Norges miljø- og
biovitenskapelige
universitet

Master's Thesis 2016
30 Credits

Norwegian University of Life Science
Faculty of Environmental Science and Technology
Department of Environmental Science

COMPARATIVE ENVIRONMENTAL PERFORMANCE OF SMALL SCALE WASTEWATER TREATMENT SYSTEMS IN NORWAY – A LIFE CYCLE ANALYSIS

Krishna K.T.K. Magar
Specialization in Sustainable Water and Sanitation, Health and Development

TABLE OF CONTENTS

TABLE OF CONTENTS……………………………………………………………………..i
ACKNOWLEDGEMENT……………………………………….…………………v

ABSTRACT………………………………………………………………………………vi

ABBREVIATIONS……………………………………………………………………..x

LIST OF FIGURES……………………………………………………………………xii

LIST OF TABLES……………………………………………………………………xiv

LIST OF UNITS…………………………………………………………………………xv

1. INTRODUCTION…………………………………………………………………1
   1.1.Background Introduction………………………………………………………1
   1.2.Objective of the study…………………………………………………………2

2. LITERATURE REVIEW…………………………………………………………….3
   2.1. Water Quality and Scarcity……………………………………………………3
   2.2. Wastewater treatment…………………………………………………………4
   2.3. Process involved in wastewater treatment……………………………………….5
      2.2.1. Preliminary treatment……………………………………………………5
      2.2.2. Primary treatment………………………………………………………..6
      2.2.3. Secondary treatment……………………………………………………..6
      2.2.4. Tertiary treatment……………………………………………..........6
   2.4. Aerobic and Anaerobic process………………………………………………..6

   2.5. Sustainability of Wastewater management system……………………………….7
      2.5.1. Economic ………………………………………………………………..8
      2.5.2. Environmental ……………………………………………...........9
      2.5.3. Socio-cultural………………………………………..............................9

   2.6. Types of Wastewater treatment system………………………………………….10
      2.6.1. Centralized wastewater treatment system ………………………………...10
      2.6.2. Decentralized wastewater treatment system……………………………….11

   2.7. Wastewater treatment in Norway………………………………………………..14

   2.8. Small scale de-centralized wastewater treatment system in Norway……………15

         2.8.1. Constructed wetlands…………………………………………………17

2.8.2. Soil infiltration system……………………………………………………..20

2.8.3. Sand filtration system…………………………………………………… 23

2.9. Life Cycle Assessment (LCA)……………………………………………………23

2.9.1. Four Phases of LCA framework ………………………………………..24

2.9.1.1. Goal and Scope definition………………………………….26

2.9.1.1.1. Boundary conditions……………………………...26

2.9.1.1.2. Functional unit……………………………………27

2.9.1.1.3. Data quality requirement…………………………27

2.9.1.1.4. Comparison between systems…………………….27

2.9.1.2. Life Cycle Inventory (LCI)…………………………………27

2.9.1.3. Life Cycle Impact Assessment (LCIA)…………………….28

2.9.1.3.1. Category definition……………………………….29

2.9.1.3.2. Classification……………………………………..31

2.9.1.3.3. Characterization…………………………………..31

2.9.1.3.4. Normalization…………………………………….32

2.9.1.3.5. Valuation………………………………………….32

2.9.1.4. Interpretation………………………………………………..33

2.9.2. Limitations of LCA…………………………………………………...33

2.9.3. LCA software available………………………………………………….34

2.9.3.1. SimaPro 7…………………………………………………...34

2.9.3.1.1. Goal and Scope definition in SimaPro 7………….34

2.9.3.1.2. Inventory Analysis in SimaPro 7…………………34

2.9.3.1.3. Impact Assessment in SimaPro 7………………….35

2.9.3.1.4. Interpretation in SimaPro 7……………………….35

2.9.4. LCA for sustainability of wastewater treatment system……………...35

3. METHODOLOGY…………………………………………………………………..38

3.1. Systems under study……………………………………………………38

3.1.1. Høyås farm wastewater treatment system……………………38

3.1.2. Kaya grey water treatment system……………………………40

3.1.3. Natural wastewater treatment system at Vidaråsen Camphill, Andebu………………………………………………………………42

3.2. Goal and Scope definition of the study…………………………………47

3.2.1. Goal of the study……………………………………………...47

3.2.2. Scope of the study……………………………………………47

3.2.2.1. Functional Unit in the study……….……………….47

3.2.2.2. System boundaries of the study……………………..47

3.2.3. Assumptions made in this study………..……………………..49

3.3. Life Cycle Inventory analysis (LCI) of the study………………………50

3.3.1. Construction phase inventory…………………………………51

3.3.2. Operational phase inventory…………………………………..51

3.4. Life Cycle Impact Assessment (LCIA)…………………………………54

3.4.1. Global Warming Potential (GWP)……………………………55

3.4.2. Ozone layer Depletion Potential (ODP)……………………...55

3.4.3. Eutrophication Potential (EP)………………………………...55

3.4.4. Acidification Potential (AP)…………………………………56

4. RESULTS, DISCUSSIONS AND INTERPRETATION………………………...57

4.1. Results of Høyås farm WWT system…………………………………..58

4.2. Results of Kaya grey water treatment system…………………………..61

4.3. Results of Vidaråsen WWT system……………………………………65

4.4. Overall discussions of the systems……………………………………..68

4.5. Comparative impact assessment of three systems under study………...71

5. CONCLUSION AND RECOMMENDATION…………………………………75

5.1. Conclusion……………………………………………………………...75

5.2. Recommendations………………………………………………………76

REFERENCES……………………………………………………………...............77

ANNEX 1: Treatment performance of wastewater treatment systems under study.

ANNEX 2: Water emissions and sludge quantity from wastewater treatment systems under study.

ANNEX 3: Air emissions from wastewater treatment systems under study.

ANNEX 4: Summary of construction materials, emissions, sludge and energy.

ANNEX 5: Quantity estimation sheet of construction materials of wastewater treatment systems under study.

ANNEX 6: Cross section diagram of treatment units, product specification of Filtralite filter media, individual summary of construction materials.

ANNEX 7: Assembly layout diagrams of AP, EP, GWP & ODP of WWT systems under study.

ANNEX 8: Specification per substance of WWT systems under study.

ACKNOWLEDGEMENT

I would like to express my sincere gratitude to the “Department of Environmental Science”, NMBU, for allowing me to write this thesis as a requirement for Master’s degree in Sustainable Water and Sanitation, Health and Development.

My heartly thanks and appreciation goes to my supervisor Asst. Prof. Dr. Manoj Pandey whose valuable guidance, assistance and encouragement throughout the study period made me capable to complete this thesis. I am very much thankful to Prof. Petter D. Jenssen, my Co-supervisor for all the support and assistance rendered.

I am thankful also to my wife Janaki Thapa Magar and my son Junier Khamcha, who have provided me a great support and courage during this period. Also I would like to thank to my family and friends for their valuable support during the period of my study.

Krishna K.T.K. Magar

ABSTRACT

Globally, the development of wastewater treatment systems evolved in order to treat wastewater so as to mitigate and reduce the public health issues as well as environmental impacts resulting from the discharge of untreated wastewater. To achieve this objective, treatment of wastewater is carried out with different technologies, some centralized and other decentralized. With further development in the wastewater management sector, sustainability of the wastewater treatment system with minimum environmental degradation became a global concern because all human individuals either living today or in future, have equal rights. Therefore, based on the sustainable development approach of wastewater treatment systems, various methods have been practiced to analyse and compare the wastewater treatment systems looking from the environmental, economic, technical and social point of view. Life Cycle Assessment (LCA) is one of them and has been successfully practiced globally, in order to analyse the environmental burdens and the potential impacts associated with a Wastewater Treatment (WWT) system. LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or system throughout its life cycle i.e. the stage from "cradle-to-grave" (ISO 144040:2006(en)). It has become a successful tool in identifying opportunities to improve the environmental performance hence playing an integral role in decision making towards sustainability.

This study is focused on identifying and analysing the environmental burdens from three different decentralized WWT systems that are in operation in Norway using LCA. Kaja grey water treatment system is based on source separation technique which treats only the grey water generated by 48 persons, Høyås farm WWT system treats domestic wastewater only from a household of 8 persons and Vidaråsen WWT system that treats domestic wastewater from from 200 peoples along with wastes from a dairy, a bakery, a laundry, an animal husbandry, a food-processing workshop and a herb-garden. The boundary of the LCA study is limited only up to construction and operation phases and the functional unit considered was wastewater generated per person equivalent over duration of 20 years. CML2 baseline 2000 (Centre for Environmental Science, University of Leiden, The Netherlands) of SimaPro 7 software, has been used in analysing the environmental impacts limited to Acidification Potential (**AP**), Eutrophication Potential (**EP**), Ozone Layer Depletion Potential (**ODP**) and Global Warming Potential (**GWP**).

For Høyås farm WWT system, **AP** (99.6% of the total value) is resulted during the construction phase. The main factor contributing to the impact is the production process of filter media “Filtralite-P” (41%) and pre-fabricated fibre glass components (31.3%). Likewise, **ODP** (98.9% of the total value) is also generated during the construction phase and the key resulting factor to the impact is the production process of filter media “Filtralite-P” (62.6%). Similarly, **EP** (96.55% of the total value) is resulted during the operation phase. Total-N (89.4%) and Total-P (7.2%) are the main elements contributing to the impact. **GWP** is resulted in both phases, 57.64% in operation phase and 42.24% in construction phase. Methane emission is the major greenhouse gas contributing 60.12% followed by carbon dioxide emission contributing 21.5% to GWP (Annex 8).

For Kaja grey water treatment system, **AP** (99.9% of the total value) and **ODP** (99.63% of the total value) is contributed during the construction phase. The main factor contributing to both of the impacts is the production process of filter media “Filtralite-P” (78.9 % of total AP and 89.9% of total ODP). Likewise, **EP** (87.5% of the total value) is generated during the operation phase. Total-N (74%) and Total-P (13%) are the main element resulting to the impact. Similarly, **GWP** is generated in both phases, 55.38% in construction phase and 44.61% in operation phase. Methane emission is the major greenhouse gas contributing 45% followed by carbon dioxide emission contributing 42.9% to the impact. In the construction phase, GWP is caused by CO_2 emission during the production of Filtralite-P (37.6%) and polystyrene foam (11.9%).

Similarly, for Vidaråsen WWT system, **AP** (98.54% of the total value) and **ODP** (96.36% of the total value) is generated during the construction phase. The main factor contributing to both of the impact is the production process of filter media “Filtralite-P” (61.3 % of total AP and 82.6% of total ODP). Likewise, **EP** (98.04% of the total value) is contributed during the operation phase. Total-N (65.62%) and Total-P (32.3%) are the main elements in the effluent causing the impact. Similarly, **GWP** (98.58%) originates during the operation phase. Methane emission is almost 100% responsible for this impact and is contributed by the emissions from septic tank, facultative pond and constructed wetlands during the operation period.

From the results of environmental impacts of all the three systems, it is seen that **AP** and **ODP** originate in the construction phase of every systems. The major factor contributing to these impacts in all the three treatment systems is the production process of filter media

"Filtralite-P" (expanded clay). Productions of pre-fabricated fibre glass components are also responsible for these impacts. In all the three systems, **EP** is occuring during the operation phase and Total-N is the main element responsible for the impact. Likewise, **GWP** in two of the systems is mainly originated during operation phase but in one system it is originated in both the construction and operation phase. Greenhouse gases contributing to GWP are methane (CH_4) emission from the treatment units during the operation stage and carbon dioxide (CO_2) emission during the production process of Filtralite-P in the construction phase.

Comparative assessment of three systems show that Kaja grey water treatment system is the system with best environmental performance. The system is based on source separation technique occupying a very small area with a low number of treatment units (a septic tank, a bio-filter unit and a horizontal flow constructed wetland) and treats grey water from 48 persons. The Kaja grey water treatment system contributes the least to **EP** and **GWP** among the three systems. However, the environmental performance scenario could be different if the system boundary is expanded to include the vaccum toilet system including the required plumbing elements. Høyås farm WWT system has the highest contribution to **AP, EP** and **ODP** among the three systems. This could be one of the findings that it is more reliable and environment friendly to treat wastewater from a group of houses or clusters rather than building up a treatment system only for a single household as in case of Høyås farm. Similarly, Vidaråsen WWT system has the highest contribution to **GWP.** This is resulted because the scale of the system is higher than other systems so it has higher operational greenhouse gas emissions.

The important finding from this study is, though Filtralite-P has been regarded as a high quality filter media for phosphorus removal (ÁdÁm, et al., 2007), its production process has significant impacts in the environment regarding **AP, GWP** and **ODP.** According to (Roseth, 2000; Adam, et al., 2007) Filtramar (shell-sand) has higher phosphorus adsorption capacity than Filtralite-P. So recommendation can be made to analyse the environmental impacts, with Filtramar (shell-sand) used as an alternative filter media in on-site wastewater treatment systems.

Environmental impacts associated with transport of sludge have minor contribution but still there could be options for reducing the sludge disposal cost and the potential impacts resulting during its transport. Like, in case of Vidaråsen WWT system, where the sludge volume generated is high, sludge drying reed-beds can be constructed near to the site so that a significant reduction in the sludge volume can be achieved.

ABBREVIATIONS

AP	:	Acidification Potential
BF	:	Bio-filter
BOD	:	Biological Oxygen Demand
CFC	:	Chloroflurocarbons
CH_4	:	Methane
CML	:	Centre for Environmental Science
COD	:	Chemical Oxygen Demand
CO_2	:	Carbon dioxide
CW	:	Constructed Wetland
EFP	:	Enhanced Faculative Pond
EP	:	Eutrophication Potential
FAET	:	Freshwater Aquatic Eco-toxicity
$FeCl_3$	:	Iron (III) Chloride
FU	:	Functional Unit
GaBi	:	Ganzheitlichen Bilanzierung
GWP	:	Global Warming Potential
HCFC	:	Hydrochloroflourocarbons
HSSFW	:	Horizontal sub-surface flow wetland
HTP	:	Human Toxicity Potential
IPCC	:	Intergovernmental Panel on Climate Change
ISO	:	International Standardization Organization
LCA	:	Life Cycle Assessment
LCI	:	Life Cycle Inventory
LCIA	:	Life Cycle Impact Assessment
NH_3	:	Ammonia
N_2O	:	Nitrous Oxide

NO_2 : Nitrogen dioxide

NO_X : Nitrogen oxides

ODP : Ozone layer Depletion Potential

PC : Pumping Chamber

PF : Phosphorus Filter

PO_4^{-3} : Phosphates

POCP : Photochemical Ozone Creation Potential

PTF : Pre-treatment Filter

PVC : Polyvinylchloride

SETAC: Society of Environmental Toxicology and Chemistry

SF : Sand Filter

SO_2 : Sulphur dioxide

SP : Stabilization Pond

ST : Septic Tank

STE : Septic Tank Effluent

TETP : Terrestrial Eco-toxicity Potential

TN : Total Nitrogen

TOC : Total Organic Carbon

TP : Total Phosphorus

UN : United Nations

UNICEF: United Nation International Children's Emergency Fund

UV : Ultra Violet

VOC : Volatile Organic Carbon

VSSFW: Vertical sub-surface flow wetland

WCED: World Commission on Environment and Development.

WHO : World Health Organization

WWT : Waste Water Treatment

WWTP: Wastewater Treatment Plant

WWTS: Wastewater Treatment System

LIST OF FIGURES

Fig. 2.1.(a) : Aerobic process in WWT system.

Fig. 2.1.(b) : Anaerobic process in WWT system.

Fig. 2.2 : Representation of centralized wastewater collection and treatment system.

Fig. 2.3 :Representation of de-centralized wastewater collection and treatment system.

Fig. 2.4 : Distribution of on-site wastewater treatment systems in Norway.

Fig. 2.5 : The latest generation of constructed wetlands for cold climate with integrated aerobic bio-filter in Norway.

Fig. 2.6 : Horizontal flow constructed wetland with pre-treatment.

Fig. 2.7 : Vertical flow constructed wetland with pre-treatment.

Fig. 2.8 : Soil infiltration system.

Fig. 2.8.1. : Surface infiltration.

Fig. 2.8.2. : Open system, rapid infiltration.

Fig. 2.8.3 : Buried system, slow rate infiltration.

Fig. 2.8.1, 2.8.2 and 2.8.3 : Example design concept of soil infiltration system.

Fig. 2.9 : Sand filter system.

Fig. 2.10 : LCA framework according to ISO 14040 series.

Fig. 2.11 : Life Cycle Inventory Analysis overview.

Fig. 2.12 : Elements of LCIA phases.

Fig. 2.13 : An overview of the steps followed in LCIA.

Fig. 2.14 : Methodological steps in LCA.

Fig. 3.1 : Small scale wastewater treatment plant at Høyås farm.

Fig. 3.2 : Complete recycling system at student dormitories based on separate treatment loops for blackwater and greywater.
Fig. 3.3 : Cross-sectional view of Enhanced Faculative Pond (EFP).
Fig. 3.4 : Cross-sectional view of pre-filter 1 and fre-filter 2.
Fig. 3.5 : Plan view of Enhanced Faculative Pond (EFP).
Fig. 3.6 : Layout diagram of wastewater treatment system at Vidaråsen Camphill.
Fig. 3.7 : System boundary of Høyås farm WWT system in this study.
Fig. 3.8 : System boundary of Kaya grey water treatment system in this study.
Fig. 3.9 : System boundary of Vidaråsen WWT system in this study.
Fig. 3.10 : Representation of environmental inputs and outputs in LCI analysis.
Fig. 4.1 : Impact Characterization of Høyås farm WWT system.
Fig. 4.2 : Normalization of impacts of Høyås farm WWT system.
Fig. 4.3 : Impact Characterization of Kaya grey water treatment system.
Fig. 4.4 : Normalization of impacts of Kaya grey water treatment system.
Fig. 4.5 : Impact Characterization of Vidaråsen WWT system.
Fig. 4.6 : Normalization of impacts of Vidaråsen WWT system.
Fig. 4.7 : Impact Characterization of three treatment systems under study.
Fig. 4.8 : Normalization of impacts of three treatment systems under study.
Fig. (i) : Cross-section of WWT system in Hoyas farm.
Fig. (ii) : Cross section of Septic Tank.
Fig. (iii) : Cross section of Bio-filter.
Fig. (iv) : Cross section of Sand Filter.

LIST OF TABLES

Table 2-1 : Individual percentage removal efficiency of a septic tank.

Table 2-2 : Percentage removal efficiency of constructed wetland.

Table 2-3 : Percentage removal efficiency of soil infiltration system.

Table 2-4 : Most important Impact categories and possible indicators

Table 3-1 : Average treatment results of Høyås farm WWT system from studies.

Table 3-2 : Average outlet concentration (mg/L) and treatment performance (%) of Kaya Grey water treatment system.

Table 3-3 : Design information's of treatment units of Vidaråsen WWT system.

Table 3-4 : Average effluent concentrations and % removal from different treatment units (mg/L).

Table 3-5 : Summary of construction materials used in Høyås farm, Kaya system and Vidaråsen WWT system.

Table 3-6 : Grey water composition measured in septic tank effluent in Kaya grey water treatment system.

Table 3-7 : Percentage of P, N, BOD_5 and COD a person produces per day.

Table 3-8 : Greenhouse gas emissions from septic tank.

Table 3-9 : Greenhouse gas emissions from constructed wetland.

Table 3-10 : Greenhouse gas emissions from natural pond system.

Table 3-11 : Normalization value used in CML2 baseline 2000 method.

Table 4-1 : Summary of calculated operational input inventory data.

Table 4-2 : Impact characterization of Høyås farm WWT system.

Table 4-3 : Normalization of impacts of Høyås farm WWT system.

Table 4-4 : Impact characterization of Kaya grey water treatment system.

Table 4-5 : Normalization of impacts of Kaya grey water treatment system.

Table 4-6 : Impact characterization of Vidaråsen WWT system.

Table 4-7 : Normalization of impacts of Vidaråsen WWT system.

Table 4-8 : Impact characterization of three systems under study.

Table 4-9 : Normalization of impacts of three systems under study.

Table (i) : Summary of materials used for construction of Høyås farm WWT system.

Table (ii) : Summary of materials used for construction of Kaya grey water treatment system.

Table (iii) : Summary of materials used for construction of Vidaråsen WWT system.

LIST OF UNITS

kg : Kilograms

L : Liters

g : gram

mg : Milligrams

kWh : Kilo Watt Hour

m^3 : Cubic meter

m : Meters

p.e. : Person equivalent

1.0. INTRODUCTION

1.1. Background

In the past century, scientists discovered that the main cause of outbreaks of diseases like typhus, cholera, hookworm, trachoma and diarrhoea was due to direct contact of human beings with their own excreta and spreading of pathogenic micro-organisms present in the excreta (Wilderer, et al., 2000; Massoud, et al., 2009). To protect and control the human population from getting infected, centralized sewer systems were developed. The domestic wastewater, industrial wastewater and storm water runoff was connected to the central sewer system and was transported away from the human settlements through the sewer network. The sewer network ended up into the surface waters. Later, it was realized that this too could create health hazards to the people who live down-stream of the discharge point and also to the aquatic life. So the development of wastewater treatment technology became the main option to improve the quality of surface water. The centralized wastewater collection and treatment evolved to address the issue (Wilderer, et al., 2000).

