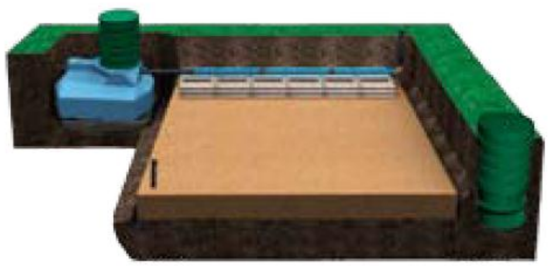
Life cycle analysis of two rural small-scale wastewater treatment systems in Sweden

Final report



In-Drän Biobädd 5ce | In-Drän Markbädd 5

Course AG2800 Life Cycle Assessment

KTH – Royal Institute of Technology

Group 2

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Abstract

Treatment of wastewater from households is of great importance to the environment. In particular, wastewater treatment is associated with eutrophication issues, as recognized by the Swedish EPA. Households that are not connected to municipal wastewater treatment networks need to rely on rural wastewater treatment equipment setups, which is common throughout Sweden. This study examines two different rural wastewater treatment equipment setups available on the Swedish market today, called In-Drän Markbädd 5 and In-Drän Biobädd 5ce, using an attributional, comparative life cycle assessment approach. The purpose is to be able to recommend what equipment setup is preferable from an environmental cradle-to-grave perspective. The information provided in this report will also be useful for household owners as well as resellers, developers and authorities who want to increase their environmental awareness of such products. Data was collected from manufacturers, databases, similar research and literature regarding environmental aspects, emissions, material use, energy use etc. for all components and processes associated with producing the two different equipment setups. The data was then analysed using the software SimaPro Version 7.3.3 and the ReCiPe Midpoint (H) impact assessment method to produce results for 18 different impact categories. The preliminary results of the analysis show that eutrophication issues are the most important impact categories related to the life cycle of both products. The product Markbädd has a lower negative environmental impact on marine eutrophication, while the product Biobädd has a lower negative environmental impact on freshwater eutrophication. The largest contribution to other environmental impact categories for Markbädd comes from component assembly processes, while the largest contributions for Biobädd comes from electricity usage. Sludge treatment has similar, very large environmental impacts for both products but was excluded from the main results for comparative purposes. The conclusion can be drawn that Markbädd is recommended for household owners living in coastal areas while Biobädd is recommended for inland household owners.

Contents

1 Introduction

Wastewater disposal has always been an issue of global concern. Releasing contaminated water from industries or households into nearby waterways can cause severe environmental issues. Methods have been developed to purify and decontaminate wastewater from households and industries through various measures such as nutrient reduction, sludge removal, chemical, biological and physical processes as well as infiltration. Thus the pollutants contained in wastewater can be greatly decreased before being discharged into the surface or groundwater through percolation. Municipal wastewater and sewage treatment plants play an important role in this aspect. Wastewater treatment is particularly important to limit eutrophication related issues. Sweden has a national environmental goal to only have natural eutrophication by the year of 2020 and the goal is so far considered as difficult to reach, meaning this is an important and relevant topic (Naturvårdsverket, 2013). For villages and houses outside the reach of municipal large-scale systems, other wastewater treatment products are installed for the purification process. The size and capacity of these systems can vary depending on the number of households connected. The removal rates of pollutants and environmental burdens associated with production and disposal of the different equipment types vary a lot depending on what equipment setup is used. Therefore it is of great interest for rural householders, who want to install a wastewater treatment system for their houses, to have good knowledge of what equipment types available on the market are the most environmentally friendly.

To analyse the environmental consequences associated with such products, Life Cycle Analysis (LCA) is a useful tool. The procedure of performing an LCA is one of investigating all environmental burdens associated with all life stages of a product. This is commonly referred to in LCA methodology as a ''cradle to grave'' approach, in which the product is analysed during its production, use and disposal phase (Baumann & Tillmann, 2004). LCA is a tool that belongs to the same category of environmental analytical tools as Environmental Impact Assessment (EIA) and Strategic Environmental Assessment (SEA) and has become popular in environmental analysis worldwide during recent years, with several LCA dedicated software programs existing on the market (Baumann & Tillmann, 2004). In this report the results of a comparative LCA study regarding two different equipment setups for rural small-scale wastewater treatment from households is presented. The products studied exist on the market in Sweden today and are produced and sold by the company Fann VA-Teknik.

1.1 Rural wastewater treatment in Sweden

In Sweden, the situation for rural wastewater treatment systems is as follows (VA-Guiden AB, 2014; SMED (Swedish Environmental Emission Data), 2006):

- 750 000 houses without access to municipal sewage systems;
- 450 000 permanent living houses with rural sewage systems;
- 250 000 vacation/non-permanent living houses with rural sewage systems;
- 650 000 rural sewage systems with connected water toilets (no separation of wastewater types);
- 125 000 rural sewage systems with connected water toilets and only a sludge separator, which is illegal since the 1960:s. (Naturvårdsverket, 2008)
- Distribution between system types is shown in Table 1.

Table 1. Distribution of sewage system types in 2006 consisted of (Naturvårdsverket, 2008)

Rural sewage system type	Percentage of Swedish usage, 2006 [%]
Infiltration beds	37
Soil treatment systems	17
Only sludge separator	26
Sealed collection chamber	10
Other sewage systems	10

The most common rural wastewater treatment configurations do not separate water types (toilet water and household water, see above - 650 000 out of 750 000 are of this type) before gathering and treating wastewater, so for the purpose of this comparative LCA we will only consider those types of systems. Household water is often referred to as grey water or BDT water in Swedish terms (BDT is short for Bad, Dusch, Tvätt – Bath, Kitchen and Laundry). Three common wastewater treatment systems that are sold on the market today are described by JTI (2011) in an informative pamphlet. The system types are:

- Infiltration beds (infiltrationsanläggning in Swedish);
- Soil treatment systems with chemical precipitation (markbädd in Swedish);
- Small-scale water treatment plant (minireningsverk in Swedish).

Infiltration beds and soil treatment systems are mostly driven by gravity and use the natural cleaning properties of soil to treat wastewater (JTI, 2011). Infiltration beds, soil treatment systems and most system configurations that separate wastewater types before treatment contain two product components called a septic tank (slamavskiljare in Swedish) and a distribution well (fördelningsbrunn in Swedish) (JTI, 2011). A septic tank is mostly used to separate solid waste like toilet paper and excrements from the wastewater, which then form sludge at the bottom of the container (JTI, 2011). Therefore the septic tank has to be emptied at frequent intervals, as it fills up (JTI, 2011). A common type of septic tank in Sweden is called trekammarsbrunn (three-chamber well) (JTI, 2011). On its own a septic tank is not sufficient to treat wastewater to acceptable quality and must be complemented with other installations, according to law (Naturvårdsverket, 2008). The distribution well has the main function to gather the wastewater from the septic tank and distribute it to the following installations (in separate pipes if needed) in a controlled and homogenous flow (JTI, 2011).

1.2 Infiltration beds

Infiltration beds are made up of specific soil layers (JTI, 2011). The wastewater is discharged into the soil layers and treated by infiltrating through the soil (JTI, 2011). Phosphorus and nitrogen (eutrophication chemicals) is reduced when infiltrated while bacteria inside the infiltration bed treat organic material (JTI, 2011). The wastewater eventually reaches the groundwater and is transported away (JTI, 2011). Therefore an infiltration bed requires some distance from the groundwater level to make sure that treatment processes have sufficient time to take place (JTI, 2011). Some infiltration beds do not require any energy input during the usage phase and can function fully even during electricity blackouts (JTI, 2011). A sketch made by JTI (2011) of a normal infiltration bed system is shown below in **¡Error! No se encuentra el origen de la referencia.**.

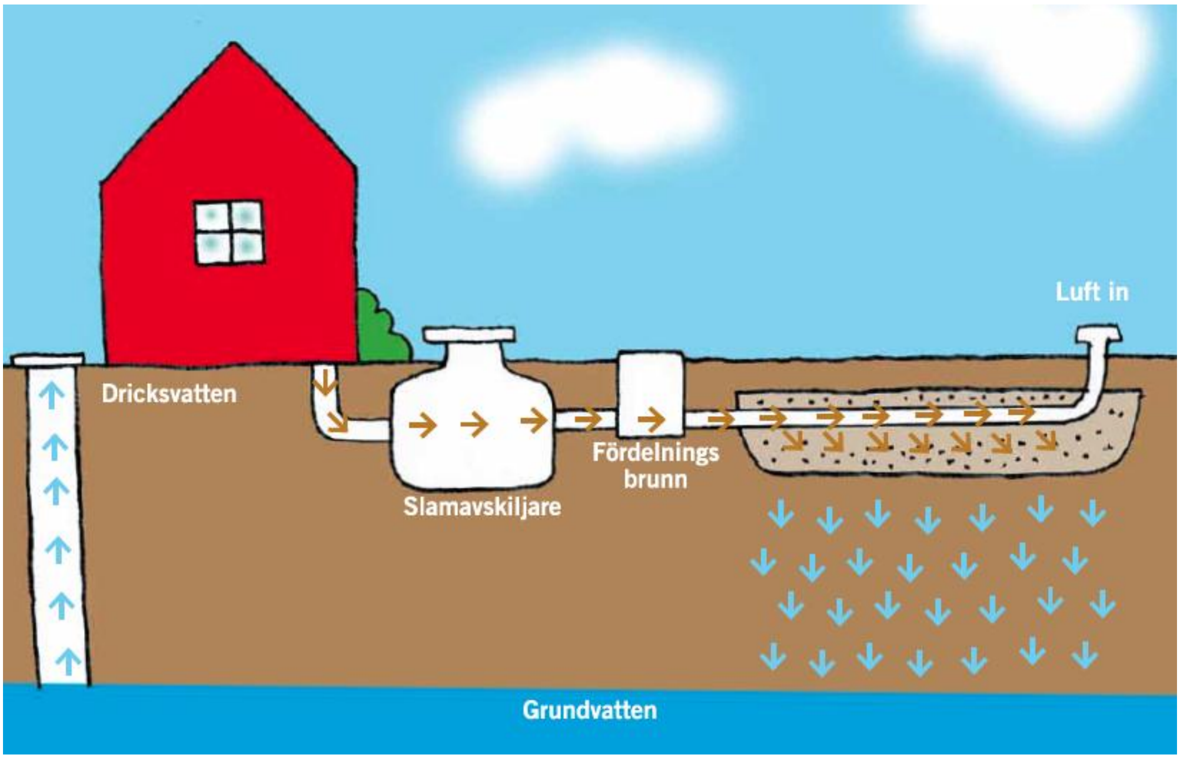

Figure 1. Typical infiltration bed system for small-scale household wastewater treatment. Source: (JTI, 2011)

1.3 Soil treatment systems

Soil treatment systems differ from infiltration beds in that the wastewater is not discharged into the groundwater but instead collected and redirected through a water quality test/sampling well after treatment (JTI, 2011). Since soil treatment systems do not use as thick soil layers as infiltration beds (less soil that the wastewater has to travel through), they are in particular much less effective at treating phosphorus on their own (JTI, 2011). Therefore chemical compounds are added to the wastewater after discharge from the household (JTI, 2011). The chemicals react with phosphorus and precipitate as solid sludge, collected in the sludge separator (JTI, 2011). Installation of a phosphorus precipitation unit contributes to an overall increase in the total amount of sludge formed in the septic tank over time (Sörelius Kissling, 2013) in **¡Error! No se encuentra el origen de la referencia.** In Figure 2.

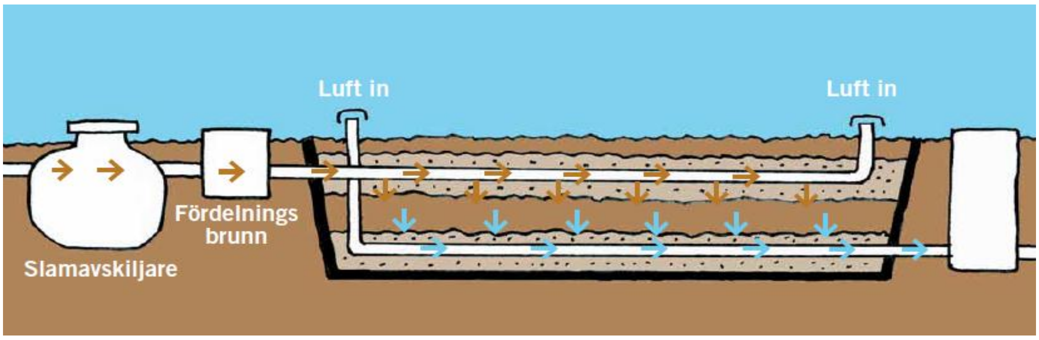

Figure 2. Typical soil treatment system fro small scale household wastewater treatment. Source. (JTI, 2011)

1.4 Small-scale water treatment plant

A small-scale water treatment plant is basically a miniature technical installation that functions in a way similar to municipal wastewater treatment plants – function details are very product dependent (JTI, 2011). Small-scale water treatment plants are not considered in the scope of this report.

