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Manure Potential Using Anaerobic Digestion

A study of the Economic Potential of Manure in Ostrobothnia, Finland

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Abstract

The purpose of this thesis was to evaluate the economic value of manure in the Ostrobothnia region. The study starts with the introduction of manure management concept and discusses the importance of it. Then the aspect of manure as a fertilizer is explored as well as the value addition chain which involves processing it using aerobic co-digestion.

The next part deals with specific data regarding manure in Ostrobothnia. The data contains the number of livestock according to breed and the manure production with their respective nutrient content and biogas potential. This is followed by mathematical models for evaluating the manure value in different scenarios.

First scenario is using the manure as a fertilizer without any treatment. In this case, the value is compared to commercial fertilizer even though the nutrient solubility rate is low. The other scenario is using anaerobic digestion to treat the manure before using the digestate as fertilizer. This has multiple benefits including improving the soluble nitrogen, renewable energy production and emission savings.

Language: English Key words: manure, co-digestion, anaerobic, biogas,

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Terminology and Abbreviations

GHG	Greenhouse gas
BAT	Best Available Technology
P	Phosphorous
N	Nitrogen
CO_2	Carbon Dioxide
CH_4	Methane
N_2O	Methane
N_2	Nitrogen Dioxide
NH_3	Ammonia
NH_4^+	Ammonium cation
NH_3^-	Ammonia anion
H_2S	Dihydrogen Sulfide
CAP	Common Agricultural Policy
R & D	Research and Development
DAP	Diammonium phosphate
P_2O_5	Phosphorous pentoxide
Urea	Chemical compound obtained from protein metabolism
Nm^3	Normal cubic meter
BMP	Biochemical Methane Potential
KWh	Kilowatt hour
GWh	Gigawatt hour
TWh	Terawatt hour
A/D	Anaerobic digestion
RES	Renewable energy sources
Substrate	Any organic matter

1 Introduction

The environment has taken center stage as one of the major global challenges in this era. One sector which contributes to global GHG emissions is agriculture. As population increases so does the demand for food and especially livestock products. This has led to large scale farming and with it comes the challenge of managing vast waste such as manure.

Manure is a very versatile resource which can be used as a fertilizer and also to produce renewable energy namely biogas. Biogas is obtained from the decomposition of organic matter which means all organic waste can be converted into useful energy theoretically. However, in practice there is a lot of consideration before choosing the type of waste used ranging from legislative to economic. Transportation costs play a huge role in determining the viability of a substrate.

This thesis will cover the economic benefits of manure in Ostrobothnia region. For biogas production, the manure is mixed with other substrates to maximize the production. Apart from electricity and heating, the biogas produced can be upgraded to biomethane or RNG and used as a transport fuel.

1.1 Background

Biogas is seen as one of the most promising transitional fuel as the world is aiming to move to a green economy. There has been growing concerns about the security of energy supplies within the EU. As of 2013, more than two thirds (69.1 %) of the EU imports of natural gas came from non-EU members namely Russia and Norway [1]. This has led to EU countries looking for alternatives. In 2009 the European biogas association was formed which is mandated to promote biogas and biomethane production and use [2]. Biomethane has proved to work as LNG and CNG after the removal of contaminants [3]. According to the biomethane roadmap, co-digestion of energy crops and manure has produced the most energy efficient biofuel [4].

In Finland, there is an excess of manure in South- West and Ostrobothnia regions due to intensive livestock production [5]. In Ostrobothnia in particular, accounts for around 97% of fur farming. Fur animal manure is very rich in P and N nutrients but the farmed area is too small to utilize the manure. Spreading this would lead to the accumulation of P in soil [5, pp.

23, 24] and subsequently cause P leaching to the immediate surrounding such as The Baltic Sea.

If the manure was transported to other areas in Finland, it would be utilized better and eradicate the P deficit for crops in other areas. The challenge lies with the logistic costs which are too high to justify this (prohibitive). Another viable option is biogas production. Since it is localized the logistics cost are reduced significantly. Other benefits are highlighted in Table 1 and the details of these benefits are discussed later in chapter 3.

Table 1:Benefits of using co-digestion adopted from [3]

Energy	Agriculture	Environment
• Generation of biogas for energy and fuel • Energy self sufficiency	• Better metabolism of nitrogen • Better P ratio	• Reduced N leaching • Reduced GHG • Create an economy

1.2 Method

The given task is to investigate the economic value of manure in Ostrobthnia region. In order to achieve this goal, the task will be divided into theoretical and practical part. The theoretical part covers the basics of manure management and the value addition in manure processing. This is done by reviewing a number of literature sources, as well as doing some calculations to estimate the economic potential. The practical part will contain mathematical modeling of different scenarios using collected data from the region to make comparisons. The values for the biogas potential are obtained from the Novia University of Applied Sciences laboratory where co-digestion potential estimates for different substrates was done.

The laboratory work was conducted by an EPS group called waste converters which did a biogas potential study for the region. Although various substrates were tested, the focus will be on fur animals and pig manure co-digestion. The results will then give a forecast into the value of manure in the region.

1.3 Theoretical Background

The concepts of manure management and biogas are introduced through analyzing books, internet sources, scientific journals and environmental reports. The key concepts are the current practices in managing manure and future developments based on the current trends. The biogas part will focus on using manure in biogas production and the development of co-digestion as a means of biogas production.

2 Manure management

In the past livestock keeping went hand in hand with arable farming in small family land. The manure was used as fertilizer hence there was no waste from the farm. Modern farming practices have led to specialization which has led to focusing farms on few types of foodstuff and to some extent whole regions. This has led to the separation of livestock from arable land and consequently the livestock producers see the manure as a “waste product” [6, p. 3].

Farmers engaging in large scale animal husbandry face a range of issues including:

- Odor complaints from neighboring houses.
- Penalties due to pollution of nearby water streams.
- Pollution due to air emission- ammonia, nitrogen oxide and methane.
- Water pollution through leaching.
- Soil pollution due to spreading repeatedly in the same area.
- Risk of diseases to both the livestock and general public.

It is with this backdrop that there has been an increase in research into ways of turning this precious waste into a resource. Manure management can be defined as the collection, storage, transportation and application of manure to land. It may include treatment if it is done [7, p. 1] . As [6] pointed above earlier, there is surplus in some regions and the main challenge is the redistribution of the manure. In order to choose a management method there are many factors to be considered since manure varies from animal and the type of food the animal consumes. Figure 1 shows a cycle of the manure:

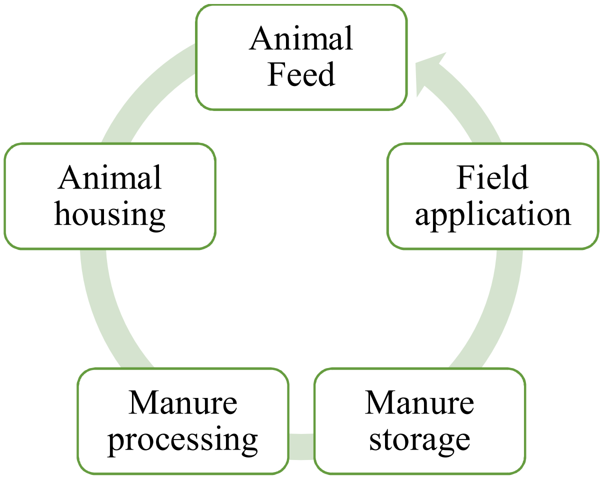

Figure 1: Manure closed loop cycle adopted from: [8, p. 3]

Manure management is getting a lot of attention in the EU currently. This is because of a number of factors such as [9, p. 3]:

- Targets to reduce loss of plant nutrient to the environment.
- Renewable energy targets based on EU 2020
- Environmental targets specifically on GHG.
- Other environmental issues such as water protection and soil protection.

A combination of all this makes the conducive environment to turn manure into a resource.

There have been substantial studies within the EU about the whole manure chain from feeding to field application. Although same animals in different regions produce different quality of manure, one study done by the Baltic manure project [8] captures a holistic view of the chain and proposes general recommendations that can be applied in different scenario.

For the animal feed, nutrient content should be managed in order to avoid a situation where nutrients such as P and N are less utilized and instead they are excreted. In order to reduce this, precise feeding strategies have to be developed as well as using substitute feeds that are easier to metabolize [8, pp. 6-7].

