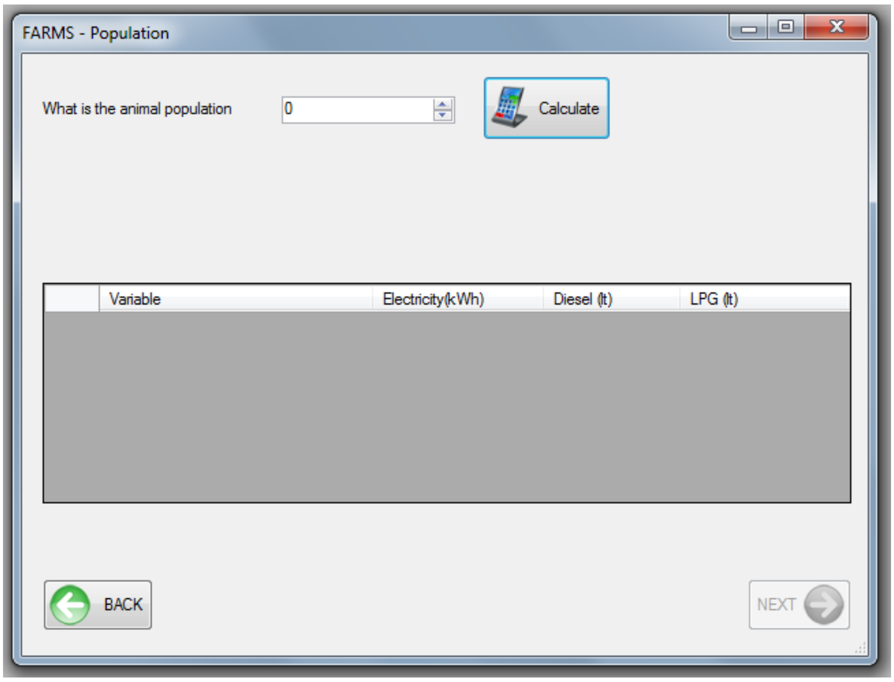
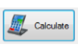


Fig.6

Cows: enter the total population of the farm including dairy cattle, calves, bulls etc.

Pigs: enter the total population of the farm including sows, piglets etc. If you have only the number of sows available, multiply by 10 to obtain the total population of the farm.

Poultry: enter the total population of the farm in one year. If you have only the number of bird-places available, multiply the number by 5.5 to convert in poultry population.

Step 1.6. Click on 

. Data will appear below (Fig.7), regarding annual energy consumption of the farm.

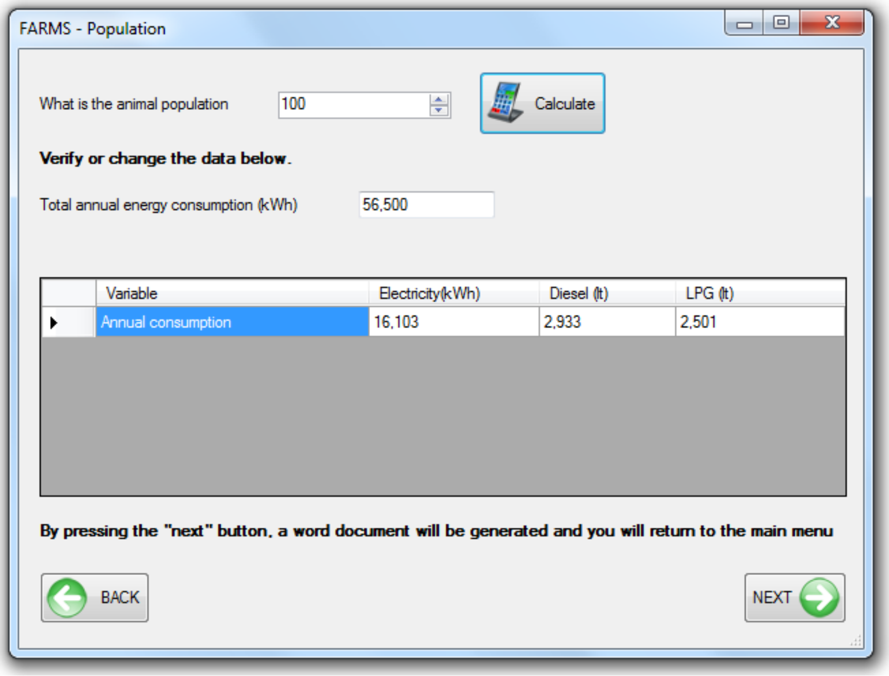


Fig.7

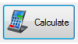
If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

Attention: If you have data and you are going to replace the suggested values, pay attention to the units.

Diesel - If you have consumption in kg, divide by 0.85 to convert to litres.

LPG – If you have consumption in kg, divide by 0.54 to convert to litres.

The button 

will be activated only after you have entered the population and clicked 

.

Step 1.7. By clicking on the 

button a word file with the detailed results will open and you will return at the main menu. You can save the word file with the name you want and at the location you want.

Option 2 Reduction of greenhouse gas emissions with anaerobic digestion in a farm

Step 2.1. At the main menu window, click on the second circle on the left of the option “Reduction of greenhouse gas emissions with anaerobic digestion in a farm” (Fig.8).

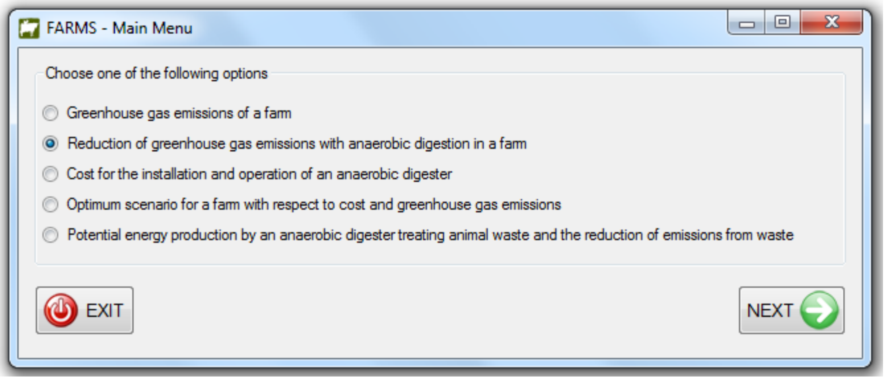


Fig.8

Step 2.2. The window that appears requests the user to enter details for the farm (Fig.9).

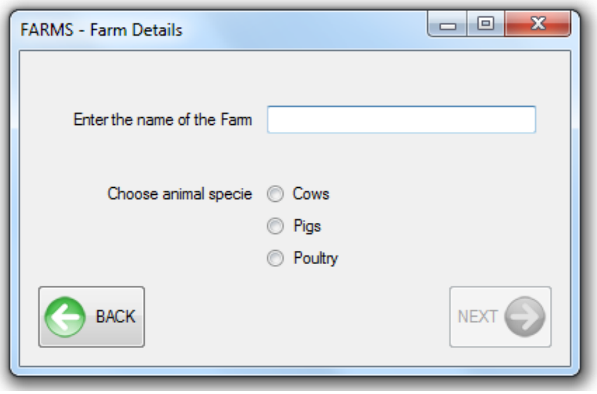


Fig.7

Enter the name of the farm in the white field and choose one of the animal species (cows, pigs and poultry) of the farm by clicking on the circle on the left. If your farm is housing more than one species, an option will be available to enter other species at a later stage.

Step 2.3. Click the  button. The button will not be activated until all the necessary data is entered or chosen.

Step 2.4. (Fig.10) The new window that opens, displays the default values for the parameters that are necessary for the calculations.

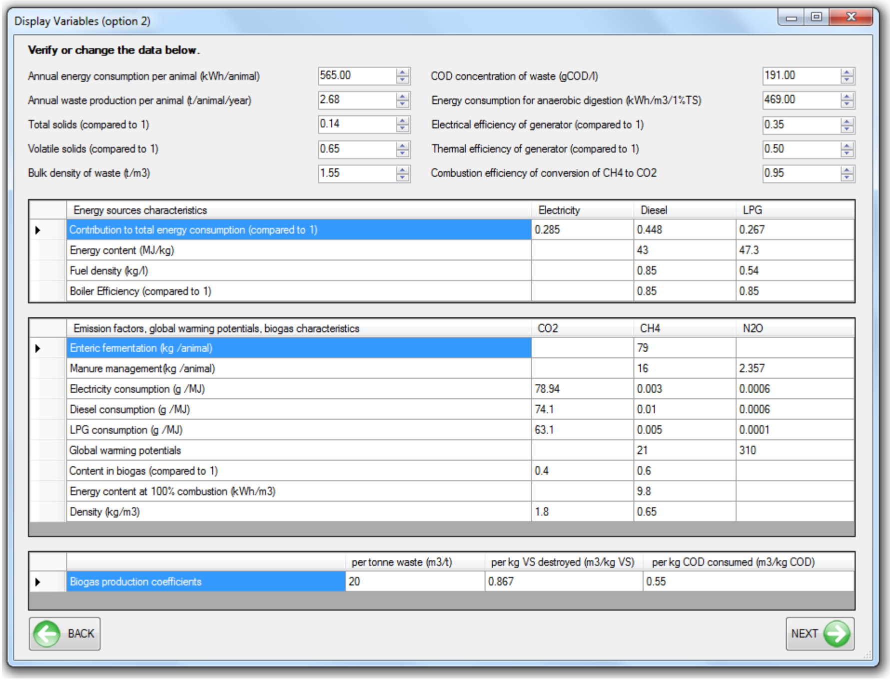


Fig.10

If you have available data you can enter your data. Data cannot be entered in the cells that are empty. A list of all the default values is given at the end of this guidebook. Click the 

button.

Step 2.5. Enter the animal population in the white field of the new window (Fig.11).

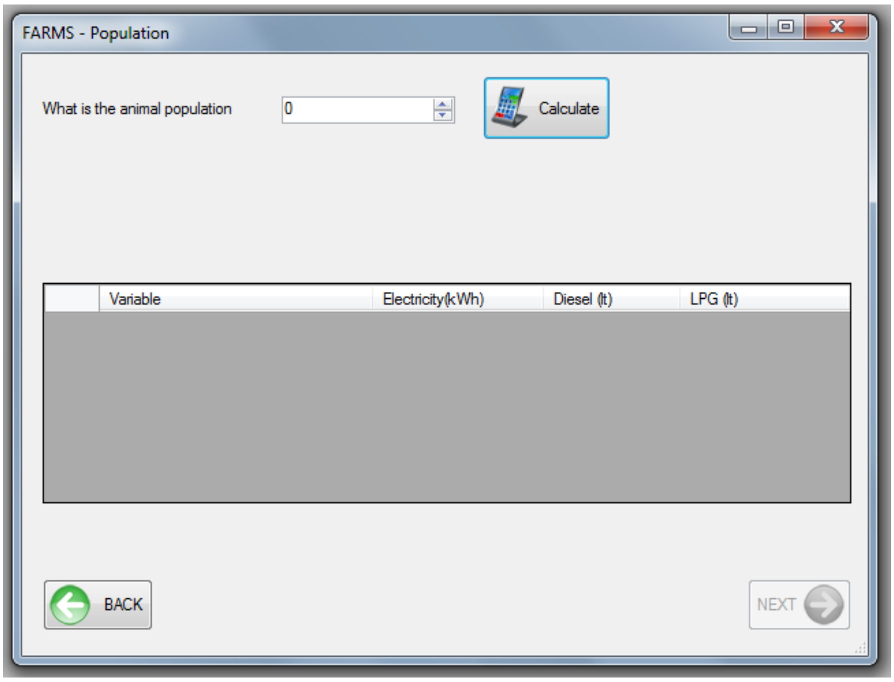


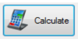
Fig.11

<u>Cows</u>: enter the total population of the farm including dairy cattle, calves, bulls etc.

<u>Pigs</u>: enter the total population of the farm including sows, piglets etc. If you have only the number of sows available, multiply by 10 to obtain the total population of the farm.

<u>Poultry</u>: enter the total population of the farm in one year. If you have only the

number of bird-places available, multiply the number by 5.5 to convert in poultry population.

Step 2.6. Click on 

. Data will appear below (Fig.12), regarding annual energy consumption of the farm and annual animal waste production.

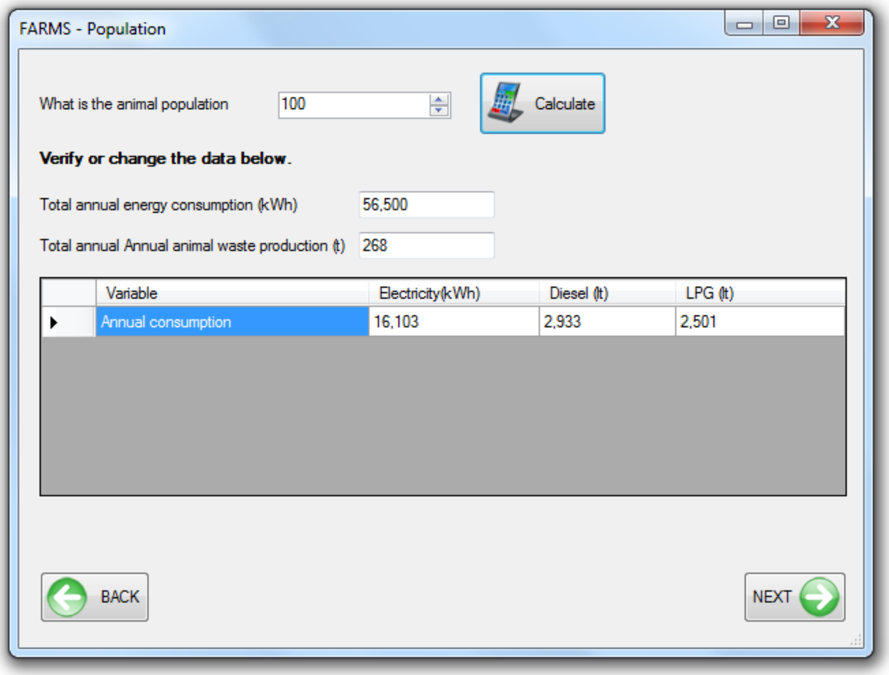


Fig.12

If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

<u>Attention</u>: If you have data and you are going to replace the suggested values, pay attention to the units.

Diesel - If you have consumption in kg, divide by 0.85 to convert to litres.

LPG – If you have consumption in kg, divide by 0.54 to convert to litres.

Waste – If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

Step 2.7. By clicking on the 

button a pop-up window will appear (Fig.13).