1.5 Wastewater pollutants

Wastewater from households without separation of toilet and grey water contain pollutants that must be treated before being discharged into the environment. Avloppsguiden (VA-Guiden AB, 2014) provides information about pollutant loads in household wastewater, as described originally by Naturvårdsverket (2006a, 2006b). According to this information, wastewater from one person in Sweden contains about:

- 0,6 kg of P (phosphorus) per year
- 5 kg of N (Nitrogen) per year
- 18 kg organic material per year (BOD)
- Infectious substances
- Sometimes other dangerous compounds (for example medicinal compounds and objects flushed down toilets that are not supposed to be disposed of in that manner)
- 60 m^3 water per year if connected to both a toilet water and grey water or 40 m^3 water per year if only discharging grey water

2 Goal and scope

The overall goal of this study is to evaluate the environmental impacts of 2 different wastewater treatment configurations for single-detached houses in rural conditions. Thus it is possible to make recommendations to decision makers about which equipment choice is the better from an environmental point of view.

The questions to answer are: Is there a large variability of quality/scale/environmental impacts for different configurations? How important is the manufacturing/installation process to the total impact on the life cycle of this WWT system? Which one is the least-impact configuration? Is the sludge collection and treatment process a large part of the lifecycle of these rural wastewater treatment configurations?

To answer these questions, a single-family, hypothetical detached house disconnected from sewage collection systems is considered. Therefore the authors considered existing solutions available in the market to treat wastewater. A 5 Person Equivalent wastewater load to the treatment system is assumed, which is the contained treating capacity limit of these devices. Note that normally, these kinds of wastewater systems are modular and can be scaled-up when needed, so that they can treat higher wastewater loads.

2.1 Description of the Equipment Alternatives

The products chosen have the representative equipment parts produced by the Swedish company Fann VA-Teknik. The names of the products are In-Drän Markbädd 5 and In-Drän Biobädd 5ce. Both Markbädd and Biobädd correspond to the category of soil treatment systems except for the fact that treated water is finally discharged to the groundwater, like for infiltration beds. They are considered by the authors of this report to receive household non-separated wastewater from both toilet and other household processes. The main differences except for materials used to produce the products are that Biobädd has an overall higher pollutant removal rate than Markbädd. Biobädd also uses electricity to operate a fan for ventilation during the use phase, while Markbädd does not. Both products are otherwwase driven by gravity. Therefore it is assumed that results will indicate that Markbädd contributes more to eutrophication issues, while Biobädd contributes more to environmental impacts associated with electricity use. The products are also connected to a septic tank produced by Fann VA-Teknik called SA4006ce and a phosphorus precipitation unit called EkoTreat. Removal rates of phosphorus for Markbädd are increased from 70 % to about 90 % when connected to an EkoTreat unit, while the removal rate increment for Biobädd is less noticeable. It is assumed for the purpose of this report that both equipment setups contain an EkoTreat unit, which is otherwise not required and sold separately. The components are installed (in the way they receive wastewater from households) as EkoTreat unit (installed in house, precipitation chemicals directly added to water discharged from households) --> Septic tank SA4006ce (where sludge is collected and emptied at intervals. EkoTreat contributes to more sludge formation overall) --> Markbädd 5 or Biobädd 5ce --> discharged wastewater to groundwater. For illustrations of how the installed system is configured, see Figure 3 and Figure 4. For more detailed product descriptions, see product information from Fann VA-Teknik (2007, 2013a, 2013b, 2014) found in the reference list.

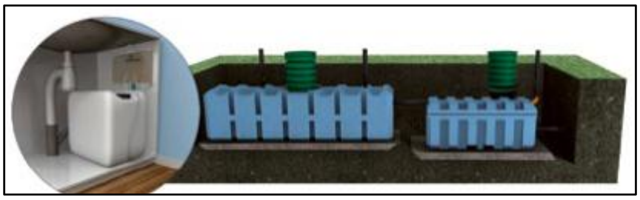

Figure 3. Illustration showing the wastewater treatment equipment system Biobädd . Source: (Fann VA-Teknik AB, 2014)

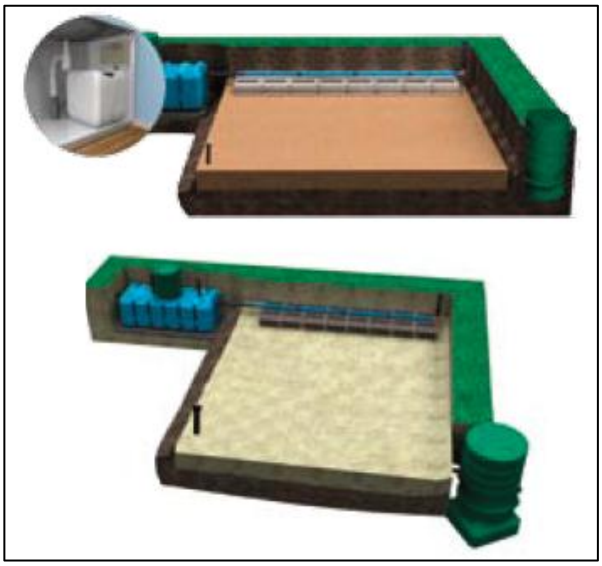

Figure 4. Illustration showing the wastewater treatment equipment system Markbädd. Source: (Fann VA-Teknik AB, 2014)

According to the manufacturer (Ambrosson, 2014), the lifespans of both Markbädd and Biobädd are the same, about 20-30 years. For the purpose of this study the lifespan of both products has therefore been considered as 25 years. The LCA study is conducted for the entire lifespan of the product as for example electricity use is calculated for 25 years of usage.

2.2 Functional Unit

A functional unit is a measure of the function of the system under analysis that the LCA orbits around and perform as a reference to which the inputs and outputs can be correlated. This facilitates comparison of two essentially different systems in consideration. A good functional unit should describe what function is provided, how much of the function is provided, for how long it is provided and to what qualitative extent it is provided (Baumann & Tillmann, 2004). The Functional unit used in this study is defined as one alternative of equipment setup (hereafter named Biobädd or Markbädd systems) that treats water for a household (5 person Eq.) for the assumed life span (25 years for both equipment setups).

2.3 Target Audience

The intended audience of this work is the Swedish rural household owner community, wastewater treatment systems installers and resellers who want to increase their environmental knowledge of different systems they work with, as well as local authorities (at a municipal level) who wants to make recommendations or establish incentives to users who prefer more environmentally friendly wastewater treatment methods.

2.4 Description of LCA in Project

This study corresponds to a comparative, attributional LCA of two different small-scale wastewater treatment systems. An attributional LCA means that the LCA is made with the intention of studying a known product in detail to find out what its current impacts are and to see what processes and/or parts of its life cycle have the largest impact contributions (Baumann & Tillmann, 2004). The LCA study includes the impact of wastewater treatment systems through their whole lifecycle, including raw materials extraction, device fabrication, installation, use phase and disposal at the end of the lifecycle. Exclusions from the LCA study include for example production of phosphorus precipitation chemicals and electricity production. For more information on what is included and what is excluded in the LCA study, refer to the flowchart in Figure 5. Geographical boundaries are set to Sweden. The reason for this is that the products considered are designed to comply Swedish environmental laws and produced in Sweden, so it is assumed that they are sold and used in Sweden as well. Data requirements are that data used should as far as possible be representative for existing market solutions found in Sweden today, which is part of the reason for choosing products that exist on the market today and gathering a lot of data from the manufacturers.

2.5 System Boundaries

The LCA study conducts cradle-to-grave impact assessment of the products. The products considered for comparative LCA are produced from same raw materials; polyethylene and polypropylene and the phosphorus reduction unit is made of stainless steel. The material extractions and production processes occur at the same plants. Furthermore, the waste disposal scenarios have similar endings, which is into landfills and incineration. However, the production of energy being consumed by these construction phase processes is considered within the system boundary, since it is included within the database of all other electricity-consuming processes. The sludge management is also given importance as a part of disposal phase. The main components of the studied system are presented in the flowchart as shown in Figure 5.

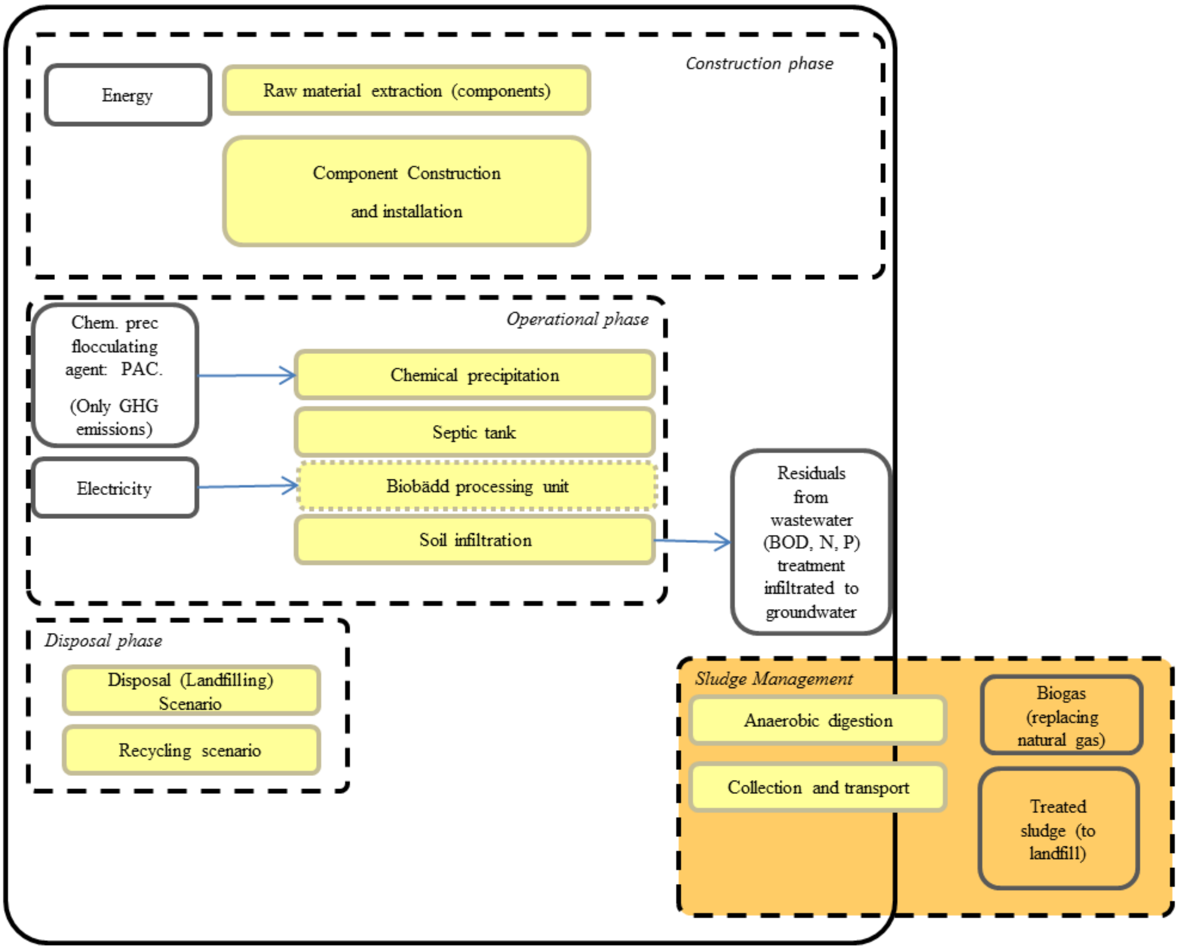

Figure 5 . Flowchart showing system boundaries for the LCA study of both treatment systems. Adapted from (Eveborn, 2010).

2.5.1 Time Boundaries

The time limit for the products is considered as 30 years. During this period the construction, operation and waste disposal of the systems are accounted.

2.5.2 Geographical boundaries

The geographical boundaries describe the regional transmission of the products from the stage of raw materials to the end disposal stage. The basic materials of the products are assumed to be extracted and produced globally. The LCA modelling is done for small-scale wastewater treatment plants installed for single households in the rural areas of Sweden. Hence, the assembly of these materials into required products, the consumption and waste disposal are carried out inside Sweden.