Animal housing contributes to the manure properties. The manure in a housing contains water which is used for diluting. Another additive in the housing is the beddings, which also affects the properties. Different bedding materials like straw, peat or sawdust result in different properties [8, pp. 8-10]. The Figure 2 shows the impact of housing on manure:

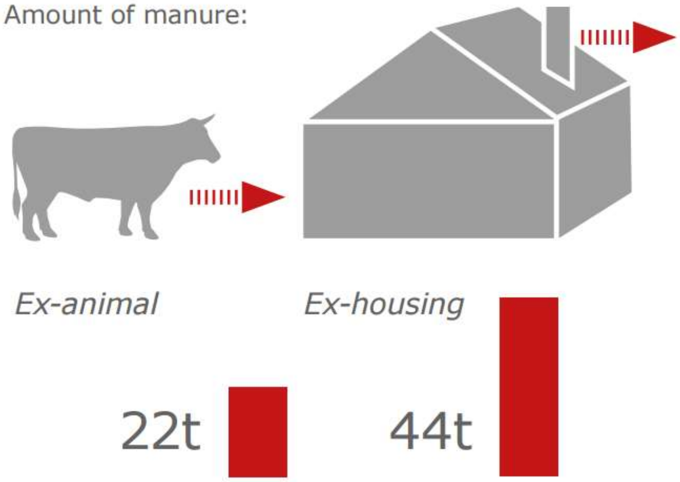

Figure 2: Impact of housing on manure *source: [8, p. 10]*

Manure processing is done for many factors such as logistics, nutrient utilization, reducing odor and economic incentives. The type of technology chosen depends on the farm owner's perspective.

2.1 Manure production

There is little information about the amount of manure produced by animals since it varies due to factors such as feeds, housing and the climatic region. To get an accurate measurement, one should model the whole process of manure production and analyse the result based on the context of the farm.

The example of a farm is shown in Figure 3. The manure production can be divided into different stages in the production chain represented by orange boxes. As the production chain goes down the more the production analysis becomes complex due to losses and additional material such as bedding and cleaning water.

The important part of the manure is the dry content, organic matter and the nutrients N and P which are important for the growth of plants. In the EU, manure is considered as part of an agricultural system and taken into consideration when making a gross nutrient balance.

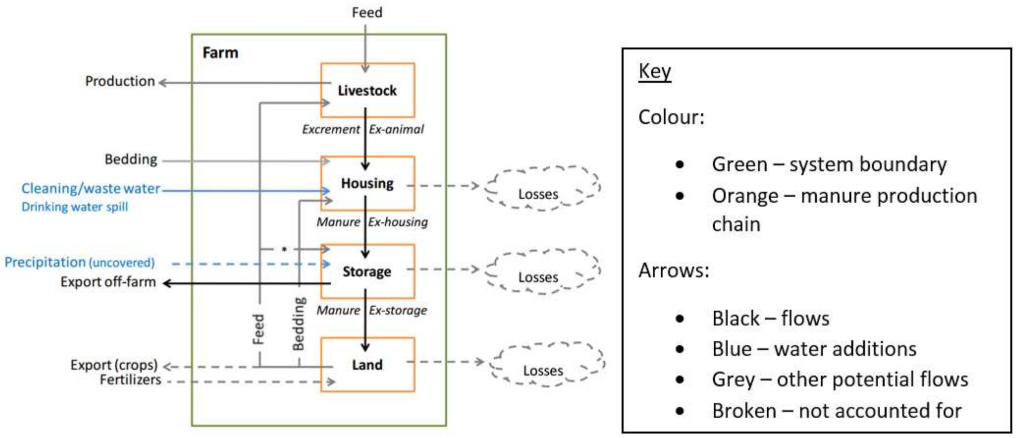

Figure 3: Manure production model source:[40, p. 7]

Gross nutrient balance is an indicator which estimates potential surpluses or deficit of nutrients (N and P) on agricultural land. The indicator accounts for all inputs and outputs on the farm. Some of the inputs include mineral fertilizer, animal manure and nitrogen fixation by legumes. The outputs contain harvested crops, animal feed and grass. Nitrogen that escapes into the atmosphere is not taken into account because of difficulty of estimating [10]. It is divided into Gross Nitrogen Balance and the Gross Phosphorus Balance. The Figure 4 below shows an example of nutrient content in a farm.

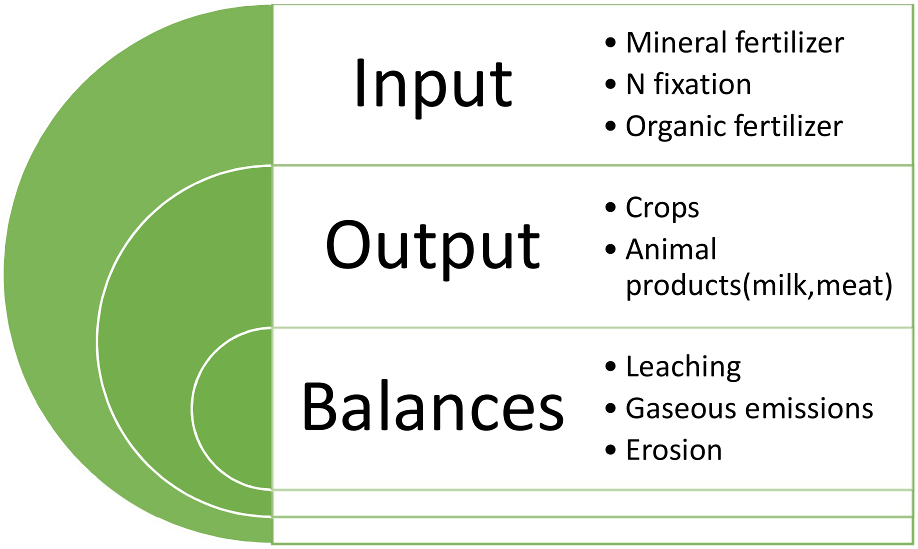

Figure 4: Nutrient balance source: modified from [10]

The nutrients are tracked and the best case scenario is when all the inputs are utilized in the internal flows. Intensive farming can lead to excess manure production or excess use of fertilizer leading to some environmental problems as can be seen in Figure 4. Low input of P and N could lead to soil degradation which lowers productivity.

The indicator is used to highlight the potential risk to the environment. The actual risk depends on the type of soil, climatic conditions and farm management practice among other factors.

Using nutrient balance, the manure production can be characterized as an input nutrient or by the amount and type of livestock in a country.

2.2 Manure processing

This can be defined as , "a group of controlled processes that change the physical and/or chemical properties of the livestock manure" [9, p. 7] either to reduce the harmful effects or then use it as a resource such as nutrient or energy. There are many technologies available for manure processing which depend on the type of manure and the cost. Other than these factors the rest is same as reasons for manure management.

Processing technologies range from a single process to combined processes depending on the objective thus classification is based on this. The Table 2 below shows 45 processing technologies identified in Europe and classified according to their objectives:

Table 2: Processing technologies source: [11, p. 7]

Technique	**Objective**	**Number of technologies**
Separation techniques	Separating manure into solid and liquid fraction	10
Additives and other pre treatments	Preparation for further treatment	4
Anaerobic treatment	Biogas production	2
Solid fraction treatment	Treating solid manure	9
Liquid fraction treatment	Treating liquid manure	17
Air cleaning	Cleaning air used during manure treatment	3

This thesis will particularly focus on the anaerobic treatment with the goal of reducing emissions from manure management. The choice of the processing is important since it directly relates to the storage and field application phase. The Figure 5 below depicts the risk of N losses and methane.

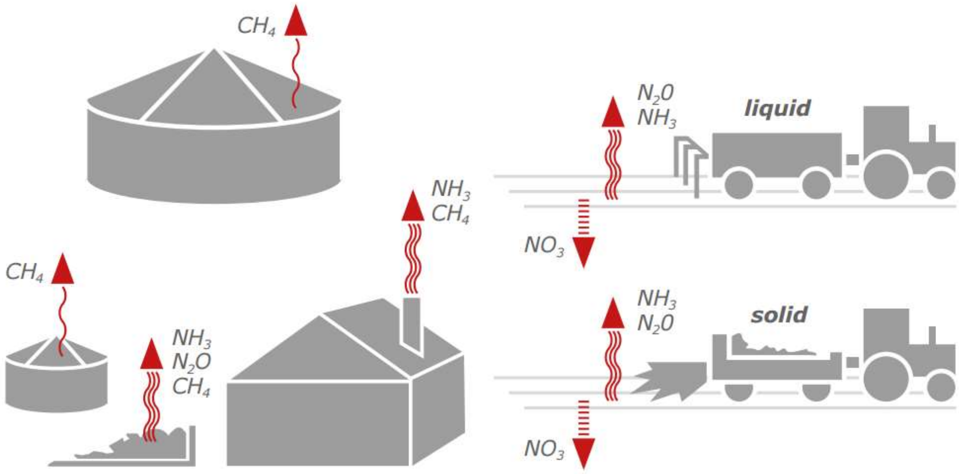

Figure 5:N losses in manure storage and transportation source: [8, p. 9]

The red arrows show the losses either to the atmosphere or leakage to water. Ammonia contributes to eutrophication and acidification. Nitrogen dioxide and methane contribute to global warming.