Due to industrialization and increase in human population, people began to migrate from rural areas to urban areas. With the increase in urban population density, the waste generation also increased in the urban and city areas. The uncontrolled and untreated disposal of domestic, municipal, industrial and agricultural wastes either in solid, liquid or gaseous forms increased the level of pollution to land, water and air contributing to environmental degradation. This became one of the serious threats to the sustainability of human civilization (Jhansi, et al., 2013). In addition, water scarcity and its quality deterioration also became a global concern issue for every developing society. So to preserve the public health, reduce the environmental degradation and prevent the sources of clean water from getting contaminated, it became essential to adopt effective wastewater management systems. This was possible with adequate treatment of wastewater, safe disposal of treated wastewater, efficient use of water resources and water reuse practices (Jhansi, et al., 2013). The environmental impacts that results from the waste depends on the quantity and nature of waste generated and the treatment process adopted for the waste management. Effective wastewater management systems are still limited in most of the developing countries as compared to developed countries (Jhansi, et al., 2013). In addition, it is a great challenge and necessity to manage the huge amounts of sewage sludge produced from the wastewater treatment plants in an economical and environmentally acceptable way and it has also become a matter of public health concern (Jhansi, et al., 2013). Later, as an alternative, decentralized approaches of wastewater treatment were developed which employs a combination of on-site and /or cluster systems (Massoud, et al., 2009). Centralized wastewater treatment systems require a high level of investments due to high cost of infrastructure construction, operation cost, maintenance cost and highly skilled personal (Massoud, et al., 2009). So constructing a centralized treatment system does not seem reliable for small and dispersed communities in rural and semi-urban areas (Massoud, et al., 2009; Seidenstat, 2003). Decentralized wastewater treatment systems become preferable to such areas because these systems operate in small scale, are less expensive and easier to construct, easy to operate and maintain, the treatment is carried out in the close vicinity of the origin and this facilitates reuse of wastewater (Massoud, et al., 2009; Jhansi, et al., 2013). This paper focus on identification of the environmental impacts resulting from three different decentralized wastewater treatment systems that are in operation in Norway, using a Life Cycle Assessment (LCA) tool. LCA addresses the environmental aspects and the potential environmental impacts throughout a product's life-cycle from the stage of raw material production, during its use and operation and includes potential-recycling and reuse as well as the final waste disposal i.e. follows the system and its components from "cradle-to-grave" (ISO 14044:2006(en)).

1.2. Objectives of the study

The aim of the study is to assess the environmental performance of the decentralized wastewater treatment systems in cold climate. The specific objective of the study are:

• To perform inventory analysis of material use, resource consumption and theenvironmental releases from the decentralized small scale wastewater treatment systems in cold climates, specifically in Norway.

• To identify the environmental hot spots of the systems investigated.

• To perform improvement analysis aimed to improve the environmental-performance of the systems evaluated.

2.0. LITERATURE REVIEW

In this chapter, introduction on wastewater treatment, methods practiced on treatment of wastewater, factors affecting the sustainability of wastewater treatment system and Life Cycle Assessment (LCA) tool for analysing the environmental impacts of small-scale decentralized wastewater treatment system are described briefly.

2.1. Water quality and scarcity:

Globally, billions of people are out of reach to safe water and adequate sanitation (Massoud et al., 2009). Per capita availability of fresh water is decreasing rapidly in the entire world where mostly the developing countries are facing the water scarcity problems (Kivaisi, 2001). Due to increased pollution, the quality of available fresh water is also deteriorating. According to the World Health Organization (WHO) and the Water Supply and Sanitation Collaborative Council, about 82 percent of the rural populations of developing countries lack access to sanitation facilities which finally lead to several waterborne diseases (Massoud, et al., 2009). In developing countries, insufficient clean water and improper sanitation facilities are the main cause of diseases and outbreaks (Jhansi, et al., 2013). As discussed earlier, the reason behind this is due to direct contact of human beings to excreta and spreading of pathogenic micro-organisms, untreated sewage, industrial wastes, organic matters, inorganic chemicals, toxic substances and other disease-causing agents which are directly discharged into the aquatic environment without any treatment. Furthermore, the groundwater and the surface water sources are getting contaminated due to surface runoff and infiltration of domestic wastewater, poorly constructed pit latrines and excess use of fertilizers in the agriculture sector (Kivaisi, 2001).

The population growth forecasts that the global population will reach 9 billion in 2030 and it indicates that most of the population growth will occur in the developing countries with a strong migration from rural to urban areas (Jhansi, et al., 2013). It is a real fact that for every developing country, the demand for water supply and sanitation becomes the first priority then the wastewater treatment. Everyone prioritizes to fulfil their water supply and sanitation needs first, than only they can think of solutions for wastewater treatment. This problem becomes more crucial in dry and water-deficient areas. Henceforth, to reduce the problem of fresh water scarcity saving, pollution control for water reserves, wastewater recycling and reuse becomes an important practice to conserve the water resources especially in areas which are facing water deficiency. In addition, use of an appropriate and affordable wastewater treatment technology that are simple to operate, more environment-friendly and low investment cost could be a valuable measures for effective wastewater management.

According to the estimates of United Nations Food and Agriculture Organization, out of 7.3 billion people in the world, about 795 million people were suffering from chronic undernourishment in 2014 – 2016 of which 780 million people are from developing countries (FAO 2014; Hunger Notes, 2016). In the rural areas of many developing countries, access to adequate food depends greatly on access to natural resources, including water because water is the key source for food security (UN.org. 2014). Therefore, practices on saving of water resources and recycling, reuse of available water becomes an important factor to be considered in developing countries facing water scarcity which could somehow to some extent solve the problem of hunger in the world.

Another most important aspect of treating the wastewater is, domestic wastewater contains organic matter and the three main nutrients for plant production (i.e. nitrogen, phosphorous and potassium) (Jenssen, et al., 2007). Among these three valuable nutrients, nitrogen fertilizer consumes energy during production and phosphorous fertilizer is a limited mineral resource (Jenssen, et al., 2007). According to Jenssen, et al., (2007), nutrients from domestic wastewater and organic household waste, are almost sufficient in producing enough food for the world population.

Henceforth, it becomes necessary to design and implement a sustainable wastewater treatment system so as to reduce the human health problems and preserve the natural environment.

2.2. Wastewater treatment

Wastewater is the water which is no longer suitable for its most recent uses. Generally, contaminated water such as the water from kitchens, toilets, showers, industrial waste mixed water, agricultural runoffs, storm water etc. can be called as wastewater. Wastewater is harmful to human health and natural environment if it is consumed or used directly without any treatment because it contains harmful agents such as pathogenic micro-organisms, bacteria, virus, organic and inorganic matter, toxic substances, heavy metals, nutrients like phosphorous and nitrogen, sulphur, chloride and gases like methane (CH_4), carbon dioxide (CO_2), nitrogen (N_2), hydrogen sulphide (H_2S) and ammonia (NH_3) that can possibly cause several waterborne diseases to humans and aquatic animals. In addition, an excess presence of phosphorus and nitrogen in wastewater is the major cause of eutrophication and oxygen depletion in natural water bodies if the wastewater is directly disposed to the natural water bodies without any treatment (Tchobanoglous, et al., 1991). Wastewater can be treated and recycled so that it can cause minimum health problems and can be reused or released to the environment safely. Therefore, wastewater treatment is a process adopted to convert wastewater into an effluent that can be safely returned back to the water cycle with minimum environmental issues or can be re-used (En.wikipedia.org, 2016).

General parameters that are to be considered and measured in a treated wastewater are; Total–P, Total-N, organic pollution, pathogenic micro-organisms, odour, colour, turbidity and hardness. Organic pollution is measured by parameter COD (Chemical Oxygen Demand), BOD (Biological Oxygen Demand) and SS (Suspended Solids). COD describes the amount of oxygen required to oxidize all organic and inorganic matters present in the wastewater sample (Scholzel, 1999). BOD describes the oxidizing process, biologically with the help of bacteria. Usually, BOD is measured as BOD_5, which means the amount of oxygen consumed over a five-day measurement period. Likewise, suspended solids describe the quantity of organic or inorganic matters that is not dissolved in water (Scholzel, 1999). Total-P is the total quantity of phosphorous content and Total-N is the total quantity of nitrogen content in the water. All these parameters (i.e. COD, BOD, SS, Total-P and Total- N) are measured in "mg/l" or "g/m^3".

2.3. Processes involved in wastewater treatment:

According to the function they perform and their complexity, processes involved in wastewater treatment can be classified into four major groups (Scholzel, 1999), which are as follows:

2.3.1. Preliminary treatment

This process involves with the removal of easily separable components like solid materials and debris. Usually, this process is achieved by screening and grit removal and is performed to increase the effectiveness of the later treatment processes and prevent damages in the later treatment units (Scholzel, 1999). Bar screens are usually used for this process.

2.3.2. Primary treatment

This process involves with the removal of solid materials (i.e. organic solid matter, human waste etc.). Sedimentation, Flotation and Filtration mechanisms as per the need, are involved during the process. Sedimentation and flotation tanks are usually used in huge centralized treatment plants whereas septic tanks are usually used in small-scale treatment systems (En.wikipedia.org, 2016). The main mechanism that occurs is the solids and particles heavier than water gets to settle down at the bottom of the tanks and are scrapped and pumped out in the form of sludge from the bottom. Floating grease like soap scum, wood chips, feathers etc. is removed by skimmers. After the sedimentation unit, the wastewater undergoes filtration step where colloidal suspensions of fine solids are removed. Reduction of BOD up to 40% can be achieved after the primary treatment process (Scholzel, 1999).

2.3.3. Secondary treatment

This process involves in a biological process where the dissolved and suspended organic matters as well as nutrients nitrogen and phosphorus are removed (En.wikipedia.org, 2016). Organic matters are converted to stable forms by bacteria during the biological process (Scholzel, 1999). Secondary treatment involves with both the aerobic and anaerobic processes. In a centralized wastewater treatment system, disinfection method is carried out in order to kill the pathogenic bacteria and viruses. Examples of secondary treatment in decentralized WWT systems are aerobic bio-filter, reed bed systems and stabilization ponds (Scholzel, 1999).

2.3.4. Tertiary treatment

Tertiary treatment is the final treatment process which involves in a polishing process where further purification of the treated effluent to desired levels is carried out. Specific pollutants like nitrogen, phosphorus, specific industrial pollutants, viruses, parasites etc. are usually removed during this process (Scholzel, 1999). Processes like membrane filtration, ozonation are carried out in the centralized treatment system, likewise constructed wetlands are practiced in small-scale treatment systems (En.wikipedia.org, 2016).

2.4. Aerobic and anaerobic processes

Biological treatment processes is an important and integral part of any wastewater treatment system because wastewater contains organic and inorganic materials. The main phenomenon involved in biological treatment is the use of bacteria and other microorganisms to remove contaminants by assimilating them (Schultz, 2005). Aerobic and anaerobic processes are the two main mechanisms that take place with the presence or absence of oxygen during treatment in a biological treatment process of wastewater. Both the process are involved in degradation of organic matter in the presence or absence of oxygen where the bacteria and microorganisms assimilate the bio-degradable organic impurities thereby converting them into by-products such as methane gas, carbon dioxide gas, water and excess biomass (sludge) (Schultz, 2005).

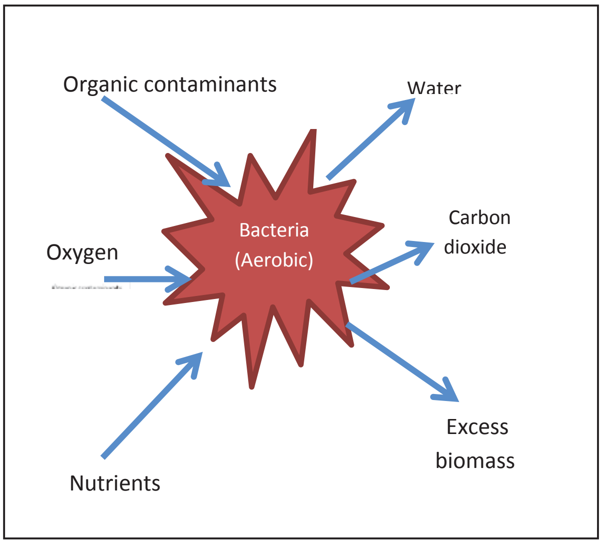


Fig. 2.1.(a) Aerobic process

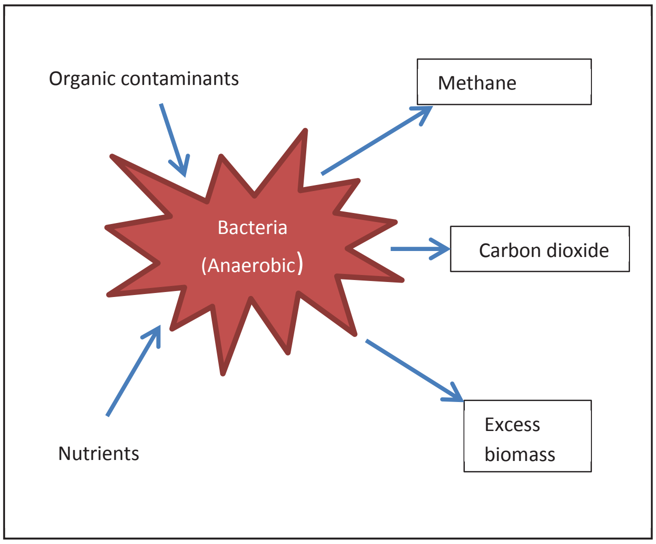


Fig. 2.1.(b) Anaerobic process

2.5. Sustainability of Wastewater management system

World Commission on Environment and Development (WCED, 1987) defines sustainable development as, *"development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs"* (Balkema, et al., 2002). This focuses on the concept that all human individuals living today or in future, have equal rights (Balkema, et al., 2002). However, different generations may have to deal with different problems, circumstances and cultures. Wastewater management is one of the key function for the improvement in global health, sanitation and reduction in spreading of diseases (Muga, et al., 2008). Hence, sustainability of wastewater management system becomes an important factor to be considered. The sustainable technology should be based on a long and global view. It should be compatible and adaptable to the natural, economic, technical and social environment offering a possibility for further development (Balkema, et al., 2002). Wastewater sewer networks and the treatment technologies (i.e. centralized and decentralized treatment systems) were primarily designed for the protection of human health and environmental degradation (Jhansi, et al., 2013). .

Studies show that, in the case of centralized treatment system, the mixing of different wastewater streams containing pathogens and toxic compounds from industries and organic matters and nutrients from household sewage, makes the treatment process more complex and requires high level of resources like energy, money, space and expertise while still leading to environmental burden through emissions (Balkema, et al., 2002). Though, the centralized WWT system treats large quantity of wastewater to the desired quality safe for discharge but it consumes high energy and chemicals during treatment process leading to environmental pollution thus affecting the natural environment and ecosystem (Muga, et al., 2008). However, the alternative system (i.e. decentralized treatment systems) as well has dis-advantages though the degree of effects may be considerably less. So it becomes a global concern to develop and select an appropriate wastewater treatment technology so that a balanced environmental, economic and social sustainability is maintained for a given condition (Muga, et al., 2008). Sustainability of wastewater technology could, therefore, be viewed from three different prospective, namely economic, environmental and socio-cultural which are often so-called the sustainability indicators (Balkema, et al., 2002).

2.5.1. Economic:

Economic sustainability in wastewater management sector focuses on meeting and satisfying human needs through the optimum usage of scarce resources so that the investment made does not exceed the benefits (Balkema, et al., 2002). The investment refers to the capital cost and the operational costs including the energy costs, management costs, maintenance costs, the cost of technical experts and the user costs. Therefore, the investment cost of a particular treatment technology in wastewater management can determine the economic affordability to a community. Various tools like cost-benefit analysis, life cycle costing, energy analysis and total cost assessment are used to quantify the expected financial costs and benefits (Balkema, et al., 2002). However, the social and environmental costs are difficult to quantify.

2.5.2. Environmental:

Environmental sustainability in wastewater management sector is principally based on the fact that the functions of the environment should have the ability to sustain the human ways of life (Balkema, et al., 2002). In order to preserve the environmental and ecological balance; protection, efficient utilization of natural resources and taking up emissions should be maintained with which a long-term development could be ensured (Balkema, et al., 2002). The environmental issues in wastewater management include the energy consumption during construction, operation and demolition phase of wastewater treatment systems and finally the emissions from the treatment facilities either in the form of solid, liquid or gaseous states to the surrounding air, water or soil. In addition, the pollution produced while generating electricity for the treatment plant also have considerable contribution to the environmental issues (Jenssen, et al., 2007).

Life Cycle Assessment (LCA) can be used as a tool to assess the environmental impacts and sustainability of a wastewater treatment system (Emmerson, et al., 1995).

In the Life Cycle Assessment first, the goal and scope of the study are defined. Then based on the mass and energy balances, life cycle inventory of environmental aspects are carried out. Lastly, the environmental aspects are categorized in the environmental impact categories, such as global warming, eutrophication, acidification, ozone depletion, human toxicity etc. (Stranddorf, et al., 2005). So the scale of environmental impacts can provide a basis to the decision makers whether to choose the technology or go for an alternative one.

2.5.3. Socio-cultural

The socio-cultural sustainability refers to the objective that the people's social-cultural needs are to be secured in an equitable way so that there is no any instability in people's morality and relationships (Balkema, et al., 2002). This can develop people's interest and ownership to organize their society (Balkema, et al., 2002). Acceptance and selection of a balanced set of indicators using a holistic approach may differ from community to community depending on the geography, culture and the population served (Muga, et al., 2008). According to the Inter-American Development Bank, "*Citizen participation, properly channeled, generates savings, mobilizes financial and human resources, promotes equity and makes a decisive contribution to the strengthening of society and the democratic system*" (Jhansi, et al., 2013). So a proper social analysis can lead to ensure the sustainability of WWT system.

Thus, selection of wastewater treatment technology should not be based only on the technical scenario but rather it should also consider the surrounding socio-economic and environmental factors. Therefore, a multi-disciplinary approach along with the coordination and cooperation with socialists, economists, environmentalists, biologists, health officials and the public should be performed while selecting an appropriate wastewater treatment system for a given condition (Jenssen, et al., 2007).

2.6. Types of Wastewater treatment systems

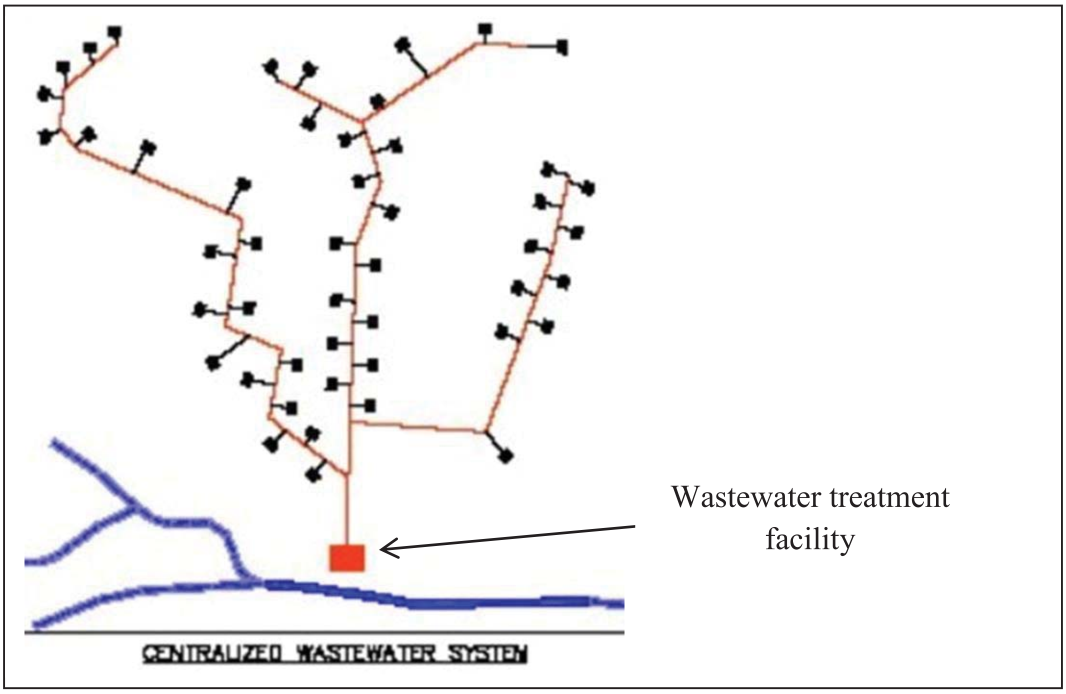
The main objective of wastewater treatment system is to protect and promote the public and environmental health as well as saving the aquatic life (Kivaisi, 2001). In order to break the cycle of diseases, provide a clean environment and control in eutrophication of surface water reserves; wastewater should be treated to eliminate the pollutants and harmful micro-organisms before it is discharged to any form of receiving water bodies (Wendland, et al., 2010; Kivaisi, 2001). In general, two major treatment processes are practiced in the sector of wastewater treatment.

(i) Centralized wastewater treatment process and,

(ii) Small-scale decentralized wastewater treatment process.