2.6 Allocation

2.6.1 Allocation in Sludge Treatment

The production of biogas by anaerobic digestion in sludge treatment causes the allocation problem since biogas has the same function as natural gases and the same environmental impacts. As biogas is produced in sludge treatment process, it is assumed in our project to have the same function as the same amount of natural gases. Hence the problem should be solved by avoiding the environmental burdens from natural gases. Detailed solution is shown in Annex 1

2.6.2 Allocation in Disposal Phase

In disposal phase metals are recycled which causes allocation problem since the recycled metals would be used again into the production industry, which has avoided the burdens of pig iron and iron scraps. Detailed solution is shown in Annex 1.

2.7 Work Methodology

An LCA that is made according to the present LCA ISO standard (ISO, 2006) consists of four phases.

1. Goal and scope definition: Where the purpose and limitations of the LCA study are defined in detailed.
2. Inventory analysis: Where all data regarding product properties is gathered and analysed.
3. Impact Assessment (LCIA): Consists of three mandatory and a number of optional steps. The mandatory steps are impact category definition, classification and characterization. Impact category definition is where a number of important impact categories to consider further are defined. Examples of such impact categories are marine eutrophication and human toxicity. Classification means assigning the inventory results to the different impact categories. Characterization means quantifying the effects of the now impact category assigned inventory results. Optional steps include for example normalization and weighting. Normalization means comparing the characterization results to a common reference value (dividing by). For example if we are considering an impact category such as land use for a product, then a reference value could be something like the average land use in Europe to produce similar products. Weighting means that the practitioners assign multiplying scores to the characterization results that are considered to be the most important ones. This means that weighting is fundamentally a subjective matter and weighting results will almost always differ depending on who performs the method. For this reason, ISO recommends against using weighting for comparing products in an LCA that will be distributed publicly and can be used for marketing reasons.
4. Interpretation of results: In this part interpretation and analysis of the previous steps in the LCA study is presented.

The inventory analysis and impact assessment steps have been performed in this LCA study by using the LCA software SimaPro Version 7.3.3. SimaPro is analytical LCA software developed and maintained by the company PRé Consultants, operating in the Netherlands and North America. More information regarding the product is available on PRé Consultants webpage at: http://www.pre-sustainability.com/simapro (PRé Consultants, 2014). SimaPro uses a number of databases developed and maintained by a multitude of organizations and companies. The database used the most for the purpose of this report is called EcoInvent 2.2. This version of EcoInvent is released during May 2010. EcoInvent is developed and maintained by a collaboration between the Swiss Federal Institute of Technology Zürich (ETH Zürich), Swiss Federal Laboratories for Materials Testing and Research (Empa), Lausanne (EPF Lausanne), the Paul Scherrer Institute (PSI) and the Institute for Sustainability Sciences (Agroscope). The collaboration is called Ecoinvent, the Centre for

Life Cycle Inventories. More information regarding the EcoInvent database can be found on their webpage at: http://www.ecoinvent.org/about-us/ (EcoInvent, the Centre for Life Cycle Inventories, 2014). The impact assessment results are calculated using the ReCiPe Midpoint (H) indicator v.06, which is available in SimaPro. The method transforms inventory results into indicator scores (characterization, normalization etc.) that can be analysed. There are several ways to use the ReCiPe method; the one chosen for this study is the Hierarchist midpoint indicator method. Hierarchist is a cultural perspective approach that considers the model in a consensual, scientific way and is backed up by some scientific bodies with sufficient recognition in the environmental community (Baumann & Tillmann, 2004, p. 161). Normalization is done in the ReCiPe method by using reference values based on the average environmental loads associated with one average European citizen. Midpoint analysis means that impacts are considered earlier in the cause-effect chain and are for example defined as chemical or physical changes (Baumann & Tillmann, 2004, p. 131-132). The alternative is called endpoint analysis and means to consider impacts later in the cause-effect chain, which are usually things like biological changes (Baumann & Tillmann, 2004, p. 131-132). More information about ReCiPe can be found on PRé Consultants webpage at: http://www.pre-sustainability.com/recipe (PRé Consultants, 2014).

3 Inventory analysis

Materials and processes contained in the life cycle of the two different wastewater treatment systems are shown in Table 2 and Table 3, including the categories and amounts respectively regarding either the Biobädd or the Markbädd system. The majority of the materials and the processes are retrieved from the Ecoinvent unit/system process database, however there are some important ones that could not be found in the database; therefore we included some other databases in our model, which is stated in the comment below the table. More detailed inventory data regarding each assembly and the whole life cycle of the two systems can be found in Annex 1.

Some of the data are directly acquired from relevant materials and the manufacturers. These include the amount of stainless steel, plastics (PE and PP) and sand/gravel/stone, as well as processes such as moulding, electricity consumption.

Some data are indirectly calculated based on known information, which included some assumptions. These are materials as plugs and cables, and processes including welding, transport, emissions to groundwater and emissions from PAC.

Decisions on the rest of the processes are based on assumption created from the expert opinions of the report authors, including data regarding the sludge treatment and disposal phase.

The removal rates of Markbädd are: 95 % BOD, 90 % Phosphorus (with EkoTreat), 70 % Nitrogen (Avloppsguiden, 2011). The removal rates of Biobädd are: 98 % BOD, 99 % Phosphorus (with EkoTreat), 55 % Nitrogen (Fann VA-Teknik AB, 2013b).

3.1 Materials

Table 2. Material input and output of both systems.

Materials	Biobädd system	Markbädd system
Stainless steel [kg] *	4	4
Polyethylene [kg]	340	230
Polypropylene [kg] *	236	289
Sand, gravel and stone [kg] **	10000	31500
Plugs [p]	1	1

Cables [m]	2	2

* ELCD database

** EU & DK Input Output database

Materials without a star mark are retrieved from EcoInvent unit/system process database

3.2 Processes

Table 3. Processes input and output of the two systems.

Processes	Biobädd system	Markbädd system
Welding of steel [m]	1,9	1,9
Transport, lorry>16t [tkm]	301,4	694,57
Injection moulding [kg]	343	283
Electricity consumption [kWh]	6800	100
GHG emissions from PAC [kg CO2-eq] * **	654,469	654,469
Emissions of P to groundwater [kg] * **	0,75	7,5
Emissions of N to groundwater [kg] * **	281,25	187,5
Emissions of BOD to groundwater [kg] * **	45	112,5
Sludge treatment [kg]	198275	198275
Avoided burden of natural gases by biogas produced in sludge treatment [m3] * **	2308,91	2308,91
Transport, sludge collection [tkm]	1015,092	1015,092
Landfill of PP [kg]	236	289
Landfill of PE [kg]	340	230
Landfill of stainless steel [kg]	1,2	1,2
Recycling of stainless steel [kg]	2,8	2,8

* ELCD database

** EU & DK Input Output database

*** Self-defined process

Materials without a star mark are retrieved from EcoInvent unit/system process database.

4 Life – cycle impact assessment

The above described Life-cycle Inventory (LCI) data are used in the software SimaPro to calculate the hereby presented Life-Cycle Impact Assessment (LCIA) for both units studied by using the harmonized ReCiPe (H) Midpoint (Goedkoop *et al.*, 2013) analysis for the eighteen available midpoint indicators, which are: Climate change, Ozone depletion, Human Toxicity, Photochemical oxidation, Particulate matter form, Ionizing radiation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation, natural land transformation, water depletion, Metal depletion and Fossil depletion.

4.1 LCIA results

Markbädd and Biobädd systems' life-cycle impact analysis results are presented in Figure 6 and Figure 7, respectively. Some of the most significant impact contributions to the Markbädd system come from the equipment components Markbädd unit and the septic tank, while the dominating impact contributions to the Biobädd system are associated with electricity use (as expected). Transport processes seem to be relatively large contributors in both cases as well. Marine and Freshwater eutrophication impact categories are almost exclusively related to the wastewater treatment process itself in both equipment, as treated water discharged to groundwater still contain certain amount of unremoved phosphorus, nitrogen and organic matters. Note that these graphs do not consider sludge treatment and deposition.

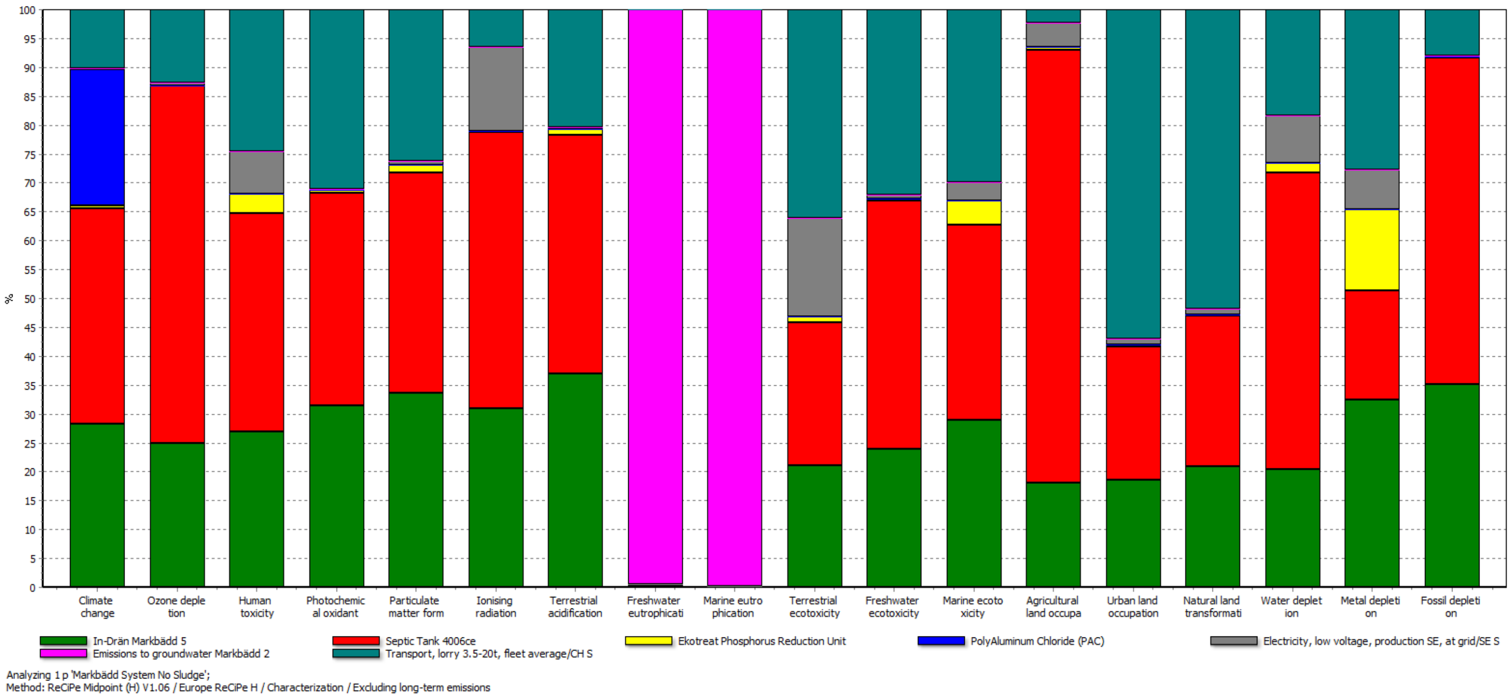

Figure 6 . Markbädd LCIA system analysis results. Impact categories from left to right are: Climate change, Ozone depletion, Human toxicity, Photochemical oxidant, Particulate matter form, Ionizing radiation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation, Natural land transformation, Water depletion, Metal depletion, Fossil depletion. Y-scale is percentage of contribution to impact category from 0 to 100 %. Red bars are associated with the Markbädd unit, Green bars are associated with the septic tank, Yellow bars are associated with Ekotreat phosphorus precipitation unit, Blue bars are associated with the PAC chemical, Grey bars are associated with electricity production, Purple bars are associated with phosphorus, nitrogen and BOD:s in discharged treated water to groundwater and Cyan bars are associated with transport.