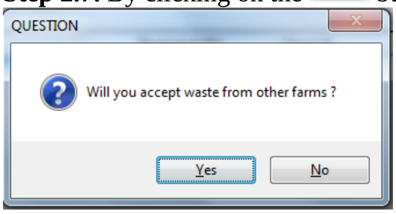
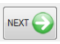
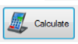
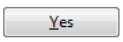


Fig.13

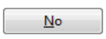
The button 

will be activated only after you have entered the population and clicked 

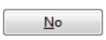
.

Click on 

if waste from other farms will be added to the AD in addition to the waste produced by the initial farm.

Click on 

if no other waste will be added to the AD.

If you clicked on 

, go to **Step 2.10**.

Step 2.8. The new window that appears (Fig.14) concerns the waste from other farms.

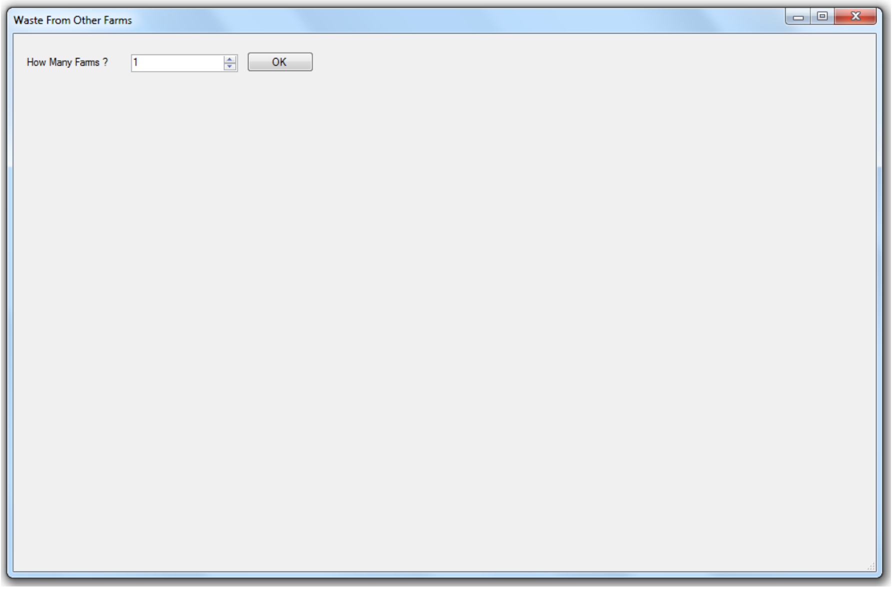


Fig.14

Enter the number of farms in the white field by typing the number or by clicking the small arrows on the right hand side of the white field .

Click on 

for additional fields and data to appear (Fig.15)

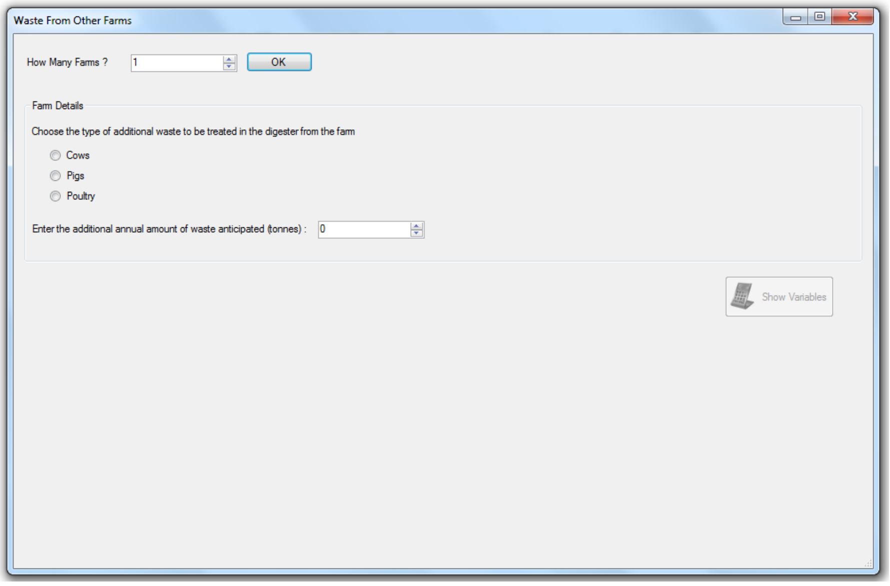
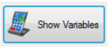


Fig.15

Click one of the animal species from which the waste originate by clicking on the circle on the left.

Enter the amount of waste anticipated per year in the white field in tonnes. If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

The 

will now be activated. Click to view the default values that will be used in the subsequent steps (Fig.16).

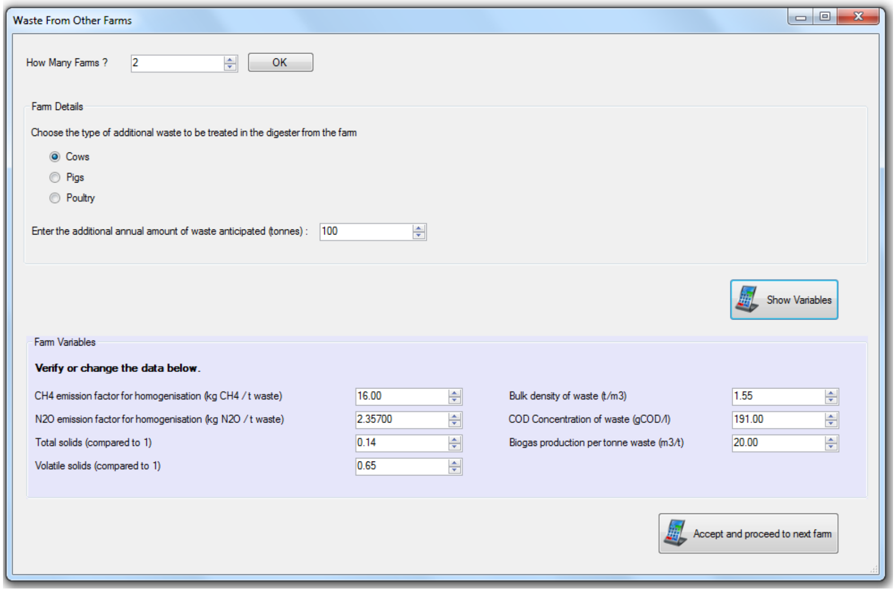
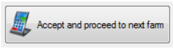
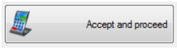
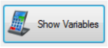
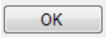
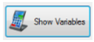
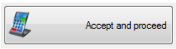
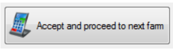


Fig.16

If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

If the number of farms is more than 1, the button at the bottom right hand corner will be  . Otherwise it will be  .

Note: if you want to change the number of farms after you have clicked on , enter the number of farms, click  and then . The button on the right hand side will change from  to  .

Step 2.9. If you have entered more than one farm, the same window will appear. Follow the same instructions as **Step 2.8**.

Step 2.10. The new window that appears (Fig.17) concerns the production of biogas from waste during AD. Here you have the option to choose the method by which the potential biogas production will be estimated.

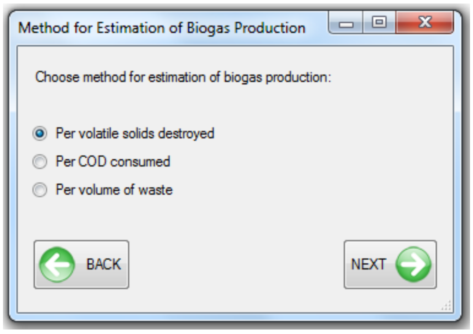


Fig.17

<u>Per volatile solids destroyed</u> – In theory, all the volatile solids (VS) available should be destroyed during anaerobic digestion. According to the biochemical reactions taking place, for each kg of VS destroyed, 0.867 m^3 biogas is produced.

<u>Per COD consumed</u> – In theory, all the COD available should be consumed by anaerobic organisms during anaerobic digestion. According to the biochemical reactions taking place, for each kg of COD consumed, 0.55 m^3 biogas is produced.

<u>Per volume of waste</u> – according to the characteristics of the waste and the biochemical reactions taking place during the anaerobic digestion, there is a theoretical amount of waste that is produced per unit mass of waste: cattle 25 m^3

biogas /t waste, pigs 36 m^3 biogas /t waste, poultry 80 m^3 biogas /t waste.

Choose one of the three methods by clicking on the circle on the left and click NEXT to proceed.

Step 2.11. The new window (Fig.18) concerns the use of the energy produced from the biogas combustion. Since there is no distribution network for thermal energy in Cyprus, only the electricity can be sold. The two options given by FARMS are All energy used onsite and remaining electricity sold and All thermal used onsite, all electrical sold. Choose what is more appropriate for your case and click NEXT to proceed.

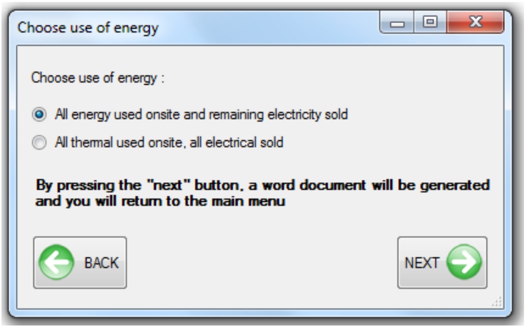
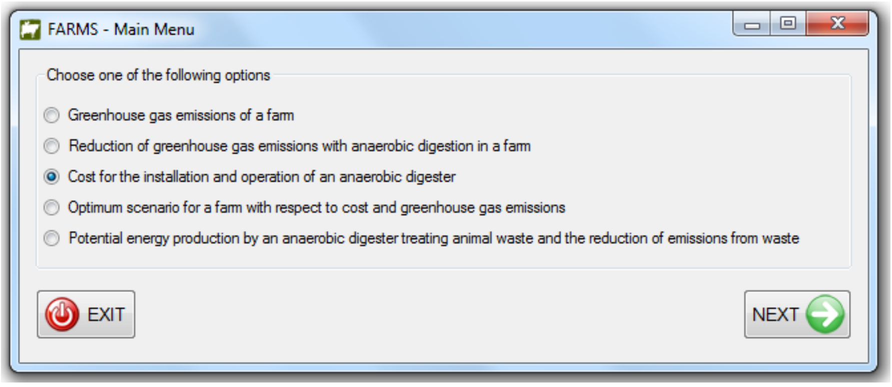


Fig.18

A word file with detailed results will be generated and open and you will return at the main menu. You can save the word file with the name you want and at the location you want.

Option 3 Cost for the installation and operation of an anaerobic digester

Step 3.1. At the main menu window, click on the third circle on the left of the option “Cost for the installation and operation of an anaerobic digestion” (Fig.19).



Step 3.2. The window that appears requests the user to enter details for the farm (Fig.20).

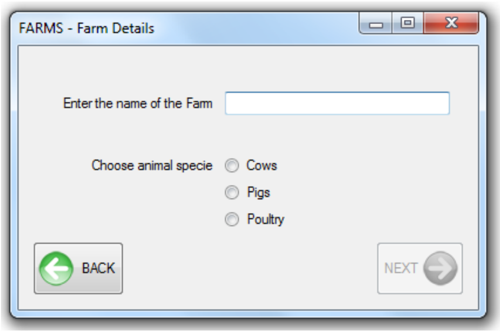


Fig.20

Enter the name of the farm in the white field and choose one of the animal species (cows, pigs and poultry) of the farm by clicking on the circle on the left. If your farm is housing more than one species, an option will be available to enter other species at a later stage.

Step 3.3. Click the  button. The button will not be activated until all the necessary data is entered or chosen.

Step 3.4. The new window that opens (Fig.21), displays the default values for the parameters that are necessary for the calculations.

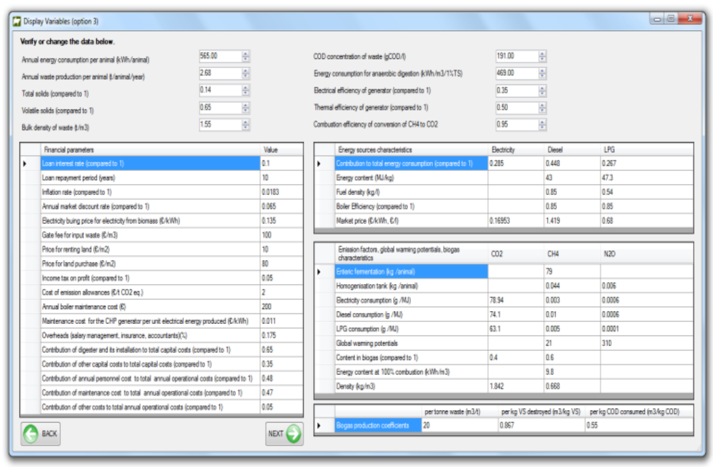


Fig.21

If you have available data you can enter your data. Data cannot be entered in the cells that are empty. A list of all the default values is given at the end of this guidebook. Click the NEXT button.

Step 3.5. Enter the animal population in the white field of the new window (Fig.22).

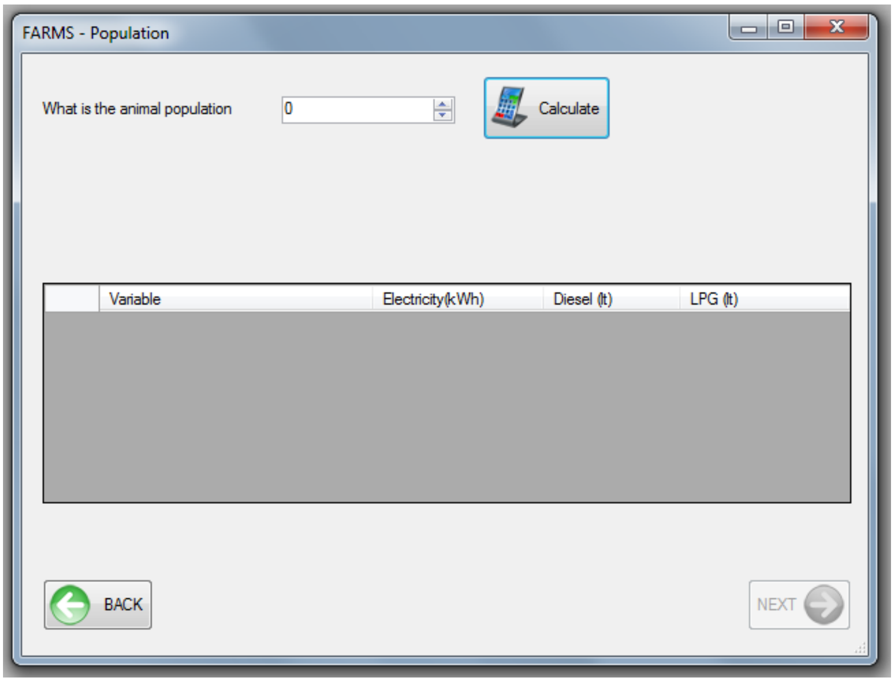


Fig.22

Cows: enter the total population of the farm including dairy cattle, calves, bulls etc.