2.6.1. Centralized wastewater treatment system

Centralized wastewater treatment system also called "end-of-pipe" technology, consists of a sewer network that collects wastewater from households, industries, institutions and even storm water runoff and transports it to a wastewater treatment plant (Tchobanoglous, et al., 1991). The main objective of the centralized WWT system is to eliminate the pollutants, pathogens, micro-organisms and other harmful impurities from the wastewater and recycle the generated waste sludge into a form that can further be used as a soil fertilizer (Wilderer, et al., 2000). The treated wastewater is then discharged to the nearby water bodies like river, lake, sea or ocean. Therefore, these systems involve in advanced treatment processes that collect, treat and discharge large quantities of wastewater (Massoud, et al., 2009). A huge capital investment in construction of sewer networks and infrastructures, pumping costs, water treatment costs, high energy consumption and highly trained operators are associated with centralized WWT systems (Wilderer, et al., 2000). The main advantage of this system is that these systems are reliable for the treatment of large quantities of wastewater collected from densely populated areas such as municipalities, cities and are transported and treated away from the human settlements (Massoud, et al., 2009). However, these systems may sound unreliable for small and isolated settlements with low population densities, areas with dispersed households and areas where water is scarce (Massoud, et al., 2009).

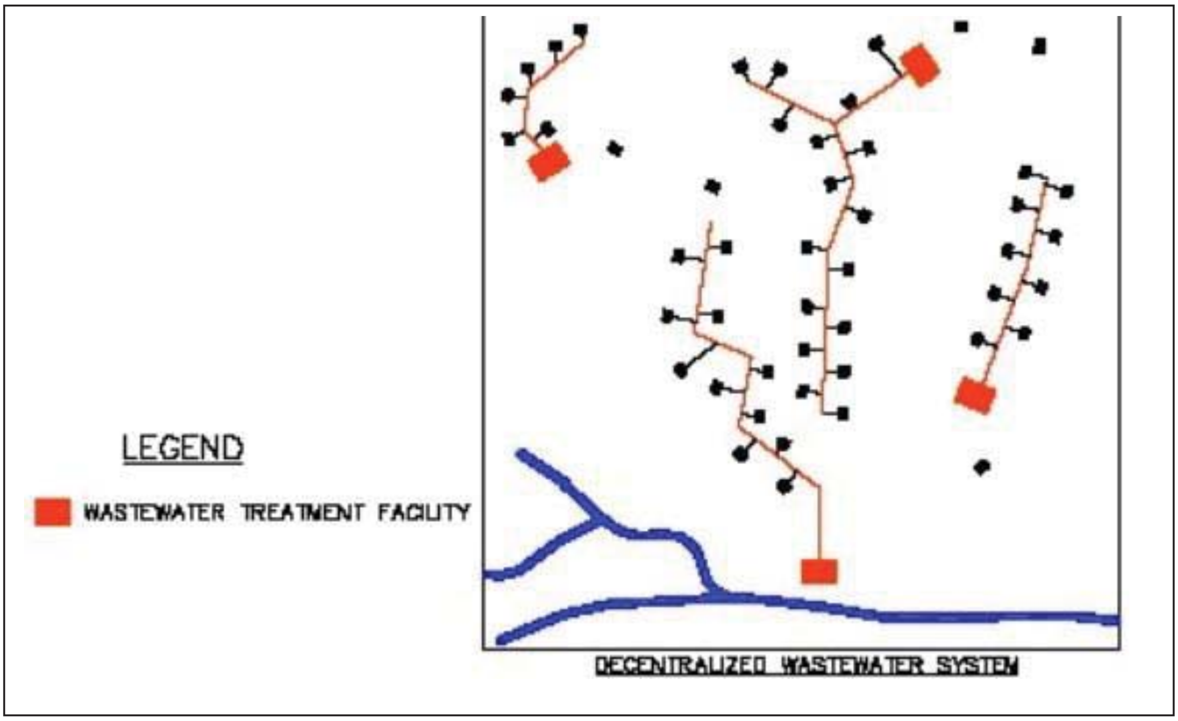


(source: Fxbrowne.com 2005)

Fig. 2.2: Representation of centralized wastewater collection and treatment system.

2.6.2. Decentralized wastewater treatment system

The decentralized approach focuses on the treatment of wastewater and reuse of the treated water, nutrients, and by-products in the direct location of the settlements (Tchobanoglous, et al., 1991). These systems are designed to operate at small scale, have minimal investment cost and maximum flexibility to solve wastewater and other water-related problems. The length of sewer network is comparatively short so they have less disruptive construction. The collected wastewater is treated rather close to the origin so it is also called on-site and/or cluster treatment system, where wastewater and the sludge treatment process are executed. The final treated water could be discharged to a nearby surface water body or used either for groundwater recharge, flushing toilets or for gardening purpose and the treated sludge could be used for making compost and then can be used, on-site, as a fertilizer source (Wilderer, et al., 2000). The treatment system require basic operation skills, consumes low energy, are less resource intensive and more ecologically sustainable form of sanitation (Massoud, et al., 2009). Hence, these systems are easy to construct, cheaper, environment-friendly, are more flexible and can easily adapt to the local conditions (Jhansi, et al., 2013).



(source: Fxbrowne.com 2005).

Fig. 2.3: Representation of decentralized wastewater collection and treatment system.

Now it becomes a matter of discussions that whether centralized treatment systems are more reliable and environmentally friendly as compared to small-scale decentralized treatment systems in terms of resource requirements like energy, money, space, expertise as well as emissions of gasses leading to environmental impacts like global warming, acidification, ozone depletion etc. There are certain advantages and disadvantages of both the treatment systems. Studies show that neither any of the two approaches can exclude the importance of the other and vice versa (Libralato, et al., 2012).

There are some general statements from different authors based on the essential information's like; life-span of the system, financial costs, energy usage and reuse of water and by-products etc. on both of the wastewater treatment systems presented below.

Centralized WWT systems	De-centralized WWT systems	Source
Capable of treating large quantities of wastewater, but its sophisticated collection and transport networks costs more than 60% of the total budget.	Collection and transport cost is minimal and rather focuses on effective treatment and disposal of wastewater.	(Massoud, et al., 2009; Libralato, et al., 2012)
Less chances of water recycling, reuse and nutrients recovery.	Permits the reuse of treated WW e.g. watering of green zones, flushing toilets etc.	(Libralato, et al., 2012; Wilderer, et al., 2000; Ho, et al., 2004).
Possible to cause disruptions to traffic and other public utilities during maintenance of collection or transport networks.	Excludes these inconveniences since they have shorter and smaller pipe lines.	(Libralato, et al., 2012).
Requires more expensive approaches of treatment because the large volume of WW collected is heavily diluted with domestic & industrial wastes along with harmful toxic substances.	These systems allow options like separation of urine with faeces, black water with grey water so that effective recovery of valuable resources is possible.	(Massoud, et al., 2009; Wilderer, et al., 2000; Libralato, et al., 2012; Ho, et al., 2004).
Possibilities of disruptions in the system in case of natural disasters like earthquake, flooding's etc. resulting in heavy pollution in the receiving water bodies.	The system consist small units so they do not cause inconvenience in a larger scale if in case of such natural disasters.	(Libralato, et al., 2012; Wilderer, et al., 2000; Ho, et al., 2004).
The system consumes high quantity of electrical energy so it could be unfavourable and inadequate for poor and developing countries facing electrical deficiency.	The systems are based on natural treatment approaches so the energy consumption is very less.	(Libralato, et al., 2012; Wilderer, et al., 2000).

The systems are unsuitable for isolated or scattered settlements & require large area.	These systems are suitable and are a long-term solution for such settlements & can also accommodate in small available space.	(Massoud, et al., 2009; Libralato, et al., 2012).
Failure in single unit can affect the performance of whole treatment system.	Failure in single unit do not cause the collapse of the whole system.	(Wilderer, et al., 2000).
Environmental sustainability is questionable.	There is higher level of assurance of environmental sustainability.	(Libralato,, et al., 2012).
	It's assumed that building and operating more numbers of such treatment systems could be more expensive than one large centralized system serving the same number of population.	(Wilderer, et al., 2000).

In summary, centralized wastewater treatment technology could be the applicable option in the context of urban densely populated areas with less available free space in developed countries to treat the wastewater, despite the fact that these systems require high economic costs and contribute to ecological and environmental burdens (Libralato, et al., 2012). On the other hand, decentralized wastewater treatment systems are worldwide recognized and accepted by the water professionals and the lawmakers as a sustainable solution in wastewater treatment hence, have been more frequently taken into consideration during the last decades (Libralato, et al., 2012; Haberl, et al., 1995).

2.7. Wastewater treatment in Norway:

Studies show that due to the effect of glaciation in the Norwegian topography, the Norwegian landscape contains a large number of deep lakes (Källqvist, et al., 2002). It has been accounted that, about 2500 lakes with a surface area exceeding 1 km^2 and around 208000 numbers additional smaller lakes with surface area in between (0.01 – 1) km^2, exists within the country's periphery (Källqvist, et al., 2002). Sewer systems were started to build up at around 1900, which carried the wastewater directly into the rivers, lakes or fjords (Environment.no. 2008). Before 1970, there were few wastewater treatment plants in Norway, which provided the mechanical and biological treatment of waste water (Källqvist, et al., 2002; Environment.no 2008). Studies and research showed that eutrophication was the major problem in many water bodies of Norway, particularly in lakes. The major cause of eutrophication was due to phosphorus content that supported in the production of algae (Källqvist, et al., 2002). This was due to the direct discharge of domestic wastes, nutrients, organic matters, agricultural and industrial wastes to the lakes and coastal waters (Environment.no 2008) Therefore, large-scale development in the Norwegian wastewater treatment technology started around 1970 and was further strengthened in the late eighties (Källqvist, et al., 2002). The treatment technology also included chemical treatment process focussing on removing or reducing the phosphorus content for preventing excess algal growth in fjords, lakes and rivers (Environment.no 2008). In Norway, around 80% of the population are connected to the municipal wastewater treatment plants and remaining 20% have separate treatment solutions (Källqvist, et al., 2002). Studies show that chemical treatment plants cover 36 % of Norway's hydraulic capacity whereas chemical and biological plants cover 28 %, mechanical plants cover 23%, biological plants cover 2%, other types account for 2% and about 9% of all wastewater is discharged untreated (Environment.no 2008). Around 2500 municipal wastewater treatment plants have been built in Norway where the belonging County Governors and the municipalities are the responsible authorities (Norskeutslipp.no 2016).

2.8. Small scale decentralized wastewater treatment systems in Norway:

Norway is not challenged with water deficiencies like many other countries but it has a robust commitment of the necessity to preserve resources and protect the environment (Plumbing Connection, 2016). For this purpose, small-scale decentralized wastewater treatment systems are being practiced in recent decades all over the country. But stringent regulations in the effluent concentration regarding phosphorous, nitrogen and organic matter content has been set by municipalities and health authorities. Approximately, 17% of populations are served by on-site wastewater treatment systems (< 50 Pe) in Norway and around 340000 such systems are in operation (Al Nabelsi, et al., 2013; Paruch, et al., 2011). Natural treatment systems like soil infiltration (Jenssen, et al., 1990), constructed wetlands (Jenssen, 2010), ponds (Browne, et al., 2005), source separation (Jenssen, 2005) and combinations of these systems are the decentralized options practiced in Norway. The figure below shows the distribution of different on-site wastewater treatment systems in Norway (Johannessen, 2012).

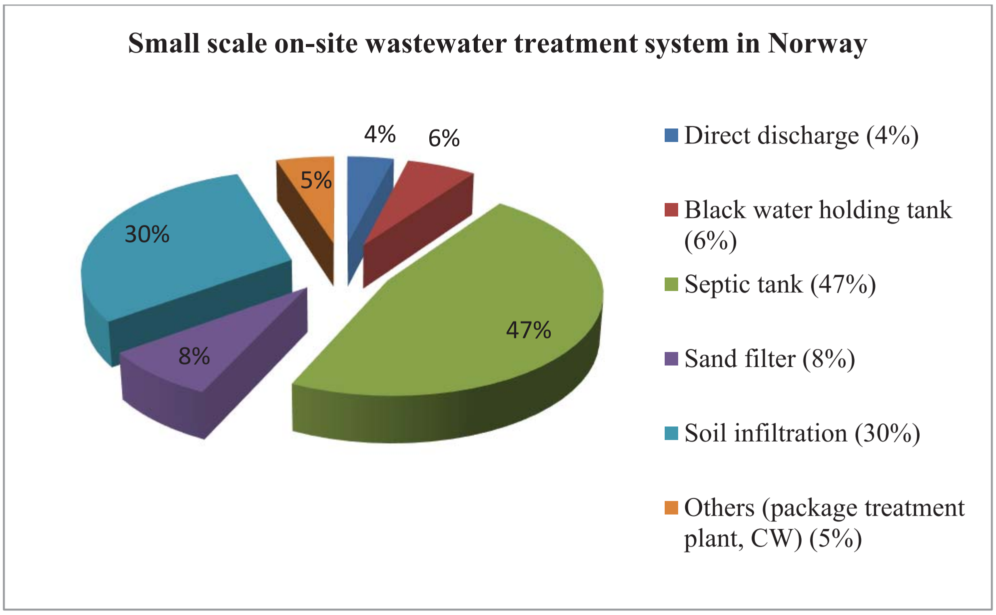


Fig. 2.4: Distribution of on-site wastewater treatment systems in Norway (Al Nabelsi, et al., 2013; Johannessen, 2012).

As seen in the figure above, the commonly used are septic tank systems, soil infiltration systems and sand filters systems. Septic tanks are designed for on-site treatment of domestic sewage and are commonly used as a pre-treatment unit in constructed wetlands, soil infiltration systems, sand filter systems, pond systems and biological filter systems (Al Nabelsi, et al., 2013) so that the succeeding treatment processes can deliver efficient results. Individual, removal efficiency of septic tank is shown in Table 2-1 below:

Table 2-1: Individual percentage removal efficiency of a septic tank (Al Nabelsi, et al., 2013; Jenssen, et al., 2006).

Parameters	**Removal efficiency**
Total - P	(5 – 10) %
Total - N	(5 – 10) %
Organic matter (BOD)	(20 – 30) %
Suspended solids	(30 – 60) %

2.8.1. Constructed wetlands

Constructed wetlands were first practiced in Germany and later used in rural areas of other different countries (Wendland, et al., 2010). Constructed wetlands are natural on-site wastewater treatment systems where biological and physical treatment takes place when the wastewater flows through a planted sealed base soil filter (Wendland, et al., 2010). After many years of performance evaluations made by many researchers, this method has become a successful practice for on-site wastewater treatment because it is cheap, simple to construct, produce less sludge, easy to operate and efficient to maintain (Kivaisi, 2001; Haberl, et al., 1995). Constructed wetlands could be classified in three different systems (Haberl, et al., 1995):

(i) Free floating system
(ii) Rooted emergent system and
(iii) Sub-emergent system

Most of the European constructed wetland treatment systems are based on the rooted emergent system which is further designed as surface flow system and sub-surface flow system (Kivaisi, 2001). The bed of the wetland system is filled either with soil, sand, gravel or light-weight aggregate (LWA) with the flow pattern either horizontal or vertical (Wendland, et al., 2010). The functional phenomenon of constructed wetland system includes physical processes (sedimentation and filtration), chemical processes (precipitation and adsorption), biological processes (microbial interactions) and uptake by vegetation (Kivaisi, 2001; Watson et al., 1989). The treatment performance depends on the microbiological bacterial activity that takes place in the biofilm bed, physical-chemical and plants physiological processes in the plant and ground system (Wendland, et al., 2010; Bodenfilter.de, 2016). The cover plants in the constructed wetland enhance the micro-organisms to accumulate in the roots of the plants thus acting as a layer for isolation during cold seasons (Haberl, et al., 1995). Generally, the constructed wetlands undergo through a pre-treatment step for sedimentation of solids and organic loads to avoid clogging by introducing a septic tank followed by bio-filter unit or natural ponds prior to the wetland (Wendland, et al., 2010). The solids and sludge collected in the septic tank are trucked out away for further treatment.

In recent decades, constructed wetlands with pre-treatment facilities are gaining popularity in Nordic climate conditions due to its high treatment performance (Jenssen, et al., 2010;

Jenssen, et al., 2005). In Norway, the first subsurface flow constructed wetland was built in 1991 to treat the domestic wastewater (Jenssen, et al., 2005). Norwegian constructed wetlands (CWs) are generally with horizontal subsurface flow (HSFCWs) regimes and the majority of them are categorized as small (< 50 pe) on-site decentralized wastewater treatment systems (Paruch, et al., 2016). According to Paruch, et al., (2016), the performance of the HSFCWs over many years of operation under cold climatic conditions have shown a high and stable treatment efficiency which is shown in Table 2-2 below:

Table 2-2: Percentage removal efficiency of constructed wetland (Paruch, et al., 2016; Jenssen, et al., 2005).

Parameters	**Removal efficiency**
Total - P	> 90%
Total - N	> 40-60%
Organic matter	> 90% BOD
Microbes	> 99% bacteria

.

In Norway, most of the CWs are built with a concept based on using septic tank and aerobic vertical down-flow bio-filter as preceding treatment units before a subsurface horizontal-flow constructed wetland (Krogstad, et al., 2007; Jenssen, et al., 2005).

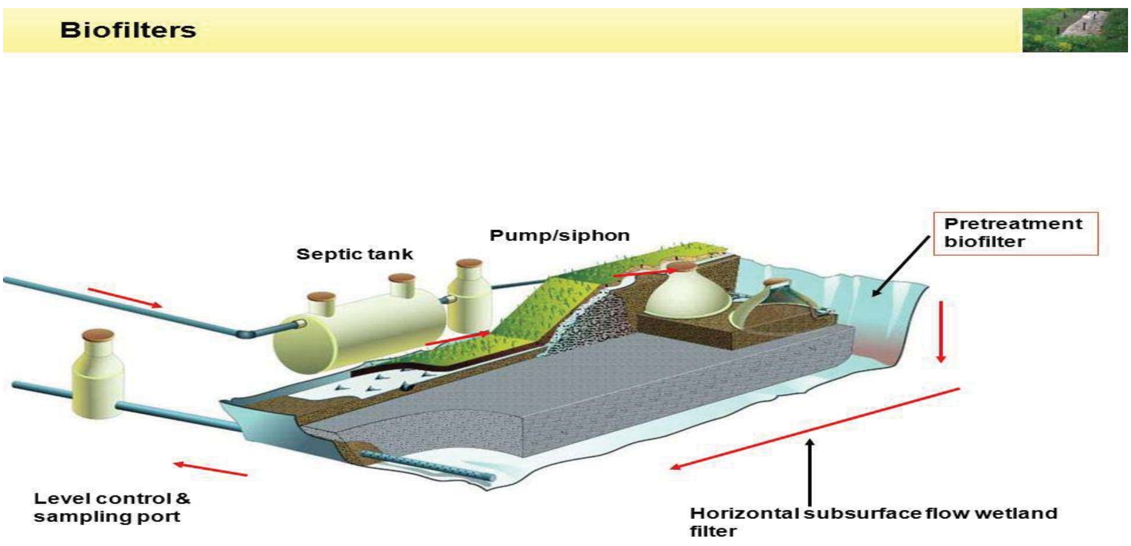


Fig. 2.5: The latest generation of constructed wetlands for cold climate with integrated aerobic bio-filter in Norway (source: Jenssen and Vråle., 2003).

The effluents from the septic tank are pre-treated in the aerobic bio-filter to remove BOD and achieve nitrification during cold climates (Jenssen, et al., 2005; Paruch, et al., 2016; Pandey, et al., 2013). The filter media used in the bio-filter as well as in the wetland is mainly focused on removing phosphorus (P) from the wastewater and reuse the filter media saturated with P as a fertilizer for agricultural purpose (Adam, et al., 2007). However, before the reuse of the filter media as fertilizer, its quality with respect to pathogens and heavy metals should be proven safe and acceptable for human and environmental health.

In Norway, different types of light-weight aggregates (LWA) and shell-sand are most frequently used as filter materials in constructed wetlands (Adam, et al., 2007; Mæhlum, 1998; Zhu, et al., 1997). Studies have shown that, commercial available LWA (Filtralite – P) has P removal potential up to 12,000 mg P kg^{-1} (Adam, et al., 2007; Jenssen and Krogstad, 2003) and shell-sand have the P sorption capacity ranging from 14,000 – 17,000 mg P kg^{-1} (Adam, et al., 2007; Søvik, et al., 2005).

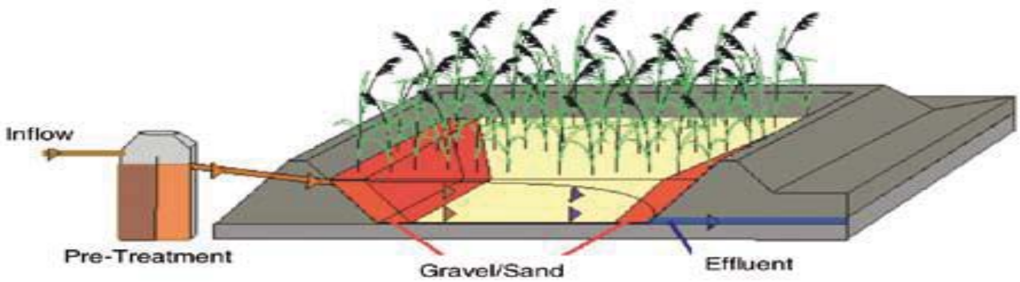


Fig. 2.6: Horizontal flow constructed wetland with pre-treatment (source: Bodenfilter.de, 2016)

In horizontal flow constructed wetland, the wastewater flows from one side to the other side of the wetland horizontally.