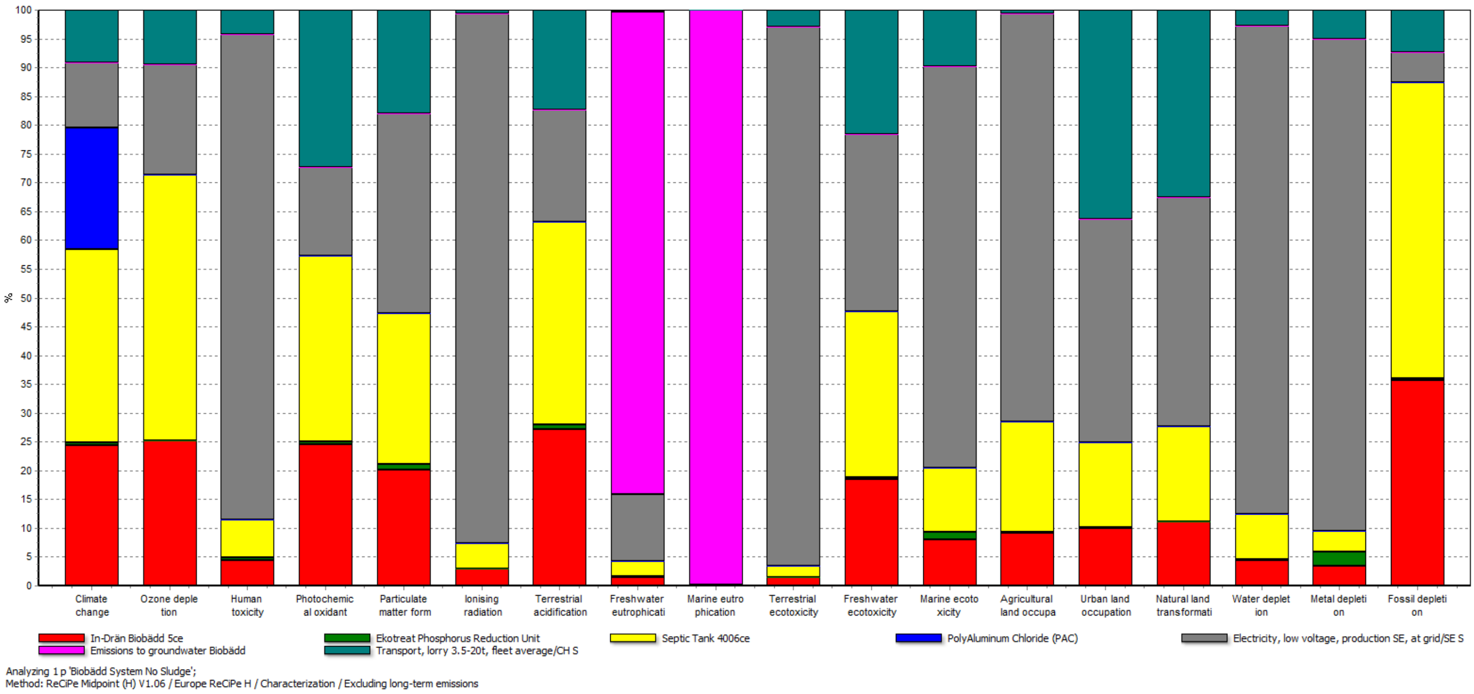

Figure 7 . Biobädd LCIA system analysis results. Impact categories from left to right are: Climate change, Ozone depletion, Human toxicity, Photochemical oxidant, Particulate matter form, Ionizing radiation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation, Natural land transformation, Water depletion, Metal depletion, Fossil depletion. Y-scale is percentage of contribution to impact category from 0 to 100 %. Red bars are associated with the Biobädd unit, Green bars are associated with Ekotreat phosphorus precipitation unit, Yellow bars are associated with the septic tank, Blue bars are associated with the PAC chemical, Grey bars are associated with electricity production, Purple bars are associated with phosphorus, nitrogen and BOD:s in discharged treated water to groundwater and Cyan bars are associated with transport.

4.2 Equipment comparison

When comparing product characteristics other than wastewater treatment performance, the main differences between equipment types that can be attributed are mostly related to the different material requirements. The most relevant differences between equipment types are that Biobädd demands an extra plastic unit (meaning a total demand of extra 70 kg HDPE, compared to Markbädd), while Markbädd demands more gravel for the infiltration bed (total difference of 21,5 tons of gravel). Another important difference is the existence of an electric fan in the Biobädd tank, which demands about 268 KWh $year^{-1}$ of electricity.

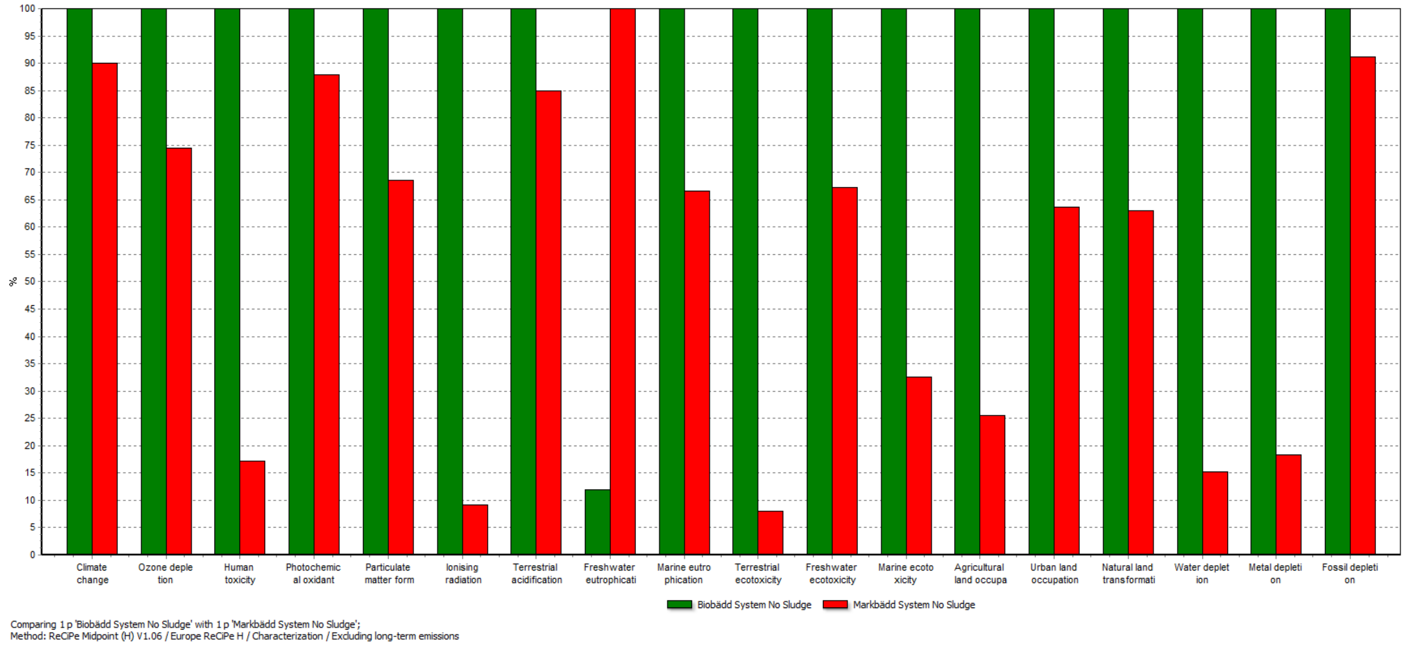

Figure 8 . Comparison of characterized results between Markbädd system (red) and Biobädd system (green). Short term emissions only, midpoint assessment, excluding sludge treatment. Impact categories from left to right are: Climate change, Ozone depletion, Human toxicity, Photochemical oxidant, Particulate matter form, Ionizing radiation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation, Natural land transformation, Water depletion, Metal depletion, Fossil depletion. Y-scale is percentage of contribution to impact category from 0 to 100 %.

Figure 8 shows a comparison of characterized results of the midpoint impact analysis. It can be seen that, excluding eutrophication-related impacts, Markbädd has an overall better environmental performance, mainly because of the simpler equipment configuration. The most important observed differences in midpoint impact when comparing the equipment types are associated with electricity use by the fan in the Biobädd system. The electricity use in the fan alone accounts on the selected categories for: 1.537 Kg Uranium 235 eq in Ionizing radiation, 246,32 kg 1,4-diclorobenzene equivalent in Human toxicity, 1,24 kg 1,4-DB eq in Terrestrial ecotoxicity, 1,67 kg 1,4-DB eq in Marine ecotoxicity, 109,36 m^2a in Agricultural land occupation, 30,01 m^3 in Water depletion, and 177,35 Kg Fe eq in Metal depletion. Considering the importance of the electricity use in impact assessment it is appropriate to analyse this further, even though electricity generation is not in the defined foreground system of the LCA system boundaries.

The impacts related with electricity production are distributed in a wide range of categories due to the diversity of energy sources and activities and interconnections between activities in the electricity market, which all are considered in the EcoInvent database. As can be seen in Figure 9, the impact is driven by electricity generation itself with the different energy sources (Uranium, coal, biomass, waste, etc.), but also from distribution systems, mainly related with mining activities necessary for distribution lines..

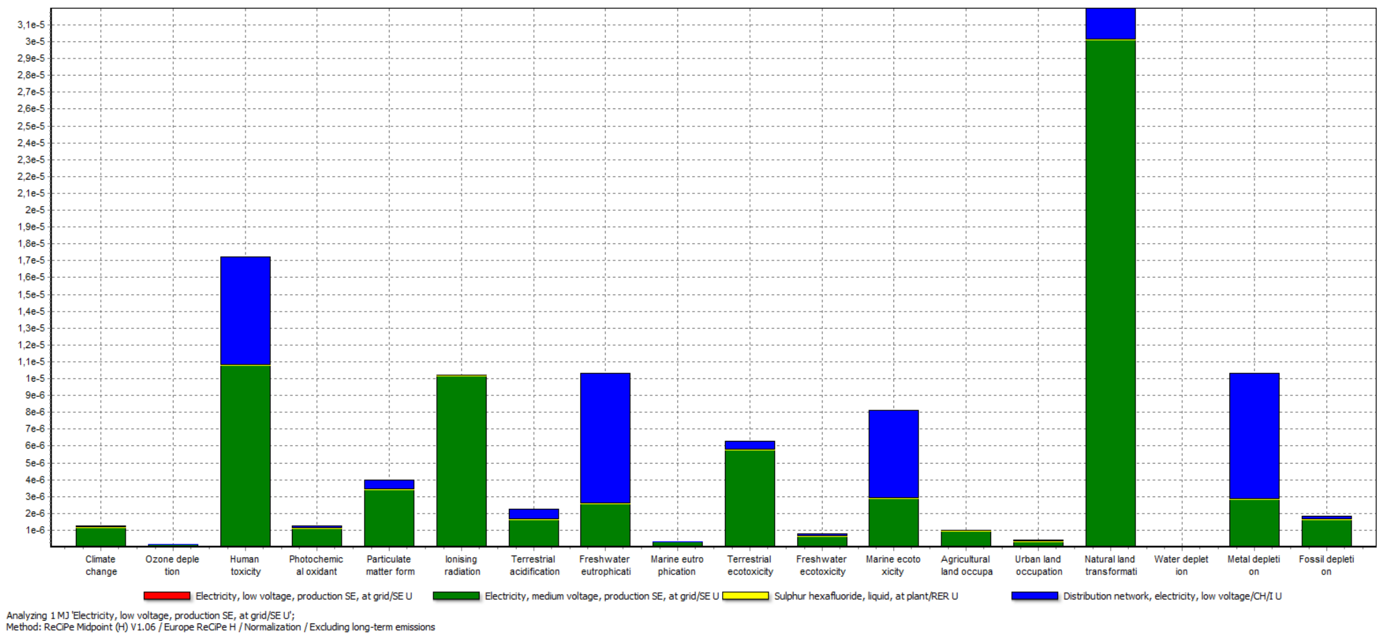

Figure 9 . Impact analysis from electricity production, low voltage, SE. Graphs are normalized. Impact categories from left to right are: Climate change, Ozone depletion, Human toxicity, Photochemical oxidant, Particulate matter form, Ionizing radiation, Terrestrial acidification, Freshwater eutrophication, Marine eutrophication, Terrestrial ecotoxicity, Freshwater ecotoxicity, Marine ecotoxicity, Agricultural land occupation, Urban land occupation, Natural land transformation, Water depletion, Metal depletion, Fossil depletion. Y-scale is quantitative values of contribution. Green bars are associated with production of Swedish medium voltage electricity at grid, Blue bars are associated with the distribution network of low voltage electricity.

Figure 10 shows a comparison of normalized results for both units under analysis (without considering sludge treatment, disposition and long term emissions). The most important impacts for both units under study are related to Freshwater and Marine eutrophication. This is expected as wastewater (even treated) discharged to groundwater are considered as important contributors to eutrophication processes, as explained earlier in this report.