Pigs: enter the total population of the farm including sows, piglets etc. If you have only the number of sows available, multiply by 10 to obtain the total population of the farm.

Poultry: enter the total population of the farm in one year. If you have only the number of bird-places available, multiply the number by 5.5 to convert in poultry population.

Step 3.6. Click on Calculate. Data will appear below (Fig.23), regarding annual energy consumption of the farm and annual animal waste production.

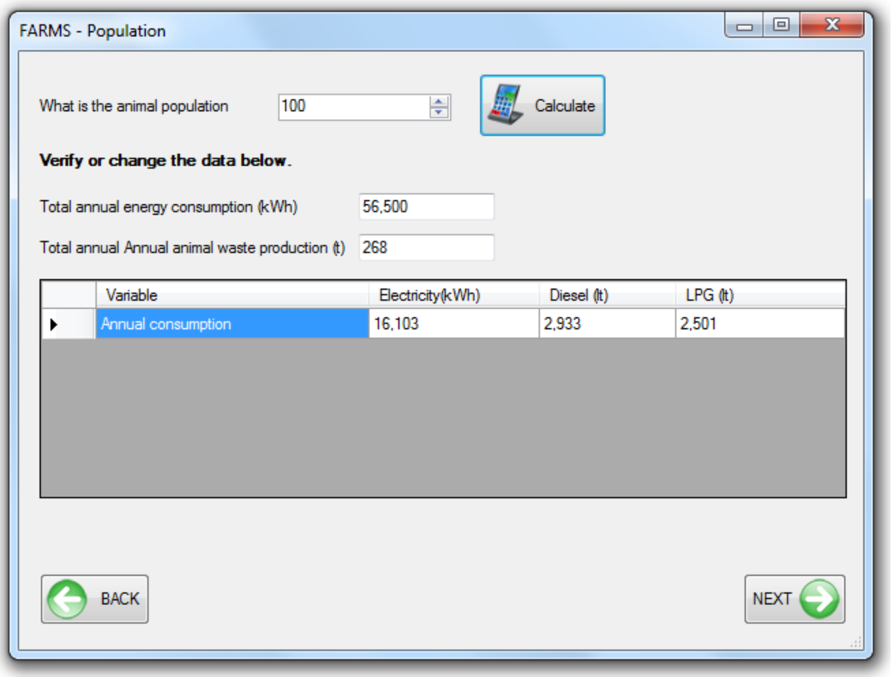


Fig.23

If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

<u>Attention</u>: If you have data and you are going to replace the suggested values, pay attention to the units.

Diesel - If you have consumption in kg, divide by 0.85 to convert to litres.

LPG – If you have consumption in kg, divide by 0.54 to convert to litres.

Waste – If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

Step 3.7. By clicking on the  button a pop-up window will appear (Fig.24).

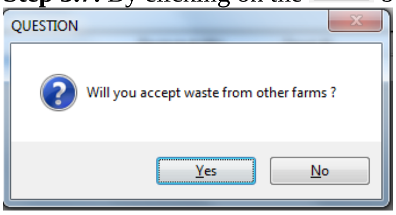
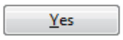
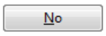
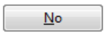


Fig.24

The button  will be activated only after you have entered the population and clicked .

Click on  if waste from other farms will be added to the AD in addition to the waste produced by the initial farm.

Click on  if no other waste will be added to the AD.

If you clicked on , go to **Step 3.20**.

Step 3.8. The new window that appears (Fig.25) concerns the waste from other farms.

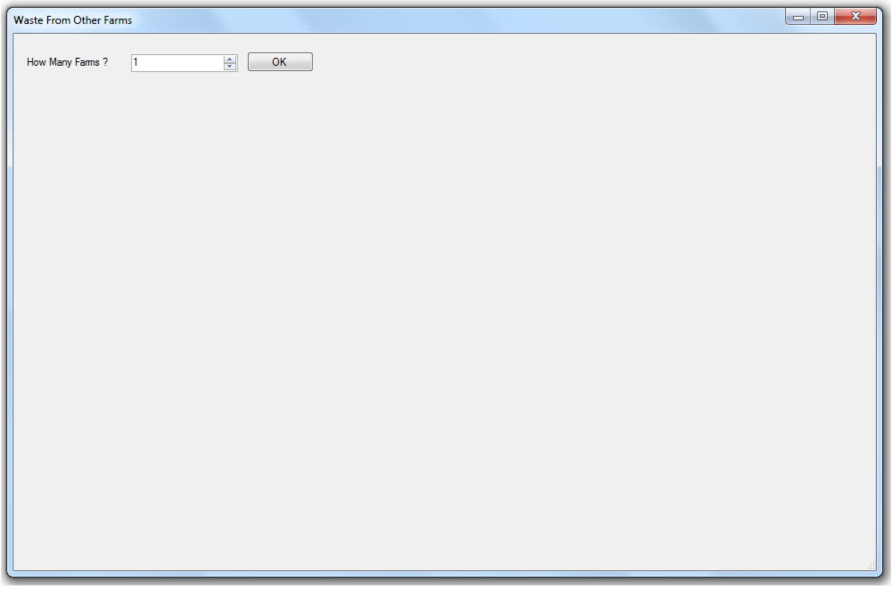


Fig.25

Enter the number of farms in the white field by typing the number or by clicking the small arrows on the right hand side of the white field.

Click on OK for additional fields and data to appear (Fig.26)

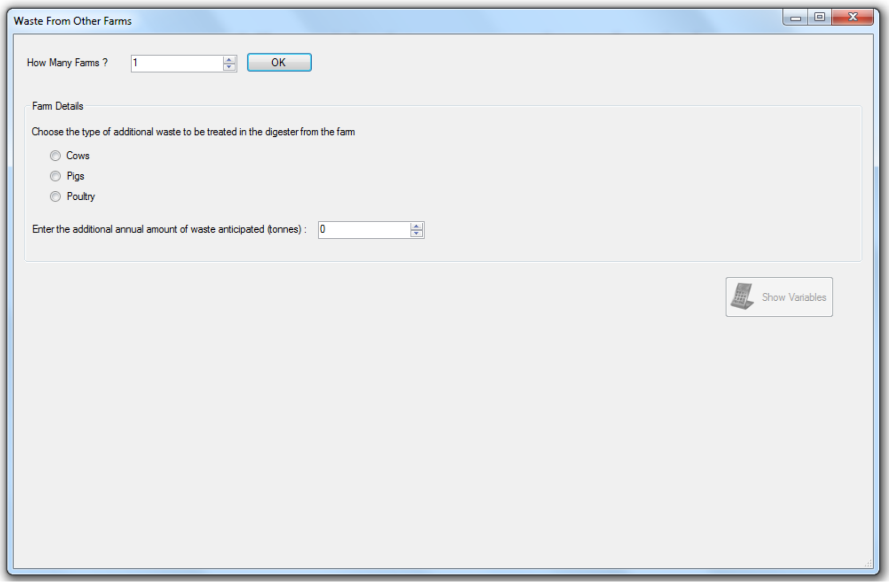


Fig.26

Click one of the animal species from which the waste originate by clicking on the circle on the left.

Enter the amount of waste anticipated per year in the white field in tonnes. If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

The Show Variables will now be activated. Click to view the default values that will be used in the subsequent steps (Fig.27).

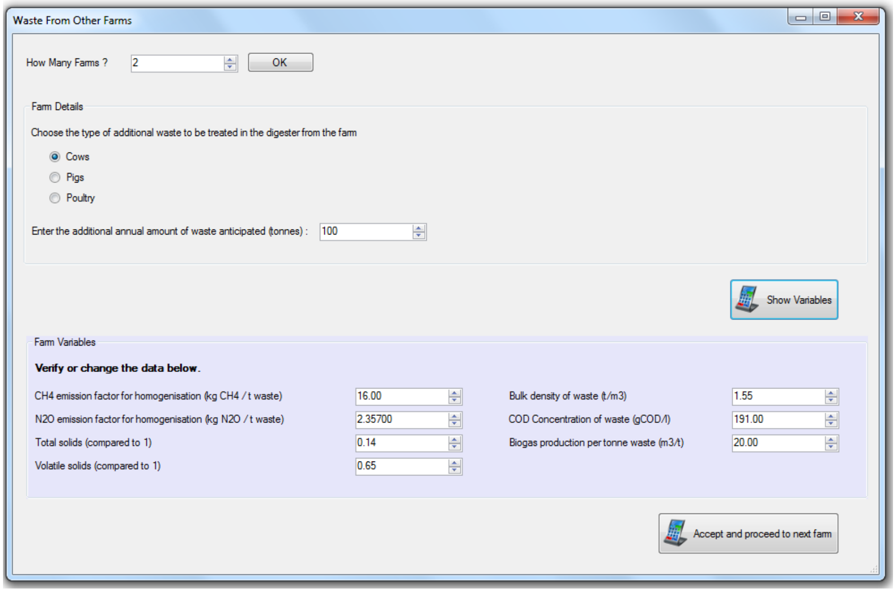
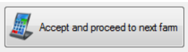
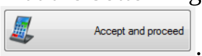


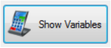
Fig.27

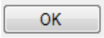
If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

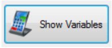
If the number of farms is more than 1, the button at the bottom right hand corner will be 

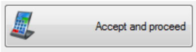
. Otherwise it will be 

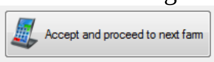
.

Note: if you want to change the number of farms after you have clicked on 

, enter the number of farms, click 

and then 

. The button on the right hand side will change from 

to 

.

Step 3.9. If you have entered more than one farm, the same window will appear. Follow the same instructions as **Step 3.8**.

Step 3.10. The new window that appears (Fig.28) concerns the production of biogas from waste during AD. Here you have the option to choose the method by which the potential biogas production will be estimated.

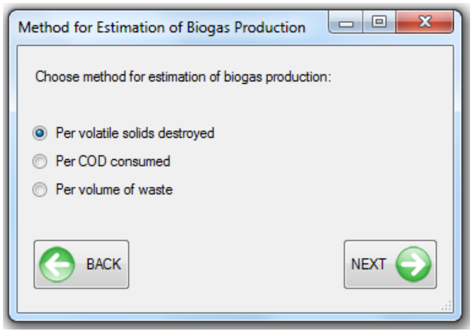


Fig.28

Per volatile solids destroyed – In theory, all the volatile solids (VS) available should be destroyed during anaerobic digestion. According to the biochemical reactions taking place, for each kg of VS destroyed, 0.867 m^3 biogas is produced.

Per COD consumed – In theory, all the COD available should be consumed by anaerobic organisms during anaerobic digestion. According to the biochemical reactions taking place, for each kg of COD consumed, 0.55 m^3 biogas is produced.

Per volume of waste – according to the characteristics of the waste and the biochemical reactions taking place during the anaerobic digestion, there is a theoretical amount of waste that is produced per unit mass of waste: cattle 25 m^3 biogas /t waste, pigs 36 m^3 biogas /t waste, poultry 80 m^3 biogas /t waste.

Choose one of the three methods by clicking on the circle on the left and click 

to proceed.

Step 3.11. The new window (Fig.29) concerns the use of the energy produced from the biogas combustion. Since there is no distribution network for thermal energy in Cyprus, only the electricity can be sold. The two options given by FARMS are "All energy used onsite and remaining electricity sold" and "All thermal used onsite, all electrical sold". Choose what is more appropriate for your case and click 

to proceed.

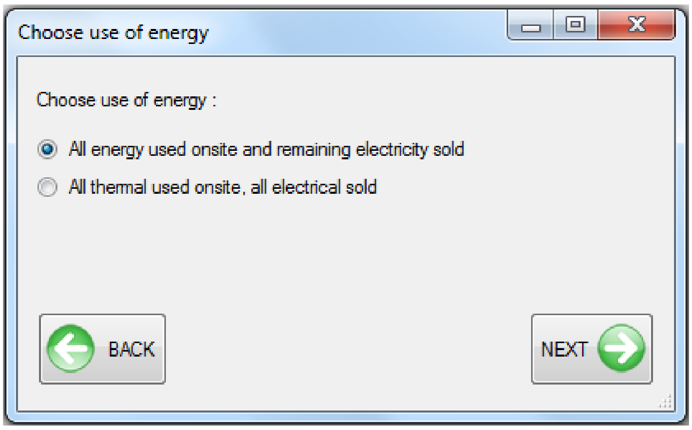


Fig.29

Step 3.12.

1. The window that appears concerns the requirements of the anaerobic digester. The first option of this stage is the type of digester (Fig.30).

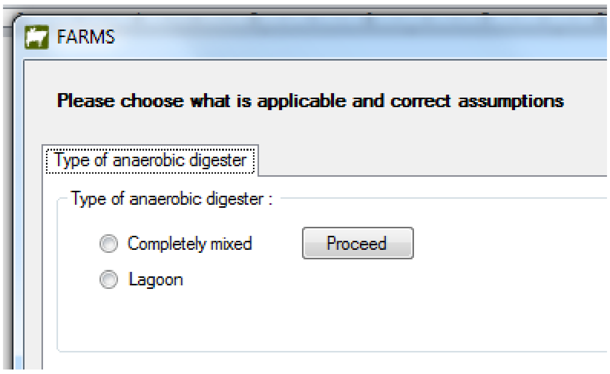


Fig.30

If the digester you are going to use is a metallic tank with mixing, then choose "completely mixed". If you are going to use a long earthen basin with no mixing, then choose "lagoon". Click on the respective circle on the left and then 

to go to the next stage.

2. Then the default parameters for the design of the digester will appear (Fig.31). These depend on the type of digester chosen in **1**.

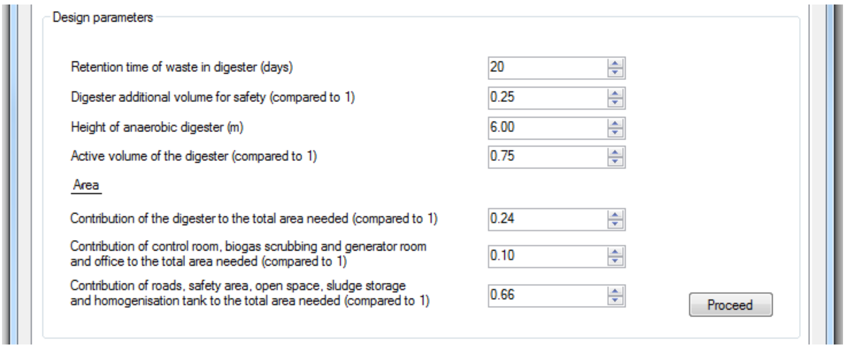


Fig.31

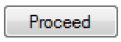
<u>Retention time of waste in the digester</u>: this is the time that a “batch” of waste is kept in the digester. Typically, this time is approximately 20 days for completely mixed digesters and 100 days for lagoons.