2.3 Manure nutrient balance

Nutrient balance is a calculation tool for tracking the nutrient flow in a farm. It can be used as an indicator for the risk of nutrient leaching and pollution thus enabling one to be able to target specific areas to reduce the nutrients environmental impact. Nutrient balances also provides a basis for reducing farm costs. There are different kinds of nutrient balance calculation for example based on farm, field, region or even a country.

Farm balance is the difference between nutrients to the farm and nutrients from the farm. Nutrients coming to the farm could be seed, feed and fertilizer whereas those leaving the farm could be milk, eggs, grain, manure and slaughtered animals. For farms engaging only in crop production, the farm balance is equal to the field balance. Introduction of other nutrient sources has to be taken into account. In order to get good results, the data should be as accurate as possible [12]. The Table 3 shows the relationship between animal density and nutrient flow. It is evident from the three scenarios described that having too many animals becomes a challenge when it comes to manure management.

Table 3:Farm based nutrient balance source: modified from [13]

Manure Nutrient Balance	**Deficit**	**Balanced**	**Excess**
Animal density	Low (0-200kg biomass/ha)	Medium (200-500 kg biomass/ha)	High (>500kg biomass/ha)
Feed source(% off farm)	<50%	50-80 %	>80%
Land for manure application	Enough	Limited	Less
management strategy	Deficit balance strategy	Nutrient balance strategy	Excess nutrient strategy
Economics effect	Positive	Neutral	Negative
Pollution potential	Low	Low-average	High

Examples of management for different scenarios would be:

i. Excess nutrient management – The aim of the strategy would be to remove manure nutrients from the farm. This could be done by selling manure, giving away manure, destocking or acquiring more land.

ii. Balanced nutrient management – The aim of this strategy is to maximize the safe use of manure nutrients. One can achieve this through; spreading manure on legumes, avoiding manure altogether and increasing crop production.

iii. Deficit nutrient management – The aim of this strategy is maximizing efficient use of manure. In order to achieve this, various tactics could be used such as spreading the manure near the crop utilization time (spring in Europe), using cover crops to prevent nutrient loss and making right nutrient doses for crops (not spreading manure on leguminous plants because they do not need N) [13].

2.4 Manure environmental impact

Agriculture has a big global footprint in terms of land use and the environment. As population increases so does the demand for agricultural produce. This has led to more pressure on the environment since agricultural sector is a major source of emissions in the environment. Animal husbandry is among the biggest contributor to the GHG emissions in the agricultural sector [14].

Livestock produce emissions are estimated at 7.1 Gt CO_2 equivalent yearly which translates to 14.5% of "human-induced GHG emissions" [15]. The predominant emissions in this sector are CH_4 and N_2O. As at 2007 the estimates for the two were 3.1 Gt CO_2 equivalent and 2 Gt CO_2 equivalent respectively [16]. Furthermore, 80% of NH_3 emissions in Europe are due to animal excreta [17]. It is with this backdrop that it is important to understand the animal husbandry impact to the environment.

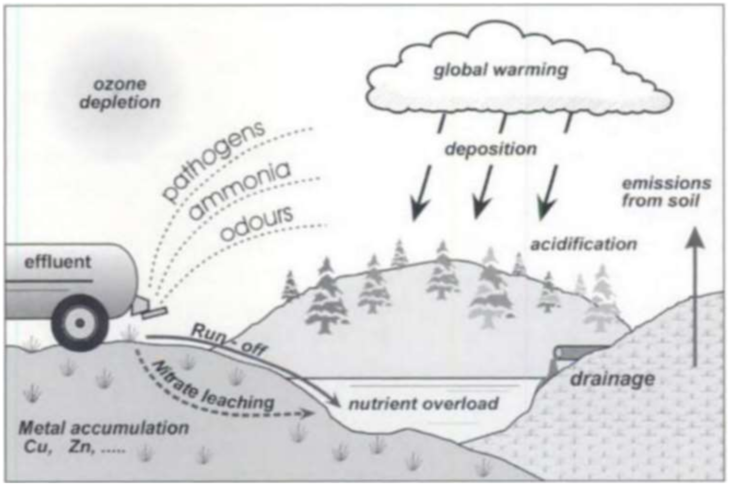

Figure 6: potential environmental impact from animal husbandry source: [6]

Figure 6 demonstrates that emissions from the animal husbandry range from air to water and ground pollutions. Before discussing the different pathways the emissions take, it is vital to understand the nitrogen cycle since this is the highest contributor of the emissions.

2.4.1 Nitrogen cycle

Nitrogen is a key nutrient in the survival and growth of all living organisms. The atmosphere is made up of around 79% Nitrogen however, many living organisms cannot use it because it is in inert form. Only leguminous plants and few bacteria have the capability to utilize this nitrogen and change it into a form that can be used by all organisms. The processes that are involved in the N conversion to different forms constitute the N cycle.

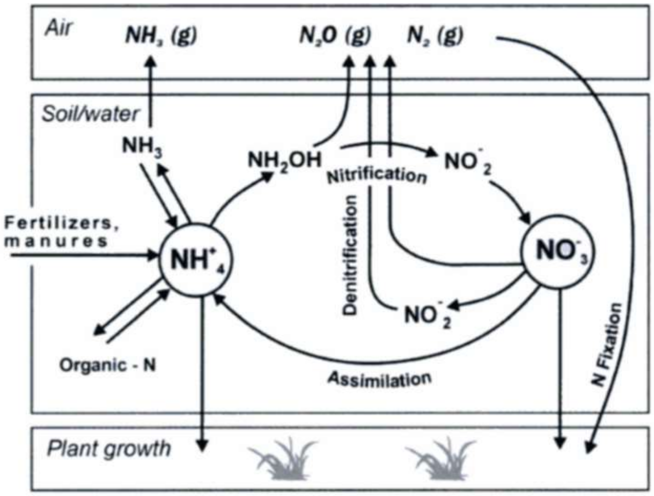

Figure 7: N cycle in animal husbandry context

The main processes involved in the N cycle are:

- N fixation – The N_2 is converted to NH_3 and NH4+ by biological means or NO_3^- through high energy physical processes. The biological process involves an enzyme called nitrogenase which breaks the bonds and combines it with hydrogen. The enzyme works in absence of oxygen. Oxygen free zones in nature are found in some species of plants. An example is the nodules of leguminous plants where the bacterium, Rhizobium, is found. Physical processes could be combustion, volcanic action, lightning and industrial processes.

- Nitrification – This is a process of converting ammonium and ammonia to nitrate. This is achieved through two steps. In the first step, the ammonia is oxidized by soil bacteria breaking it down to a nitrite. After that a bacterium called Nitrobacter oxidizes the nitrite to a nitrate. This is an important process because it rids ammonia which is more toxic than nitrate. During this process, N_2O can be formed as a byproduct.

- Assimilation – This is the process which plants and animals use the NO3- formed through fixation and nitrification. The plants absorb the nitrogen through the roots, and process it. Animals feed on the plants and get the nitrogen in their system.

- Ammonification – It is the conversion of organic nitrogen (amino acids) into ammonia. This is done through the decomposition of dead plants and animals.

- Denitrification – This is the breakdown of NO3- to N_2 and in some cases N_2O is produced depending on the activity. This is the last stage where the fixed N is returned back to the atmosphere.

- Mineralization – This is a process whereby organic matter is used by organisms as an energy source. The excess N is broken down by microbes and the excess N is excreted making it available to other organisms [6, pp. 58-63].

The environmental impact caused by poor manure management is discussed in the next subchapters.

2.4.2 Air Emissions

Liquid manure contains urea which can easily change to ammonia gas and escapes to the atmosphere in a process called ammonia volatization which could lead to acid deposition. Acidification in the nearby surrounding leads to leaching of important elements like calcium and magnesium. At the same time, it leads to mobilization of toxic ions of aluminium which is deadly to fish [18].Apart from this the deposition also leads to excessive N loading to the environment which causes eutrophication related problems. This could potentially lead to loss of some species especially in the aquatic environment.