When it comes to comparative results, it can be seen that the Markbädd system has an overall better environmental performance compared to Biobädd related to marine water eutrophication, but worse performance related to freshwater eutrophication. This is because, in general, eutrophication processes are driven by the availability of a limiting nutrient. In the case of freshwater, it is generally assumed than eutrophication processes are limited by the availability of phosphorous, and in marine ecosystems is limited by the availability of nitrogen (Gustafsson *et al.*, 2007). The Biobädd system has a higher removal rate of phosphorous than Markbädd, leading to a lower midpoint impact on freshwater resources. In the case of marine ecosystems the opposite situation occurs: marine eutrophication processes are limited by nitrogen availability and Markbädd system has a better performance in nitrogen removal, which leads to a lower marine eutrophication midpoint impact than Biobädd. These results are very important since wastewater treatment has a very important role in limiting eutrophication issues.

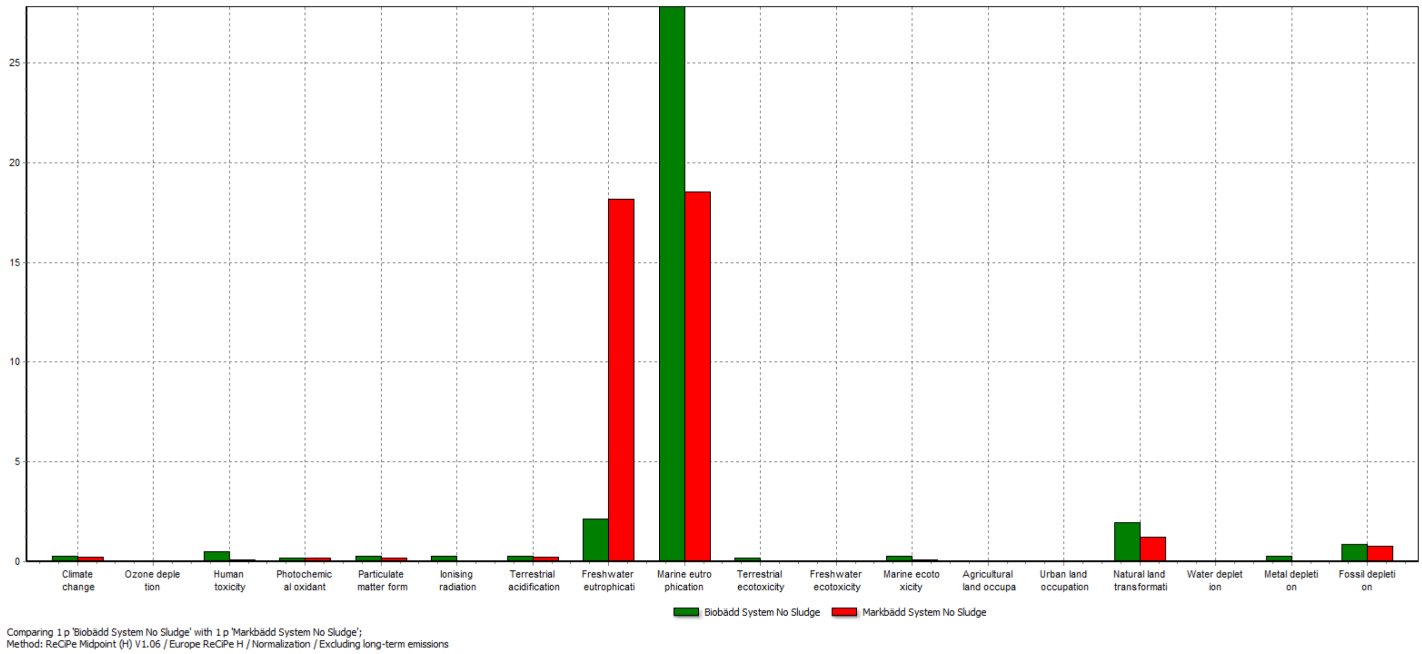

Figure 10 . Comparison of normalized results between Markbädd system (green) and Biobädd system (red). Short term emissions only, midpoint assessment, excluding sludge treatment. The two impact categories that are of greatest interest are Freshwater eutrophication (middle left) and Marine eutrophication (middle right). Y-scale is quantitative values of contribution, from 0 to 26.

Notice that these results only accounts for the treated wastewater load of N, P and BOD for both systems since the authors could not access to more detailed information on removal rates of other compounds for the equipment under study. And due to the relative importance of the removal rates in the overall LCIA results, is recommended for further studies to include a more complete characterization of treated wastewater. It is then expected to result in an overall increase for midpoint impacts in other categories.

In Figure 11 is presented the LCIA normalized results, considering sludge management. It can be seen that the significance of sludge for human toxicity in the analysis is great, even though the sludge is considered to be used for anaerobic digestion and biogas production prior to final disposal. After analysing the EcoInvent database process for anaerobic digestion in SimaPro, it is found that the impact on human toxicity is almost solely due to phosphorous emissions to the soil generated during the digestion process (99,25%). This impact is equally important for both equipment's because it is considered an equivalent generation of sludge in both cases. It is likely that this human toxicity related to phosphorus is due to the fact that phosphorus can be dangerous when inhaled in large concentrations as gas compounds (United States EPA, 2000), which could be considered in the Ecoinvent database. Overall, the sludge treatment plays a vital role in quantitative terms for analyzing impacts of the different equipment setups. In fact, it is significant enough that it becomes difficult to distinguwash difference in other environmental impacts between the two equipment setups if sludge treatment is included in the analysis. Since the sludge treatment process is defined as identical for the two products, it is therefore decided by the authors of this report after analysis not to consider the sludge treatment for the conclusions in this report (for what equipment setup is recommended etc.). This includes processes for collecting and transporting sludge. Additionally, this also means that the choice of only considering CO_2 emissions related to the life cycle of the phosphorus precipitation chemical PAC does not effect relevant results, since the PAC is collected and removed together with the unconsidered sludge.

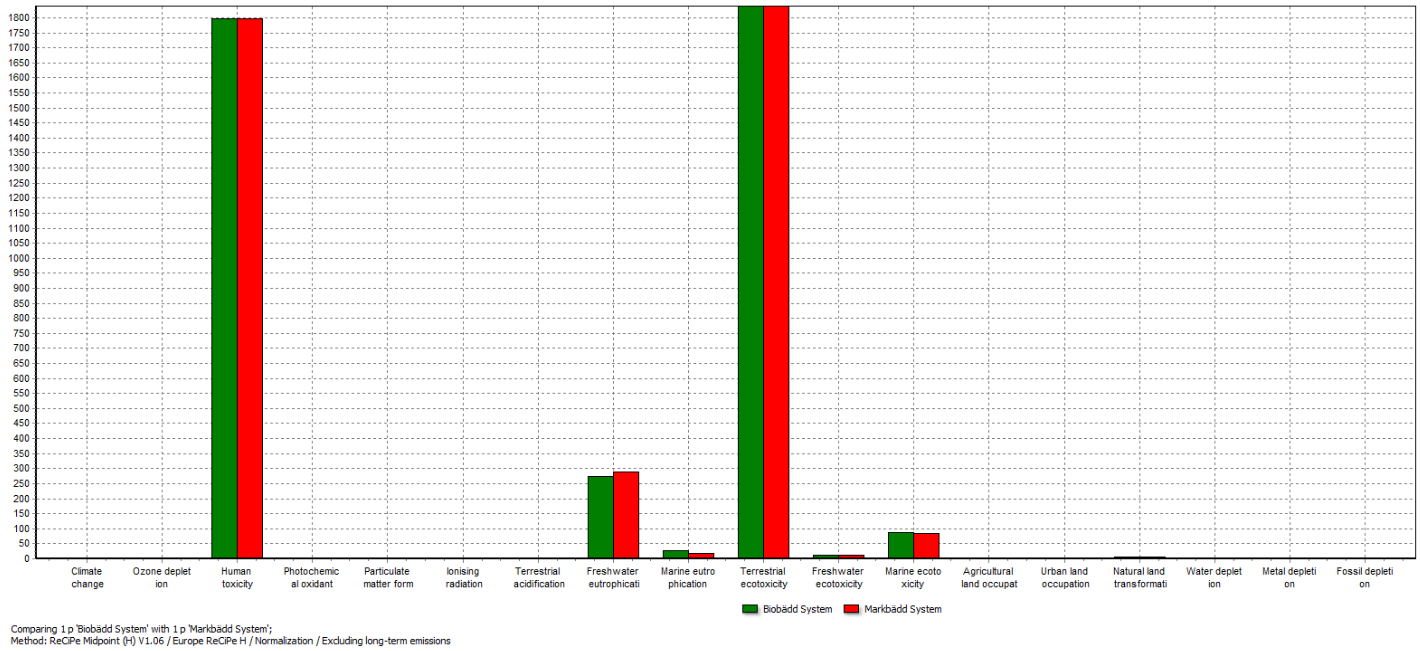

Figure 11 . Comparison of normalized results between Markbädd (green) and Biobädd (red). Short term emissions only, midpoint assessment, including sludge treatment. The impact categories of interest are Human toxicity (left), Freshwater eutrophication (middle left), Terrestrial ecotoxicity (middle right) and Marine ecotoxicity (right). Y-scale is quantitative values of contribution, from 0 to 1800.

Note that except for the fact that anaerobic digestion shows an important (negative) impact in the field of human ecotoxicity, it does also have positive impacts related to the avoided production of natural gas replaced by biogas output from the anaerobic digestion. One kilogram of sludge equivalent can be used to produce 0,0116 m^3 of biogas, which replaces the same amount of natural gases.

Long term impacts are generally reported as most important regarding landfilling and mining activities (Doka, Hellweg, & Hungerbühler, 2002). In this report, the authors decided not to include long-term impacts, since including them would not introduce relevant changes in the results for equipment being sold and used in the market today and it is also considered that including them would introduce an important degree of uncertainty to the analysis results. Nevertheless it can be stated that, as expected, the only relevant changes that long term impacts would introduce to the LCIA results (after analysis in SImaPro) would be in the Human toxicity categories, with approximately 4,5 times higher impact for Markbädd system no sludge and 5,6 times higher impact for Markbädd system. Notice that including long-term emissions does not change the fact that Biobädd system has a higher impact compared to Markbädd in that impact category. In this study, end-point impacts related with the considered products are not included as LCIA results of interest, because including them would introduce a high degree of uncertainty for the results.

4.3 Sensitivity analysis

A sensitivity analysis exercise is performed by making changes in parameters driving relevant results to environmental performance of both equipment. First a wastewater treatment performance sensitivity analysis is performed. A sensitivity analysis of the electricity production was also performed, by switching the electricity grid to average European production conditions, obtaining no significant differences between baseline and sensitivity scenario. Therefore, detailed results are not presented here for space constraints reasons.

4.3.1 Wastewater treatment performance

As wastewater treatment performance often depends on biological and biochemical process, there is often a relatively high degree of variability, depending on environmental conditions, equipment capacity demand (i.e. overload), and wastewater characteristics. The reported by manufacturer wastewater removal rates are modified in both equipment to see the variation in impacts directly related to their performance, meaning freshwater and marine eutrophication.

For Markbädd system, the following modification is introduced to address the change in eutrophication-related impacts:

- Drop of BOD removal rate from 95% to 80%, related to person Eq.
- Drop of P removal from 90% to 80% related to person Eq.
- Drop of N removal from 70 to 50% related to person Eq.

Results are presented in **¡Error! No se encuentra el origen de la referencia.**. Notice that freshwater eutrophication is more sensitive to these modifications than marine eutrophication.