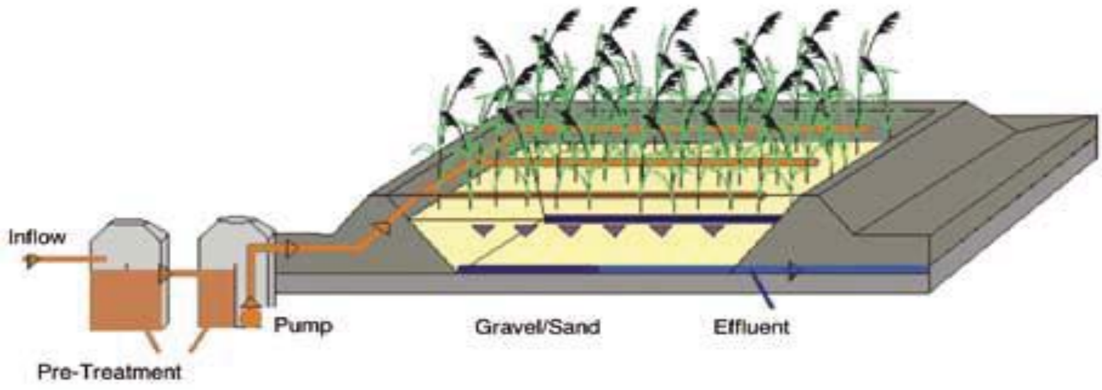


Fig. 2.7: Vertical flow constructed wetland with pre-treatment (source: Bodenfilter.de, 2016).

In vertical flow constructed wetland, the wastewater flows and seeps from the top to the bottom vertically.

Basic advantages and disadvantages of constructed wetlands (Wendland, et al., 2010).

Advantages	Disadvantages
- Low cost. - Less energy required. - Simple in operation and maintenance. - Can adopt seasonal variations. - No noise pollution. - Removes pathogenic micro-organisms well. - Produce less sludge. - Have high buffering capacity.	- More space required - Separate sludge handling needed periodically.

2.8.2. Soil infiltration system

Soil infiltration systems are natural systems for wastewater treatment and require a large area and are based on infiltration / percolation through the native soil.

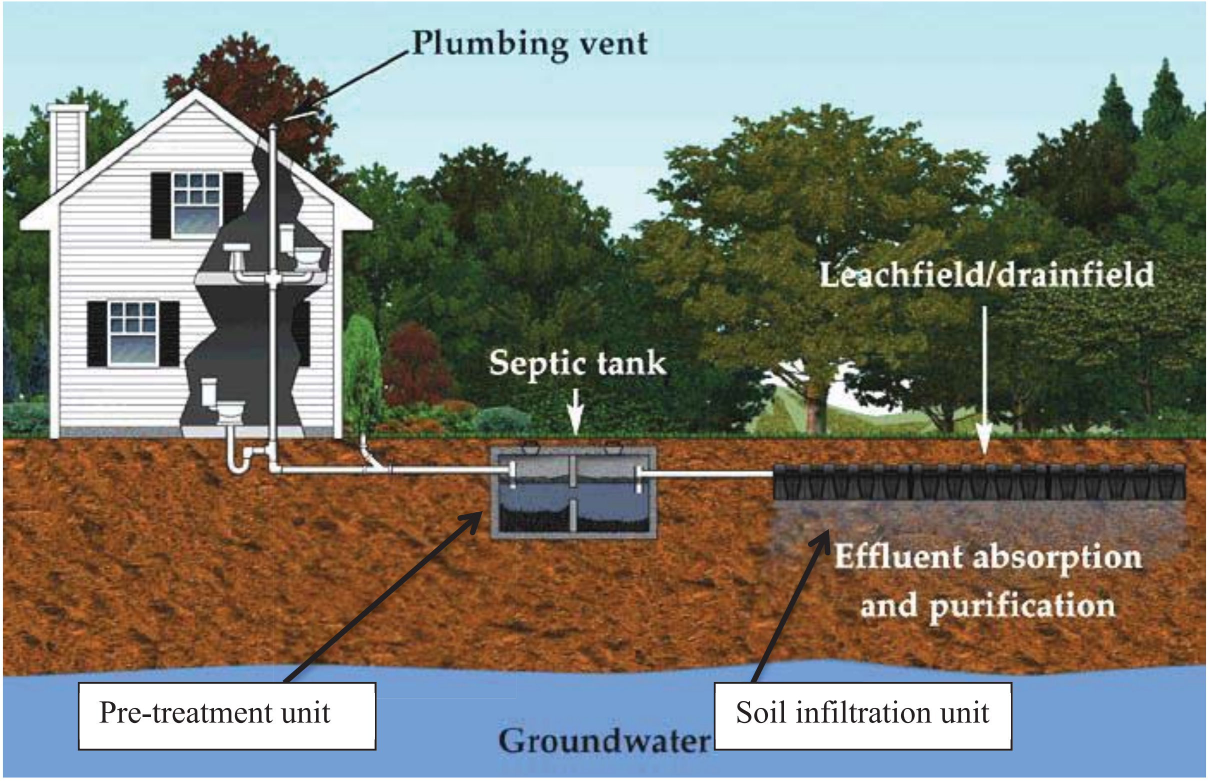


Fig. 2.8: Soil infiltration system (source: Mcengr.com 2016)

Soil infiltration system is considered as technically simple, low cost, less routine operation and maintenance and an effective alternative system for treatment and disposal of wastewater from small communities in rural areas and commercial establishments (Jenssen, et al., 1990). The system consists of three basic components; pre-treatment, distribution and soil infiltration units. The pre-treatment unit removes the suspended solids, oils, greases etc. so that clogging of the system piping and soil pores gets prevented. Then the distribution system transmits the pre-treated effluent to the soil surface in a prescribed manner. Finally, the soil infiltration unit works for the treatment of wastewater via infiltration/percolation. The pre-treated water is spread through horizontally laid pipes and infiltrates down through the soil and ultimately reaches to the local ground water system. Soil infiltration systems can be categorized into three types as below:

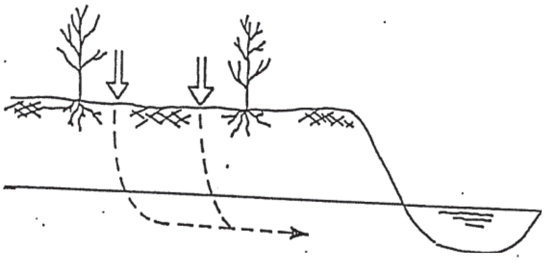


Fig. 2.8.1: surface infiltration

(a) Surface infiltration, slow rate of infiltration,
(b) Open system, rapid infiltration and
(c) Buried system, slow rate of infiltration

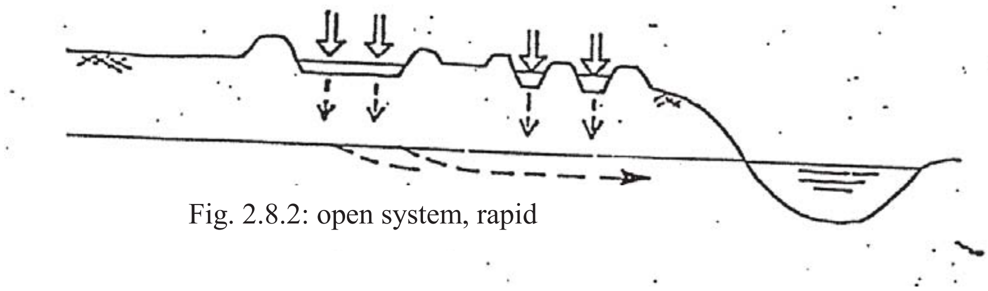


Fig. 2.8.2: open system, rapid

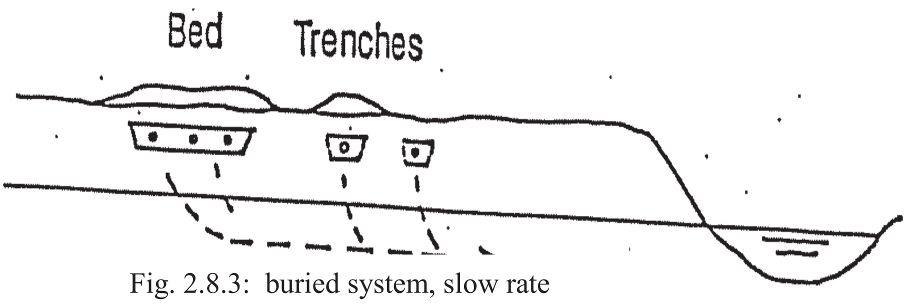


Fig. 2.8.3: buried system, slow rate

Fig. 2.8.1, 2.8.2 and 2.8.3: Example design concept of soil infiltration system (Jenssen, et al., 1990).

Before a soil infiltration system has been chosen, site suitability should be confirmed because all soils are not suited for subsurface infiltration and treatment (Jenssen, et al., 1990). Treatment efficiency of soil infiltration system is shown in Table 2-3 below (source: Tchobanoglous, et al., 1991).

Table 2-3: Percentage removal efficiency of soil infiltration system.

Parameters	Removal efficiency
Total - P	> 90%
Total - N	> 30% (20 – 60)%
Organic matter (BOD)	> 90%
Suspended solids	> 90%

Bacteria	4 – 6 log reduction

2.8.3. Sand filtration system

In sand filters treatment system, the effluent from the septic tank is applied on top of the sand filled trenches. The wastewater then infiltrates through the sand layer (usually 70 – 90 cm) and gets collected at the bottom and by means of drainage pipe the treated water comes out as effluent.

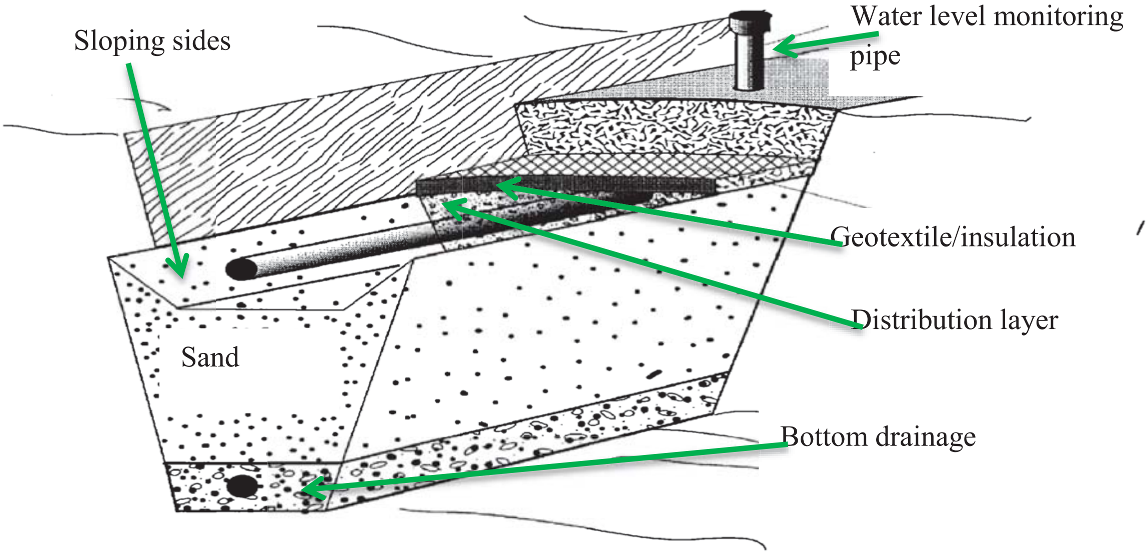


Fig. 2.9 : Sand filter system (source: Jenssen, 1999)

2.9. Life Cycle Assessment (LCA)

The first international consensus on the definition of LCA came at the beginning of the 1990's by the Society of Environmental Toxicology and Chemistry (SETAC), which defines LCA as;

"An objective process to evaluate the environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used and wastes released to the environment, and to evaluate and implement opportunities to affect environmental improvements. The assessment includes the entire life cycle of the product, process or activity, encompassing extracting and processing raw materials; manufacturing,

transportation and distribution; use; re-use, maintenance; recycling and final disposal". (Muñoz, et al., 2006; Fava, et al., 1993).

As defined in ISO 14040:2006(en), *"LCA is the compilation and evaluation of the inputs, outputs and the potential environmental impacts of a product or system throughout its life cycle"*.

Both the definition highlight that, LCA addresses the environmental aspects of a product or a system, throughout its entire life cycle i.e. the stage from "cradle-to-grave" (ISO 14040:2006(en)).

According to ISO 144040:2006(en), LCA can assist in,

- Tracing out openings to improve the environmental performance.
- Providing information for decision makers during planning, priority setting and design or re-design of product or process.
- Choosing relevant indicators of environmental performance.

In the Life Cycle Framework, there are mainly four different phases. First, the goal and scope of the study are defined. Secondly, based on the mass and energy balances, life cycle inventory of environmental aspects are traced out. Thirdly, impact assessment of the environmental aspects are carried out and categorized in the environmental impact categories, such as global warming, eutrophication, acidification, ozone layer depletion etc. (Balkema, et al., 2002). Finally, interpretations among different options are made, like improvement options or go for a new option. LCA is an iterative process, so results of the last phase (i.e. interpretation) can lead to changes in the first phase (i.e. goal and scope definition) (Almanza, 2012).

2.9.1. Four phases of LCA framework:

Standards for LCA on environmental management is described in the ISO 14040 series. The framework of LCA consists of four different stages and is described in the ISO 14040 – 43 standard series. This includes;

- ISO 14041 : Goal and scope definition
- ISO 14041 : Inventory analysis
- ISO 14042 : Impact assessment
- ISO 14043 : Interpretation

  (source: Grimstad.uia.no 2016).

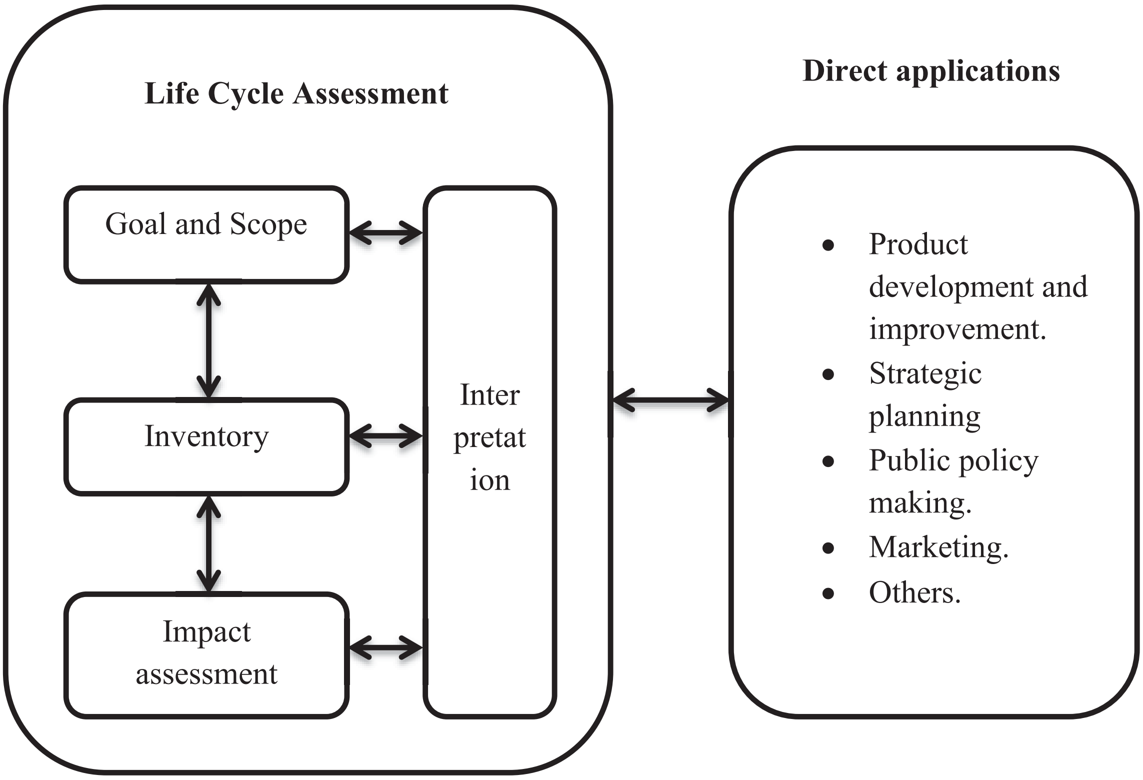


Fig. 2.10: LCA framework according to ISO 14040 series

2.9.1.1. Goal and Scope definition

This is the first phase of LCA where key elements like objective, scope and the main hypothesis of the study are defined. So the elements defined in the goal and scope will lay the basis of rest of the study (Almanza, 2012).

During goal definition, the issues to be considered are:

- the reason for carrying out the study.
- the need of LCA to carry the study.
- the primary target audience for the study.
- goals, values and principles of the proposed application.
  (source: Grimstad.uia.no 2016).

The scope of the study should consider and clearly define some items like:

- the system and its boundary (conceptual, geographical and temporal) conditions
- functional unit
- prior limitations
- initial data quality requirements
- comparisons between systems
- impact models associated with the study.

The scope should be well defined so that it provides a clear picture of details to ensure that the whole analysis is compatible with and sufficient to address the stated purpose. If the LCA study is made for a comparative assertion, an analysis of material and energy flows should be performed and included in the scope of the study (ISO 14040:1997(E)).

2.9.1.1.1. Boundary conditions:

The boundary conditions define the boundaries of a system that is being studied, therefore, an upstream and downstream cut-offs are set (Lundin, et al., 2002). The unit processes or activities that will be included within the LCA system under study should be identified and explained clearly in this section (Negelah, 2008). Several factors including the proposed application of the study, assumptions made, cut-off benchmarks, targeted audience and data and cost limitations determine the system boundaries of the study being carried out (ISO 14040:1997(E)). The system boundary can be marked in a process flow-diagram which consists of the unit processes included in the system and their inter-relationship. The assumptions, on which the cut-off limitations of inputs and outputs are made, should be clearly defined in the boundary conditions.

2.9.1.1.2. Functional unit:

While defining the scope of the LCA study, the functions of the system or product must be clearly stated. The functional unit is the quantified description of the system or product for use as a reference unit in the inventory phase. It should be consistent with the goal and scope of the study. So it is an arbitrary parameter of standardization used to describe the final results (ISO 14040:1997(E)). The functional unit is used as a basis for calculation and for comparison between different systems fulfilling the same function (Almanza, 2012), hence it must be clearly defined and measurable.

2.9.1.1.3. Data quality requirements:

Data quality requirements specify the characteristics of the data needed for the study. It should address the aspects like the sources of the data, its precision, representatives, completeness, reliability, time-related coverage, geographical coverage and the technology coverage (ISO 14040:1997(E)).

2.9.1.1.4. Comparison between systems

In comparative studies, systems are compared in various parameters like the functional unit, system boundaries, data quality, rules on evaluating inputs and outputs and impact assessment. Any differences noted on these aspects, between the systems, should be identified and mentioned before interpreting the results. (ISO 14040:1997(E)).

2.9.1.2. Life Cycle Inventory (LCI) :

Inventory analysis is a technical process that involves the collection of necessary qualitative/quantitative environment relevant data and relates them to the functional unit of the study. Then the calculation is made in order to quantify the inputs and outputs of the system for its entire life cycle as defined in the scope definition. (ISO 14040:1997(E)). Inventory analysis is performed for each unit process that in included within the system boundaries. Inventory analysis becomes an important step for quantifying the energy and raw material consumptions, air/water/soil emissions, waterborne effluents, solid wastes and other environmental releases incurred by the system throughout the entire life cycle (Negelah, 2008). This process is carried out either by direct measurements in the site, theoretical data's from designed documents and from already existing databases and publications. These data's of inventory analysis serve as inputs during the impact assessment of the study (Negelah, 2008).

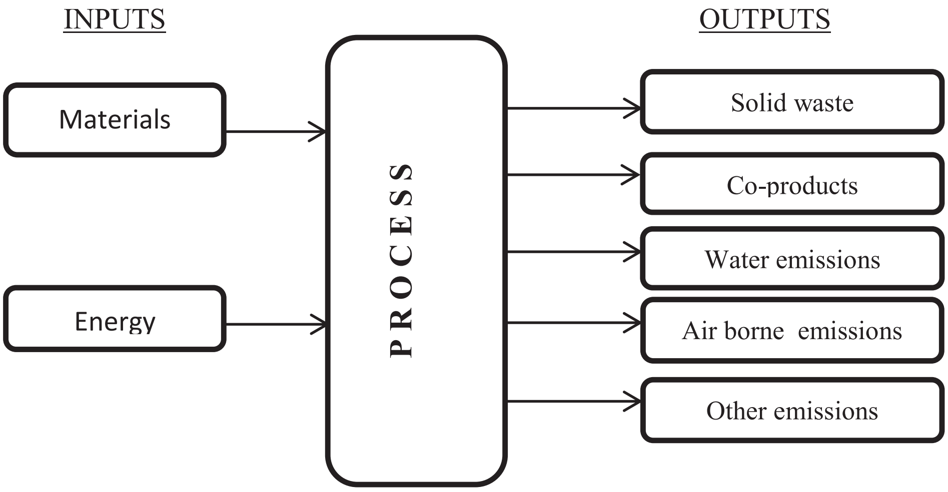


Fig. 2.11: Life Cycle Inventory Analysis overview (source: Almanza, 2012)

2.9.1.3. Life cycle Impact Assessment (LCIA) :

Impact Assessment is the third phase of LCA study. Inventory analysis provides quantified list of environmental loads (air and water emissions, wastes raw material consumption etc.) generated by the system but the environmental damages associated with them is still unknown. Life cycle impact assessment further works in managing the results of inventory analysis and categorizing them in relation to human health, natural environmental health and resource availability (Almanza, 2012). According to ISO principles, the impact assessment phase is aimed to evaluate and characterize the magnitude and significance of potential environmental burdens identified in the life cycle inventory analysis phase (Negelah, 2008; ISO 14040:1997(E)). Generally, this phase includes following elements (Sonnemann, et al., 2004; Almanza, 2012):

i. Selection of impact categories based on the goal and scope of the study.
ii. Assigning the data's of inventory analysis to the selected impact categories (classification)
iii. Characterizing the inventory data within impact categories (characterization).

iv. Normalization of the impact characterized and

v. Valuation /weighting of the impacts.