<u>Digester additional volume for safety</u>: the digester is not filled with waste up-to the maximum level possible. Additional volume is allowed for safety reasons. This is typically 25%. The value is presented and should be entered compared to 1; i.e. 25% would be 0.25.

<u>Height of the digester</u>: this is the height of the digester without the biogas cap; i.e. the height of the digester in which the waste is going to be. The typical height of the digesters in Cyprus is 6m. For completely mixed digesters it is the height of the tank, while for the anaerobic lagoon, it is the depth of the earthen basin.

<u>Active volume for the digester</u>: the digester is not filled with waste up-to the maximum level possible. The maximum level of waste in the digester is typically 75% of the total height. This means that if the digester has an active of volume of waste that is 75% of the total volume of the digester. The value is presented and should be entered compared to 1; i.e. 75% would be 0.75.

<u>Area</u>: the next three parameters are associated with the distribution of area to the necessary components for anaerobic digestion. The default contribution for completely mixed is 24% for the digester, 10% for the control room, biogas collection and scrubbing, generator room and office and 66% of other areas (namely roads, safety area, open space, sludge storage and homogenization tank. The default contribution for lagoons is 7% for the digester, 3% for the control room etc. and 90% for other areas. The value is presented and should be entered compared to 1; i.e. 7% would be 0.07. These contributions vary considerably depending on the area available.

Once you have changed or reviewed the values, press on 

to continue.

3. According to the parameters accepted, the area requirements are calculated and presented (Fig.32). These values can be changed if you have your own estimates for area distribution. Once you have changed or reviewed the values, press on 

to continue.

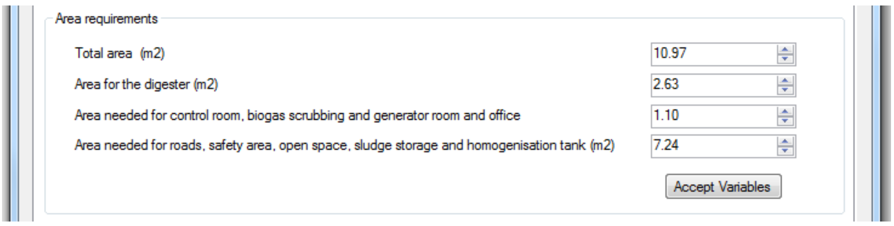


Fig.32

4. A new tab will appear and open in the same window (Fig.33).

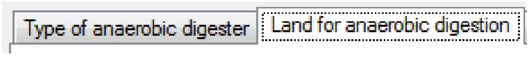


Fig.33

This new tab “Land for anaerobic digestion”, first requests the user to give information concerning land availability. Three options are given (Fig.34), available, rent and purchase. You can click on the most appropriate option for your case: if you have the land area estimated in **3**, choose “Available”, if you are going to rent the land choose “Rent” and if you are going to buy the land choose “Purchase”. Once you choose the most appropriate, click on  to continue.

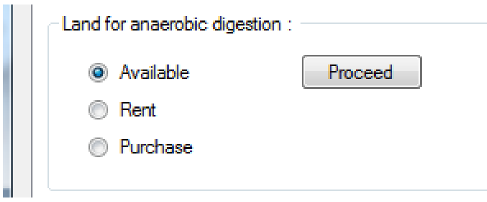


Fig.34

5. A new box will appear below, that depends on your choice in **4**, concerning the default land prices for purchase and rent. If you have chosen “Available” the box will be as shown in Fig.35, since there is no need to buy or rent land.

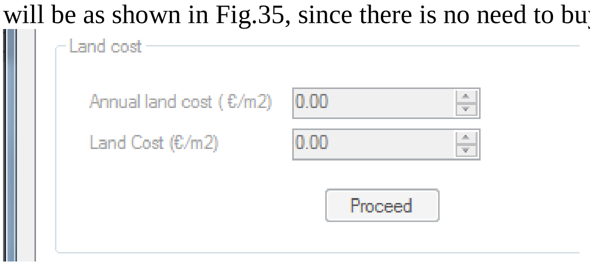


Fig.35

If you have chosen “Rent”, the box will be as shown in Fig.36. The default price given to annual rent is 10 €/m^2. You can change the price according to the price you expect in the area the digester is going to be installed.

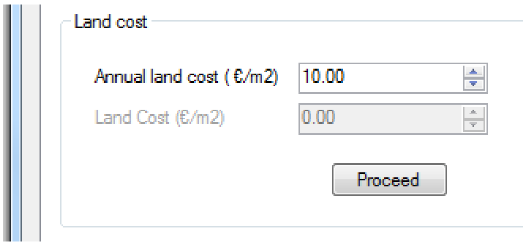


Fig.36

If you have chosen “Purchase”, the box will be as shown in Fig.37. The default price given to land cost is 80 €/m^2. You can change the price according to the price you expect in the area the digester is going to be installed.

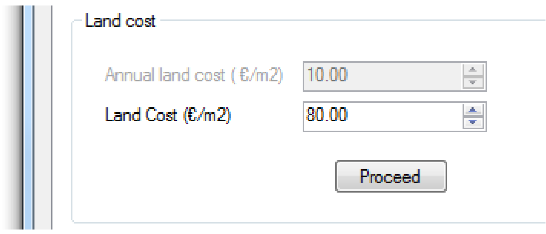


Fig.37

If you change your choice in **4** and press  the latest option will be held

FARMS to proceed with the calculations.

Click Proceed to continue.

6. The new box that will appear below, show the estimates for capital investment necessary (Fig.38).

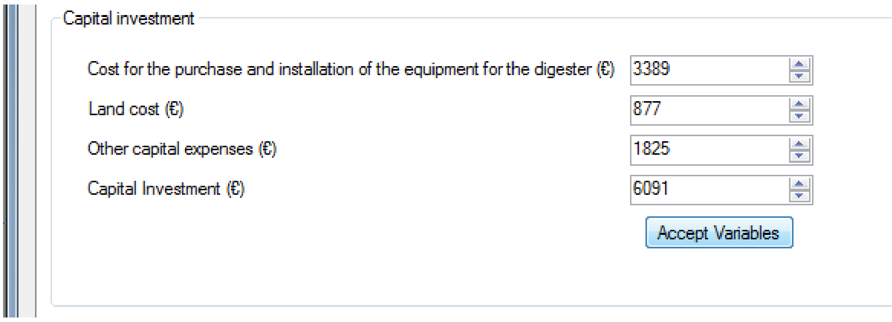


Fig.38

The values presented have been estimated using the information provided by the user in previous stages. If you have chosen that land will be rented, “land cost” will be 0, since it is not included in the capital investment, but in the annual expenses. Again, you can change the data and enter your estimates for cost.

Once the necessary information is satisfying, press on Accept Variables to continue.

7. A new tab will appear and open in the same window, “Capital investment” (Fig.39).

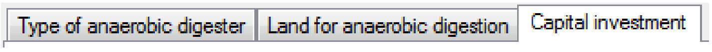


Fig.39

The first box that appears for the funding options of the capital investment (Fig.40). If the money is available and no external funding will be necessary chose “All available”. If you are going to take a loan to cover the investment, click on “Loan”.

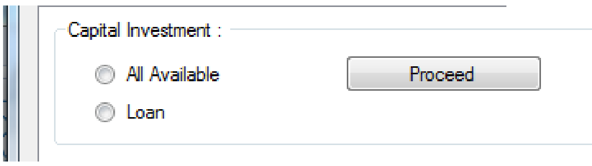


Fig.40

Click Proceed to continue.

8. If you have chosen “All available” in **7**, go to **9**. If you have chosen “Loan” in **7**, the following box will appear, that shows the loan parameters (Fig.41).

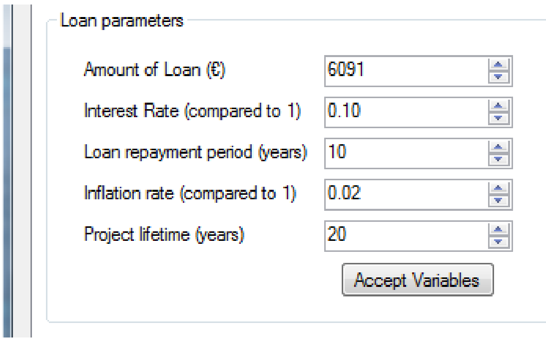


Fig.41

The "Amount of loan" is the same as the cost for the capital investment estimated in previous stages. The "Interest rate" is specific for the loan and is to be agreed with the financing institution; as default is set at 10%. "Loan repayment period" is again that has to be agreed with the financing institution; the default is set at 10 years. "Inflation rate", according to the available information at the time the model was developed, was 2%. However, another value could be more appropriate depending on the financial conditions of the country. "Project lifetime" is the lifetime based on which the digester is designed; the default for the model is 20 years. All values can be changed according to the specific conditions for the digester. Once the data is satisfying, click on 

to continue.

9. A message will appear by the right hand corner of the window, by the 

button which is self-explanatory: "By pressing the "next" button a word document will be generated and you will return to the main menu" (Fig.42).

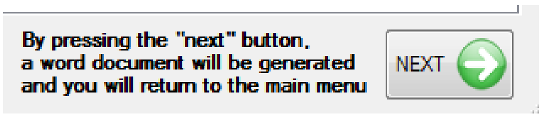


Fig.42

Option 4 Optimum scenario for a farm with respect to cost and greenhouse gas emissions

Step 4.1. At the main menu window, click on the third circle on the left of the option “Optimum scenario for a farm with respect to cost and greenhouse emissions” (Fig.43).

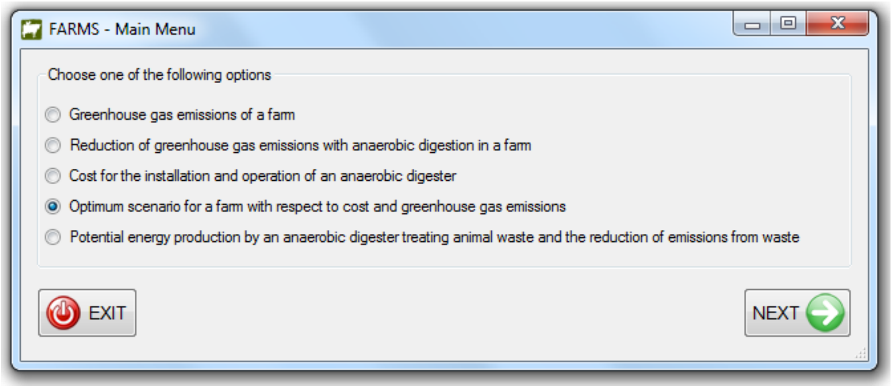


Fig.43

Step 4.2. The window that appears requests the user to enter details for the farm (Fig.44).

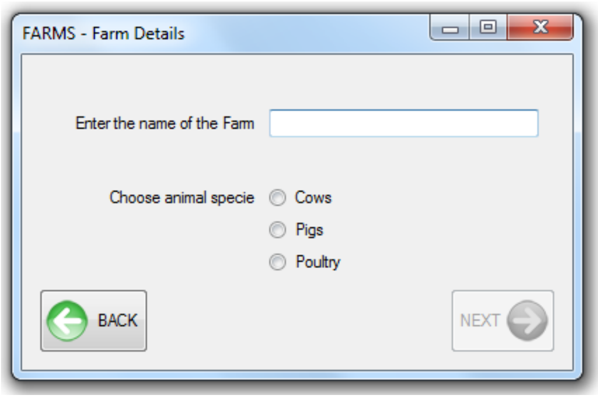


Fig.44

Enter the name of the farm in the white field and choose one of the animal species (cows, pigs and poultry) of the farm by clicking on the circle on the left. If your farm is housing more than one species, an option will be available to enter other species at a later stage.

Step 4.3. Click the 

button. The button will not be activated until all the necessary data is entered or chosen.

Step 4.4. The new window that opens (Fig.45), displays the default values for the parameters that are necessary for the calculations.

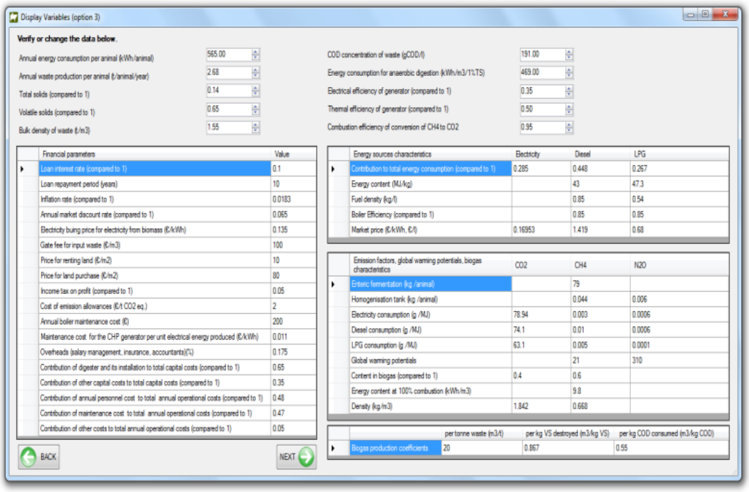


Fig.45

If you have available data you can enter your data. Data cannot be entered in the cells that are empty. A list of all the default values is given at the end of this guidebook. Click the [NEXT] button.

Step 4.5. Enter the animal population in the white field of the new window (Fig.46).