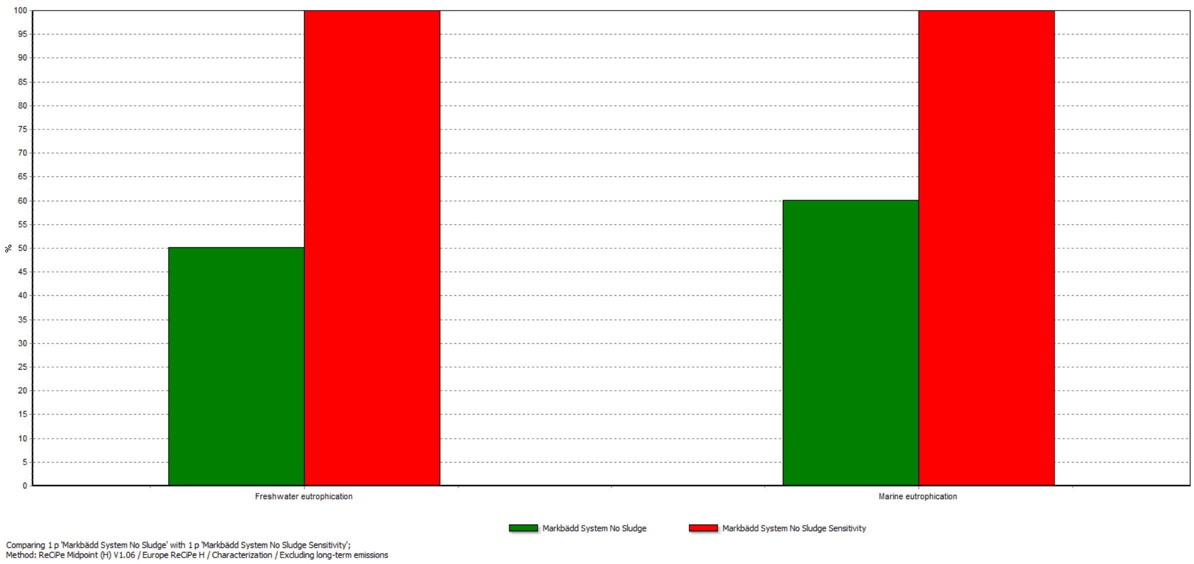

Figure 12 . Eutrophication related impact sensitivity analysis characterization results for Markbädd system. Red bars show sensitivity analysis results while green bars show original results.

For Biobädd system, the following modifications are introduced:

- Drop in BOD removal rate from 98% to 85%
- P removal from 99 to 85
- N removal 55 to 40

Results are presented in **¡Error! No se encuentra el origen de la referencia.**. Notice the opposite effect, with freshwater eutrophication showing to be very sensitive to changes in performance.

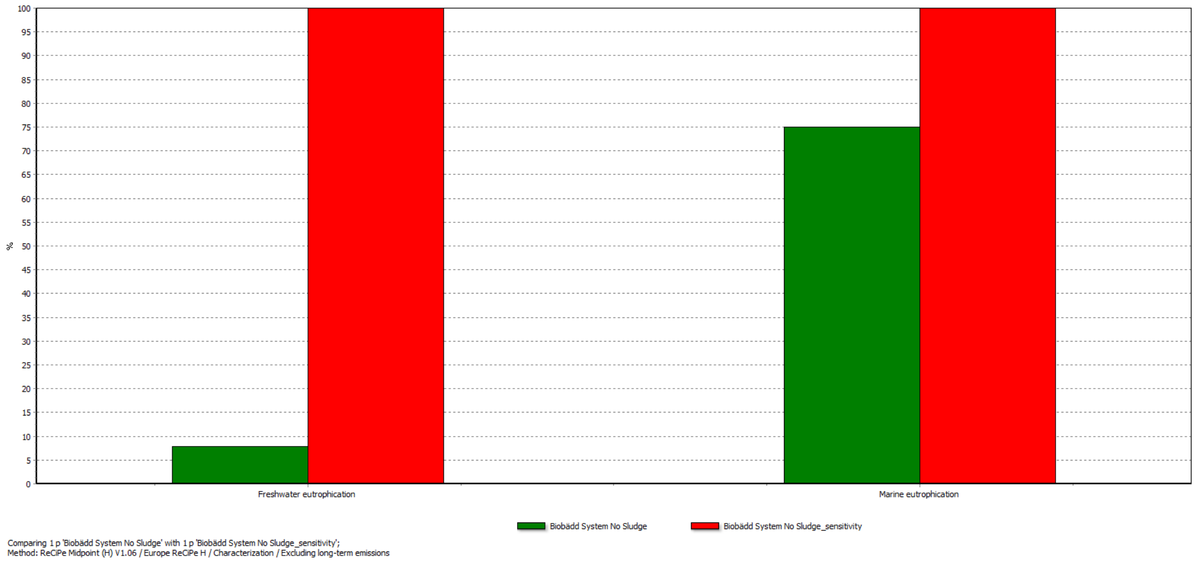

Figure 13 . Eutrophication related impact sensitivity analysis characterization results for Biobädd system. Red bars show sensitivity analysis results while green bars show original results.

5 Interpretation and Conclusions

The LCIA results of the two treatment configurations have shown different assemblies/processes contributing the most to the final environmental impacts related to each system, despite the relatively similar configurations of both. For the Biobädd system, when excluding sludge treatment, the electricity production is a dominating factor in several impact categories, as a much larger amount of electricity would be consumed during the system's life span due to the existence of a fan in the system. For the Markbädd system, assembly of the Markbädd unit and the septic tank are the dominating contributors to overall impacts. This relates to the larger amount of gravel needed in the process, as well as higher plastic usage. Transport of both systems from the manufacturers to the households is another significant impact source, mainly related to the use of diesel and metals.

The results of the comparative LCIA for the two treatment configurations have shown that the environmental impacts related to each system differ to a large extent, especially concerning human toxicity, freshwater eutrophication and marine eutrophication. These three impact categories have shown to be affected much more than other impact categories and are therefore the main things considered when the authors of this report performs recommendations about what equipment setup to use. The impacts on these categories are mainly related with wastewater treatment performance. In terms of this, though the environmental impacts from the two configurations differ quite a lot in those categories (e.g. ionizing radiation, metal depletion etc.), the overall impacts could be seen as negligible.

The normalization result, which compares impacts to the average European case, has shown that eutrophication issues from these systems in both freshwater and marine aquatic systems are the most important environmental impacts to consider related to the life cycle of the two wastewater treatment systems. This is pretty much related to the different removal rates of the nutrients (phosphorus and nitrogen). Although the removal rates are overall high, they are not 100 %. The Biobädd system has a higher removal rate of P, resulting in a lower impact on freshwater eutrophication, because of reasons previously explained. The Markbädd system, to the opposite, has a higher N removal rate but a lower one for P removal, which resulted in the fact that the Markbädd system has higher impact on freshwater eutrophication, but lower on marine eutrophication. This could be important for deciding which equipment system to install for your own house depending on where the house is located (whether it is in the inland, or beside the seashore).

Water treatment performance, which strictly relates to nutrient removal rate in our case, can be in practice more complex in respect to metals and pharmaceutical residues. These factors are not taken into account in our study since the manufacturer provided only information of nutrients and BOD as counting factors. However the environmental impacts might be of much interesting if more affecting factors are considered, which requires further study in depth. Biobädd is shown to be more sensitive than Markbädd to changes in performance, especially related to freshwater eutrophication impacts. Therefore a further more detailed study on equipment performance variability would help to address uncertainty.

Electricity consumption, from the normalization result, is also a vital parameter, though not as crucial as water treatment performance. The environmental impact of electricity consumption mainly lies in the generation and distribution of electricity, which under European conditions, mainly arises from for example the use of nuclear power for generation and the mining of copper for distribution. In the case of Biobädd system, as it has a fan used for ventilation that consumes 6700 kWh during its life span, which means it has a larger impact on the environment for electricity realted issues when compared to the Markbädd system. Due to its significance in the overall environmental impacts, electricity consumption can be an important issue when making decision on which treatment system to choose.

The above discussion does not include consideration of sludge treatment, which if added could result in a totally different result. From the impact assessment result, sludge collection, transport and treatment has such a large environmental impact that impacts from other components become negligible. This is because of the anaerobic digestion process selected as disposal method, where bounded phosphorus can escape to the nature in gas forms or to the soil in high and potentially toxic concentrations, thus potentially entering human body through inhalation or entering the terrestrial ecosystem. This explains the fact that the impact categories of human toxicity and terrestrial toxicity are highly affected when considering sludge treatment.

From the discussion above, we could state that there is no simple single better choice, and that the most environmentally friendly choice would depend on local conditions. The Markbädd system could be very harmful to freshwater as it contributes a lot to freshwater eutrophication issues. Therefore as mentioned before, if living close to the sea or ocean, Markbädd system might be a good choice, but when living in the inland Biobädd system seems to be a much better option, though the environmental impacts from the larger electricity consumption cannot be avoided.

Additionally, which is not considered in our study but very important for decision-making, the economic value of the two systems should not be ignored. The cost of Biobädd unit is 29500 SEK and the cost of Markbädd is 14700 SEK. Considering the additional cost of electricity for Biobädd, Markbädd is the more economical choice.

6 References

Ambrosson, J. (2014, November 19). Fann VA-Teknik, Product Manager: Interview about product technical specifications [E-Mail Conversation]. (J. Persson, Interviewer)

Avfal lSverige. (2010). *El Retur - Sweden: World leader in WEEE Collection and treatment.* Malmö.

Avloppsguiden. (2011). *Marknadsöversikt: Produkter för enskilt avlopp.* Uppsala: Kunskapscentrum små avlopp.

Baumann, H., & Tillmann, A.-M. (2004). *The Hitch Hiker's Guide to LCA: An orientation in life cycle assessment methodology and application* (1:7 ed.). Malmö: Studentlitteratur.

Doka, G., Hellweg, S., & Hungerbühler, K. (2002). *The example of long-term emissions in the life cycle assessment of waste disposal systems.* Swiss Institute of Technology Zürich, Chemical Engineering Department, Safety and Technology Group. Zürich, Switzerland: Swiss Institute of Technology Zürich.

EcoInvent, the Centre for Life Cycle Inventories. (2014, December 01). *EcoInvent Information*. Retrieved December 09, 2014, from EcoInvent Website: http://www.ecoinvent.org/about-us/

Eveborn, D. (2010). *Bed filters for phosphorus removal in on-site watewater treatment: Removal mechanisms and sustainability.* Royal Institute of Technology (KTH), Department of Land and Water Resources Engineering. Stockholm: KTH-Environmental Geochemistry and Ecotechnology.

Eveborn, D., Baky, A., Norén, A., & Palm, O. (2008). *Erfarenheter och kunskapsläge vid tömning av slamavskiljare.* Uppsala: JTI.

Everborn, D. (n.d.). *Bed filters for phosphorus removal in on-site wastewater treatment: removal mechanisms and sustainability.*

Fann VA-Teknik AB. (2007). *Ekologisk Avloppsrening: naturens egen reningsmetod på ett vetenskapligt sätt.* Stockholm: Fann VA-Teknik AB.

Fann VA-Teknik AB. (2013a). *Ekologisk Avloppsrening med IN-Drän Teknologi.* Stockholm: Fann VA-Teknik AB.

Fann VA-Teknik AB. (2013b). *IN-Drän Biobädd 5ce.* Stockholm: Fann VA-Teknik.

Fann VA-Teknik AB. (2014). *Produktguide 2014: Fann avloppsrening med naturens egen reningsmetod.* Stockholm: Fann VA-Teknik.

Goedkoop, M., Heijungs, R., Huijbregts, M., De Schyver, A., Struijs, J., & Van Zelm, R. (2013). *ReCiPe 2008 - a life cycle impact assessment method which comprises harmonized category indicators at the midpoint and endpoint level.*

Greenwood, N. N., & Earnshaw, A. (2014, 12 10). *Volume to weight conversion*. Retrieved 12 10, 2014, from Aqua-calc: www.aqua-calc.com/calculate/volume-to-weight

Gustafsson, J.-P., Jacks, G., Simonsson, M., & Nilsson, I. (2007). *Soil and water chemistry: Compendium for course AE2801 Environmental Chemistry and Risk Assessment.* Stockholm: KTH.

Gustavsson, M. (2003). *Vad händer med slammet i Västra Götaland?* Norrköping: Linköpings Universitet.

Homa, I. J., & Hoffmann, I. E. (2014). *Life Cycle Analysis of Leading Coagulants: Executive Summary.* Brussels: www.incopa.org.

http://www.chinacar.com.cn. (2014, 12 10). *CLW5120TPB3 Diesel Consumption*. Retrieved 12 10, 2014, from Chinacar: www.chinacar.com.cn/dbgg/32797.html

ISO. (2006). *ISO 14040:2006 - Environmental Management, Life Cycle Assessment, Principles and Framework.* Geneva, Switzerland: ISO: International Organization for Standardization.

JTI. (2011). *Enskilt Avlopp: Vilken teknik passar dina förutsättninga?* Uppsala: Kunskapscentrum Små Avlopp.