During denitrification, N_20 is formed which is a GHG that negatively impacts the ozone layer. Apart from N_2O, another GHG produced is the CH_4 which is more potent than even CO_2.When manure is stored under aerobic conditions, it undergoes decomposition which leads to formation of CH_4.When the CH_4 escapes to the atmosphere it affects the ozone layer [19].

Air pollution from the odour is quite common near farms handling manure. Although considered more of a nuisance, it still impacts the environment negatively. Other sources of air pollution are particulate matter which mostly comes from the feeds and livestock housing. Particulate matter causes respiratory diseases and could even lead to death [20].

2.4.3 Land Emissions

Excess application of manure can lead to clogging of the soil pores hence reducing water penetration and oxygen diffusion. The lowered oxygen levels lead to creation of anaerobic zones which could lead to production of CO_2, N_2O and H_2S which impact negatively to the environment.

Another effect due to over fertilization is risk of contaminating the soil with heavy metals such as copper and zinc which are present in the manure. This could lead to changes in the soil biology (enzyme and microbe environment) thus leading to soil degradation and poor fertility. The heavy metals could also accumulate in the food chain leading to a wider risk of health issues in humans and animals.

There can also be presence of weed seeds in manure which can affect crop production. Although digestion reduces their germination potential, some species can survive.

2.4.4 Water Emissions

Water pollution by manure occurs either by leaching and run-off from the soil surface, leaching into ground water or accidental flows into water ways. N and P are the primary nutrients that pose the risk of water pollution. P rarely leaches but if overloaded can be as harmful as N and lead to eutrophication in freshwater bodies.

When NH_3 does not volatize, it is nitrified making it not soluble in soil minerals or organic matter. In case of excess water such as rain or flood it can be leached into the ground. High concentrations of NO3 make the ground water not safe for drinking. The ground water in certain circumstances can flow into surface water leading to algal bloom in water bodies resulting into death of marine species.

There has been deliberate action especially in Europe to mitigate these negative impacts caused by poor manure and nutrient management. For example, the nitrate concentration in European waters reduced by 20% between 1999 and 2001 as depicted in Figure 8. This can be attributed to the raft of measures introduced to reverse the environmental impact of agriculture including EU wide legislations [21].

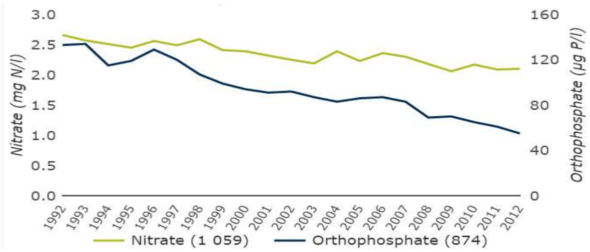

Figure 8: Changes in EU water quality *source: [21]*

2.5 Legislation

Even before the establishment of the EU countries in Western Europe had an existing policy for agricultural development called CAP. It aimed at promoting agricultural development during the tough times faced by European countries after years of war and constant food shortages. This policy stands today and as in 2013 the policy is gearing towards a greener farming practises [22].

The legislation governing manure management is broad and varies from different countries. Some laws cut across EU whereas others are specific to countries or regions. The laws governing this sector can be grouped as follows:

i. Regulations – they directly address the manure management.

   a. EU directives – Theses are mandatory for all countries. The directives are adopted into national legislation for example The Nitrates Directive (Directive 0676/1991)

   b. National legislation – These laws specifically deal with local problems with the environment example Environmental Protection Act (86/2000) and decree (169/2000) in Finland.

   c. National guidelines – these may not be mandatory but if not followed and an incidence occurs then could lead to penalty to the offender.
   d. National schemes – aimed at improving the farm management practise and can be accompanied with incentives such as funding improved housing for livestock.

ii. Related regulation – they indirectly touch on manure management.
   a. Water protection legislation – This law is not specific to livestock management although pollution by the sector leads to prosecution.
   b. Public health regulation – Odour nuisance can be covered under this law.
   c. Air quality – The PM emissions can fall under this law.

iii. National rules – They give very specific guidelines for manure management
   a. Minimum storage periods for manure typically 12 moths but varies from country to country.
   b. Specific time for land spreading generally not winter.
   c. Manure spreading method for example spraying.
   d. Manure storage methods (covering to avoid emissions)
   e. Compulsory manure management plan.
   f. Book keeping at farm level and nutrient balancing [23].

Legislation has had a big impact on the agricultural practises and this has led to a shift in the methods used. The legislation goes hand in hand with the R&D which has been geared towards promoting sustainable agriculture.

3 Manure value

Manure has always been seen as a waste product especially by extensive livestock farmers. This is due to the excess amount of nutrients produced and the burden of handling the waste within rigorous laws governing the sector. Issues such as storage and logistics compound the magnitude of the problem thereby burdening the farmers. In the recent past however, people's perception has started to change and people are acknowledging the positive value of manure as a source of plant nutrient and a fuel source [24].

3.1 Manure fertilizer value

The value of manure as a fertilizer is a complex concept since the 'value' is determined by market forces. Due to lack of developed market, the value can be deduced by relating it with commercial fertilizer through a process called hedonic pricing. The challenge of comparing the two is overcome by making assumptions based on prevailing circumstances. Changes in the assumption will directly affect the value. Some of the factors that affect the value include:

- The source of manure – this varies the constitution of nutrients in the manure. For example, solid manure packs more nutrients than slurry manure hence the solid one is more valuable.
- The soil needs – determines dosing amount.
- The type of crop – some crops require more N than others.
- Legal obligations – based on the legislation of specific country.
- Negative components – this could be weed seeds or other unwanted matter.

The 'value' of manure has to be based on units that can be comparable to the current fertilizer use [25, p. 1].

3.1.1 Value units

Usually there are three units that put fertilizer use in context and can also be used in manure valuing. These units are:

- Euro/ha – this unit gives a direct comparison between the cost of fertilizing one ha of land using manure vis-à-vis fertilizer.
- Euro/1000 ton –where the fertilizer need of the crop is met, the cost/ha will be constant for all kinds of manure. In this case the application rate will differ from the different manure sources. This unit can be used to compare the value of different manure types.
- Total euros of annual manure production – In a farm it it important to understand the total impact of management practice annually. For example, when one applies manure according to phosphorous limit, it might reduce value/ha or value/1000 ton but overall increase output per ha. This impact is more beneficial than the negative impact of the first two [25, p. 2].

3.1.2 Fertilizer form

In order to get the value of the nutrients contained in the manure it is important to match the nutrient with the fertilizer substitute. The key N and P products in the market are Urea and DAP respectively. The P however is in form of P_2O_5.

Urea contains 46% N and DAP contains 46% phosphate(P_2O_5) and 18% N. When setting the price, the % nutrient should be taken into account to give more accurate estimates [26].

3.1.3 Transportation cost

When considering the value of the manure, transportation costs play a negative role. The cost is borne by the manure producer and is dependent on the type of manure and distance transported. The unit cost is charged at ton/km. The ton could be used for nutrients or total manure volume.

From the units above it is quite evident that hauling solid manure gives more value to the manure. In the case of slurry/liquid manure, only a fraction of the nutrients is carried while the rest is water [27].

3.2 Manure biogas value

Biogas is a renewable energy source which is produced by “bacterial degradation of biomass under aerobic conditions” [28, p. 1].The biomass used can be classified into different categories depending on the source. One of the sources is manure which is considered as part of animal waste as can be seen in Figure 9.

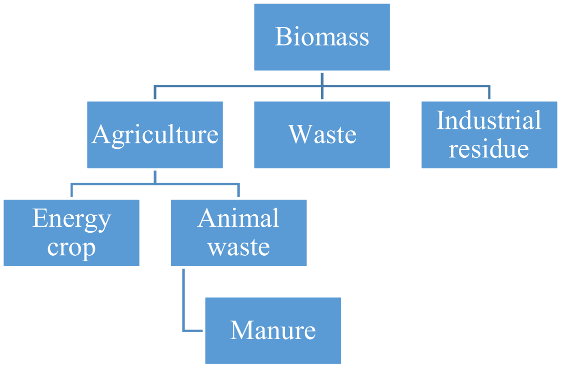

Figure 9: Biomass classification

Apart from energy value, anaerobic digestion has proved to be cost-effective for waste treatment as seen in studies carried out in Europe [29] [30].

Using manure as the sole feedstock results to low biogas yields, instead, mixing it with other feedstock such as energy crops significantly increases the yield .This concept is called co-digestion [31, p. 197].