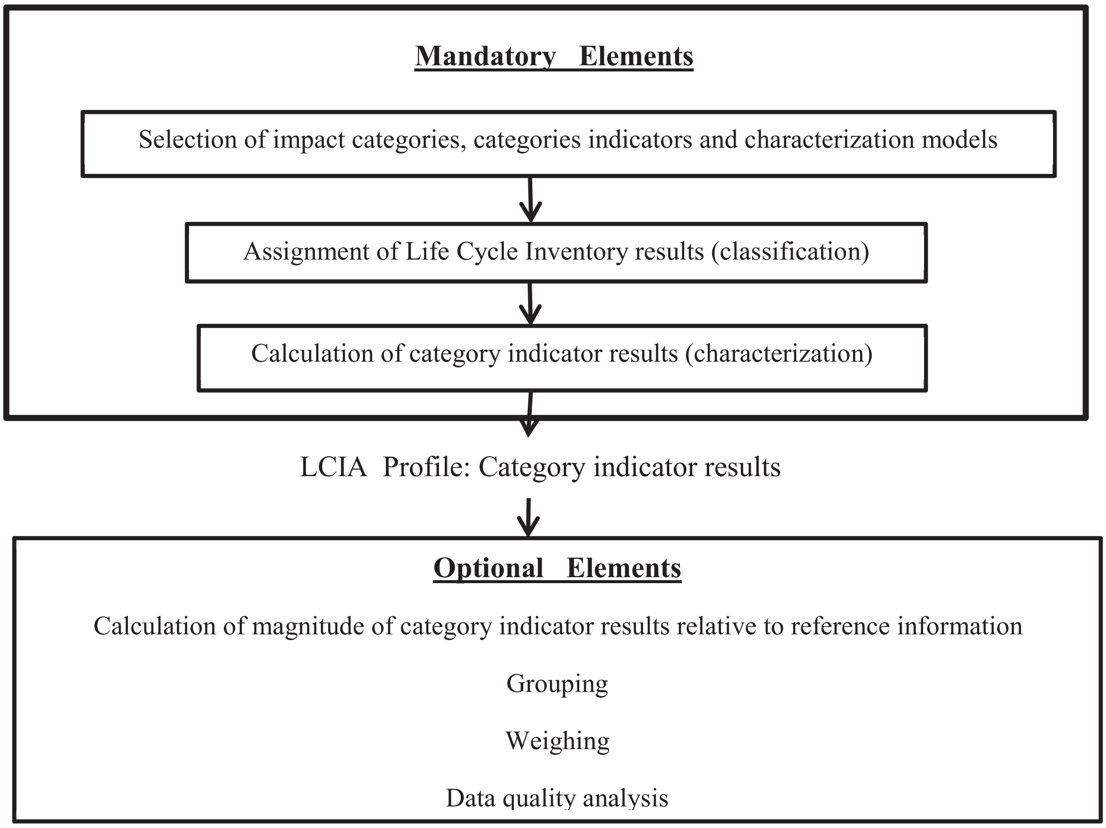


Fig. 2.12: Elements of LCIA phases (Almanza, 2012)

2.9.1.3.1. Category definition

The environmental issues resulted from the product or system contribution are investigated in this section. Based on the inventory results and in relation to the goal and scope of the study, impact category is selected (Almanza, 2012). There are many impact categories in LCI and the most common are global warming, stratospheric ozone depletion, eutrophication, acidification, photo-oxidant formation, eco-toxicity, human toxicity, biotic and abiotic resources (Stranddorf, et al., 2005).

Table 2-4: Most important impact categories and possible indicators (Frances, 2013; Jacquemin, et al., 2012).

Impact Category	**Possible Indicator**
Input related categories	
Extraction of Biotic resources	Replenishment rate
Extraction of Abiotic resources	Resource depletion rate
Output related categories	
Global warming	Kg CO_2 as equivalence unit for **GWP**
Stratospheric ozone depletion	Kg CFC-11 as equivalence unit for **ODP**
Eutrophication Potential	Phosphate (PO_4^{-3}) equivalence unit for **EP**
Acidification Potential	Release of SO_2 as equivalence unit for **AP**
Human toxicity potential (HTP)	**HTP**
Eco-toxicity	Freshwater Aquatic Eco-toxicity potential **(FAET)**
Photo-oxidant formation	Kg ethane as equivalence unit for photo-chemical ozone creation potential (**POCP)**

The impact categories mentioned in the above Table 2-4, are the most used impact categories in LCA's of wastewater but in this study, we are considering only the impacts of global warming, ozone depletion, eutrophication and acidification.

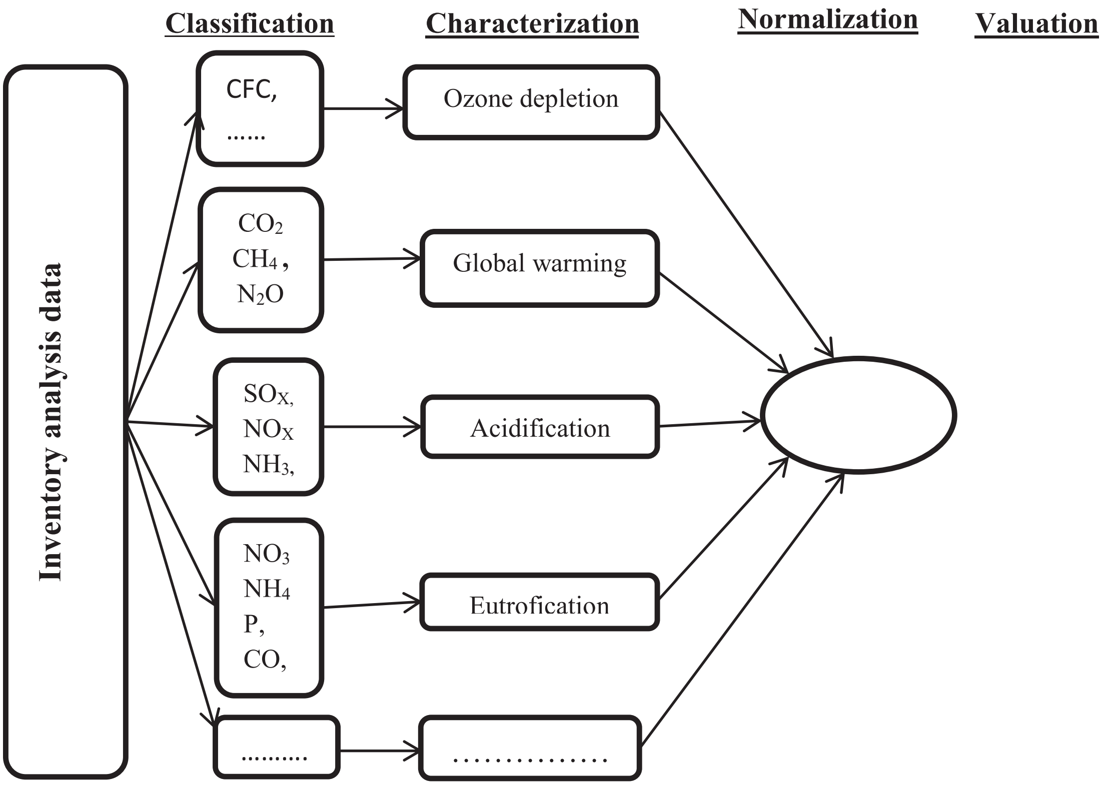


Fig. 2.13: An overview of the steps followed in LCIA (Finnveden et al., 2000; Negelah, 2008)

2.9.1.3.1. Classification:

The grouping of data's from the inventory data table is classified into different environmental releases that support to different impact categories. The classifications may be Global warming potential (GWP), Ozone layer depletion potential (ODP), Eutrophication Potential (EP), Acidification potential (AP) etc. The inventory results are grouped into the same impact category. For example, phosphorous and nitrogen belongs to the impact category of eutrophication whereas methane, carbon dioxide and nitrous oxide belong to the impact category of global warming.

2.9.1.3.2. Characterization:

After classification of environmental releases, impact characterization is done. Characterization is the assessment of the magnitude of potential impacts and characterizing the impacts in its corresponding environmental impact category (Akwo, 2008). So characterization includes various environmental impacts and issues of concern, based on the classifications made. For example, Nitrous oxide (N_2O) has a global warming potential of 298 relative to CO_2 and Methane (CH_4) has global warming potential of 25 relative to CO_2 over a 100 year time horizon (Fuchs, et al., 2011; ISO 14044:2006). So the characterization factor for CO_2 and CH_4 are 1 and 25 respectively, likewise, for CO_2 and N_2O the characterization factor are 1 and 298 respectively. Then, during impact characterization of GWP, inventory result is multiplied with the characterization factor (Goedkoop, et al., 2010).

2.9.1.3.3. Normalization

Normalization is the ways that potential impacts of the system can be compared or relate it to a broader data set or situation, for example, comparing and relating the system's global warming potential to a country's yearly global warming potential (Muñoz, et al., 2006; Almanza, 2012).

For example, the normalized global warming potential (GWP) for any considered product or system is calculated as;

$$\text{Normalized GWP} = \frac{\text{GWP}}{\text{Normalization reference of GWP}}$$

Where, normalization reference is the unit impact potential per person per year in the area (i.e. global, regional or local) and Normalization reference for GWP can be calculated to **8.7 ton CO_2 – eq./capita/year** (Stranddorf, et al., 2005).

2.9.1.3.4. Valuation

Valuation is the assessment made for the similar importance of environmental burdens identified in the classification, characterization and normalization stages (Almanza, 2012; Roy, et al., 2009). Valuation allows weighting of the impacts so as to compare or aggregate them.

Example for calculation of Characterization and Normalization:

If the amount of CO_2 produced = 20 kg and amount of CH_4 produced is 15 kg. Then, Characterization factor is 1 for CO_2 and 25 for CH_4.

Therefore, Global warming potential (GWP) = 20 kg CO_2 (GWP=1) + 15 kg CH_4 (GWP=25) = [(20*1) + (15*25)] kg CO_2 equivalent = **395 kg CO_2 equivalent**.

Now, **Normalized GWP** = [GWP] / Normalization reference for GWP = 395 / 8.7

= **45.4 kg CO_2 equivalent**.

2.9.1.4. Interpretation:

Life cycle interpretation is the final phase of LCA study where final evaluations, conclusions and further recommendations for the study carried out are made (Almanza, 2012). The identifications and findings of inventory analysis and impact assessment are combined together and evaluated in relation to the goal and scope of the study (ISO 14040:1997(E)). This evaluation may include both quantitative and qualitative measures of improvement and analyze the completeness, sensitivity and consistency checks of the product or the system that is being applied (Roy, 2009; Negelah, 2008). All these evaluations made during the interpretation may result as a form of conclusions and recommendations to the decision makers whether to make changes, make improvements or go for an alternative solution.

2.9.2. Limitations of LCA

There are certain limitations of LCA which can be summarized as below (Muñoz, et al., 2006; Almanza, 2012):

- LCA addresses potential rather than actual impacts.
- LCA focuses on physical characteristics but does not include the market mechanisms or other secondary effects on the technological development.
- LCA regards all processes as linear, both in the economy and the environment.
- LCA focuses on environmental issues associated to products and processes but it does not address the economic and social consequences.
- Data availability.

2.9.3. LCA software available

To accomplish an LCA, software has been developed to simplify the LCA studies. To study on WWT systems, SimaPro 7, Umberto, TEAM, EcoPro, Eco-IT and Gabi 5 software have been used among others (Frances, 2013). Every software have different features for assessment so are distinct from each other. For this study SimaPro 7 software has been used.

2.9.3.1. SimaPro 7

SimaPro 7 is the worldwide used computer software tool for life cycle assessment. The software is used in managing and storing data, calculating and analyzing the environmental impacts and performing the sensitivity analysis of the LCA study. The software was developed and released in 1990 and is distributed by PRé Consultants, based in Netherlands (PRé sustainability 2012) (Herrmann, et al., 2015). In SimaPro 7, the impacts of WWT systems are broadly divided into four main categories; (i) ecosystem quality (ii) human health (iii) climate change and (iv) natural resources (Alanbari, et al., 2014). The LCA phases are structured in accordance with ISO 14040 and ISO 14044 standards in SimaPro.

2.9.3.1.1. Goal and Scope definition in SimaPro7

Description of goal and scope for each project is available in the software with three sections which are (Alanbari, et al., 2014):

- Text field: In this section, description of different aspects of goal and scope definition is made.
- Libraries section: In this section, we can pre-define the library with standard databases relevant for the project to be studied.
- Data quality section: In this section, the characteristics of data can be pre-defined.

2.9.3.1.2. Inventory Analysis in SimaPro 7

This software contains details of input and output databases describing resources use, materials use and emissions to air and water. It includes all the stages; construction, operation and demolition of the product or system throughout its entire life cycle and provides the inventory result by interpreting the process structure (Goedkoop, et al., 2010).

2.9.3.1.3. Impact Assessment in SimaPro 7

In SimaPro7, a wide variety of impact assessment methods via classification, characterization, normalization and valuation of impacts are available so as to perform the LCA study. The software includes different methods for impact assessment; CML 2 baseline 2000, Eco-indicator 95, Eco-indicator 99, EPS 2000 and CML 92 (Goedkoop, et al., 2010).

2.9.3.1.4. Interpretation in SimaPro 7

This section is designed as a checklist that covers the relevant issues specified in the ISO standards (Alanbari, et al., 2014).

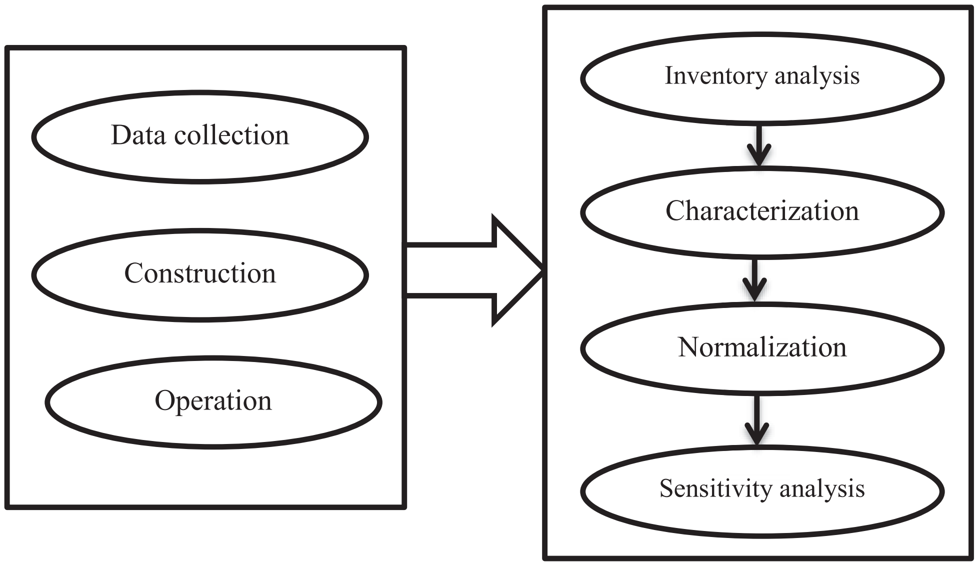


Fig. 2.14: Methodological steps in LCA.

2.9.4. LCA for sustainability of wastewater treatment system

Environmental sustainability is a concern and a stated objective for every developed and developing nation. As discussed earlier, wastewater treatment systems are designed and operated to control, minimize or eliminate the water pollution and the environmental impacts caused by wastewater discharges (Barjoveanu, et al., 2010). Besides this, the treatment process consumes energy, chemical reagents and produce sludge (Almanza, 2012; Barjoveanu, et al., 2010) during its life period. So for a long-term ecological and environmental sustainability, the aim of WWT systems should also consider minimizing the loss of resources, reduce the energy consumption, quantity of waste generation and enable nutrients recycling (Pasqualino, et al., 2009).

The aim of environmental sustainability analysis is therefore, to understand and address the environmental aspects, to preserve and protect the natural ecological and environmental balance by efficient utilization of environmental resources and energy, nutrient recycling and taking up emissions so that it can support for long-term development (Balkema, et al., 2002; Pasqualino, et al., 2009). Many studies and analysis have been made for ensuring sustainable solution of the environmental impacts. LCA is one of the efficient tool and has been used to explore the environmental sustainability of wastewater treatment systems by estimating the environmental loads, quantifying the environmental impacts, categorising the impacts and finding solutions either by improvements or by selecting other treatment alternatives and different unit processes (Barjoveanu, et al., 2010; Pillay, 2006; Lundin, et al., 2002).

The importance of energy recovery, nutrient recycling and reducing the emissions, which are some of the aspects of environmental sustainability in a WWT system has been exposed by the LCA studies (Tillman, et al., 1998; Lundin, et al., 2000; Lundin, et al., 2002).

Requirement level for removal of various pollutants in treated water has led to higher production of sludge but ways for eliminating this sludge are getting restricted more enough (Pasqualino, et al., 2009). In the case of an urban centralized wastewater treatment system, the sludge generated were traditionally incinerated and disposed off either in landfill sites or dumped into the sea. Today at present, landfilling and dumping in the water bodies, has been banned in many developed countries including Europe (Svanström, et al., 2004; Pasqualino, et al., 2009). In addition, sludge incineration also led to emissions of substances like mercury and dioxins and generates ashes, a hazardous waste (Palme, et al., 2005). So recycling sludge to a level free from heavy metals, pathogenic microorganisms and toxic organic compounds is the best option for sludge handling which can be used as a fertilizer for agricultural purpose and land reclamation thereby substituting the mineral fertilizer (Svanström, et al., 2004; Pasqualino, et al., 2009). For example, the N and P from recycled sludge fertilizer can substitute the equivalent amount of N and P mineral fertilizer. Therefore, recycling of waste sludge to fertilizer and saving of energy that is required while producing mineral fertilizer can be achieved at the same time. Another valuable component from a wastewater treatment plant is the bio-gas produced during the anaerobic digestion process of sludge. Methane that is present in the bio-gas can be used as a renewal energy source thereby replacing the use of fossil fuels used in the production of energy and electricity. Hence, reduction in air emission and electricity consumption can be achieved by the use of methane as an energy source as well as the recycled sludge can replace the mineral fertilizer and save the energy used in its production (Belhani, et al., 2008; Pasqualino, et al., 2009).

Therefore, in the context of sustainability of wastewater treatment facilities, LCA could be a systematic tool to evaluate and where possible reduce the environmental impacts caused by the treatment system at various stages over the entire life period and provide a basis for assessing potential improvements in the environmental performance of the system (Pillay, 2006; Lundin, et al., 2002).

CHAPTER – 3 METHODOLOGY

This chapter includes the description of wastewater treatment systems chosen for the study. Inventory data are calculated, analysed and presented in this chapter.

3.1. SYSTEMS UNDER STUDY

The study was carried out for three small scale decentralized wastewater treatment systems in Norway which are at present all in operation.

3.1.1. Høyås farm wastewater treatment system

The Høyås farm wastewater treatment plant is located at Brekkevein 120, Gnr/Bnr. 48/3, Ås municipality with geographical coordinates 59° 38' 5.5''N and 10° 47' 13''E (Al Nabelsi, et al., 2013). The system was designed for treatment of wastewater generated by 8 persons in average, with a maximum of 25 persons per day throughout a year and each person producing a daily load of 200 litres of wastewater (Al Nabelsi, et al., 2013).

The design concept is based on four main units; a septic tank, an aerobic bio-filter, phosphorus filters and finally sand filters. The system consists of a pre-fabricated fiberglass septic tank with total volume capacity 9.5 m^3, further divided into three chambers with volumes 6.9 m^3, 1.3 m^3 and 1.3 m^3 in chambers 1st, 2nd and 3rd respectively based on the specification of VA-Miljøblad nr.48 (Al Nabelsi, et al., 2013).

The septic tank provides preliminary treatment of the wastewater allowing the solids to settle down at the bottom of the tank, oils and fats to float at the top forming a scum layer, digestion of organic matter and discharge the treated wastewater as an effluent to the following units (Al Nabelsi, et al., 2013). The effluent from the septic tank flows to a pumping chamber of volume capacity 2 m^3 which allows controlled discharge to the following treatment unit (Al Nabelsi, et al., 2013). According to the study made by (Mironga, 2014), the pumping chamber consumes an average energy of **0.397875 kWh per day (i.e. 144.83 kWh per year)**.