Lenntech. (2014, 12 10). *Polypropylene*. Retrieved 12 10, 2014, from Lenntech: http://www.lenntech.com/polypropylene.htm

Ltd, T. I. (2014, 12 10). *Polyaluminium chloride*. Retrieved 12 10, 2014, from Aditya Birla Chemicals: www.adityabirlachemicals.com/products/chlorine_derivatives/polyaluminium_chloride.html #

Naturvårdsverket. (2006a). *NFS 2006:7 : Naturvårdverkets allmänna råd om små avloppslösningar för hushållsspillvatten.* Stockholm: Naturvårdsverket.

Naturvårdsverket. (2006b). *Rapport 5815: Näringsbelastning på Östersjön och Västerhavet 2006.* Stockholm: Naturvårdsverket.

Naturvårdsverket. (2008). *Små avloppsanläggningar: handbok till allmänna råd.* Stockholm: Naturvårdsverket.

Naturvårdsverket. (2013). *Miljömålen: Årlig uppföljning av Sveriges miljökvalitetsmål och etappmål 2013.* Stockholm: Naturvårdsverket.

PRé Consultants. (2014, December 01). *ReCiPe Information*. Retrieved December 09, 2014, from PRé Consultants Website: http://www.pre-sustainability.com/recipe

PRé Consultants. (2014, December 01). *SimaPro Information*. Retrieved December 09, 2014, from PRé Consultants SimaPro Website: http://www.pre-sustainability.com/simapro

SFS 2001:512. (2001). *Förordning om deponering av avfall.* Stockholm: Miljödepartementet.

SMED (Swedish Environmental Emission Data). (2006). *Indata mindre punktkällor för PLC5 rapporteringen 2007.* Norrköping: SMHI.

Svensk Gastekniskt Center AB. (2012). *Basic Data on Biogas.* Malmö.

Sörelius Kissling, H. (2013). *''Rätt avlopp på rätt plats'' - Livscykelanalys av tre enskilda avloppsanläggningar.* Uppsala: SLU.

Tapco Inc. (2012). *Bulk material density table.*

Thiriez, A., & Gutowski, T. (2008). *An environmental analysis of injection molding.* Massachusets Institute of Technology.

United States EPA. (2000, January 01). *Phosphorus Hazard Summary*. Retrieved December 10, 2014, from United States EPA Website: http://www.epa.gov/ttnatw01/hlthef/whitepho.html

VA-Guiden AB. (2014, November 01). *Avloppsguiden*. Retrieved November 17, 2014, from Avloppsguiden: Siffror om avlopp: http://husagare.avloppsguiden.se/siffror-om-avlopp.html

7 Annex 1. Complete inventory data

7.1 The production and transport of Ekotreat Phosphorus Reduction Unit

Table 4. Inventory data of Ekotreat

Ekotreat Phosphorus Reduction Unit		
Materials	**Amount**	**Unit**
Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER S	4	kg
Plugs, inlet and outlet, for computer cable, at plant/GLO U	1	p
Cable, connector for computer, without plugs, at plant/GLO U	2	m
Processes	**Amount**	**unit**
Welding, arc, steel/RER U	1,9	m
Transport, lorry >16t, fleet average/RER U	0,64	tkm

The main body of Ekotreat Phosphorus Reduction Unit is made of 4 kilograms of stainless steel. (Avloppsguiden, 2011)The data of the material is retrieved from the ELCD database in SimaPro, which included raw material extraction and processing, i.e. it could be assumed that the material here is ready-made stainless steel scraps that can be used directly for welding. The size of the unit is 0,00875 m^3, of which the height is 0,25 m, the length is 0,35 m and the width is 0,1 m. (Fann VA-Teknik AB, 2014)

The unit also consists of one plug and one cable since the operation of the unit is electricity demanding. These two components are retrieved from the EcoInvent unit process database in SimaPro. For the production of the unit, it is assumed out of the authors' experience that one piece of the plug and 2 meters of the cable are used.

The process involved in the production of Ekotreat is the welding of the unit. Welding is used for creating the cuboidal shape of the unit. It is assumed to have a lid through which chemicals could be added periodically, for which the welding is done for 0,25*4+0,35*2+0,1*2=1,9[m]. The process is found in the EcoInvent unit process database.

Another involved process is the transport of the unit from the manufacturer to the household. The transport distance is assumed to be 160km for 4 kilograms of steel, which corresponds to a transport of 0,64 tkm. Since both the manufacturer and the household are assumed to be located in Sweden, lorry is used all the time as the mode of transport. The data for both the processes are retrieved from EcoInvent unit process database in SimaPro.

So as to Ekotreat, no coatings, no paintings and other materials or processes that are not necessary are not considered in the production of the unit.

7.2 The production and transport of Septic Tank 4006ce

Table 5. Inventory data of Septic tank

Septic Tank 4006ce		
Materials	**Amount**	**Unit**
Polyethylene, HDPE, granulate, at plant/RER U	230	kg
Polypropylene fiber (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	118	kg
Processes	**Amount**	**Unit**
Injection moulding/RER S	230	kg
Transport, lorry >16t, fleet average/RER U	40	tkm
Transport, lorry >16t, fleet average/RER U	20,51	tkm

The septic tank is made of 230 kilograms of polyethylene (PE). (Fann VA-Teknik AB, 2014) The data for the material are found in the EcoInvent unit processes database. The size of the septic tank is 5,6 m^3, of which the height is 1,3 m, the length is 3,6 m and the width is 1,2 m.

Fiber cloth is used as a protective layer underneath the tank, and also to cover the septic tank on the top. The material used is polypropylene (PP) fiber, which is retrieved from the ELCD database. One piece of fiber cloth is used per assembly with a size of 10*1,25*0,01[m^3]. The density is calculated to be 946kg/m^3, from which the weight is obtained as 118kg. (Lenntech, 2014)

The manufacturing process for the polyethylene is presumed to be injection moulding (weight= 230 kg) since as per the manufacturer it is the rotational moulding that is used, which points out that the results could be different in these terms. The process is retrieved from the EcoInvent system processes database in SimaPro.

The transport processes include the transport of both PE and PP for 174 kilometres, which corresponds to a transport of 40 tkm for the septic tank and 20,51 tkm for the fiber cloth. Same as for Ekotreat, lorry is used as the transport mode. The transport data are retrieved from the EcoInvent unit process database.

Same as to the Ekotreat unit, no coatings, no painting or other unnecessary materials or processes are considered.

7.3 The production and transport of In-Drän Biobädd 5ce

Table 6. Inventory data of In-Drän Biobädd 5ce.

In-Drän Biobädd 5ce		
Materials/Assemblies	**Amount**	**Unit**
Polyethylene, HDPE, granulate, at plant/RER U	110	kg
Polypropylene fiber (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	118	kg

_16 Sand, gravel and stone from quarry, EU27	10000	kg
Polypropylene injection moulding E	3	kg
Processes	**Amount**	**Unit**
Transport, lorry >16t, fleet average/RER U	19,69	tkm
Transport, lorry >16t, fleet average/RER U	20,56	tkm
Transport, lorry >16t, fleet average/RER U	200	tkm
Injection moulding/RER S	110	kg

The Biobädd 5ce is made of 110 kilograms of polyethylene (PE) along with 3 kilograms of polypropylene (PP). The polyethylene material composition is the same as the one used for the manufacturing of septic tank. (Ambrosson, 2014) The same amount of fiber cloth, made of polypropylene is used as for the septic tank. The amount of used fiber cloth is the same as for the septic tank, which is one piece weighing 118 kg.

Sand, gravel and stone are used as the fillings around the Biobädd for stabilization and infiltration. The volume used is assumed to be 5 m^3 and the density of the gravel is 2 tons/m^3 (Tapco Inc., 2012), which makes the amount 10000 kilograms. The data are retrieved from EU & DK Input Output Database.

The manufacturing process is similar to that of the septic tank, including only moulding of the plastics, which is 110 kilograms for PE and 3 kilograms for PP. The data are found in the Ecoinvent system processes.

Transport processes are considered for all materials for a distance of 20 kilometers. Still lorries are used as the transport method. The amount of transport is 19,69 tkm for the filtration bed itself (that included both PP and PE), 20,56 tkm for the fiber cloth and 200 tkm for the gravel. The data are found in the Ecoinvent unit processes.

As it is unnecessary, coatings, paintings or other less important materials are not taken into account.

7.4 The production and transport of In-Drän Markbädd 5

Table 7. Inventory data of In-Drän Markbädd 5.

In-Drän Markbädd 5		
Materials/Assemblies	**Amount**	**Unit**
_16Sand, gravel and stone from quarry, EU27	31500	kg
Polypropylene fibres (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	48	kg
Polypropylene fibres (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	5	kg
Polypropylene fibres (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	118	kg
Processes	**Amount**	**Unit**

Injection moulding/RER S	53	kg
Transport, lorry >16t, fleet average/RER S	3,42	tkm
Transport, lorry >16t, fleet average/RER S	630	tkm

The Markbädd 5 consisted of 8 modules, each of which weighed 6 kilograms. Thus the equipment is made of 53 kilograms of polypropylene fiber, of which 48 kg is used for producing the modules and 5 kg is used for producing pipes and other assembly appliances. (Ambrosson, 2014) The material is found in the ELCD database.

The fiber cloth that is also made of polypropylene fiber is used in a similar way as for the septic tank and the Biobädd, which is also one piece that weighed 118 kg.

Sand, gravel and stone are used in the same way as for the Biobädd as the stabilizing and infiltrating fillings around the Markbädd; however the volume is different, that is 5*3,5*1 m^3, the amount of which is 31500 kilograms. The material could be found in the EU & DK Input Output Database.

The manufacturing process is similar to that of the septic tank, including only moulding of the plastics, which is 53 kilograms for polypropylene fiber.

Transport processes are considered for all materials for a distance of 20 kilometres, which are 3,42 tkm for the plastics and 630 tkm for the gravel. Lorries are used for transport.

As it is unnecessary, coatings, paintings or other less important materials are not taken into account.

7.5 The process of PAC production involved in the use phase of Ekotreat

Table 8. Inventory data of PAC.

Process of PAC production		
Known outputs to technosphere. Products	**Amount**	**Unit**
PolyAluminium Chloride (PAC)	1	kg
Emissions to air	**Amount**	**Unit**
Carbon dioxide	0,537	kg

Polyaluminium chloride (PAC) is used as the precipitating chemicals as well as the coagulants and flocculants, which means that the chemicals would be regularly consumed and should be added once a year. The doze to be injected is 15 l/person/yr. (Avloppsguiden, 2011) The density of PAC is 0,65 kg/l. (Ltd, 2014) Regarding the life span of 25 years of the equipment, the total amount of PAC used per functional unit would be 1218,75 kg.

Since no information could be found in any of the database for PAC, we created a new process concerning the potential environmental impacts from the production and usage of PAC; in this case only the greenhouse gas emissions related to the PAC production are included since these are the only information we could find. 1 kg of PAC produced could result in the emission of 0,537 kg of GHG emissions that are expressed as carbon dioxide (CO2) equivalent. (Homa & Hoffmann, 2014)

7.6 The process of sludge treatment involved in the waste treatment process of the whole system (both for Biobädd and Markbädd)

Table 9. Inventory data of sludge treatment of both systems.

Process of sludge treatment		
Known outputs to technosphere. Products	**Amount**	**Unit**
Sludge treatment	1	kg
Known outputs to technosphere. Waste and emissions to treatment	**Amount**	**Unit**
Disposal, biowaste, to anaerobic digestion/CH U	1	kg

Sludge is formed and sediment in the septic tank and should be removed one per year. From a research by Sörelius Kiessling, sludge production for 2,6 persons with chemical precipitation for one year is 5,5 m^3 (Sörelius Kiessling, 2013). This means for a household with 5 person equivalent, 11 m^3 of sludge is produced per year that should be collected and removed. The density of sludge is 721 kg/m3, which made the total amount of sludge to be treated for an equipment during its life span to be 198 275 kilograms (Greenwood & Earnshaw, 2014). The sludge treatment process is created specifically for this case.

The sludge is disposed to a biowaste digester and composted to biogases. It is assumed that 1 kg of sludge is entirely treated as biowaste to anaerobic digestion. This process could be found in the Ecoinvent unit processes database, but is modified to fix the allocation problem.

7.7 The process of biogas production related to sludge treatment

Table 10. Biogas production of both systems regarding sludge treatment.

Process of biogas production		
Waste specification	**Amount**	**Unit**
Disposal, biowaste, to anaerobic digestion/CH U	1	kg
Known outputs to technosphere. Avoided products	**Amount**	**Unit**
Biogas, from sewage sludge, at storage/CH U	0,011645079	m3

The allocation problem is to avoid the environmental burden from natural gases when there is production of biogases from the sludge treatment. It is assumed that the burdens from a certain amount of natural gases are avoided from the same amount of biogases. The average production of biogas from sludge is 0,0084 m^3 from 1 litre of sludge (Svensk Gastekniskt Center AB, 2012). Therefore in this process it could clarified that 0,0116 m^3 of natural gases are the avoided products for the treatment of 1 kg of sludge.