Benefits attributed to co-digestion include:

- Improved nutrient balance – using different substrates improves the nutrient ratio since different substrates contain different ratios of nutrients. This creates a more stable digestion environment and increases the quality of the fertilizer produced in the digestate.

- Improves the flow of substrates to the digester especially when bulky substrates are mixed with liquid substrates such as pig slurry.

- More feedstock translates to more gate fees which increase the income hence shortening the payback time [32].

The economic value of the biogas from the co-digestion of manure can be measured as:

- The feed in tariff is in €/kW which varies from country to country.
- Carbon credits which are sold using €/credit due to the savings accrued from prevention of GHG emissions.

Figure 10 below summarizes the economic value for the manure:

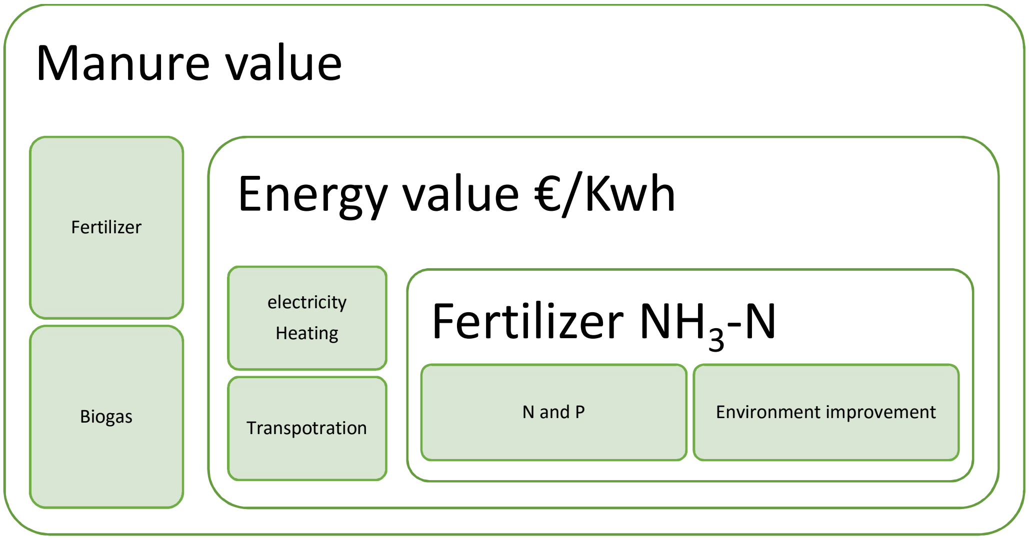

Figure 10: Economic value summary

4 Manure management in Finland

In Finland, the husbandry sector produces almost 20 million tons of manure. [33, p. 4].This manure is rich in nutrients such as N and P which plants need. The manure can also produce biogas for heating and energy. If upgraded, it can also be turned to bio-LNG and bio-CNG.

Due to the advantages of manure management the Finnish government has included incentives in the biogas production [34, p. 22]. Some of the incentives include:

- Directing agricultural investments and subsidies to construction of biogas plants in the farms.

- Tax-free benefits for the biogas producers.
- Introducing feed-in tariffs for biogas plants of less than 20MW

The Finnish Ministry of Agriculture and Forestry conducted a research to investigate the reuse of manure and other organic waste products called “Hyötylanta”. This research was divided into 4 parts namely:

- Developing manure as a fertilizer and nutrient efficiency.
- Processing manure and other organic waste products.
- Economical assessment of manure use at farm and regional level.
- Life cycle analysis of the environmental benefits of manure processing and assessment of sustainability of alternative treatments.

It was established reusing the organic matter was the only sustainable solution. Also in terms of cost, efficient use of manure could amount to 10 million euros in the Finnish agriculture. The overall environmental impact was found to be moderate since the effects are cancelled out by the benefits gained when the manure is processed such as better absorption in the soil. These findings have enabled the government to prioritize and start exploiting ways of utilizing organic matter such as manure.

Apart from these initiatives legislation has played a key role in propelling manure management. The legislation for manure is based on the EU legislation which is adopted to country-specific conditions. Manure is linked to emissions and pollution control legislation and also nutrient management in the agricultural sector. Some key challenges have been whether to consider manure as a byproduct or waste due to the fact that waste is regulated more [35, p. 7] .The waste status has been discussed in Finland and there is a court decision about horse manure which has undergone briquetting (A Supreme Administrative Court decision KHO:2009:61).

4.1 Ostrobothnia profile

Ostrobothnia is a region located in the west of Finland and is constituted of 15 municipalities as depicted in Figure 11. The region has a population of about 180,384 and has a large population of Swedish - speaking Finns. In the agricultural enterprises it ranks third in the whole of Finland. Most of the agricultural land use is animal husbandry.

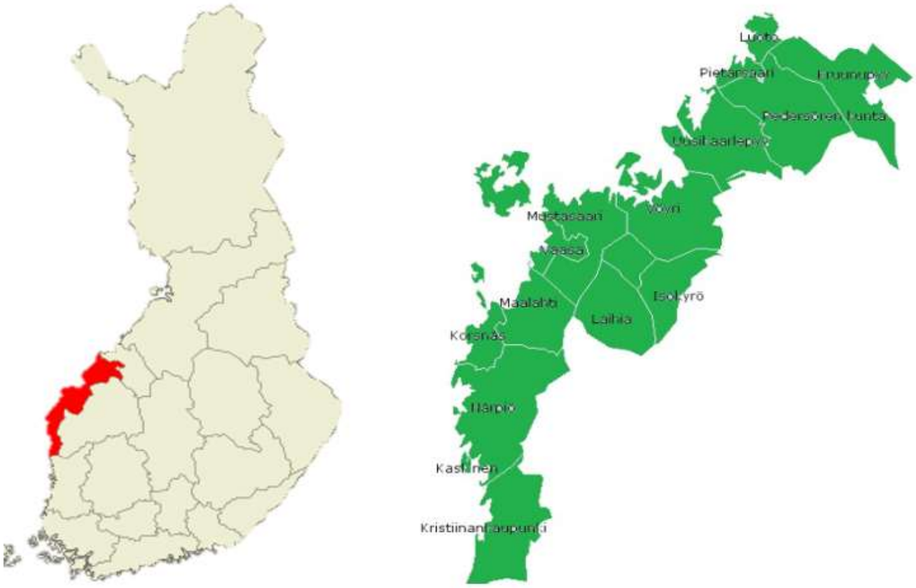

Figure 11: Ostrobothnia map

Focusing on the animal husbandry, the leading animal stock is fur animals which has about 80% of the national total. Figure 12 shows the livestock population for each type of livestock.

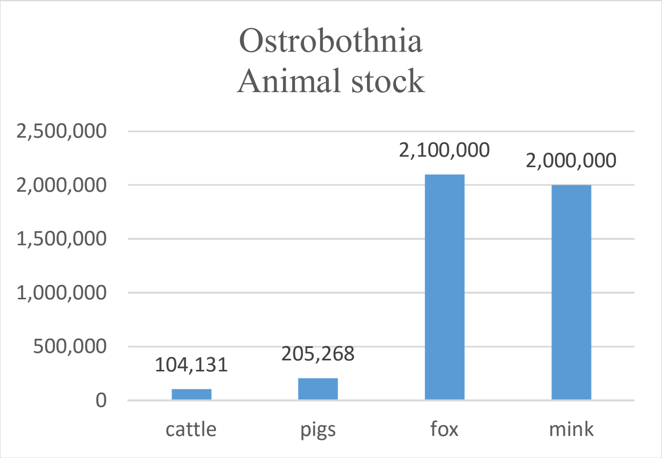

Figure 12: Animal stock

Vaasa a city in Ostrobothnia has developed an ambitious program to establish biomethane transportation system as presented by Johan Saarela from Stormossen and Heidi Hirsimäki from City of Vaasa in the energy week 2016.The energy week is a is an international event organized by the university of Vaasa and a platform for exchanging ideas and presenting sustainable systems [36].

4.2 Manure Value Potential

The potential for manure in Ostrobothnia is evaluated based on two scenarios as shown in the flow chart in Figure 13. The first option is using the manure as a fertilizer which is already a common practise. The second scenario involves using manure as a substrate in biogas production then using the digestate as a fertilizer substitute.

For part A, the data will come from the data collected about the Ostrobothnia region regarding the number of animals in the region. The number will be multiplied by the estimated manure for one animal in a year. Step B will be a developing a scenario for using manure as fertilizer and as a biogas substrate. After creating the scenario, mathematical modeling will be used to calculate the potentials. Finally, the results will be analyzed to give a picture of the potential of manure in the region.