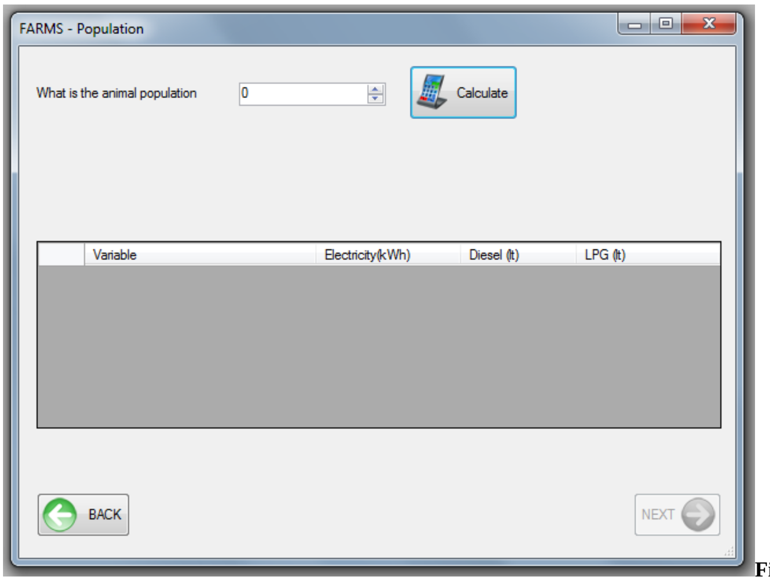


Fig.46

<u>Cows</u>: enter the total population of the farm including dairy cattle, calves, bulls etc.

<u>Pigs</u>: enter the total population of the farm including sows, piglets etc. If you have only the number of sows available, multiply by 10 to obtain the total population of the farm.

<u>Poultry</u>: enter the total population of the farm in one year. If you have only the number of bird-places available, multiply the number by 5.5 to convert in poultry population.

Step 4.6. Click on [Calculate]. Data will appear below (Fig.47), regarding annual energy consumption of the farm and annual animal waste production.

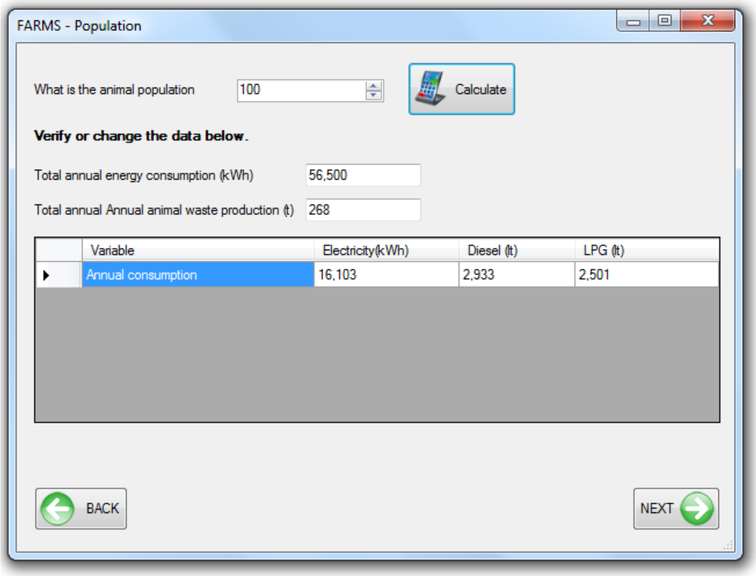


Fig.47

If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

<u>Attention</u>: If you have data and you are going to replace the suggested values, pay attention to the units.

Diesel - If you have consumption in kg, divide by 0.85 to convert to litres.

LPG – If you have consumption in kg, divide by 0.54 to convert to litres.

Waste – If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

Step 4.7. By clicking on the 

button a pop-up window will appear (Fig.48).

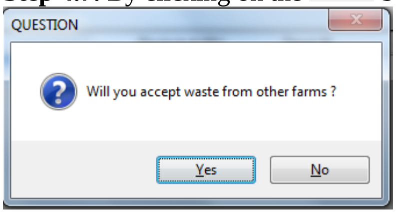
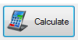
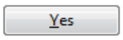


Fig.48

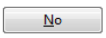
The button 

will be activated only after you have entered the population and clicked 

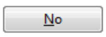
.

Click on 

if waste from other farms will be added to the AD in addition to the waste produced by the initial farm.

Click on 

if no other waste will be added to the AD.

If you clicked on 

, go to **Step 4.20**.

Step 4.8. The new window that appears (Fig.49) concerns the waste from other farms.

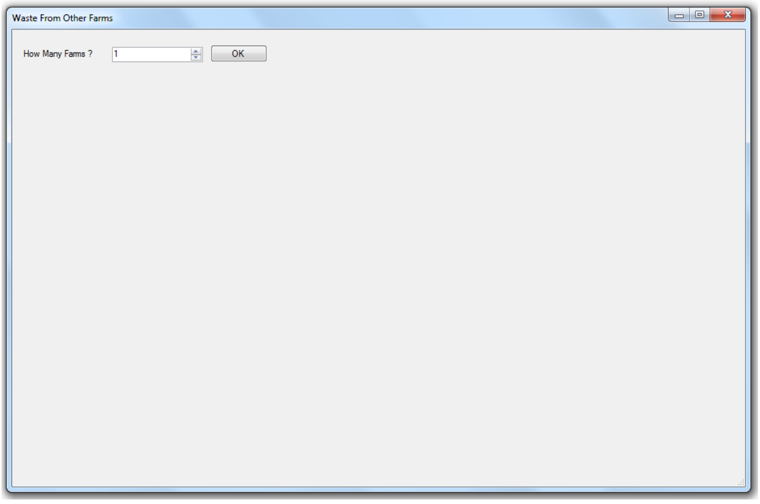
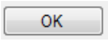


Fig.49

Enter the number of farms in the white field by typing the number or by clicking the small arrows on the right hand side of the white field .

Click on 

for additional fields and data to appear (Fig.50)

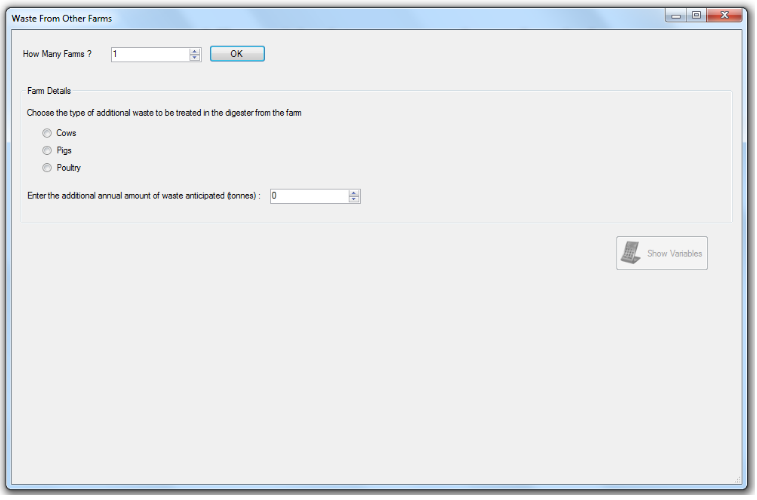
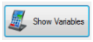


Fig.50

Click one of the animal species from which the waste originate by clicking on the circle on the left.

Enter the amount of waste anticipated per year in the white field in tonnes. If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

The 

will now be activated. Click to view the default values that will be used in the subsequent steps (Fig.51).

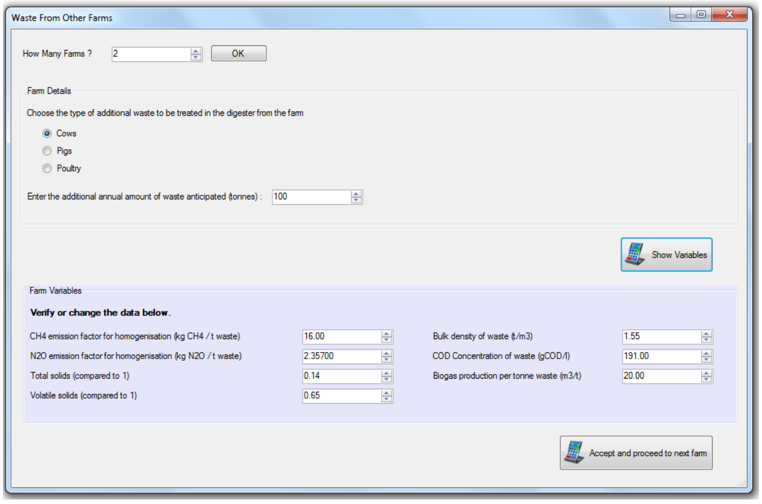
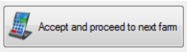
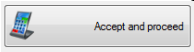


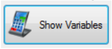
Fig.51

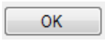
If you have data you can replace the data in the white fields with your data. If any of the energy sources are not consumed at you farm you can type 0 in the field or leave it blank.

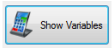
If the number of farms is more than 1, the button at the bottom right hand corner will be 

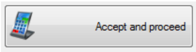
. Otherwise it will be 

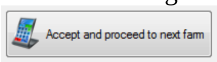
.

Note: if you want to change the number of farms after you have clicked on 

, enter the number of farms, click 

and then 

. The button on the right hand side will change from 

to 

.

Step 4.9. If you have entered more than one farm, the same window will appear. Follow the same instructions as **Step 4.8**.

Step 4.10. The new window that appears (Fig.52) concerns the production of biogas from waste during AD. Here you have the option to choose the method by which the potential biogas production will be estimated.

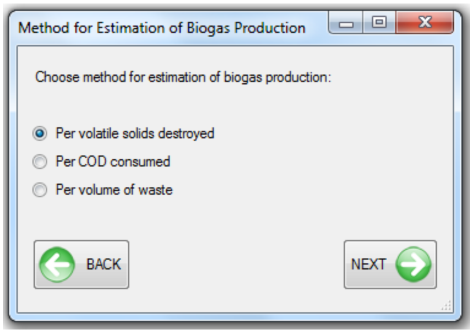


Fig.52

Per volatile solids destroyed – In theory, all the volatile solids (VS) available should be destroyed during anaerobic digestion. According to the biochemical reactions taking place, for each kg of VS destroyed, 0.867 m^3 biogas is produced.

Per COD consumed – In theory, all the COD available should be consumed by anaerobic organisms during anaerobic digestion. According to the biochemical reactions taking place, for each kg of COD consumed, 0.55 m^3 biogas is produced.

Per volume of waste – according to the characteristics of the waste and the biochemical reactions taking place during the anaerobic digestion, there is a theoretical amount of waste that is produced per unit mass of waste: cattle 25 m^3

biogas /t waste, pigs 36 m^3 biogas /t waste, poultry 80 m^3 biogas /t waste.

Choose one of the three methods by clicking on the circle on the left and click  to proceed.

Step 4.11. The new window (Fig.53) concerns the use of the energy produced from the biogas combustion. Since there is no distribution network for thermal energy in Cyprus, only the electricity can be sold. The two options given by FARMS are “All energy used onsite and remaining electricity sold” and “All thermal used onsite, all electrical sold”. Choose what is more appropriate for your case and click  to proceed.

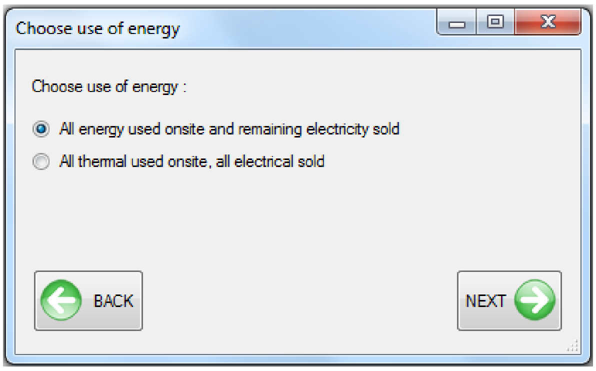


Fig.53

Step 4.12.

1. The window that appears concerns the requirements of the anaerobic digester. The first option of this stage is the type of digester (Fig.54).

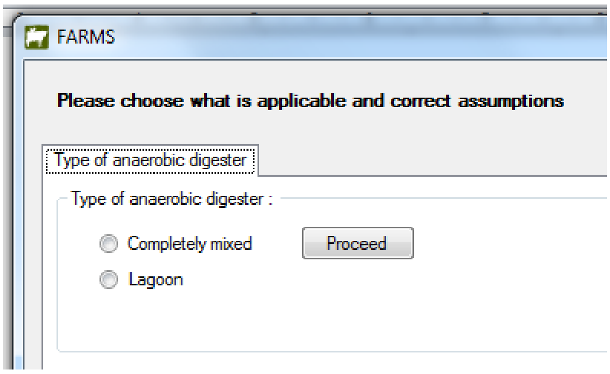
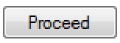


Fig.54

If the digester you are going to use is a metallic tank with mixing, then choose “completely mixed”. If you are going to use a long earthen basin with no mixing, then choose “lagoon”. Click on the respective circle on the left and then  to go to the next stage.

2. Then the default parameters for the design of the digester will appear (Fig.55). These depend on the type of digester chosen in **1**.

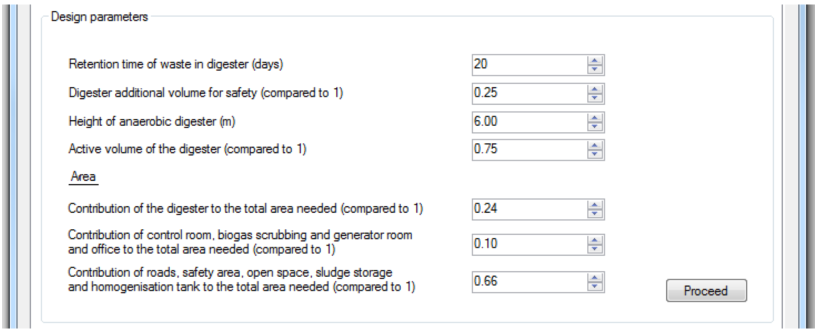


Fig.55

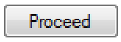
Retention time of waste in the digester: this is the time that a "batch" of waste is kept in the digester. Typically, this time is approximately 20 days for completely mixed digesters and 100 days for lagoons.

Digester additional volume for safety: the digester is not filled with waste up-to the maximum level possible. Additional volume is allowed for safety reasons. This is typically 25%. The value is presented and should be entered compared to 1; i.e. 25% would be 0.25.

Height of the digester: this is the height of the digester without the biogas cap; i.e. the height of the digester in which the waste is going to be. The typical height of the digesters in Cyprus is 6m. For completely mixed digesters it is the height of the tank, while for the anaerobic lagoon, it is the depth of the earthen basin.

Active volume for the digester: the digester is not filled with waste up-to the maximum level possible. The maximum level of waste in the digester is typically 75% of the total height. This means that if the digester has an active of volume of waste that is 75% of the total volume of the digester. The value is presented and should be entered compared to 1; i.e. 75% would be 0.75.

Area: the next three parameters are associated with the distribution of area to the necessary components for anaerobic digestion. The default contribution for completely mixed is 24% for the digester, 10% for the control room, biogas collection and scrubbing, generator room and office and 66% of other areas (namely roads, safety area, open space, sludge storage and homogenization tank. The default contribution for lagoons is 7% for the digester, 3% for the control room etc. and 90% for other areas. The value is presented and should be entered compared to 1; i.e. 7% would be 0.07. These contributions vary considerably depending on the area available.