7.8 The emissions to groundwater caused by untreated P, N and BOD involved in the use phase of Biobädd

Table 11. Inventory data of groundwater emissions from Biobädd system

Process of emissions to groundwater from untreated P and N, Biobädd 5ce		
Known outputs to technosphere. Products and co-products	**Amount**	**Unit**
Emissions to groundwater Biobädd	7500000	kg
Emissions to water	**Amount**	**Unit**
BOD5, Biological Oxygen Demand	45	kg
Phosphorus, total	0,75	kg
Nitrogen, total	281,25	kg

The wastewater production per person per year is 60 m^3 if there are both BDT and grey water. The total wastewater that is treated by the equipment systems during their life span of 25 years for a household of 5 person equivalent is 60 m3/pp/yr * 5 pp * 25 yr * 1000 kg/m3 = 7 500 000 kg. (JTI, 2011)

The two equipment systems have different removal rates for BOD and the nutrients (mainly phosphorus and nitrogen), which resulted in different amounts of BOD and nutrients residues released into the recipient (groundwater in Swedish case). The removal rates of Biobädd system are 99% for phosphorus (P), 55% for nitrogen (N) and 98% for BOD. (Avloppsguiden, 2011) From the introduction it is known the average concentrations of pollutants before being treated are 0,6 kg of P, 5 of N and 18 of BOD per person per year. (JTI, 2011)

The amount of pollutant residues for a single household with 5 person equivalent during 25 years from the Biobädd system is calculated as below:

[P] = 0,6 kg/pp/yr * (1-99%) * 5 pp * 25 yr = 0,75 kg.

[N] = 5 kg/pp/yr * (1-55%) * 5 pp * 25 yr = 281,25 kg.

BOD = 18 kg/pp/yr * (1-98%) * 5 pp * 25 yr = 45 kg.

It is assumed that all the residues would end up in the groundwater with the treated water, therefore the process of emissions to groundwater caused by untreated P, N and BOD is created, where 0,75 kg of P, 281,25 kg of N and 45 kg of BOD are emitted by 7 500 000 kg of wastewater when it is treated by the Biobädd system.

7.9 The emissions to groundwater caused by untreated P and N involved in the use phase of Markbädd

Table 12. Inventory data of groundwater emissions from Markbädd system.

Process of emissions to groundwater from untreated P and N, Markbädd 5

Known outputs to technosphere. Products and co-products	Amount	Unit
Emissions to groundwater Markbädd	7500000	kg
Emissions to water	**Amount**	**Unit**
BOD5, Biological Oxygen Demand	112,5	kg
Phosphorus, total	7,5	kg
Nitrogen, total	187,5	kg

The process of emissions to groundwater caused by untreated P, N and BOD after the Marbädd system is created in the similar way as through the Biobädd system. The only difference lied in the pollutant residues amount due to the different removal rate. The removal rates of Markbädd system are 90% for P, 70% for N and 95% for BOD. (Avloppsguiden, 2011)

The amount of pollutant residues for a single household with 5 person equivalent during 25 years from the Biobädd system is calculated as below:

[P] = 0,6 kg/pp/yr * (1-90%) * 5 pp * 25 yr = 7,5 kg.

[N] = 5 kg/pp/yr * (1-70%) * 5 pp * 25 yr = 187,5 kg.

BOD = 18 kg/pp/yr * (1-95%) * 5 pp * 25 yr = 112,5 kg.

The amount of residues could be seen as the emissions to groundwater when treating 7 500 000 kg of wastewater with the Markbädd system during its life span.

7.10 Disposal scenario of both Biobädd and Markbädd system

Table 13. Inventory data of disposal phase of both systems.

Disposal phase		
Waste scenario/treatment	**Material/Waste type**	**Percentage**
Disposal, polyethylene, 0,4% water, to sanitary landfill/CH U	Polyethylene, HDPE, granulate, at plant/RER U	100%
Disposal, polypropylene, 15,9%, to sanitary landfill/CH	Polypropylene fires (PP), crude oil based, production mix, at plant, PP granulate without additives EU-27 S	100%
Disposal, steel, 0% water, to inert material landfill/CH U	Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER S	30%
Recycling steel and iron/RER U	Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304 RER S	70%
Dummy Waste Scenario	PAC	100%

As the main materials involved in the Biobädd system are plastics (including PP and PE) and metals (mainly stainless steel), the disposal phase consisted of two scenarios. In our model, it is assumed that all the wasted plastics are disposed at the landfill. 30% of the metal is disposed at the landfill as well and the rest 70% is recycled (Avfal lSverige, 2010). The recycling of metal also included the process that avoided the environmental burdens from the production of pig iron and iron scraps as the recycled metals are replacing them. PAC, which are involved in the Biobädd system, are disposed in the Dummy waste scenario since the destiny of the chemical is unclear but should not be ignored, in terms of which, should be considered in the dummy scenario.

The disposal scenarios are the same for the Markbädd system since it consisted the same materials (that are stainless steels and plastics) where the only differences lied in the amount of the materials.

7.11 The lifecycle of Biobädd system (without disposal phase)

Table 14. Inventory data of the Biobädd system (without disposal phase).

Biobädd system		
Assemblies	**Amount**	**Unit**
In-Drän Biobädd 5ce	1	p
Ekotreat Phosphorus Reduction Unit	1	p
Septic Tank 4006ce	1	p
PolyAluminium Chloride (PAC)	1218,75	kg
Processes	**Amount**	**Unit**
Electricity, low voltage, production SE, at grid/SE S	6800	kWh
Emissions to groundwater Biobädd	7500000	kg
Sludge treatment	198275	kg
Transport, lorry 3.5-20t, fleet average/CH S	1015,092105	tkm

The Biobädd system is made up of the three assemblies: Ekotreat phosphorus reduction unit, Septic tank 4006ce and In-Drän Biobädd 5ce. PAC is a regularly injected flocculent and coagulant for chemical precipitation into the phosphorus reduction unit. The total doze of injection during the equipment's life span is 1218,75 kilograms, which is explained in section 7.2.

The use phase of Biobädd system includes an important process that is the electricity consumption in respect to the electricity demand from Ekotreat and from the fan for ventilation. (Avloppsguiden, 2011) The Ekotreat unit consumes 4 kWh per year in the operational phase, which makes the total electricity consumption 100 kWh for the whole life span. (Avloppsguiden, 2011) The fan is more electricity demanding, consuming 268 kWh per year, which makes the total consumption in the life span to be 6700 kWh. (Ambrosson, 2014) The Emissions to groundwater are originated from the untreated nutrients and organic matters in the outgoing effluent. This is related to the removal rate of P, N and BOD of the system itself. The emissions have been illustrated in section xx.8. Sludge collection and treatment processes are the same for both systems. The calculation of transport system regarding sludge collection is a bit complicated. According to JTI, the sludge is collected once per year during one work day and one sludge truck is taking care of 9 households. The diesel use for one truck in one day is 9,6 litres, which means a single household will consume 1,07 litres of diesel per year for sludge collection. (JTI, 2011) One typical sludge truck manufactured in China consumes 20,9 litres of diesel travelling every 100 km. (http://www.chinacar.com.cn, 2014) The amount of sludge production per year could be calculated with the data in section xx.6, which is 793,1 kg. The amount of transport of sludge collection and transport for a single household per year is then 4,06 tkm, which makes the total amount of transport during the life span 1015,092 tkm.

7.12 The lifecycle of Markbädd system (without disposal phase)

Table 15. Inventory data of the Markbädd system (without disposal phase).

Biobädd system		
Assemblies	**Amount**	**Unit**
In-Drän Markbädd 5ce	1	p
Ekotreat Phosphorus Reduction Unit	1	p
Septic Tank 4006ce	1	p
PolyAluminium Chloride (PAC)	1218,75	kg
Processes	**Amount**	**Unit**
Electricity, low voltage, production SE, at grid/SE S	100	kWh
Emissions to groundwater Biobädd	7500000	kg
Sludge treatment	198275	kg
Transport, lorry 3.5-20t, fleet average/CH S	1015,092105	tkm

The Markbädd system consists of the Ekotreat phosphorus reduction unit, the Septic tank 4006ce and the Marbädd 5. PAC is used as the flocculent and coagulant for chemical precipitation in the phosphorus reduction unit, which means it is the same in both systems, making the amount the same as in the Biobädd system.

Electricity consumption is 100 kWh as no fan is used in the Marbädd system and Ekotreat is the only device that uses electricity. The unit is the same for both systems, meaning the electricity consumption is also the same for both systems. The emissions to groundwater caused by P, N and BOD are highly depending on the removal rate of the systems, and in respect to the Markbädd system have been stated in section 7.9. Sludge collection and transport, as well as treatment are the same for both treatment systems.

8 Annex 2. Additional illustrations

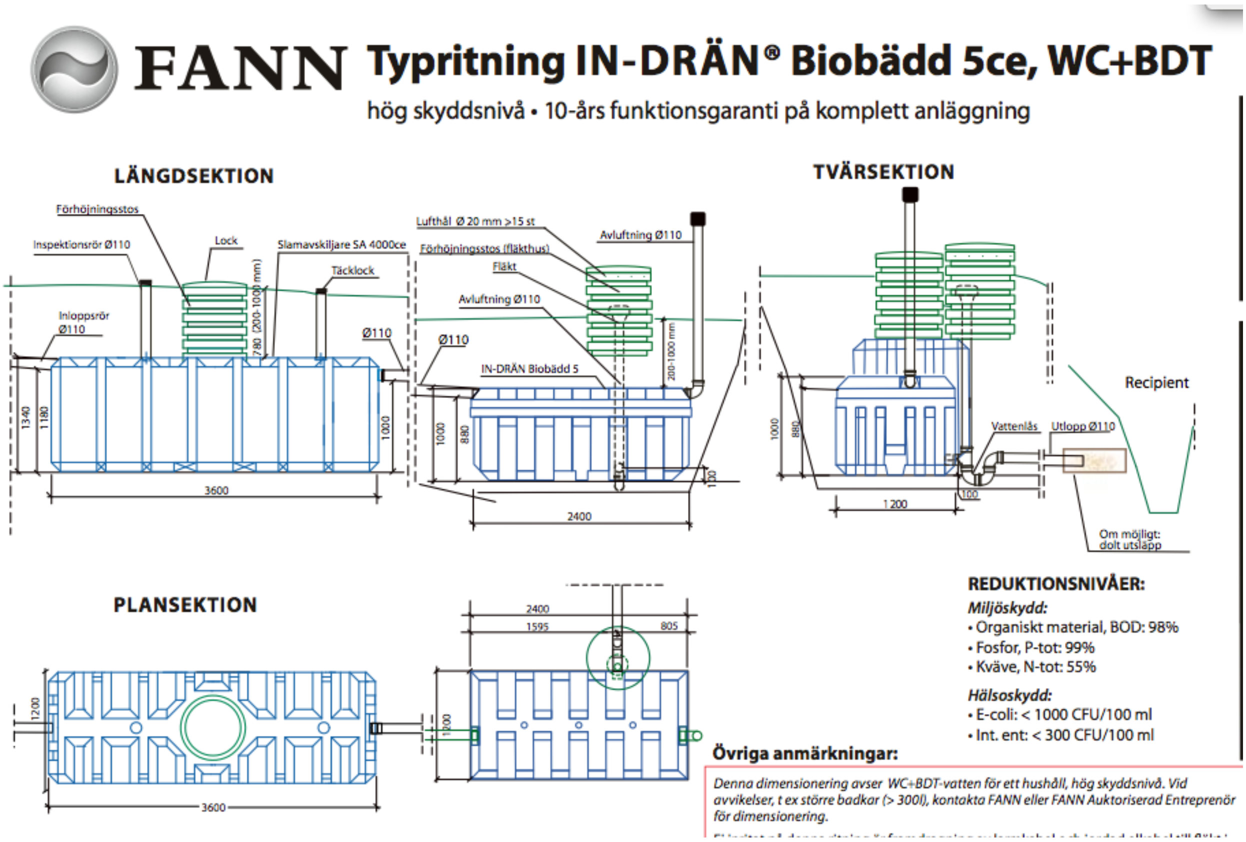

Figure 14 . Technical illustration of the complete In-Drän Biobädd 5ce system, complete with all components. Source: Fann VA-Teknik (2014).