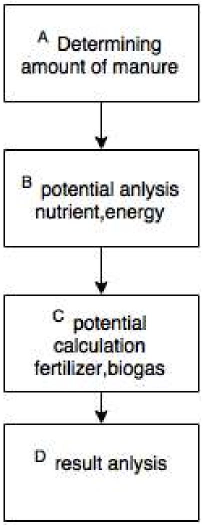

Figure 13: methodology flow chart

4.2.1 Amount of manure

Currently, there is no database containing amount of manure in Finland or any other country for that matter. For the sake of analysis, assumptions will be made on the amount of manure produced by each livestock as can be seen in Table 4. The total manure is the product of average manure for one livestock and the number of livestock.

Table 4: Ostrobothnia manure production

Parameter	**cattle**	**pigs**	**fox**	**mink**	**Total**
Number of livestock	104,131	205,268	2,100,000	2,000,000	4,409,399
Average manure production(kg/y)	1,230	1,200	43	19	2,493
Total manure production (t/y)	128,081	246,322	91,980	38,000	504,383
m3/y	362,685	697,506	260,458	107,604	1,428,253

4.2.2 Nutrient Content

The nutrient content will focus mainly on N and P although the manure also contains some trace elements such as zinc which are beneficial to the plants. most literature have some values for P and N only hence the scope used. Table 5 shows that fur animals have high N in their manure and different manure types i.e slurry or solid contain different nutrient concentration.

Table 5: Nutrient concentration in different Animals

		Nutrient value kg/m3		
Animal	**Manure type**	**P**	**soluble N**	**total N**
cattle	Solid	1	1.1	4
	Slurry	0.5	1.7	2.9
	Urine	1	1.5	2.5
pigs	Solid	2.8	1.2	4.6
	slurry	0.8	2.2	3.4
	Urine	0.2	1.3	2
fox	Solid	12.7	1.4	6.5
mink	Solid	12.1	0.9	5.2

The nutrient value is affected by other factors such as type of beddings and feed quality hence these values may not be very accurate.

4.2.3 Biogas potential

The theoretical biogas potential for the manure found in Ostrobothnia region is summarized in Table 6 in descending order of availability. The pig manure is the most common substrate in Ostrobothnia although looking at the substrates in logistical perspective, the pig manure is expensive because it does not pack as much nutrients/ton compared to the other manures.

Table 6: manure biogas potential

Animal	**Manure available M3/y**	**Biogas yield M3/t**
pigs	697,506	200-500
cattle	362,685	300-320
fox	260,458	200-500
mink	107,604	200-500

In this thesis the main focus will be the co-digestion using manure combined with other substrates such as cucumber and bio-waste.

4.2.4 Digestate as a fertilizer

The digestate is the residue from anaerobic co-digestion of the manure with other waste. During this process the nutrient content does not change but the physical and chemical process do change. Physically, the manure becomes less solid and thorough mixing ensures its quite uniform in terms of composition. Through fermentation, there is an increase in the ratio of minerals essential for plant growth. For example, mineral N increases by 20% as seen in Table 7 which means the plants will utilize more N in the digestate than the raw manure. The reduction of organic N could also lead to reduction of leaching potential of the fertilizer.

Since anaerobic digestion happens in mesophilic temperature range of 30-42 °C or thermophilic range of 43-55 °C, there is less pathogens and weed seeds compared to raw manure. Although quantifying this value is quite challenging it still counts as a value addition when justifying the use of anaerobic co-digestion for manure treatment [37].

Table 7: Nutrient composition for digestate after A/D

		Nutrient value kg/m3		
Animal	**Manure type**	**P**	**soluble N**	**total N**
cattle	Solid	1	1.3	4
	Slurry	0.5	2.0	2.9
	Urine	1	1.8	2.5
pigs	Solid	2.8	1.4	4.6
	slurry	0.8	2.6	3.4
	Urine	0.2	1.6	2
fox	Solid	12.7	1.7	6.5
mink	Solid	12.1	1.1	5.2

5 Manure Value Calculation

Manure value calculation is based on modelling scenarios based on data about Ostrobothnia in order to get estimates of the actual monetary value of the manure present in this region. In order to get reasonable results, all factors that are taken into account when doing the calculations are stated. Furthermore, all assumptions are documented with relevant justifications provided.

One scenario is determining the fertilizer potential of the raw manure. This involves determining how much manure can be used in the region based on nutrient limit legislation. The amount of manure used is then compared with the cost of inorganic matter with the same value. This gives us how much the manure could cost in the current market.

The other scenario is first treating the available manure in Ostrobothnia using anaerobic co-digestion which produces biogas, then using the enriched digestate as a fertilizer. In this case, the manure will first be seen primarily as a biogas feedstock. The biogas production potential will be used in determining the amount of biogas produced. The price of the biogas is then set using heating or lighting feed - in tariff. Calculation of the ‘green effect’ of the biogas is done using carbon equivalent emissions. The digestate is then used as a fertilizer. For the fertilizer part the same model is used as the first scenario the only difference being a change in the N nutrient.

5.1 Fertilizer only scenario

This scenario is for modelling the price of the nutrients contained in the manure with the equivalent commercial fertilizers in the market. The calculation gives a price for the nutrient N and P in €/kg. It is possible to get the value of the fertilizer for each animal or the general price for the total nutrient. For simplification reasons the latter will be used.

There are many mathematical methods of calculating the nutrient value price. One method is using matrices which are powerful in performing calculations on an array of data. The matrix system that can be used to obtain the value is as presented in equation 1.

$$A * b = x \tag{1}$$

A is the array containing the manure nutrient whereas b contains the price of equivalent commercial fertilizer. The product gives the price of the nutrients. Since the output will be in €/kg, the nutrient content should be of the form t/kg and the price €/t. Table 5 gives the values for the nutrients but in kg/t so equation 1 will be as in equation 2.

$$A^{-1} * b = x \tag{2}$$

The matrix for the fertilizer nutrients A and the price of fertilizer b will be as shown in equation 3.

$$\begin{bmatrix} F_{1N} & 0 \\ 0 & F_{2P} \end{bmatrix}^{-1} * \begin{bmatrix} P_{f1} \\ P_{f2} \end{bmatrix} = \begin{bmatrix} P_N \\ P_p \end{bmatrix} \tag{3}$$

Where F_{1N} and F_{2P} are the total nutrient content of the fertilizer and P_{f1} and P_{f2} is the price of fertilizer equivalent Urea and DAP respectively.

Using table 5 to find the total nutrient content and [38] for the price the equation to solve the price will be as shown in equation 4

$$\begin{bmatrix} 45.18 & 0 \\ 0 & 67.25 \end{bmatrix}^{-1} * \begin{bmatrix} 142.6 \\ 133.8 \end{bmatrix} = \begin{bmatrix} 3.14 \\ 1.99 \end{bmatrix} \tag{4}$$

This gives price of N and P at 3.14 and 1.99 €/kg respectively. However, the price for N is based on total N and instead should be the soluble N which is 29.18% of the total N. This could essentially mean the price of N could be 0.92 €/kg.

The conversion of the total nutrients from kg/m3 to kg/t is done using [39]. The price of the nutrients are determined from the % mass since the Urea and DAP are compounds containing other nutrients. DAP for example contains 46% P and 18% N.

The transport and spreading cost for manure in Finland under 1km distance is 2.21 €/m3. Further than the 1km an additional cost of 0.25 €/m3/km [40].

5.2 Anaerobic treatment scenario

This scenario is basically reviewing the biogas potential of the manure and the manure value of the digestate. After anaerobic digestion, the soluble N increases due to the breakdown of the nutrients during fermentation. Data for the biogas scenario will be obtained from Table 6 although instead of using the manure as substrate, it will be a co-substrate and hence the total values change. The carbon credits will be based on the amount of the green energy produced by the biogas plant.

5.2.1 Biogas Value

The Finnish government is obliged to grant incentives to biogas production using manure and other renewable resources [41]. Using data for the co-digestion of the manure in Ostrobothnia region from [42]. It is possible to model the biogas potential and the cost of energy produced in the region both in terms of the cost of the energy and the GHG emission savings since it would be the emissions produced if the manure was not treated at all.

The biogas production potential for Ostrobothnia region is as shown in Table 8.