Once you have changed or reviewed the values, press on 

to continue.

3. According to the parameters accepted, the area requirements are calculated and presented (Fig.56). These values can be changed if you have your own estimates for area distribution. Once you have changed or reviewed the values, press on 

to continue.

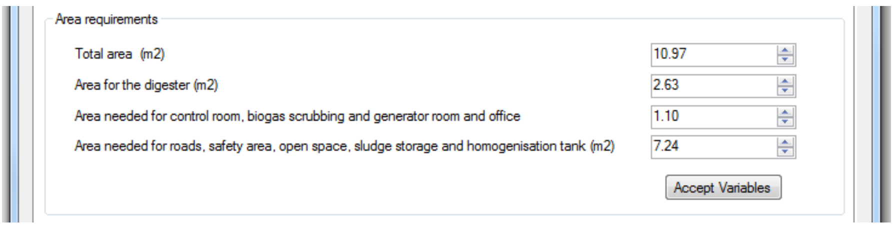


Fig.56

4. A new tab will appear and open in the same window (Fig.57).

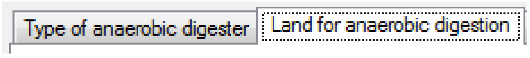


Fig.57

This new tab "Land for anaerobic digestion", first requests the user to give information concerning land availability. Three options are given (Fig.58), available, rent and purchase. You can click on the most appropriate option for your case: if you have the land area estimated in **3**, choose "Available", if you are going to rent the land choose "Rent" and if you are going to buy the land choose "Purchase". Once you choose the most appropriate, click on  to continue.

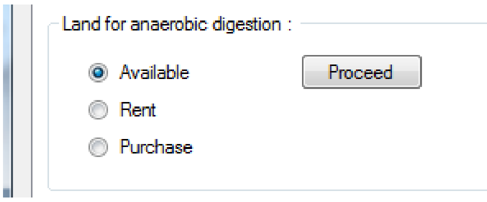


Fig.58

5. A new box will appear below, that depends on your choice in **4**, concerning the default land prices for purchase and rent. If you have chosen "Available" the box will be as shown in Fig.59, since there is no need to buy or rent land.

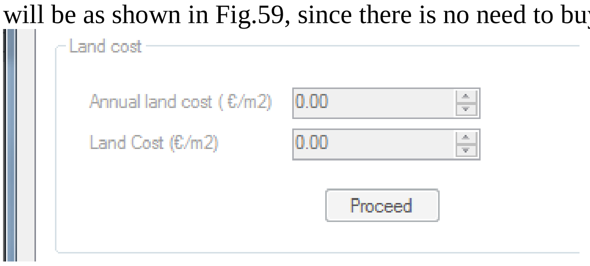


Fig.59

If you have chosen "Rent", the box will be as shown in Fig.60. The default price given to annual rent is 10 €/m^2. You can change the price according to the price you expect in the area the digester is going to be installed.

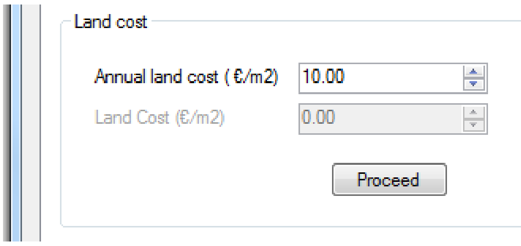


Fig.60

If you have chosen "Purchase", the box will be as shown in Fig.61. The default price given to land cost is 80 €/m^2. You can change the price according to the price you expect in the area the digester is going to be installed.

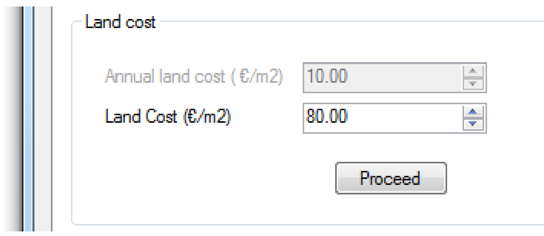
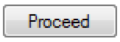


Fig.61

If you change your choice in **4** and press  the latest option will be held

FARMS to proceed with the calculations.

Click 

to continue.

6. The new box that will appear below, show the estimates for capital investment necessary (Fig.62).

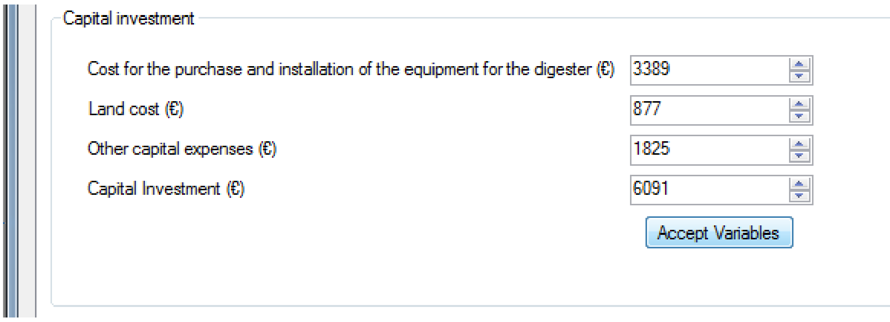


Fig.62

The values presented have been estimated using the information provided by the user in previous stages. If you have chosen that land will be rented, "land cost" will be 0, since it is not included in the capital investment, but in the annual expenses. Again, you can change the data and enter your estimates for cost.

Once the necessary information is satisfying, press on 

to continue.

7. A new tab will appear and open in the same window, "Capital investment" (Fig.63).

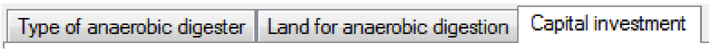


Fig.63

The first box that appears for the funding options of the capital investment (Fig.64). If the money is available and no external funding will be necessary chose "All available". If you are going to take a loan to cover the investment, click on "Loan".

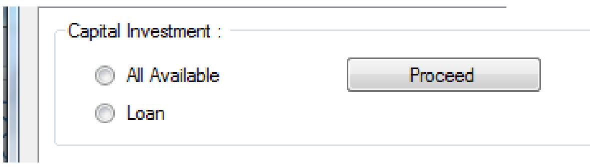
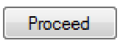


Fig.64

Click 

to continue.

8. If you have chosen "All available" in **7**, go to **9**. If you have chosen "Loan" in **7**, the following box will appear, that shows the loan parameters (Fig.65).

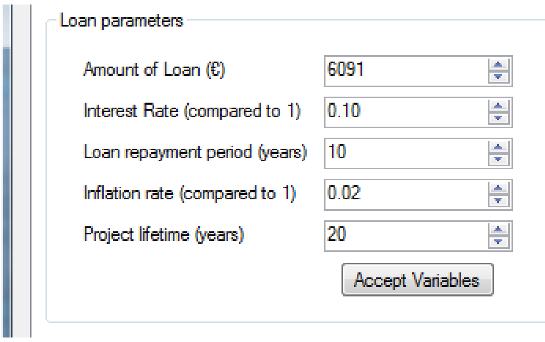


Fig.65

The "Amount of loan" is the same as the cost for the capital investment estimated in previous stages. The "Interest rate" is specific for the loan and is to be agreed with the financing institution; as default is set at 10%. "Loan repayment period" is again that has to be agreed with the financing institution; the default is set at 10 years. "Inflation rate", according to the available information at the time the model was developed, was 2%. However, another value could be more appropriate depending on the financial conditions of the country. "Project lifetime" is the lifetime based on which the digester is designed; the default for the model is 20 years. All values can be changed according to the specific conditions for the digester. Once the data is satisfying, click on 

to continue.

9. The 

button will now be activated. Click to continue.

Step 4.13. The new window that appears is for the offsite scenario (Fig.66). You are requested to enter information regarding the distance from the nearest anaerobic digester you could use and the duration of storage of the waste before their transfer to the digester. The button 

will only be activated if you enter the necessary information.

By pressing the "next" button a word document will be generated and you will return to the main menu.

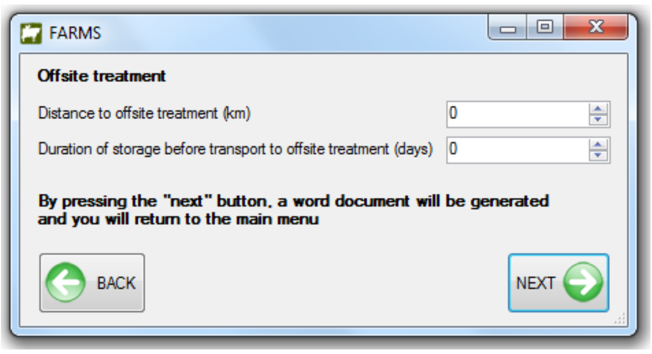


Fig.66

Option 5 — Potential energy production by an anaerobic digester treating animal waste and the reduction of waste emissions

Step 5.1. The window that appears requests the user to enter the amount of waste according to source in tonnes (Fig.67). If you have waste production in m^3, multiply by the bulk density of the waste to convert to tonnes (cows 1.55 t/ m^3, pigs 0.973 t/ m^3 and poultry 0.546 t/ m^3).

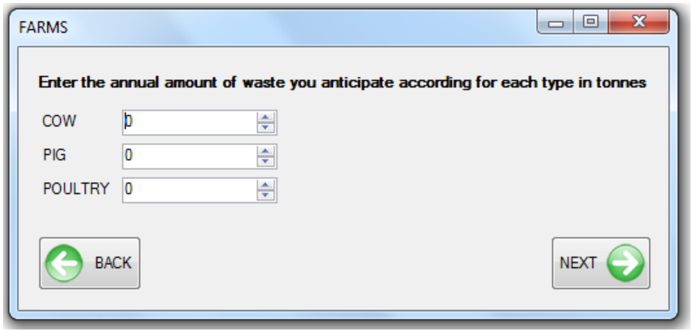


Fig.67

The  button will only be activated if you enter the amount of waste for at least one type of animal. Once you have entered the amount of waste in tonnes, click  to proceed.

Step 5.2. The new window that opens (Fig.68), displays the default values for the parameters that are necessary for option 5.

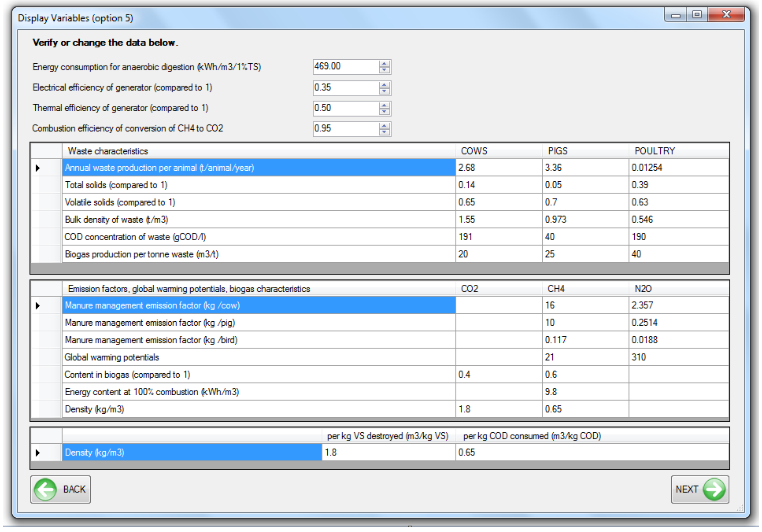


Fig.68

If you have available data you can enter your data. Data cannot be entered in the cells that are empty. A list of all the default values is given at the end of this guidebook. Click the  button.

Step 5.3. The new window that appears (Fig.69) concerns the production of biogas from waste during AD. Here you have the option to choose the method by which the potential biogas production will be estimated.

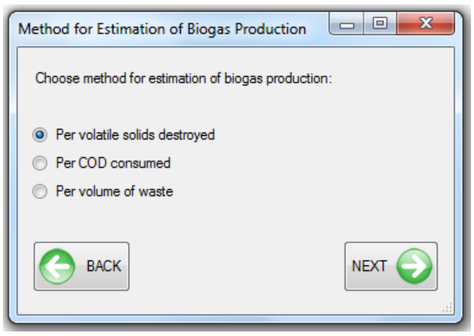


Fig.69

Per volatile solids destroyed – In theory, all the volatile solids (VS) available should be destroyed during anaerobic digestion. According to the biochemical reactions taking place, for each kg of VS destroyed, 0.867 m^3 biogas is produced.

Per COD consumed – In theory, all the COD available should be consumed by anaerobic organisms during anaerobic digestion. According to the biochemical reactions taking place, for each kg of COD consumed, 0.55 m^3 biogas is produced.

Per volume of waste – according to the characteristics of the waste and the biochemical reactions taking place during the anaerobic digestion, there is a theoretical amount of waste that is produced per unit mass of waste: cattle 25 m^3 biogas /t waste, pigs 36 m^3 biogas /t waste, poultry 80 m^3 biogas /t waste.

Choose one of the three methods by clicking on the circle on the left and click 

to proceed. A word file with detailed results will generated and open and you will return at the main menu. You can save the word file with the name you want and at the location you want.

Output

Output files

At the each of each option ran, a word file will be generated containing detailed results associated with the option. These files are not saved anywhere and are not given a filename.

You can process, name and save the file in the same manner you are processing, naming and saving any other file in word.