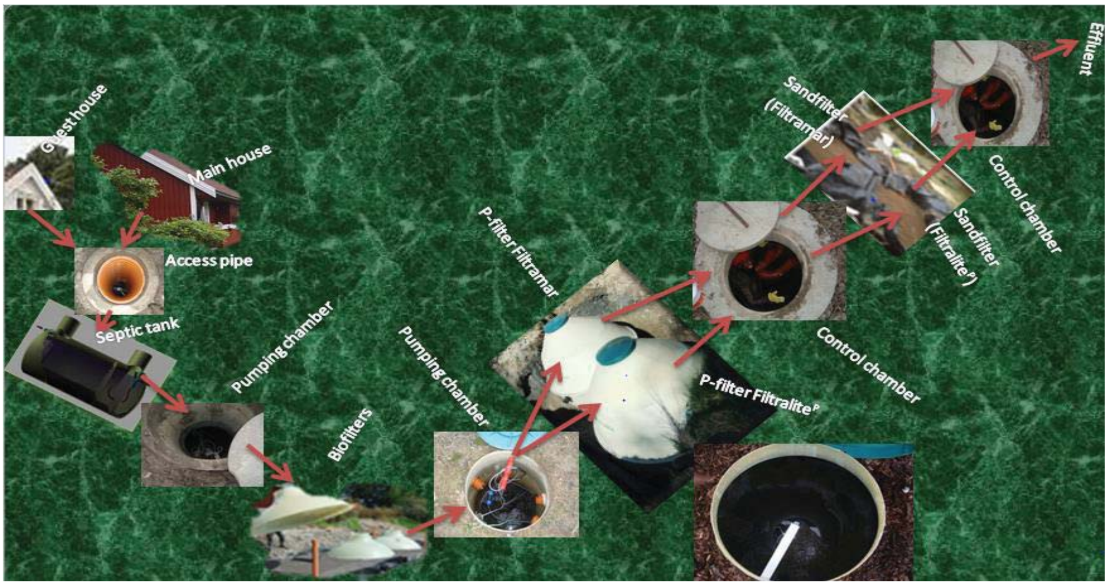


Fig. 3-1: Small scale wastewater treatment plant at Høyås farm (source: Mironga, 2014)

The septi tank effluent is pumped to the bio-filter unit which is designed according to VA-Miljøblad nr.49 and consists of three domes with centrally located nozzle assuring even distribution of influent and filled with crushed filter media, Filtralite-P HC 2.5-5mm up to 60 cm depth (Al Nabelsi, et al., 2013). Aerobic treatment process with vertical flow carries inside the bio-filter domes as the wastewater is spread over the filter media through the nozzle and gets collected down in the bottom of the unit. The treatment process in the bio-filter enhances biodegradation of organic matter resulting in the reduction of BOD, nitrification process, phosphorus removal as well as some reduction of the pathogenic micro-organisms (Mironga, 2014; NORVAR and NKF, 2001). The effluent from the bio-filter unit is then pumped equally into two separate phosphorus filter tanks installed parallel to each other which are filled with 4 m^3 Filtralite-P (LWA) in one tank and 4 m^3 Filtramar (shell-sand) in the other tank as filter materials. Both the filter tanks are made of fiberglass with 6 m^3 capacity (Mironga, 2014). Both the filter media, Filtralite-P and Filtramar (shell-sand) has been regarded as a high-quality filter media for phosphorous removal (ÁdÁm, et al., 2007). Finally, the treated effluent from both the phosphorous tanks flows into two separate impermeable sand filter trenches (size: length 10m, width 0.7m and depth 0.7m) installed parallel to each other. The sand filters allow further purification of phosphorous, bacteria and organic matters and serves as a polishing step of the wastewater (Al Nabelsi, et al., 2013). The finally treated effluent from the whole system is connected to the agriculture drainage via means of corrugated standard drainage pipes. The detail cross-section of treatment units are presented in Annex 6.

The construction of Høyås farm wastewater treatment system was completed in September 2012. Al Nabelsi, et al., (2013) observed and studied the operation performance of the wastewater system from October 2012 until January 2013. Also, Mironga, (2014) studied the operation performance from June 2013 to March 2014. The performance result of the system made by both the authors has been presented in Table 2 & 3 of Annex 1. From both the studies carried out, the average performance results of the Høyås farm treatment system is calculated in Table 4 of Annex 1 and presented in Table 3-1 below:

Table 3-1: Average treatment results of Høyås farm WWT system from studies carried out by two authors, Al Nabelsi, et al., (2013) and Mironga, (2014).

Parameters	**% removal**
Total - P	96.54
Total - N	57.58
BOD_5	94.495
COD	75.75

3.1.2. Kaja grey water treatment system

Kaja grey water treatment system is located at student dormitories of University of Norwegian Life Sciences, Ås municipality. The system was built in 1997 and was designed for 48 students with a concept of recycling system based on ecological engineering principles (Jenssen and Vråle, 2003). The system consists of three fundamental units; a septic tank as a pre-treatment unit followed by an aerobic bio-filter and a subsurface horizontal flow constructed wetland. The system treats only the grey water generated from the student dormitories. The black water is collected separately and trucked out for further treatment on monthly basis.

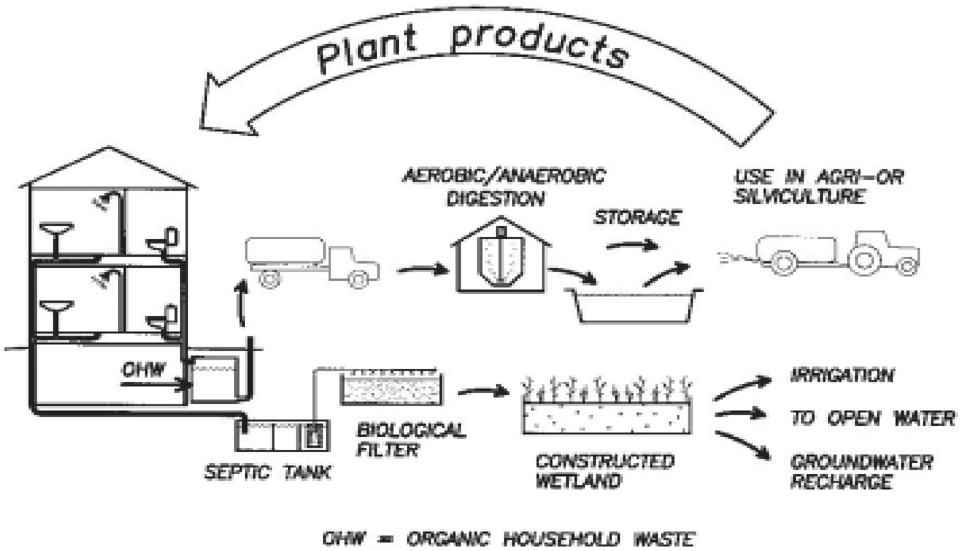


Fig. 3.2: Complete recycling system at the student dormitories based on separate treatment loops for black water and grey water. (source: Jenssen, 2002)

The treatment of grey water generated by the 48 students (average 115 litres per student in a day) (Jenssen, 2005) starts with a septic tank as a pre-treatment unit. The septic tank has a total volume capacity of 10 m^3 with three separate compartments. The effluent from the septic tank undergoes further treatment in a vertical down-flow single pass aerobic bio-filter unit. The bio-filter unit consists of a hemispherical dome with a centrally fitted nozzle which facilitates even distribution of the septic tank effluent over the bio-filter surface. The bio-filter is filled with light-weight aggregate (Filtralite-P) (grain size 2-4 mm) as filter media, to a standard depth of 60 cm and is aimed to enhance nitrification, reduction in phosphorous content, BOD content and micro-organisms (Jenssen and Vråle, 2003). Finally, the treated water from the bio-filter unit flows to a horizontal subsurface flow constructed wetland of 1m depth filled with light-weight aggregate (Filtralite-P) as filter media. The wetland section is vegetated with grass over an insulating soil cover. For treating grey water, the recommended surface area is 2-3 m^2 per person, hence the total area of the kaia treatment system is 100 m^2 (Jenssen and Vråle, 2003). The average outlet concentration and treatment performance (%) of Kaja treatment system is presented in Table 3-2 below:

Table 3-2: Average outlet concentration (mg/L) and treatment performance (%) of Kaja grey water treatment system (Jenssen and Vråle, 2003).

Parameters	**Outlet concentration (mg/L)**	**Treatment performance (%)**
Total - P	0.05	94
Total - N	2.6	70
BOD_7	5.6	94
COD	15.8	94

3.1.3. Natural wastewater treatment system at Vidaråsen Camphill, Andebu.

The wastewater treatment system is located in Vidaråsen Camphill at Andebu municipality in Vestfold county, southeast of Norway. The Camphill is a small community village of around 200 people. The treatment system was constructed in 1966 and was designed for treatment of sewage from the community which also includes effluent from a dairy, a bakery, a laundry, animal husbandry, a food-processing workshop and a herb garden (Pandey, 2016). The treatment system is based on the concept of natural treatment process utilizing the combination of ponds and horizontal/vertical flow constructed wetlands. The whole treatment system consists of a sequential treatment units as primary settling tank (septic tank) → two pre-filters (one vertical and other horizontal flow constructed wetland) → enhanced facultative pond (EFP) → three stabilization ponds → and two horizontal flow constructed wetlands (layout of the treatment system shown in fig. 3-6 below). The pre-treatment filters after the settling tanks are subsurface flow constructed wetlands and are located in series. These filter units are filled with sand and graded gravel as shown in the fig. 3-4 below. The effluent from the pre-filter units flows to an enhanced facultative pond by gravity. The EFP has been designed based on the concept of Oswald (Oswald, 1990) with a square shaped shaft (area 100 m^2 and depth 3m) at the centre of the pond. The EFP consists of five nos. of flow forms for re-circulating the wastewater so as to increase the dissolved oxygen content in the upper zone of EFP (Pandey, 2016). The effluent from EFP flows to three stabilization ponds that are located in series. The first stabilization pond also consists of flow forms for re-circulating the water. The third pond is connected to a planted filter dam at the inlet and a horizontal flow constructed wetland at the outlet as shown in the layout diagram fig 3-6 below. The effluent from the first constructed wetland flows to the second constructed wetland. Filtralite-P has been used as filter materials on both the wetland units. The final treated effluent is discharged into the Skorge river that flows on the west side of the village. The design information's of different treatment units of Vidaråsen is shown on the Table 3-3 below (Browne et al., 2005; Pandey, 2016):

Table 3-3: Design information's of treatment units of Vidaråsen WWT system (Browne, et al., 2005; Pandey, 2016).

Treatment units	**Surface area (m^2)**	**Depth (m)**	**Volume (m^3)**	**Remarks**
Septic tak	-	-	13	Average flow rate 30 m^3 / day
Pre-filter 1	200	0.6	120	Hydraulic loading 15 cm / day
Pre-filter 2	100	0.9	90	Hydraulic loading 30 cm / day
EFP	360	1.5	540	
Pond 1	600	1.2	720	
Pond 2	250	1.5	375	
Sand filter	90	-	-	
Pond 3	200	1.5	300	
C. wetland 1	90	1	90	
C. wetland 2	100	1	100	
Total	**1990**			

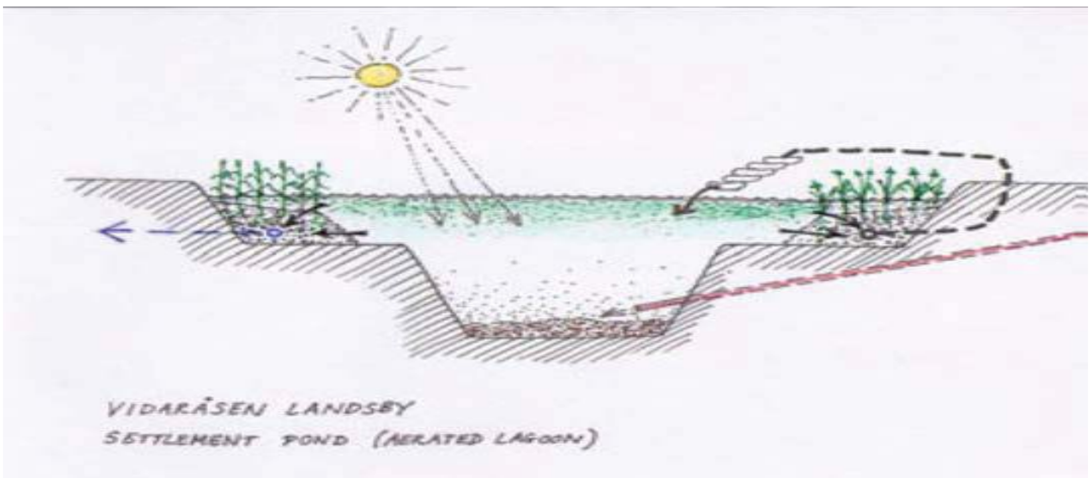


Fig. 3.3: Cross-sectional view of Enhanced Faculative Pond (EFP) (Browne, et al., 2005).

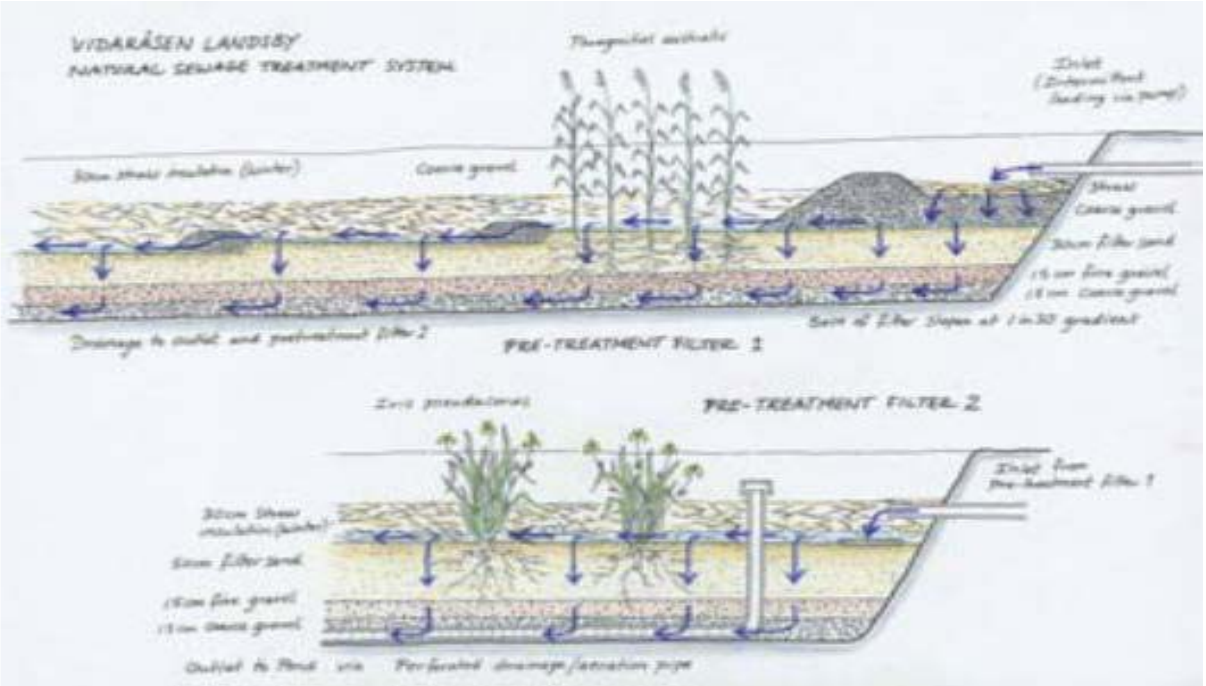


Fig. 3-4: Cross-sectional view of pre-filter 1 and pre-filter 2 (Browne et al., 2005).

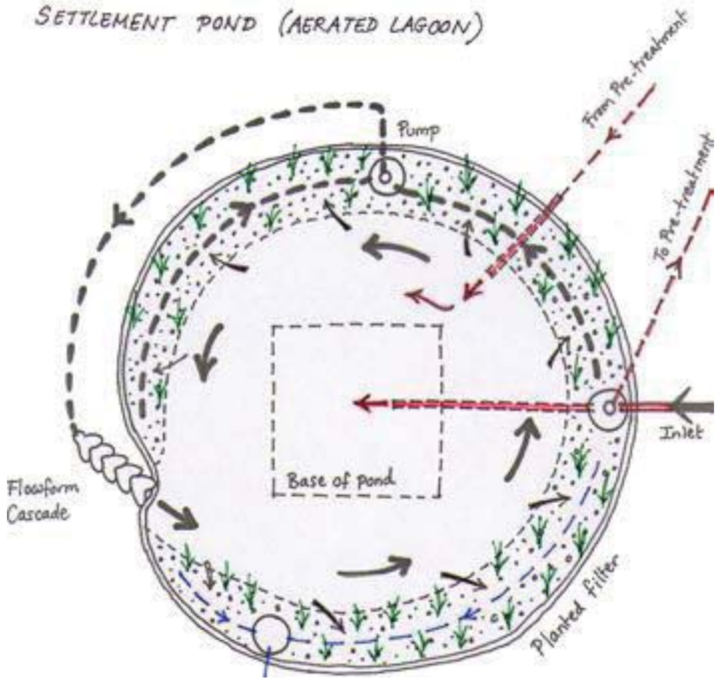


Fig. 3-5: Plan view of Enhanced Faculative Pond (EFP) (Browne, et al., 2005)

Results of first five years of operation has been shown in the Table 3-4: below;

Table 3-4: Average effluent concentrations and % removal from different treatment units (mg/l) (Browne, et al., 2005).

Parameter	**STE**	**Pre-filter**	**% removal**	**EFP**	**% removal**	**Pond 1**	**% removal**	**Pond 2+3**	**% removal**	**CW**	**% removal**
Total - P	6.8	3.6	47.06	2.16	68.23	0.88	87.06	0.52	92.35	0.25	96.32
Total - N	49.1	28.2	42.57	13.7	72.1	6.51	86.74	4.42	91	4.07	91.71
TOC	84.6	18.8	77.78	7.81	90.77	6.38	92.46	5.03	94.05	4.86	94.25
SS	130	39	70	-	-	-	-	5	96.15	< 3	> 97.7

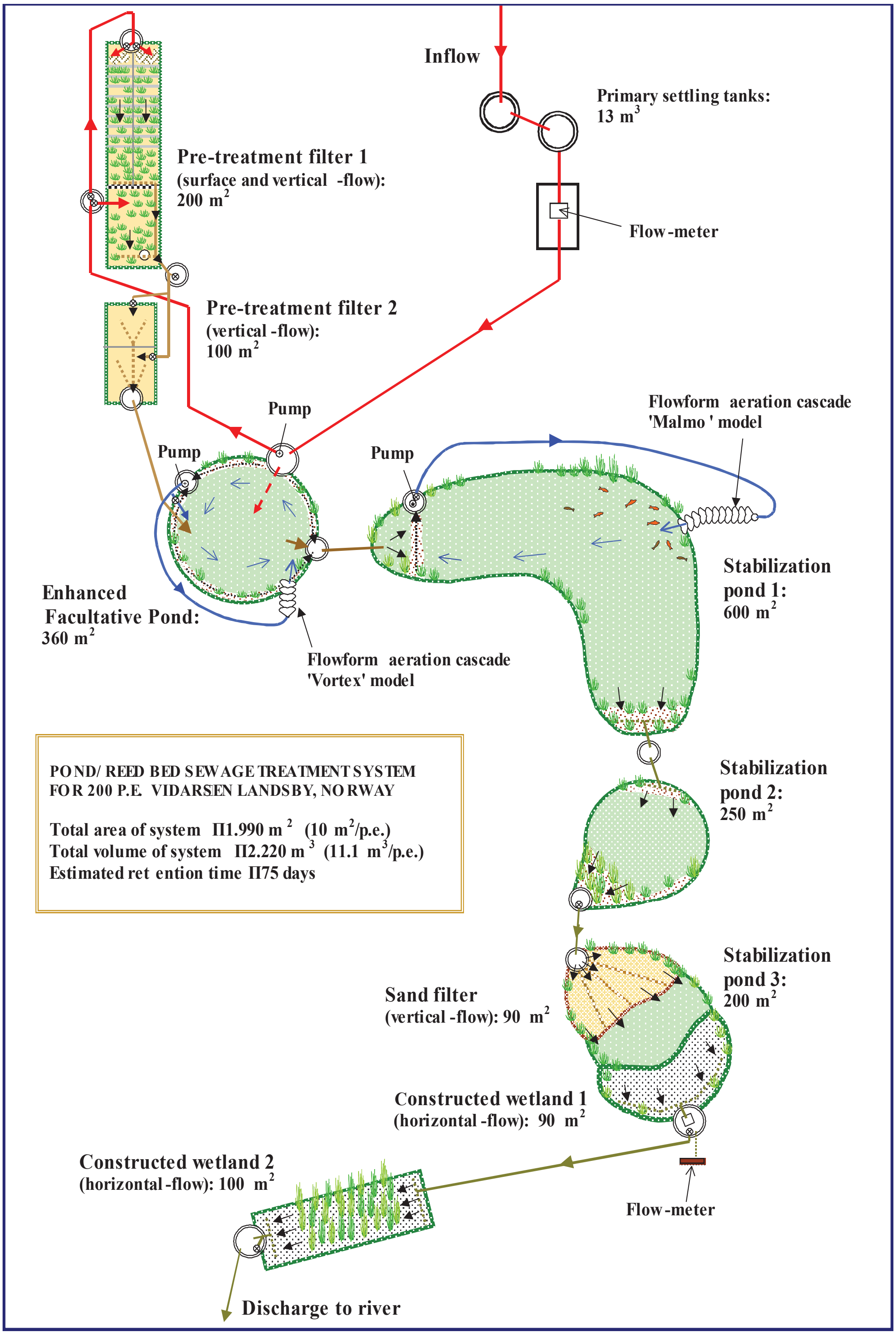


Fig. 3-6: Layout diagram of wastewater treatment system at Vidaråsen Camphill (Browne, et al., 2005; Pandey, 2016).