Table 8:Biogas potential *source: [42]*

Substrate combinations	Nm3	kWh biogas
Cucumber plants	299,000	2,891,330
Fox manure		
Pig manure	263,000	2543,210
Cucumber plants		
Used Oil	162,480	1,571,181.6
Mink Manure		
Cattle manure	-	-
Total	724,480	7,005,722

The data for cattle manure was lacking hence not included in the calculation. The BMP is based on results of the best results from using different mixtures and ratios. The conversion of methane from Nm3 to Kwh is based on [43] which gives the total potential biogas to be around 7 GWh. The actual production may vary significantly if the plant efficiency and ratios of the mixtures are taken into account.

According to [44] it is estimated Finland could produce 4-6 TWh/year biogas from waste and manure and that about 20 co-digestion plants were being planned or constructed. In a bid to support the growth of such plants the electricity market authority of Finland is offering feed-in tariffs. The rates depend on the size of the generators and efficiency. In our case, we assume our biogas meets the criteria to be granted the feed in tariff. The biogas is then utilized as electricity and heat using the parameters in Table 9. The price of the biogas produced would amount to:

Table 9: Price of biogas based on tariff scheme

Component	Electricity	Heating
Efficiency	30%	35%
Useful Energy (GWh)	2.1	2.45
Losses	15%	20%
Energy after losses (GWh)	1.785	1.96
Feed in tariff (€/MWh)	83.5	50
Energy produced(€)	149,047.50	98,000.00

These efficiency and losses used are from [45] since we cannot assume 100% efficiency in the biogas production. To minimize the scope of calculation, expenses such as the cost of building the biogas plant and transportation of the substrates are not considered.

5.2.2 Greenhouse gas emission saving

The biogas generated from manure is seen as a carbon neutral because the CO_2 is from plants which the animals feed on. This assumption holds true especially if no artificial feed is introduced in the feed. The energy produced reduces emissions in two ways:

- Reduction of emissions if the manure is not treated.

- Substituting non-renewable energy with renewable energy. This case only holds if the alternative source is not renewable like coal or oil for electricity and heating. Furthermore, the biogas can be upgraded for transportation and it replaces petrol and diesel [46].

Another important aspect of the biogas produced is that it falls into the second generation biofuel as defined in the RES directive in Art 21(2) meaning it is exempted from CO_2 tax. The reasoning behind this is using waste for energy generation is more valuable than using renewables such as energy plants because they latter create other problems [47].

In 2011 Finland's emission associated with power generation was 199.2 g CO_2/Kwh [47]. Typically, biogas has a thermal value of 22MJ/m3 which is equivalent to 6.1 kWh. Using a typical CHP engine efficiency in [46]. we obtain Table 10. Hence the total CO_2 emissions saved by 1m3 of biogas produced is 886.05 g CO_2.

Table 10: CO_2 replacement potential of manure biogas

Component	Electricity	Heating
Efficiency	40%	45%
Production (kWh/m3)	2.44	1.5
g CO_2/m3 biogas	486.05	400

Assumption: Half of the energy from heating is used by the chp.

The second part of the emissions is considering the CO_2 equivalent of the GHG emissions. The global warming potential for CH_4 and N_2O are 22 and 310 kg CO_2 respectively.

Table 11: Total GHG reductions

Amount Million ton/y	**Biogas production Million m3/y**	**Chp CO_2 reduction (t CO_2/yr)**	**CH_4 and N_2O reduction (t CO_2/yr)**	**Total reduction (t CO_2/yr)**
0.504	11.09	9759.2	13308	23067.2

Assumptions:

1) Total manure production in Ostrobothnia will be used in biogas production.

2) Gas yield for the manure is around 22 m3/t.

3) CO_2 reduction 0.88kg CO_2/m3 biogas

4) Reduced emissions of CH_4 and N_2O ≈ 26 Kg CO_2 eqv/t or 1.2 kg CO_2/m3 biogas.

5.2.3 Digestate as fertilizer

The digestate from the biogas production is higher in soluble N as observed in chapter 4 and the P remains relatively constant. When using it as a fertilizer the soluble N nutrient increases by 20% hence the value of N in the N total changes from 29.18% to 49.18%. Using the prices obtained from equation 4, the new price of the fertilizer N would be 1.54 €/kg.

One important aspect with regard to this is the transportation cost. Anaerobic treatment can be done at farm level or in a biogas plant. If the latter is chosen, then the transportation cost doubles.

6 Analysis

In the previous chapter the different scenarios have been evaluated for use of manure. The scenarios were modelled without taking the transportation into account. In this chapter it will be investigated how transportation can affect the value addition chain of the manure through anaerobic digestion. The values used for the analysis are based of the data from previous chapters.

6.1 Effect of transportation on manure management

In chapter 5 the manure is given a value although the transport cost is not taken into account. The transportation of manure is a variable of distance and the weight. The cost can be given as equation 5 below. This takes into account the distance covered by the manure.

$$y = mx + c \qquad 5$$

In equation 5 the y is the total transportation cost which is a function of the distance x and fixed cost c. The c in Finland under 1km distance is 2.21 €/m3. Further than the 1km, mx is 0.25 €/m3/km [40]. Using these values one can obtain Figure 14 which relates the transportation cost and the fixed price of the nutrients. Before anaerobic treatment the justifiable distance for transporting manure is just under 10 km. Any distances covered after this the transportation cost exceed the value of manure hence it will be a burden to the farmer. Using the manure value after anaerobic digestion the nutrient price is higher hence the ability for the farmer to transport the manure to a treatment plant within a radius of 28 km.

This model makes assumptions such as an average nutrient total and does not take into account the solid and liquid content of the manure. In order to have a better understanding the transportation should be modelled for each individual fertilizer type. Another assumption is the use of standard lorry to ferry the manure, however in practise there are specialized trucks that have higher capacity hence lower transportation costs. There has been interest in pipeline for transporting manure which would improve the competitiveness of manure over long distances.

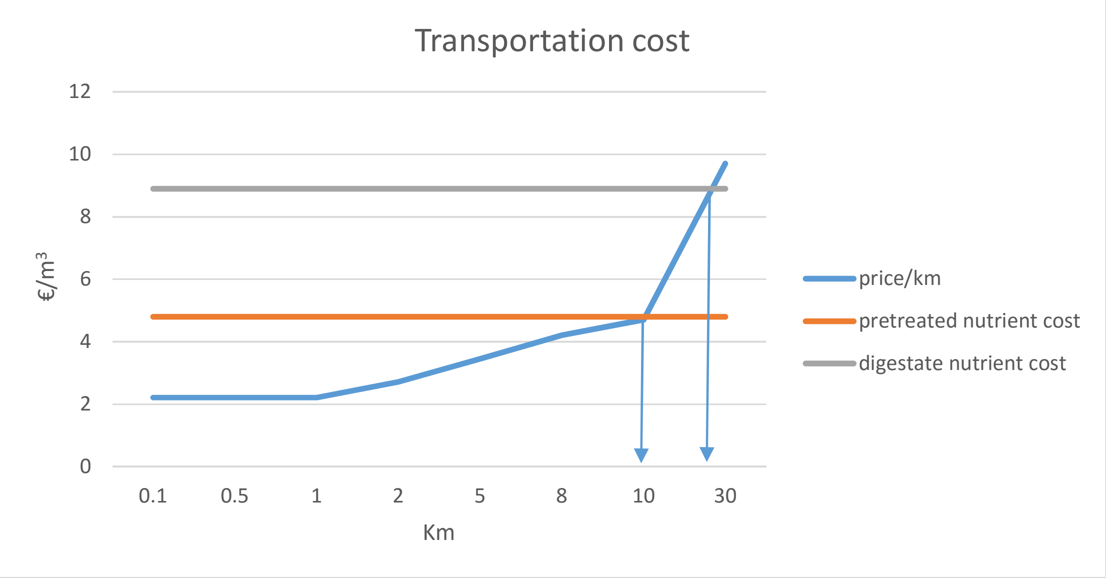

Figure 14: Transport cost implications

6.2 Biogas produced

Taking the amount of electricity and heat production in Table 9, it is possible to create a scenario for evaluating the biogas produced. In Ostrobothnia the electricity generation is mainly through renewable sources such as hydro, wind and CHP plants utilizing renewable sources. Nuclear is not part of the energy mix for the region [48].This means the biogas would not have a big impact in terms of substituting the energy production. The price of heat despite the feed in tariff is also not competitive compared to the current sources of heat production as can be seen in Table 12 [49].