Defaults

Cows

Annual energy consumption per animal	565 kWh/animal	
Contribution to total energy consumption	28.5% electricity	
	44.8% diesel	
	26.7% LPG	
Enteric fermentation emission factor (/animal/year)	79 kg CH_4	
Manure management (/animal/year)	16 kg CH_4	2.357 kg N_2O
Annual waste production per animal	2.68 t/year	
Solids concentration in waste	TS 14%	VS 65%
Biogas potential of waste	20 m^3/t	
Bulk density of waste	1.55 t/m^3	
COD concentration	191 g/l	

Pigs

Annual energy consumption per animal	60.6 kWh/animal	
Contribution to total energy consumption	28.7% electricity	
	48.3% diesel	
	23% LPG	
Enteric fermentation emission factor	1.5 kg CH_4 / animal	
Manure management (/animal/year)	10 kg CH_4	0.251 kg N_2O
Annual waste production per animal	3.36 t/year	
Solids concentration in waste	TS 5%	VS 70%
Biogas potential of waste	25 m^3/t	
Bulk density of waste	0.973 t/m^3	
COD concentration	40 g/l	

Poultry

Annual energy consumption per animal	0.777 kWh/animal	
Contribution to total energy consumption	28.3% electricity	
	41.3% diesel	
	30.4% LPG	
Enteric fermentation emission factor	0.03 kg CH_4 / animal	
Manure management (/animal/year)	0.117 kg CH_4	0.0188 kg N_2O
Annual waste production per animal	0.01254 t/year	
Solids concentration in waste	TS 39%	VS 63%
Biogas potential of waste	40 m^3/t	
Bulk density of waste	0.546 t/m^3	
COD concentration	190 g/l	

GHG

GWP		CH_4 : 21	N_2O : 310
Transport EF	774 g CO_2/km	0.08 g CH_4/km	0.30 g N_2O /km

Energy

	Electricity	Diesel	LPG
Energy content (MJ/kg)	-	43	47.3
Fuel density (kg/l)	-	0.85	0.54
Boiler Efficiency	-	85%	85%
CO_2 emission factor (g/MJ)	78.94	74.1	63.1
CH_4 emission factor (g/MJ)	0.003	0.01	0.005
N_2O emission factor (g/MJ)	0.0006	0.0006	0.0001

AD

Energy consumption for anaerobic digestion	469 kWh/m^3/1%TS

Biogas

Production coefficient	0.867 m^3/kg VS	0.55 m^3/kg COD
Content	60% CH_4	40% CO_2
Density (kg/m^3)	CH_4 : 0.65	CO_2 : 1.8
Energy content at 100% combustion of CH_4		9.8 kWh/m^3
Combustion efficiency of conversion of $CH_4$to CO_2		95%

CHP

Efficiency	35% electrical	50% thermal

Financial

Loan interest rate	10%
Loan repayment period	10 years
Inflation rate	1.83%
Annual market discount rate	6.5%
Electricity buying price for electricity from biomass	0.135€/kWh
Gate fee for input waste	100 €/m^3
Price for renting land	10 € /m^2/year
Price for land purchase	80 €/m^2
Income tax on profit	5%
Cost of emission allowances	2 €/ t CO_2 eq.
Annual generator/boiler maintenance cost	200 €/year
CHP maintenance cost	0.011 €/kWh_{el}
Overheads (salary management, insurance, accountants)	17.5% of annual cost
Capital	
Capital cost for the digester and its installation	65% of capital
Other capital costs	35% of capital
Operational	
Personnel	48% of operational
Maintenance	47% of operational
Others	5% of operational
Diesel price	1.419 €/l
LPG price	0.68 €/l
Electricity price	0.16953 €/kWh
Fine for insufficient waste treatment	2000 €
Waste transport	100 €/km

Digester

	Complete mix	Lagoon
Retention time	20 days	100 days
Height	6 m	6 m
Safety volume	25%	25%
Active volume	75%	75%
Lifetime	20 years	20 years
Area		
Digester	4%	9%
Other areas	88%	87%
Control room and biogas areas	8%	4%

Other

Lorry capacity	15 m^3

Note

Where the default value of a parameter is in %, in FARMS it will appear in comparison to 1; i.e. if a value is 5% in FARMS will appear as 0.05

Glossary

GHG	Greenhouse gas emissions
AD	Anaerobic digester
EF	Emission factor
GWP	Global warming potential
TS	Total solids
VS	Volatile solids
COD	Chemical Oxygen Demand
BG	Biogas
CHP	Combined Heat Power generator
kWh_{el}	kWh of electrical energy

Appendix D: Example output files of FARMS

ESTIMATION OF ANNUAL EMISSIONS OF GREENHOUSE GASES FOR THE FARM option 1 - cows

Animal type : COWS
Animal population : 500

Annual Energy consumption

	Consumption
Electricity	80,513 kWh
Diesel	14,665 litres
LPG	12,507 litres
TOTAL	282,500 kWh

Annual emissions from energy consumption (kg)

	CO2	CH4	NO2
Electricity	22,881	0.87	0.17
Diesel	39,718	5	0.32
LPG	20,158	2	0.03

Annual emissions from energy consumption (t CO2 eq.)

	CO2	CH4	NO2	TOTAL
Electricity	23	0.02	0.05	23
Diesel	40	0.11	0.10	40
LPG	20	0.03	0.01	20
TOTAL	83	0.16	0.16	83

Total annual emissions of greenhouse gases (t)

	Fermentation	Manure management	Energy	TOTAL
CO2	-	-	83	83
CH4	40	8	0.01	48
N2O	-	1	0.001	1

Total emissions of greenhouse gases (t CO2 eq.)

	Fermentation	Manure management	Energy	TOTAL
CO2	-	-	83	83
CH4	830	168	0.16	998
N2O	-	365	0.16	365
TOTAL	830	533	83	1,446

Annual emission of greenhouse gases with and without anaerobic digestion in farm option 2 - poultry

Animal type : POULTRY

Animal population : 50000

Additional waste from other farms (m3) : 0.00

Potential annual biogas production (m3) : 106,511

Biogas estimation based on : Volatile solids destroyed

Annual energy produced by anaerobic digestion (kWh)

Electrical : 219,200

Thermal : 313,142

Electrical energy sold annually (kWh) : 41,881

Comparison of energy bought for the farm with and without anaerobic digestion annually

	with anaerobic digestion	without anaerobic digestion
Electricity (kWh)	177,319	11,037
Diesel (l)	1,866	1,866
LPG (l)	1,966	1,966

Comparison of annual emissions of the farm with and without anaerobic digestion

	with anaerobic digestion	without anaerobic digestion	difference
Energy (t CO2 eq.)	59	11	47
CO2 (t)	59	11	47
CH4 (t CO2 eq.)	0.06	0.02	0.04
N2O (t CO2 eq.)	0.13	0.02	0.11
CH4 emissions from enteric fermentation (t CO2 eq.)	32	32	0

Manure management		414	-414
CH4 (t CO2 eq.)		123	-123
N2O (t CO2 eq.)		291	-291
Waste homogenisation	1		1
CH4 (t CO2 eq.)	0.34		0.34
N2O (t CO2 eq.)	0.80		0.80
Combustion of biogas	235		235
CO2 (t)	190		190
CH4 (t CO2 eq.)	45		45
TOTAL EMISSIONS OF THE FARM (t CO2 eq.)	326	457	-131
CO2 (t)	249	11	237
CH4 (t CO2 eq.)	77	154	-78
N2O (t CO2 eq.)	0.93	291	-290

Note

1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

Assessment of investment for the installation of an anaerobic digester in farm option 3 - pigs

Animal type : PIGS

Animal population : 5000

Type of Digester : Completely mixed

Additional waste from other farms (m3/year) : 0.00

Total waste treated by the digester (m3/year) : 15,928

Potential annual biogas production (m3) : 350,412

Biogas estimation based on : COD consumed

Annual electrical energy produced (kWh) : 721,149

Annual thermal energy produced (kWh) : 1,030,212

Electrical energy sold annually (kWh) : 260,680

Area

Area for the digester (m2) : 242

Area needed for control room, biogas scrubbing and generator room and office (m2) : 101

Area needed for roads, safety area, open space, sludge storage and homogenisation tank (m2) : 667

Total area (m2) : 1,010

Capital costs

Equipment and installation (€): 286,390

Landscaping, construction, permitting, consultants and other (€): 154,210

Cost for purchase of land (€): 0.00

Total initial Investment (€): 440,600

Annual expenses

Loan repayment (€) : 0.00 (for 10 years)

Renting cost for land (€) : 0.00

Personnel cost (€): 16,240

Maintenance cost (€): 15,902

Maintenance cost of the generator (€): 7,933

Other operational costs (€): 1,692

Energy cost (€): 109,985

Cost for emissions allowances (€): 707

Overheads (salary management, insurance, accountants) (€) : 32,340

Tax on profit (€) : 0.00

Annual incomes

Treatment of additional waste (€) : 0.00

Sales of electricity (€) : 35,192

Total (€) : 35,192

Note

1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

Cost analysis for farm option 4 - pigs with anaerobic digestion

Animal type : PIGS
Animal population : 25000
Biogas estimation based on : Amount of waste digested

The optimum choice for greenhouse gases emissions is to use anaerobic digestion that is offsite.
Total lifetime emissions using an offsite anaerobic digester (t CO2 eq.) : 25,255
Total lifetime emissions with anaerobic digestion onsite (t CO2 eq.) : 120,669
Total lifetime emissions without anaerobic digestion (t CO2 eq.) : 79,430

The optimum choice financially is to install anaerobic digestion onsite.
Total lifetime balance to install anaerobic digestion onsite (€) : -58,935,080,258,935
Total lifetime cost without anaerobic digestion (€) : 643,868,699,078,040
Total lifetime cost to use an offsite anaerobic digester (€) : 678,262,507,761,141

	Comparison of lifetime cost (€)	Comparison of lifetime emissions (t CO2 eq.)
Without anaerobic digestion	643,868,699,078,040	79,430
With anaerobic digestion	-58,935,080,258,935	120,669
Anaerobic digestion offsite	678,262,507,761,141	25,255

NOTE: Negative BALANCE corresponds to income

Detailed results

	Without anaerobic digestion	With anaerobic digestion	Anaerobic digestion offsite
Energy			
Annual energy consumption (kWh)	1,515,000	3,382,539	1,515,000
Annual electricity production (kWh)		3,974,513	
Annual thermal energy production (kWh)		5,677,875	
Annual energy needed in addition to energy produced (kWh) - electrical		0.00	
Annual energy needed in addition to energy produced (kWh) - thermal		0.00	
Electricity sold (kWh)		1,672,169	
Digester			
Type of digester		Anaerobic lagoon	
Annual waste production (m3/year)		79,639	
Additional waste from other farms (m3/year)		0.00	
Potential annual biogas production (m3)		1,931,250	
Area			
Digester (m2)		6,061	
Control room etc. (m2)		2,597	
Other (m2)		77,925	
Total (m2)		86,583	
Distance from farm (km)			1
Duration of storage before treatment (days)			2
Times of transport to digester per year			5,309
Annual emissions			
Energy consumption (t CO2 eq.)	448	981	448
Enteric fermentation (t CO2 eq.)	788	788	788
Manure management (t CO2 eq.)	2,736		
Homogenization tank (t CO2 eq.)		7	7
CHP generator (t CO2 eq.)		4,258	
Storage before treatment (t CO2 eq.)			15
Transport (t CO2 eq.)			5
TOTAL (t CO2 eq.)	3,972	6,033	1,263
Total lifetime emissions (t CO2 eq.)	79,430	120,669	25,255
Annual expenses			
Energy consumed (€)	233,322	549,926	233,322
Emissions (€)	7,943	12,067	2,526
Waste management cost (€)	9,556,701		0.00
Penalty fine (€)	2,000		
Transport of waste to digester (€)			530,928
Generator maintenance (€)	400	400	400

Digester			
Loan payment (€)		0.00	
Land rent (€)		865,831	
Personnel (€)		57,272	
Digester maintenance (€)		56,079	
CHP maintenance (€)		43,720	
Other expenses (€)		5,966	
Overheads (€)		-1,682,903	
TOTAL (€)	9,800,366		10,323,876
Total lifetime cost (€)	643,868,699 ,078,040	- 58,935,080, 258,935	678,262,507 ,761,141
Capital investment			
Purchase and installation of digester (€)		757,488	
Land (€)		0.00	
Other capital expenses (€)		407,878	
TOTAL (€)		1,165,366	
Annual income			
Accepting waste from other farms (€)		0.00	
Electricity sales (€)		225,743	
TOTAL (€)		225,743	

<u>Note</u>

1. The above results have been estimated using a <u>theoretical</u> general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

Potential energy production by an anaerobic digester treating animal waste and the respective reduction of emissions

Total amount of waste treated annually (t) : 6,230
Potential annual biogas production (m3) : 263,643
Biogas estimation based on : Volatile solids destroyed

Annual energy consumption for anaerobic digestion (kWh) : 230,588
Annual electricity production (kWh) : 542,578
Annual thermal energy production (kWh) : 775,112

Annual emissions during energy production (t CO_2 eq.) : 581
Annual emissions caused by energy consumption for the operation of the digester (t CO_2 eq.) : 66
Emissions not emitted from other manure management systems (t CO_2 eq.) : 998

Note

1. The above results have been estimated using a theoretical general approach based on data collected for Cyprus. Use these for information purpose only. If you proceed with the installation of an anaerobic digester, do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

2. For small quantities of waste, the biogas quality and quantity does not allow its use for the production of energy. These results are only theoretical. Do not base your investment only on these results, but seek the support from a professional for a specific study for your farm.

Appendix E: Questionnaire and responses for the assessment of FARMS from potential users

Software validation questionnaire

About the user

Current Work Position:

Public officer ☐ Farm owner ☐ Student ☐ Consultant ☐

Other ………………………….☐

Academic Background

…………………………………………………………………………….

Familiarity with animal waste (mark with x the most representative)

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ None ☐

Familiarity with anaerobic digestion (mark with x the most representative)

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ None ☐

Familiarity with environmental terminology (mark with x the most representative)

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ None ☐

User guide

Was the user guide easy to read and understand?

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ No ☐

Was there sufficient explanation in the user guide for the options in FARMS?

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ No ☐

Installation

Was the installation of FARMS easy?

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ No ☐

Have you encountered any problems during installation?

Yes ☐ No ☐

If yes, please describe:…………………………………………………

……………………………………………………………………………

Use

Do you consider FARMS user friendly?

Yes	☐	No	☐
If yes, please choose all applicable to FARMS:		If no, please choose all applicable to FARMS:	
Easy	☐	Complicated	☐
You can see all data used	☐	Too much data	☐
The options are clear	☐	Too many options	☐
The options are representative of the situation in Cyprus	☐	I would prefer to see only the result	☐

Animal types

Do you think there are other animals that should be included?

Yes ☐ No ☐

If yes, please write which animals:……………..…………………………

Defaults

Please rate the way the default values are presented:

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ Not Good ☐

If not good, please explain:……………..…………………………………

…………………………………………………………………………………

Have you used you own data?

Yes ☐ No ☐

If yes, please indicate for which parameters and the value you used:

…………………………………………………………………………………

…………………………………………………………………………………

…………………………………………………………………………………

Results

Please rate how realistic are the results of FARMS.

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ Not Good ☐

Cannot assess ☐

If not good, please explain:……………..…………………………………

…………………………………………………………………………………

Please rate how are results of FARMS are presented.