3.2. Goal and Scope definition of the study

3.2.1. Goal of the study:

The aim of this study is to assess the environmental performance of three small-scale wastewater treatment systems in Norway as according to the ISO standard framework. The specific objective of the study are:

- To perform inventory analysis of material use, resource consumption and the environmental impacts assocciated with the small-scale WWT systems in Norway.
- To identify the environmental hot spots of the systems investigated.
- To perform improvement analysis to improve the environmental performance of the system evaluated.

3.2.2. Scope of the study:

The study is carried out with Life Cycle Assessment (LCA) tool based on ISO standards 14040-14044 series and is limited to construction and operation phase of the three selected small-scale WWT systems. SimaPro 7 is used as the software to analyse the environmental burdens and provide specific results concerning the impacts. CML 2 baseline 2000 method has been selected for the life cycle impact assessment. Although CML 2 baseline 2000 method considers ten different impact categories; this study is limited to four impact categories which are; Global Warming Potential (GWP), Ozone Depletion Potential (ODP), Acidification Potential (AP) and Eutrophication Potential (EP).

3.2.2.1. Functional unit of the study:

As stated earlier, the functional unit allows the relation of all the data collected in the inventory phase and is the basis for comparison for the wastewater treatment system. The functional unit adopted in this study is expressed in **kg/p.e./year**. All the impacts generated by the systems in the impact assessment phase of this LCA study will be expressed referring to this functional unit.

3.2.2.2. System boundary of the study:

However all the phases of LCA study; construction, operation and demolition phase lie within the system boundary, this study is limited only to construction and operation phase. So the boundaries of this study start from construction stage and end up with operation stage. Demolition phase is excluded in this study. Transportation of construction materials and maintenance of the system are neglected in this study. Background information's related to the inputs during construction and operation stages considered in this study was been retrieved from LCI databases in SimaPro 7. The system boundaries of the wastewater treatment systems considered in this study is shown in figure below:

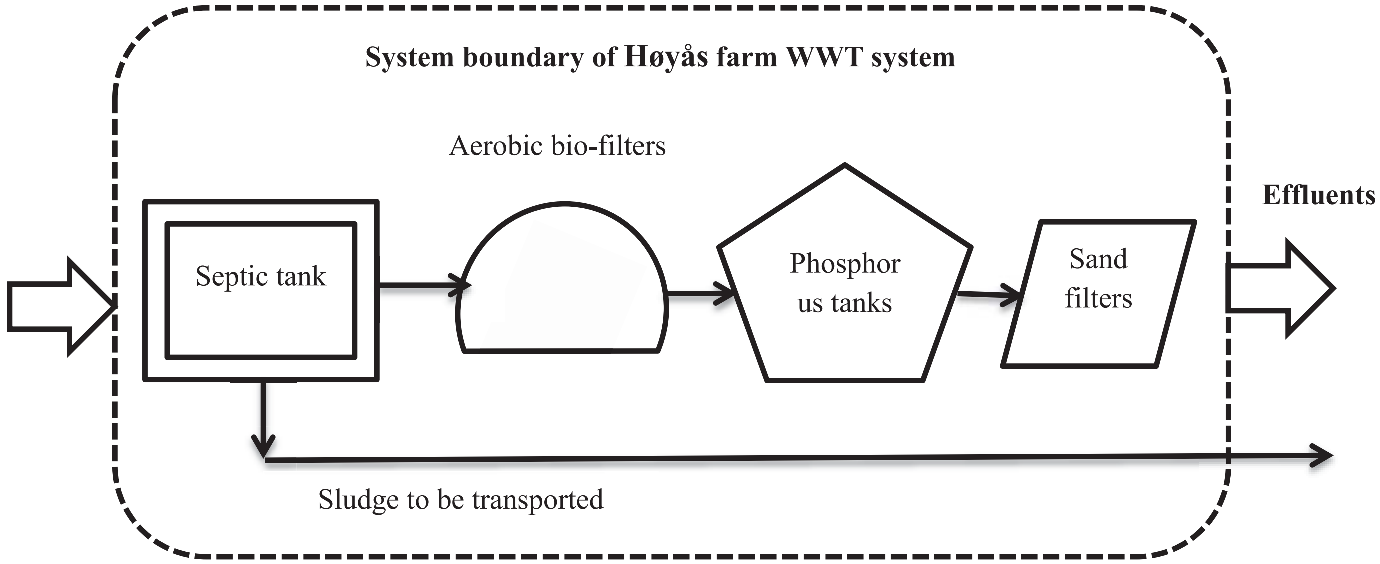


Fig. 3.7: System boundary of Høyås farm WWT system in this study.

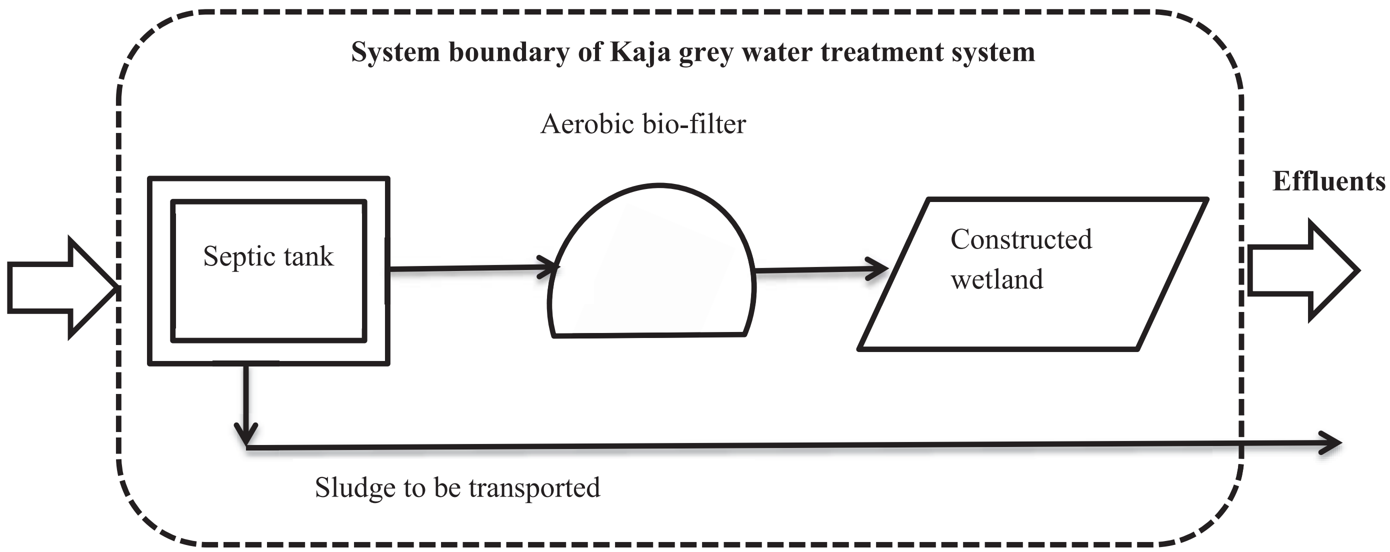


Fig. 3.8: System boundary of Kaja grey water treatment system in this study.

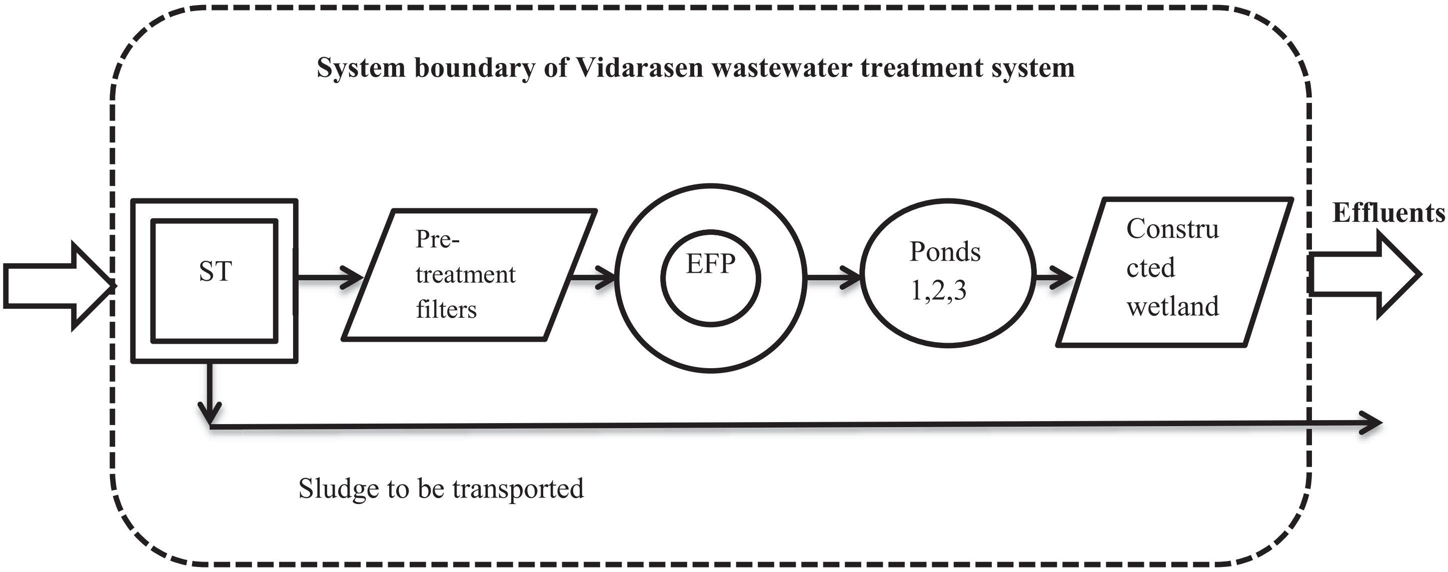


Fig. 3.9: System boundary of Vidaråsen WWT sytem in this study.

3.2.3. Assumptions made in the study:

• The quantity of soil generated during earthwork excavation is assumed to be used in the nearby lands so it is not taken into consideration during inventory analysis.

• Data for the operational energy consumption was not available for Kaja and Vidaråsen system. Therefore, the operational energy consumption value of Høyås farm **0.397875 kWh per day or 144.83 kWh per year** (Mironga, 2014) was taken as a reference for other two systems. Vidaråsen WWT system consists of three pumps so the energy consumption is estimated as 0.397875 kWh * 3 nos. per day = 1.193625 kWh per day = **434.48 kWh per year.**

• Estimation of materials quantity for flow forms used in EFP and stabilization pond 1 at Vidaråsen WWT system is neglected.

• Energy consumption during the construction works during use of excavators, transporting construction materials has been ignored during inventory data input for all the systems.

• Disposal of sludge accumulated in the septic tank of every system is assumed to be trucked out to a distance of 20 kilometres away for further treatment.

3.3. Life-cycle Inventory analysis (LCI) of the study:

As stated earlier, this phase involves in data collection and calculation procedures to quantify the environmental inputs and outputs, first quantity estimation of all the materials used during construction of the treatment systems was made with the available secondary data's. Then the data's were entered into the construction category of inventory system in SimaPro 7. Then operational data was calculated as in relation to the functional unit defined in the goal and scope of the study. Likewise, performance data's of all the systems were taken from earlier studies made by different authors and was converted into the same functional unit (kg/p.e./year). Then the operational data was entered into the operational category of inventory system in SimaPro 7. Then energy consumption and sludge transportation to a distance of 20 kilometres was entered in the operational inventory system. The outputs of inventory analysis in terms of water, air and soil emissions was further analysed for related environmental impacts (GWP, EP, ODP and AP) using SimaPro 7.

The environmental inputs and outputs of the inventory analysis are represented in the flow diagram below, fig. 3.10:

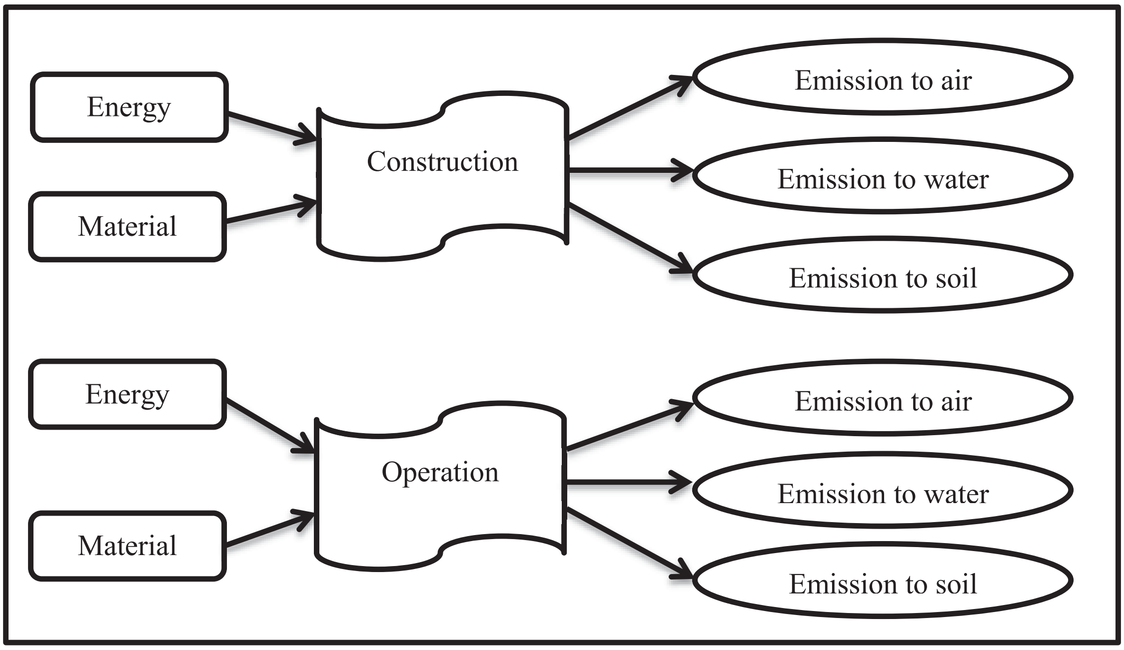


Fig. 3.10: Representation of environmental inputs and outputs in LCI analysis (source: Frances, 2013).

3.3.1. Construction phase inventory

The summary of construction materials consumed during the construction phase has been tabulated below (Table 3-5). The calculated quantities are for the functional unit (i.e. per person equivalent per year). SimaPro data base does not have process input and output for "Filtramar". Therefore, Filtramar was assumed as natural sand and the process data set available for natural sand was used for the inventory. The details of inputs are calculated and presented in Annex 5 and Annex 4.

Table 3-5: Summary of materials used for construction of Høyås farm, Kaja system and Vidaråsen WWT system:

S.N.	**Items**	**Unit**	**Høyås farm WWT system**	**Kaja grey water treatment system**	**Vidaråsen WWT system**
1.	Sand	kg/p.e./yr	280.28	29.20	80.33
2.	Gravel	kg/p.e./yr	238.15	13.24	87.00
3.	Gravel (coarse)	kg/p.e./yr	-	-	18.92
4.	Filtralite-P (2.5-5mm)	kg/p.e./yr	59.13	63.00	-
5.	Filtralite-P (0.5-4mm)	kg/p.e./yr	12.50	-	23.75
6.	Filtramar	kg/p.e./yr	22.00	-	-
7.	Fibre glass	kg/p.e./yr	8.28	0.51	0.16
8.	PVC pipe	lb/p.e./yr	15.73	1.16	1.81
9.	Geo-membrane	kg/p.e./yr	0.76	-	0.41
10.	PVC film	kg/p.e./yr	0.015	0.04	-
11.	Styrofoam (polystyrene foam)	kg/p.e./yr	-	2.06	1.25

3.3.2. Operational phase inventory:

The reference values used to quantify wastewater compositions and air emissions are presented in Table 3-6, Table 3-7, Table 3-8, Table 3-9 and Table 3-10 below:

Table 3-6: Grey water composition measured in septic tank effluent in Kaja grey water treatment system (Jenssen and Vråle, 2003; Jenssen, 2005).

Parameters	**Concentration (mg/L)**	**Mass (g / p.e. / year)**
Total - P	**0.97**	**56**
Total - N	**8.2**	**470**
BOD	**87**	**3642**

Table 3-7: Percentage of P, N, BOD_5 and COD a person produces per day (Yri, et al., 2007).

Parameters	**The amount produced (g / p.e. / day)**
Total - P	**1.6**
Total - N	**12.0**
BOD_5	**40.0**
BOD_7	**46.0**
COD	**94.0**

Table 3-8: Greenhouse gas emissions from Septic tank (Diaz-Valbuena, et al., 2011).

Emissions	**Unit**	**Rate of emissions**
Methane (CH_4)	g / person / day	**11.0**
Carbon dioxide (CO_2)	g / person / day	**33.3**
Nitrous oxide (N_2O)	g / person / day	**0.005**

Table 3-9: Greenhouse gas emissions from Constructed wetland (Fuchs, et al., 2011).

Emissions	**Unit**	**Rate of emissions**	
		HSSFW	**VSSFW**
Methane (CH_4)	mg / m^2 / day	**96.5**	**77.4**
Carbon dioxide (CO_2)	mg / m^2 / day	**1301**	**5200**
Nitrous oxide (N_2O)	mg / m^2 / day	**2.9**	**10.8**

(where, HSSFW – horizontal sub-surface flow wetland, VSSFW – vertical sub-surface flow wetland).

Table 3-10: Greenhouse gas emissions from natural pond system (Hernandez-Paniagua, et al., 2014 and SINGH, et al., 2005).

Emissions	**Unit**	**Rate of emissions**	**Remarks**
Methane (CH_4)	g / m^2 / day	**86.0**	Hernandez-Paniagua, et al., 2014
Carbon dioxide (CO_2)	g / m^2 / day	**85.0**	
Nitrous oxide (N_2O)	mg / m^2 / day	**0.51**	SINGH, et al., 2005

Average sludge accumulation rate in septic tank treating wastewater is taken as, **0.19 liters per person per day** (Brandes, 1978) i.e. **69.16 liters / person / year.** Whereas sludge accumulation rate in septic tank treating only grey water is taken as, **8.3 litres / person / year** (Brandes, 1978). The quantity of sludge generated was assumed to be trucked out to a distance of 20 kilometres from the treatment sites.

Since the reference data for CH_4 emissions from septic tank treating only the grey water was unavailable, therefore this value was taken with the proportion ratio of organic matter content, i.e. BOD content in grey water to BOD content in sewage (black water + grey water). The value was taken assuming that CH_4 gas emission is mainly associated with the organic matter content (Tchobanoglous, et al., 1991). Detail of calculation is presented in Annex 6. The comparison gives the ratio value of 1:4 . Therefore, CH_4 emission from grey water septic tank 11/4 (g/p.e./day) i.e. 2.75 g/pe/day. Similarly, N_2O emission for Kaja system was also taken from proportion ratio of Total-N concentration in grey water to Total-N concentration in combined black water and grey water assuming that N_2O emission is associated with total nitrogen content. Detail of calculation is presented in Annex 6. The comparison gives the ratio value of 1 : 9.2. Therefore, N_2O emission from grey water septic tank 0.005/9.2 (g/p.e./day) i.e. 5.43E-4 g/pe/day.

These ratios are taken as a reference while calculating the CH_4 and N_2O emission from septic tank and wetland of Kaja grey water treatment system.

The values of air emissions from a septic tank is given by (Diaz-Valbuena, et al., 2011) and for constructed wetland by (Fuchs, et al., 2011) in the case of wastewater. Due to lack of reference data, CO_2 emissions in Kaja grey water treatment system has not been taken.

3.4. Life Cycle Impact Assessment (LCIA):

The methodology used for assessment of impacts in this study is CML 2 baseline 2000 V2.05 in SimaPro 7. CML 2 baseline 2000 V2.05 is a part of the "Operational Guide to Life Cycle Assessment" of Centre for Environmental Studies, University of Leiden, The Netherlands (Zaman, 2010) and is based on an internationally accepted approach. CML 2 baseline 2000 V2.05 is based on the problem-oriented approach where the environmental impacts of each process flow are accounted (Renou, et al., 2008). In this approach, first the process flows are classified into impact categories then secondly the relative contribution of flows to each category is analysed and evaluated and finally based on the results, normalization of the impacts is done in the interpretation phase (Iriarte, et al., 2009).

Impact categories in CML 2 baseline 2000 V2.05 are; global warming, ozone layer depletion, eutrophication, acidification, abiotic depletion, human toxicity, marine aquatic eco-toxicity, fresh aquatic eco-toxicity, terrestrial eco-toxicity and photo-chemical oxidation. This study is focused only on four impact categories; global warming potential **(GWP)**, ozone depletion potential **(ODP)**, eutrophication potential **(EP)** and acidification potential **(AP)**.

Characterization values of each impact are analysed and for normalization, The Netherlands, 1997, values for the impacts are taken. The normalization values as on The Netherlands, 1997 values in LCA is given below in Table 3-11 (source: Pré Consultants, 2008):

Table 3-11: Normalization value used in CML 2 baseline 2000 V2.05 method

Impact categories	Unit	The Netherlands, 1997
Global warming potential (GWP 100)	kg CO_2 eq.	3.96E-12
Ozone depletion potential (ODP)	kg CFC-11 eq.	1.02E-6
Eutrophication potential (EP)	kg PO_4^{-3} eq.	1.99E-9
Acidification potential (AP)	kg SO_2 eq.	1.49E-9
Abiotic depletion	kg Sb eq.	5.85E-10
Human toxicity	kg 1.4-DB eq.	5.32E-12
Marine aquatic eco-toxicity	kg 1.4-DB eq.	3.14E-13
Fresh water aquatic eco-toxicity	kg 1.4-DB eq.	1.33E-10
Terrestrial eco-toxicity	kg 1.4-DB eq.	1.09E-9
Photo-chemical oxidation	kg C_2H_4	5.49E-9

(source: Pré Consultants, 2008).