Table 12: Heating prices for different fuels for CHP plants *source: [49]*

Energy source	Price €/MWh
Hard coal (VAT 0%)	28.97
Natural gas (VAT 0%)	45.69
Forest chips (VAT 0%)	19.48
Milled peat (VAT 0%)	15.31
Biogas (VAT 0%)	50

However, as mentioned in chapter 5 the biogas could be viable for use as a transport fuel in the region. The CO_2 emissions of Ostrobothnia stood at 87,000 t of CO_2 equivalent. From using aerobic digestion in the region, the emissions will reduce 23,067 t of CO_2 equivalent yearly.

7 Conclusion

Evaluating the manure potential has revealed the potential of turning it from a waste into a resource. With the assumptions used we were able to see there is an economic value in manure if proper management is chosen. Although there are many technologies which are currently being developed anaerobic digestion is widely used and a lot of test have been carried out especially on co-digestion to improve biogas yield.

Anaerobic digestion has multifaceted benefits to the environment, large scale livestock farmers and agriculture. The biogas produced reduces the emissions since it is considered carbon neutral. For the farmers having a biogas plant that takes their manure and produce electricity and heat and give slurry which is better at fertilizing is a plus for them. This reduces the cost of storage of manure and also over fertilization of the fields which lead to soil degradation and other negative effects such as odour. For the plants getting more soluble nutrients enhances the crop yield.

One factor which puts this economic evaluation of manure into context is legislation. Without legislation such as the Nitrate directive there would not be a need to process the manure. The legislation gives incentives such as feed in tariffs for electricity and heat and at the same time imposes punitive fines hence creating the ‘economy’ for manure processing.

Another factor which can also heavily affect the economic value of manure is the transportation. In this study we saw after a distance of 10km before and 28 km after A/D were the limits the farms should be located to maintain the economic value of the manure. This means the manure is only profitable if used within the region.

The biogas produced is not a benefit in itself since energy needs in Vaasa are primarily meet using renewable resources. Still it cuts emissions by up to around 4% which is a welcomed step in the move towards EU 2020 goals. Furthermore, the carbon credits can be auctioned in carbon trading markets such as EU ETS. Another possibility would be upgrading the biogas to produce biomethane for transportation.

7.1 Recommendations for further research

It cannot be refuted that there is an economic value in processing manure using A/D as shown in this study. The challenge lies in developing an economic model that can factor in all the different aspects and at the same time getting very accurate data.

To be able to estimate the amount of manure produced more accurately, a manure calculator can be developed which takes into account the variance arising from different stages of the animal for example calf and cow produce different amounts of manure.

For the nutrient content, one study would be to compare different farms in the region so as to establish the degree of variance of data for manure content. The study could use a life cycle approach so that the scope is either cradle to grave (whole farm) or gate to gate (ex- animal, ex-housing).

There is further work needed to establish the best combination ratios for manure co-digestion which yield the highest BMP. Apart from the ratios there has to be a study on the BAT to fully utilize the manure.

The transportation of manure is also an area where a more specific study should be done. The study could be either comparing the transportation cost of different manure either in terms of volume or nutrient content. Another interesting study could be doing a feasibility study for a pipeline for transporting slurry.

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Appendix 1 – Co-digestion mixtures [42]

No.	Substrates	Ratios [r] = %	Content [c] = g	Initial pH-level	Final pH-level	BMP [BMP] = Nm^3/t_{RM}
1	Slaughter waste Potato peels	40 60	21.1 31.1	5.9	6.6 (7.5, 5.7)	8.9*
2	Pig manure Cucumber pl.	60 40	121.2 81.0	7.5	7.6	18.6 16.3
3	Fish waste Bakery waste	50 50	18.1 18.5	6.3	3.8	10.9 10.8
4	Pig manure Barley malt	70 30	105.1 45.1	7.3	5.9	3.1
5	D. Bio-waste Used Oil	80 20	39.1 10.1	5.5	5.2 (5.0, 5.4)	11.7*
6	D. Bio-waste Slaughter waste	70 30	34.1 14.2	5.5	5.1	10.5 14.2
7	Used Oil Mink Manure	20 80	10.1 38.5	8.1 (7.9, 8.3)	6.7	33.5
8	Cucumber plants Fox manure	40 60	25.4 38.7	8.2	7.5	61.8 57.8
9	Pig manure Cucumber plants	80 20	157.9 40.7	7.8	7.4	25.6 27.0
10	D. Bio-waste Slaughter waste	30 70	10.4 23.3	5.3	5.5 (5.2, 5.8)	11.2 14.5
11	D. Bio-waste Used oil	70 30	29.1 12.1	4.8	4.9	12.6 8.9
12	Mink manure Fish waste	60 40	40.4 27.5	8.2	6.3	19.3 13.0
13	Fox manure Fish waste	60 40	29.1 19.2	7.9	6.6	6.5
14	Fish waste Cucumber pl.	70 30	54.2 23.2	7.1	6.7	7.5 9.7

* means a control experiment gave no results.

Appendix 2 – Estimated biomethane potential [42]

No.	Substrates	Availability [a] = t/y	Usability [u] = t/y	Bio methane [m] = Nm³
1	Slaughter waste Potato peels	78 6,400	78 117	1,740
2	Pig manure Cucumber pl.	572,000 2,000	3,000 2,000	87,250
3	Fish waste Bakery waste	160 700	160 160	3,472
4	Pig manure Barley malt	572,000 30	70 30	310
5	D. Bio-waste Used Oil	20,000 970	3,880 970	56,750
6	D. Bio-waste Slaughter waste	20,000 78	182 78	3,210
7	Used Oil Mink Manure	970 38,000	970 3,880	162,480
8	Cucumber plants Fox manure	2,000 92,000	2,000 3,000	299,000
9	Pig manure Cucumber plants	572,000 2,000	8,000 2,000	263,000
10	D. Bio-waste Slaughter waste	20,000 78	33 78	1,430
11	D. Bio-waste Used oil	20,000 90	210 90	3,230
12	Mink manure Fish waste	38,000 160	240 160	6,460
13	Fox manure Fish waste	92,000 160	240 160	2,600
14	Fish waste Cucumber pl.	150 2,000	150 65	1,850

Appendix 3 – Manure P in Finland [5]

ELY Centres	Domestic animal density (LSU ha-1)	Manure P (kg y-1)	Manure P (kg ha-1y-1)						Manure P (kg ha-1)
			All animals	Cattle	Pigs	Poultry	Fur animals	Other animals	surplus or deficiency
Central Finland(10)	0.6	660,825	8.1	6.6	0.5	0.1	0.1	0.8	-2.2
Häme(4)	0.4	845,230	5.2	3.1	1.5	0.1	0	0.4	-4.4
Kainuu(14)	0.6	281,818	10.1	9.2	0.1	0.1	0.2	0.5	0.4
Lapland(15)	0.7	416,974	10.1	9	0	0	0.1	1	0.9
North Karelia(9)	0.6	692,242	9.3	8.2	0.3	0.1	0.2	0.5	-1.1
North Ostrobothnia(13)	0.6	1,834,620	9.2	7.2	0.7	0	0.9	0.3	0.7
North Savo(8)	0.7	1,426,763	10.6	9.5	0.6	0	0	0.4	1.4
Ostrobothnia(12)	0.8	3,075,204	17.3	6.2	3.5	0.5	6.9	0.3	10
Pirkanmaa(5)	0.5	982,555	7.1	4	1.7	0.9	0	0.5	-5.2
Satakunta(3)	0.6	1,063,254	8.2	2.5	2.9	2.4	0	0.3	2.1
South Ostrobothnia(11)	0.7	2,517,664	11.5	5.2	2.8	1.5	1.6	0.3	3.5
South Savo(7)	0.7	612,563	9.8	8	0.6	0.4	0	0.8	1.7
Southeast Finland(6)	0.4	611,780	5.4	3.9	0.8	0.1	0	0.6	-3.8
Southwest Finland(2)	0.6	1,931,876	7.4	1.4	3.7	2	0	0.3	1.1
Uusimaa(1)	0.2	455,258	3	1.7	0.6	0	0	0.7	-5.6
Åland(20)	0.6	107,248	8.4	6.1	0	0.2	0.2	1.9	4
Whole country	0.6	17,515,875	8.8	4.9	1.8	0.7	0.9	0.5	0.3

Appendix 4 – Transportation costs

Cost/weight of manure ***(y)***	Distance ***(x)***	N before anaerobic treatment	N after anaerobic treatment
€/m^3	***km***	***€/m^3***	***€/m^3***
2.21	0.1	4.8	8.9
2.21	0.5	4.8	8.9
2.21	1	4.8	8.9
2.71	2	4.8	8.9
3.46	5	4.8	8.9
4.21	8	4.8	8.9
4.71	10	4.8	8.9
9.71	30	4.8	8.9