Excellent ☐ Very good ☐ Good ☐ Not very good ☐ Not Good ☐

If not good, please explain:……………..…………………………………

…………………………………………………………………………………

	Do you think the results of FARMS will assist you work?
	Yes ☐ No ☐
	Please explain:……………..…………………………………………...…
	……………………………………………………………………………
Errors	Have you received any errors during running FARMS?
	Yes ☐ No ☐
	If yes, please describe:…………………………………………………
	……………………………………………………………………………
Other software	Do you use other software for the same purpose?
	Yes ☐ No ☐
	If yes, please provide the name:……………….……..……………………
	If yes, will you continue using the other software?
	Yes ☐ No ☐
Potential Users	Please indicate who in your opinion could use FARMS.
	A farmer with no knowledge on anaerobic digestion ☐
	A farmer with no data ☐
	A student ☐
	A consultant ☐
	A decision maker ☐
	Other………………………………………. ☐
Overall assessment	Will you use FARMS for your work?
	Yes ☐ No ☐ Maybe ☐
	Will you use FARMS for data reference?
	Yes ☐ No ☐ Maybe ☐
	Please indicate your overall evaluation for FARMS (mark with x the most representative):
	Excellent ☐ Very good ☐ Good ☐ Not very good ☐ Not good ☐
	Please write any other comments you may have for FARMS:…………..
	……………………………………………………………………………

	Questionnaire	1	2	3
1	**About the user**			
	1. Current Work Position:	Public officer	Public officer	Public officer
	2. Academic Background	Mathematician	Chemical Eng.	Greek Lit
	3. Familiarity with animal waste	Not very good	Excellent	None
	4. Familiarity with anaerobic digestion	Good	Excellent	None
	5. Familiarity with environmental terminology	Good	Very good	None
2	**User guide**			
	Was the user guide easy to read and understand?	Excellent	Excellent	Excellent
	Was there sufficient explanation in the user guide for the options in FARMS?	Excellent	Very good	Excellent
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	
	You can see all data used	Yes		
	The options are clear	Yes		Yes
	The options are representative of the situation in Cyprus			
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	Yes	Yes
	If yes, please write which animals		sheeps, goats, horses	rabbits
6	**Defaults**			
	Please rate the way the default values are presented:	Excellent	Very good	Excellent
	If not good, please explain			
	Have you used you own data?	No	Yes	No
	If yes, please indicate		waste production	
7	**Results**			
	Please rate how realistic are the results of FARMS.	Very good	Very good	Cannot assess
	If not good, please explain			
	Please rate how are results of FARMS are presented.	Excellent	Very good	Excellent
	If not good, please explain			
	Do you think the results of FARMS	No	Yes	No

	will assist you work?			
	Please explain	My work is irrelevant	possibility to install AD	My work is irrelevant
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes		Yes
	A farmer with no data			Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker			Yes
	Other……………………………………..			Researcher
11	**Overall assessment**			
	Will you use FARMS for your work?	Maybe	Yes	No
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Excellent	Very good	Excellent
	Please write any other comments you may have for FARMS			user friendly

	Questionnaire	4	5	6
1	**About the user**			
	1. Current Work Position:	Public officer	Public officer	Public officer
	2. Academic Background	Chemical Eng.	Chemist	Environmental Sc.
	3. Familiarity with animal waste	Very good	Good	Good
	4. Familiarity with anaerobic digestion	Very good	Good	Very good
	5. Familiarity with environmental terminology	Very good	Very good	Good
2	**User guide**			
	Was the user guide easy to read and understand?	Very good	Excellent	Excellent
	Was there sufficient explanation in the user guide for the options in FARMS?	Excellent	Excellent	Excellent
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	
	You can see all data used	Yes	Yes	
	The options are clear	Yes	Yes	
	The options are representative of the situation in Cyprus		Yes	Yes
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	Yes	No
	If yes, please write which animals		goats	
6	**Defaults**			
	Please rate the way the default values are presented:	Very good	Very good	Very good
	If not good, please explain			
	Have you used you own data?	Yes	No	No
	If yes, please indicate	fuel consumption		
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Cannot assess	Excellent
	If not good, please explain			
	Please rate how are results of FARMS are presented.	Very good	Very good	Excellent
	If not good, please explain			
	Do you think the results of FARMS	No	Yes	Yes

	will assist you work?			
	Please explain	My work is irrelevant		data availability
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes		
	A farmer with no data	Yes		Yes
	A student	Yes	Yes	
	A consultant	Yes	Yes	
	A decision maker	Yes	Yes	
	Other……………………………………			
11	**Overall assessment**			
	Will you use FARMS for your work?	Maybe	Maybe	Yes
	Will you use FARMS for data reference?	Yes	Maybe	Yes
	Please indicate your overall evaluation for FARMS	Very good	Very good	Excellent
	Please write any other comments you may have for FARMS	very useful tool	accuracy depends on quality of data in	

	Questionnaire	7	8	9
1	**About the user**			
	1. Current Work Position:	Public officer	Public officer	Consultant
	2. Academic Background	Energy	Energy	Environmental Sc.
	3. Familiarity with animal waste	Good	Good	Excellent
	4. Familiarity with anaerobic digestion	Very good	Very good	Excellent
	5. Familiarity with environmental terminology	Not very good	Not very good	Excellent
2	**User guide**			
	Was the user guide easy to read and understand?	Very good	Very good	Excellent
	Was there sufficient explanation in the user guide for the options in FARMS?	Very good	Very good	Excellent
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	Yes
	You can see all data used	Yes	Yes	Yes
	The options are clear	Yes	Yes	Yes
	The options are representative of the situation in Cyprus			Yes
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	No	No
	If yes, please write which animals			
6	**Defaults**			
	Please rate the way the default values are presented:	Very good	Very good	Excellent
	If not good, please explain			
	Have you used you own data?	yes	yes	No
	If yes, please indicate	waste production, energy consumption, financial parameters, area	waste production, energy consumption, financial parameters, area	
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Good	Good
	If not good, please explain			

	Please rate how are results of FARMS are presented.	Excellent	Excellent	Excellent
	If not good, please explain			
	Do you think the results of FARMS will assist you work?	Yes	Yes	Yes
	Please explain	scenarios' assesment	scenarios' assesment	Cyprus data
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes	Yes	Yes
	A farmer with no data	Yes	Yes	Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker	Yes	Yes	Yes
	Other………………………………………	Researchers	Researchers	Researchers
11	**Overall assessment**			
	Will you use FARMS for your work?	Yes	Yes	Yes
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Very good	Very good	Excellent
	Please write any other comments you may have for FARMS	there are some mistakes in defatults but user can change the data and receive results that would need many calculations	there are some mistakes in defatults but user can change the data and receive results that would need many calculations	lower limits have to be added

	Questionnaire	10	11	12
1	**About the user**			
	1. Current Work Position:	Consultant	Farm owner	Farm owner
	2. Academic Background	Environmental		
	3. Familiarity with animal waste	Excellent	Very good	Good
	4. Familiarity with anaerobic digestion	Excellent	Very good	Very good
	5. Familiarity with environmental terminology	Excellent	Good	Good
2	**User guide**			
	Was the user guide easy to read and understand?	Excellent	Very good	Very good
	Was there sufficient explanation in the user guide for the options in FARMS?	Excellent	Very good	Very good
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	Yes
	You can see all data used	Yes	Yes	Yes
	The options are clear	Yes	Yes	Yes
	The options are representative of the situation in Cyprus	Yes		
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	No	No
	If yes, please write which animals			
6	**Defaults**			
	Please rate the way the default values are presented:	Excellent	Very good	Very good
	If not good, please explain			
	Have you used you own data?	No	yes	yes
	If yes, please indicate		waste production, energy consumption, digester area and costs	waste production, energy consumption
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Good	Good
	If not good, please explain			
	Please rate how are results of	Excellent	Excellent	Excellent

	FARMS are presented.			
	If not good, please explain			
	Do you think the results of FARMS will assist you work?	Yes	Yes	Yes
	Please explain	Cyprus data	scenarios' assesment	scenarios' assesment
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes	Yes	Yes
	A farmer with no data	Yes	Yes	Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker	Yes	Yes	Yes
	Other………………………………………..		Researchers	Researchers
11	**Overall assessment**			
	Will you use FARMS for your work?	Yes	Yes	Yes
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Excellent	Very good	Very good
	Please write any other comments you may have for FARMS	lower limits have to be added	additional research needed for area and cost parameters	not sure that some of the defaults are correct - BUT user can change all data to more appropriate values

	Questionnaire	13	14	15
1	**About the user**			
	1. Current Work Position:	Farm owner	Farm owner	Farm owner
	2. Academic Background			
	3. Familiarity with animal waste	Good	Good	Good
	4. Familiarity with anaerobic digestion	Very good	Very good	Not very good
	5. Familiarity with environmental terminology	Good	Good	Good
2	**User guide**			
	Was the user guide easy to read and understand?	Very good	Very good	Very good
	Was there sufficient explanation in the user guide for the options in FARMS?	Very good	Very good	Very good
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	Yes
	You can see all data used	Yes	Yes	Yes
	The options are clear	Yes	Yes	Yes
	The options are representative of the situation in Cyprus			
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	No	No
	If yes, please write which animals			
6	**Defaults**			
	Please rate the way the default values are presented:	Very good	Very good	Very good
	If not good, please explain			
	Have you used you own data?	yes	yes	yes
	If yes, please indicate	waste production, energy consumption, financial parameters	waste production, energy consumption, financial parameters, area	waste production, energy consumption, financial parameters
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Good	Good
	If not good, please explain			

	Please rate how are results of FARMS are presented.	Excellent	Excellent	Excellent
	If not good, please explain			
	Do you think the results of FARMS will assist you work?	Yes	Yes	Yes
	Please explain	scenarios' assesment	scenarios' assesment	scenarios' assesment
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes	Yes	Yes
	A farmer with no data	Yes	Yes	Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker	Yes	Yes	Yes
	Other……………………………………..	Researchers	Researchers	
11	**Overall assessment**			
	Will you use FARMS for your work?	Yes	Yes	Yes
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Very good	Very good	Very good
	Please write any other comments you may have for FARMS	it is good to have a software for Cyprus	it is good to have a software and data for Cyprus; there are some mistakes in defatults but user can change the data	I do not have much data available for my farm and this was very useful to assess things that would cost a lot if were to be done by a consultant

	Questionnaire	16	17	18
1	**About the user**			
	1. Current Work Position:	Farm owner	Farm owner	Farm owner
	2. Academic Background			
	3. Familiarity with animal waste	Good	Good	Good
	4. Familiarity with anaerobic digestion	Not very good	Not very good	Not very good
	5. Familiarity with environmental terminology	Good	Not very good	Not very good
2	**User guide**			
	Was the user guide easy to read and understand?	Very good	Good	Good
	Was there sufficient explanation in the user guide for the options in FARMS?	Very good	Good	Good
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	Yes
	You can see all data used	Yes	Yes	Yes
	The options are clear	Yes	Yes	Yes
	The options are representative of the situation in Cyprus			
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	No	No
	If yes, please write which animals			
6	**Defaults**			
	Please rate the way the default values are presented:	Very good	Very good	Very good
	If not good, please explain			
	Have you used you own data?	yes	No	No
	If yes, please indicate	waste production, energy consumption, financial parameters, area		
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Good	Good
	If not good, please explain			
	Please rate how are results of FARMS are presented.	Excellent	Excellent	Excellent

	If not good, please explain			
	Do you think the results of FARMS will assist you work?	Yes	No	No
	Please explain	scenarios' assesment		
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes	Yes	Yes
	A farmer with no data	Yes	Yes	Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker	Yes	Yes	Yes
	Other………………………………………			
11	**Overall assessment**			
	Will you use FARMS for your work?	Yes	Yes	Yes
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Very good	Good	Good
	Please write any other comments you may have for FARMS	I do not have much data available for my farm and this was very useful to assess things that would cost a lot if were to be done by a consultant		

	Questionnaire	19	20	21
1	**About the user**			
	1. Current Work Position:	Farm owner	Farm owner	Farm owner
	2. Academic Background			
	3. Familiarity with animal waste	Good	Good	Good
	4. Familiarity with anaerobic digestion	Very good	Very good	Very good
	5. Familiarity with environmental terminology	Not very good	Not very good	Not very good
2	**User guide**			
	Was the user guide easy to read and understand?	Very good	Very good	Very good
	Was there sufficient explanation in the user guide for the options in FARMS?	Very good	Very good	Very good
3	**Installation**			
	Was the installation of FARMS easy?	Excellent	Excellent	Excellent
	Have you encountered any problems during installation?	No	No	No
	If yes, please describe			
4	**Use**			
	Do you consider FARMS user friendly?	Yes	Yes	Yes
	Yes			
	Easy	Yes	Yes	Yes
	You can see all data used	Yes	Yes	Yes
	The options are clear	Yes	Yes	Yes
	The options are representative of the situation in Cyprus			
	No			
	Complicated			
	Too much data			
	Too many options			
	I would prefer to see only the result			
5	**Animal types**			
	Do you think there are other animals that should be included?	No	No	No
	If yes, please write which animals			
6	**Defaults**			
	Please rate the way the default values are presented:	Very good	Very good	Very good
	If not good, please explain			
	Have you used you own data?	yes	yes	yes
	If yes, please indicate	waste production, energy consumption, financial parameters, area	waste production, energy consumption, financial parameters, area	waste production, energy consumption, financial parameters, area
7	**Results**			
	Please rate how realistic are the results of FARMS.	Good	Good	Good

	If not good, please explain			
	Please rate how are results of FARMS are presented.	Excellent	Excellent	Excellent
	If not good, please explain			
	Do you think the results of FARMS will assist you work?	Yes	Yes	Yes
	Please explain	scenarios' assesment	scenarios' assesment	scenarios' assesment
8	**Errors**			
	Have you received any errors during running FARMS?	No	No	No
	If yes, please describe			
9	**Other software**			
	Do you use other software for the same purpose?	No	No	No
	If yes, please provide the name:			
	If yes, will you continue using the other software?			
10	**Potential Users**			
	Please indicate who in your opinion could use FARMS.			
	A farmer with no knowledge on anaerobic digestion	Yes	Yes	Yes
	A farmer with no data	Yes	Yes	Yes
	A student	Yes	Yes	Yes
	A consultant	Yes	Yes	Yes
	A decision maker	Yes	Yes	Yes
	Other…………………………………….	Researchers	Researchers	Researchers
11	**Overall assessment**			
	Will you use FARMS for your work?	Yes	Yes	Yes
	Will you use FARMS for data reference?	Yes	Yes	Yes
	Please indicate your overall evaluation for FARMS	Very good	Very good	Very good
	Please write any other comments you may have for FARMS	there are some mistakes in defatults but user can change the data and receive results that would need many calculations	there are some mistakes in defatults but user can change the data and receive results that would need many calculations	there are some mistakes in defatults but user can change the data and receive results that would need many calculations