Description of the impact categories considered for this study are as below:

3.4.1. Global Warming Potential (GWP):

Global warming is considered as a global effect and is contributed due to the effect of increasing temperature in the lower atmosphere (Stranddorf, et al., 2005). Emissions of greenhouse gasses like methane (CH_4), carbon dioxide (CO_2), and nitrous oxide (N_2O) and its content in the atmosphere reflect the incoming infrared radiation (Stranddorf, et al., 2005). This causes the temperature increase in the lower atmosphere to a level above normal resulting in the contribution of global warming. Carbon dioxide gas is taken as the equivalency factor for greenhouse gasses, so the GWP for greenhouse gasses is expressed and calculated in kg CO_2-equivalents (kg CO_2-eq.) with a time horizon of 100 years. The normalization reference for GWP has been calculated to **8.7 ton CO_2-eq. / capita / year** (Stranddorf, et al., 2005).

3.4.2. Ozone layer Depletion Potential (ODP):

Stratospheric ozone layer act as a filter to incoming ultraviolet (UV)-radiation into the earth surface. Depletion of this ozone layer will result to increased incoming UV-radiation which leads to impacts on humans, natural organisms and the eco-system, therefore it is also considered as a global impact (Stranddorf, et al., 2005). This depletion is enhanced by compounds like chloro-flurocarbons (CFCs), hydroflurocarbons (HFCs), hydro-chlorofluorocarbons (HCFCs) etc. Ozone depletion potential (ODP) are calculated relative to the potential of CFC-11 and therefore it is expressed as CFC-11 equivalents. The normalization reference for ODP has been calculated to: **0.103 kg CFC-11-eq. / capita / year** (Stranddorf, et al., 2005).

3.4.3. Eutrophication Potential (EP):

Eutrophication is caused due to the enrichment of nutrients (mainly phosphorus and nitrogen) in the aquatic environment. This results in the growth of planktonic algae and aquatic plants which lead to the reduction of water quality. Eutrophication potential (EP) is expressed in terms of phosphate equivalents (PO_4^{-3}- eq.). The normalization reference for EP has been calculated to **0.3 kg P-eq. / capita / year** (Stranddorf, et al., 2005).

3.4.4. Acidification Potential (AP):

Acidification is basically a local and regional effect and refers to the increase in acid content in the terrestrial or aquatic eco-system (Stranddorf, et al., 2005). Acidifying substances that lead to acidification are; oxides of sulphur (SO_x), nitrogen oxides (NOx) and ammonia (NH_3) (Stranddorf, et al., 2005). Acidification potential (AP) is expressed in terms of sulphuric acid (SO_2) as an equivalence factor and so is expressed as SO_2-eq. The normalization reference for AP has been calculated to **59 kg SO_2-eq. / capita / year** (Stranddorf, et al., 2005).

CHAPTER 4 RESULTS, DISCUSSIONS AND INTERPRETATION:

In this chapter, the results and findings of the study are presented. Discussions on the comparative environmental impacts of the three wastewater treatment systems are elaborated.

As mentioned in earlier chapter, CML 2 baseline 2000 methodology was used to analyse the environmental impacts of the treatment systems considered in this study.

Based on the reference values and performance efficiencies of the treatment systems, the operational input inventory data was calculated. The summary of operational input inventory data is presented in Table 4-1 below:

Table 4-1: Summary of calculated operational phase inventory data (from Annex 4).

S. N.	Emissions	Unit	Kaja system	Vidaråsen system	Høyås farm
1.	**Water emissions**				
	Total - P	kg/ p.e./yr	0.00336	0.02694	0.020151
	Total - N	kg/ p.e./yr	0.141	0.39072	1.853
	BOD_5	kg/ p.e./yr	0.21852	0.1456	0.801674
2	**Air emissions**				
	Methane (CH_4)	kg/ p.e./yr	1.02	60.43	4.004
	Carbon dioxide (CO_2)	kg/ p.e./yr		69.68	12.1212
	Nitrous oxide (N_2O)	kg/ p.e./yr	0.00044	0.0062	0.00182
3	**Sludge**	Tons/p.e./yr	5.98E-3	0.05	0.05
4	**Energy consumption**	kWh/p.e./yr	3.0173	2.1724	18.10375
5	**Transport of sludge to a distance of 20 kilometers**	Tons km/p.e./yr	1.2E-1	1	1

4.1. Results of Høyås farm WWT system:

Results in table 4-2 represented in fig. 4.1, show that both the construction and operation phase contribute to different impact categories. **AP** (99.6%) and **ODP** (98.86%) are significant in construction phase whereas **EP** (96.55%) and **GWP (57.64%)** are significant in operation phase. Brief discussions on each environmental impact category are presented below:

Table 4-2: Impact characterization of Høyås farm WWT system.

Impact category	Unit	Construction	Operation	Sludge transportation	Total
Acidification (AP)	kg SO_2 eq.	0.4 **(99.6%)**	0.000151 (0.04%)	0.00135 (0.34%)	0.402
Eutrophication (EP)	Kg PO_4^{-3} eq.	0.0282 (3.24%)	0.84 **(96.55%)**	0.0003 (0.034%)	0.87
Global warming (GWP **100)**	kg CO_2 eq.	68 (42.24%)	92.8 **(57.64%)**	0.257 (0.16%)	161
Ozone layer depletion (ODP)	kg CFC-11 eq.	4.34E-6 **(98.9%)**	6.08E-9 (0.14%)	4.02E-8 (0.91%)	4.39E-6

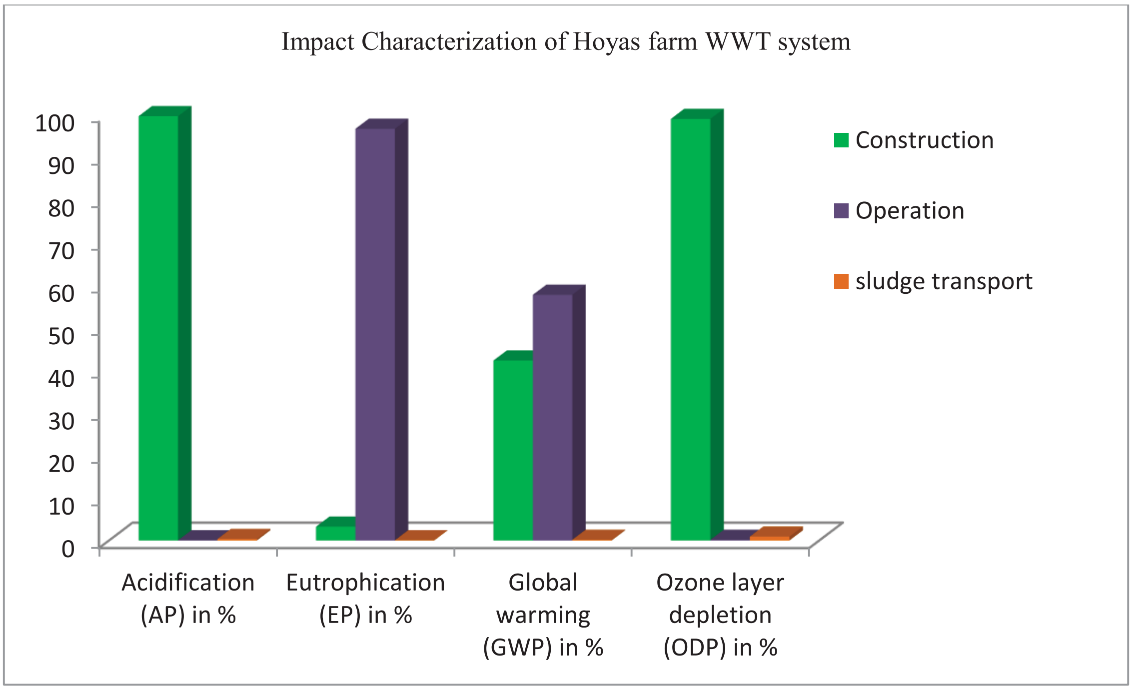


Fig. 4.1 : Impact Characterization of Høyås farm WWT system

AP: The total acidification impact values 0.402 kg SO_2 equivalence of which 99.6% is accounted during the construction stage (Table 4-2). The production process of filter material and pre-fabricated components are the main contributors for this impact. The assembly layout diagram of Høyås farm to AP presented in Annex 7 show that air emissions during production of filter material "Filtralite-P" (expanded clay) has contribution of 41%, followed by production of fibre glass components (31.3%), PVC pipe (26%) and polypropylene (1.17%). As mentioned in previous chapter, Filtralite-P has been used as filter media in the bio-filter unit and phosphorus filter tanks. Likewise, the septic tank, bio-filter domes and the phosphorus filter tanks are made of fibre glass. The air emissions contributing to the impact are Sulphur dioxides (SO_X) being the highest contributor followed by Nitrogen oxides (NO_x) and Ammonia (NH_3) (presented in Annex 8; specification per substance of Høyås farm to AP). Operation phase and sludge transportation have minor contribution to AP.

EP: The total eutrophication impact values 0.87 kg PO_4^{-3} eq. of which 96.7% is accounted during the operation phase (Table 4-2). The emission of Total-Nitrogen (0.778 kg PO_4^{-3} eq. i.e. 89.4% of total) and Total-Phosphorus (0.0625 kg PO_4^{-3} eq. i.e. 7.2% of total) in effluent water are the main contributors to the impact. The details of all the contributors to the impact are presented in Annex 8; specification per substance of Høyås farm to EP impact.

GWP: The total global warming impact value is 161 kg CO_2 eq. of which 57.64% (92.8 kg CO_2 eq.) is accounted during the operation phase and 42.24% (68 kg CO_2 eq.) is contributed during the construction phase (Table 4-2). Electrical energy consumed during pumping of septic tank effluent into bio-filter in the operation phase and greenhouse gases emission from septic tank has resulted to the impact. Carbon dioxide emission of 34.5 kg CO_2 eq. during production of filter media "Filtralite-P" (14% of 68 kg CO_2 eq.), PVC pipe (14.1%), fibre glass products (13.1%) and polypropylene contributes to GWP in the construction phase. The detail is shown in assembly layout diagram of Høyås farm to GWP in Annex 7. Greenhouse gas emissions (CH_4, CO_2 and N_2O gases) are the main contributors to the GWP. Specification per substance of Høyås farm to GWP presented in Annex 8 show that methane gas (CH_4,) emission has the highest contribution of 96.8 kg CO_2 eq. (60.12% of total) of which 92.1 kg CO_2 eq. is emitted in the operation phase.

ODP: The total ozone layer depletion impact values 4.39E-6 kg CFC-11 eq. of which 98.9% is accounted during the construction phase. Production of Filtralite-P (expanded clay) contributes 62.6% and production of fibre glass components contributes 36.3 % to the impact (assembly layout diagram of Høyås farm to ODP presented in Annex 7). The consumption of diesel energy, heat energy, electrical energy and burning of natural gas during the production process are the main elements resulting to the impact. The main air emissions contributing to this impact are Methane bromotrifluoro- Halon 1301 and Methane bromotrifluoro- Halon 1211 gas followed by other emissions (Specification per substance of Høyås farm to ODP presented in Annex 8). Operation phase and sludge transport have very minor contribution to the impact.

From the above discussions, it can be concluded that SO_x, NO_X and NH_3 emissions are the main contributors to acidification impact and Total-N is the main element contributing to Eutrophication impact. Similarly, methane is the main greenhouse gas emission followed by carbon dioxide emission from septic tank that contributes to GWP during operation phase. According to study carried out by (Leverenz, et al., 2010) and (Diaz-Valbuena, et al., 2011), septic tank is the primary source of methane and carbon dioxide emission in on-site WWT systems. Construction phase also contributes to GWP which is resulted from carbon dioxide emission during production of filter media and pre-fabricated elements. ODP is contributed during the construction phase. Therefore, we can conclude that production process of Filtralite-P (expanded clay), pre-fabricated fibre glass components and PVC pipe are the major contributing factor to the **AP** and **ODP** impacts. Similarly, the production process of such elements also have significant contribution **GWP.**

Table 4-3: Normalization of impacts of Høyås farm WWT system

Impact category	Construction	Operation	Sludge transportation	Total
Acidification (AP)	5.96E-10	2.25E-13	2.01E-12	**5.99E-10**
Eutrophication (EP)	5.61E-11	1.67E-9	5.79E-13	**1.73E-9**
Global warming (GWP 100)	2.69E-10	3.67E-10	1.02E-12	**6.37E-10**
Ozone layer depletion (ODP)	4.43E-12	6.2E-15	4.1E-14	**4.48E-12**

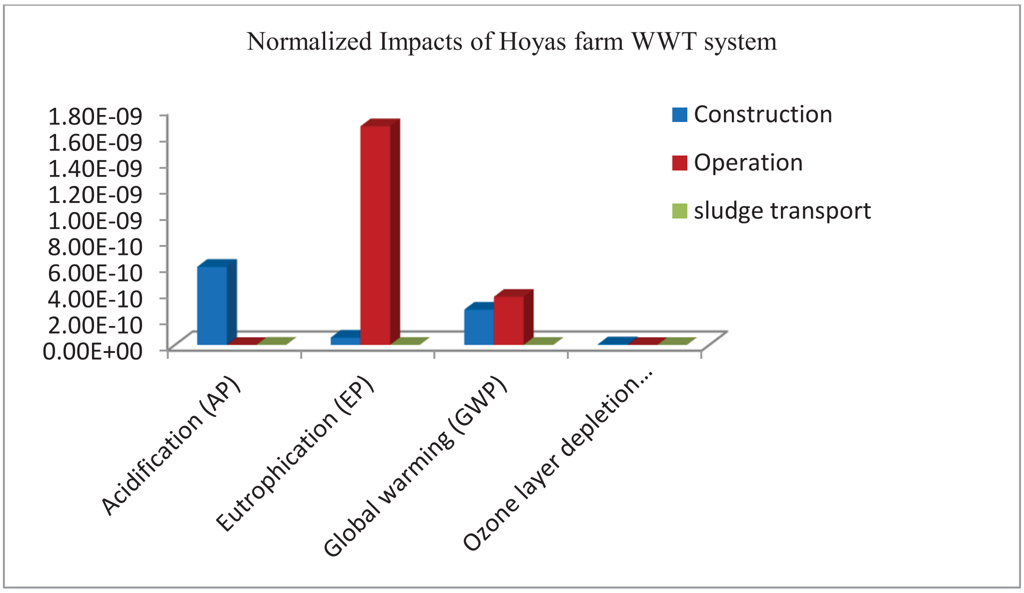


Fig. 4.2 Normalization of impacts of Høyås farm WWT system.

The normalized value of all the impacts considered in the study for Høyås farm is presented above in Table 4-3 and is represented in above bar chart Fig. 4.2. The values to AP, EP, GWP and ODP are 5.99E-10, 1.73E-9, 6.37E-10 and 4.48E-12 respectively. These values are the normalized impacts resulted by the treatment system, equivalent with the corresponding impacts of per capita per year. The normalized value show that eutrophication contributed during operation phase is a significant impact followed by acidification during construction phase.

4.2. Results of Kaja grey water treatment system:

Results in Table 4-4 represented in bar chart fig. 4.3, show that both the construction and operation phase contribute to different impact categories. **AP** (99.9%), **GWP** (55.38%) and **ODP** (99.63%) are significant for construction phase whereas **EP** (87.5%) is significant for operation phase. Brief discussions on each environmental impact category are presented below:

Table 4-4: Impact characterization of Kaja grey water treatment system.

Impact category	Unit	Construction	Operation	Sludge transportation	Total
Acidification (AP)	kg SO2 eq.	0.184 **(99.9%)**	2.51E-5 (0.01%)	0.000162 (0.08%)	0.184
Eutrophication (EP)	Kg PO_4^{-3} eq.	0.0101 (12.62%)	0.07 **(87.5%)**	3.49E-5 (0.0004%)	0.08
Global warming (GWP 100)	kg CO2 eq.	29.3 **(55.38%)**	23.6 (44.61%)	0.0308 (0.06%)	52.9
Ozone layer depletion (ODP)	kg CFC-11 eq.	2.68E-6 **(99.8%)**	1.01E-9 (0.037%)	4.82E-9 (0.18%)	2.69E-6

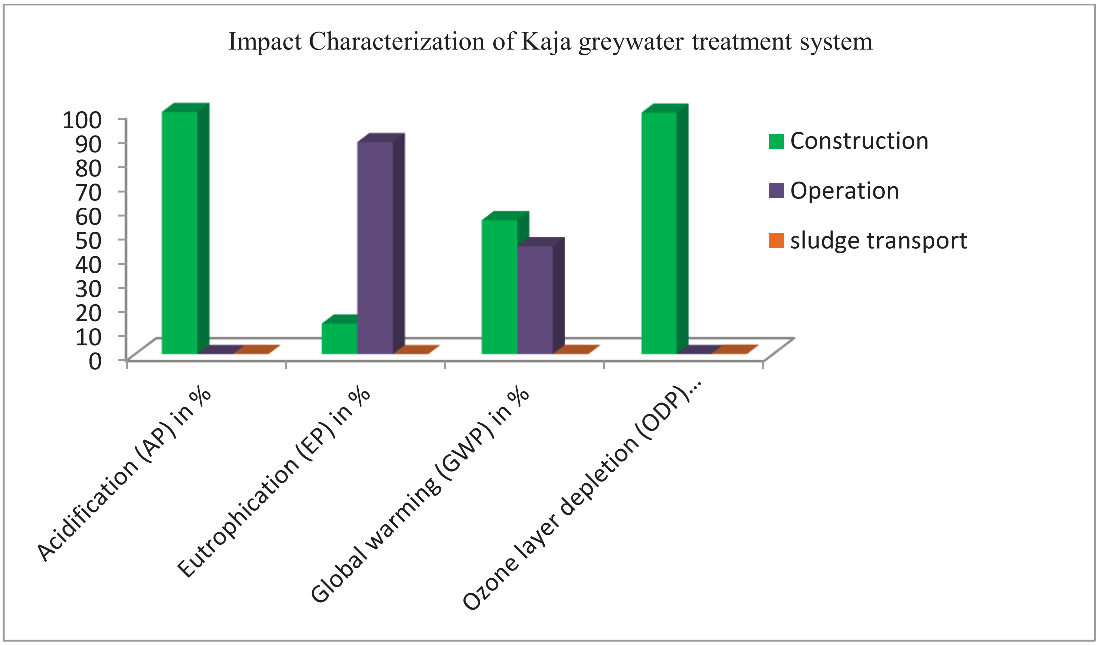


Fig. 4.3: Impact Characterization of Kaja grey water treatment system.

AP: The total acidification impact values 0.184 kg SO_2 equivalence of which 99.9% is accounted during the construction phase (Table 4-4). Production process of Filtralite-P and pre-fabricated fibre glass components are the main contributors to this impact. Air emissions during production of filter material "Filtralite-P" (expanded clay) has contribution of 78.9%, followed by production of polystyrene foam (12.3%), fibre glass component (4.22%) and PVC pipe (4.2%) (detail shown in assembly layout diagram of Kaja grey water treatment system to AP presented in Annex 7). As mentioned in methodology chapter, Filtralite-P has been used as filter media in the bio-filter unit and horizontal sub-surface flow constructed wetland (HSSFW), polystyrene (Styrofoam) foam is used as insulation on all the four sides of constructed wetland pit and septic tank, bio-filter dome are made of fibre glass. The substance contributors to the impact are Sulphur dioxides (SO_x) being the highest contributor followed by Nitrogen oxides (NO_x) and Ammonia (NH_3) (specification per substance of Kaja treatment system to AP presented in Annex 8).

EP: The total eutrophication impact values 0.08 kg PO_4^{-3} eq. of which 87.5% is resulted during the operation phase (Table 4-4). The emission of Total-N (0.0592 kg PO_4^{-3} eq.) and Total-P (0.0105 kg PO_4^{-3} eq.) in the effluent water are the main contributors to the impact. The details of all the contributors to the impact are presented in specification per substance of Kaja treatment system to EP in Annex 8.

GWP: The total global warming impact values 52.9 kg CO_2 eq. of which 55.38% is resulted during the construction phase and 44.61% during the operation phase (Table 4-4). Methane gas (CH_4,) emission has contribution of 23.8 kg CO_2 eq. (45% of total) of which 23.5 kg CO_2 eq. is released during the operation phase. Similarly, carbon dioxide (CO_2) has contributed 22.7 kg CO_2 eq. (42.9% of total) which is resulted in the construction phase. The details of all the contributors to the impact are presented in specification per substance of Kaja treatment system to GWP in Annex 8. In construction phase, the emission of CO_2 is during the production of Filtralite-P (37.6%), polystyrene foam (11.9%), PVC pipe (3.16%) and fibre glass components (2.46%) whereas in operation phase the emission of methane (CH_4) is mainly from the septic tank (details shown in assembly layout diagram of Kaja treatment system to GWP in Annex 7).

ODP: The total ozone layer depletion impact values 2.69E-6 kg CFC-11 eq. of which 99.63% is contributed during the construction phase (Table 4-4). Production of Filtralite-P (expanded clay) contributes 89.9%, production of polystyrene foam contributes 6.23% and production of fibre glass component contributes 3.65 % to the impact (details shown in assembly layout diagram of Kaja treatment system to ODP in Annex 7). The consumption of diesel energy, heat energy, electrical energy, burning of natural gas, fuel oil, foaming process etc. during the production process are the main factors ccontributing to ODP. Emission of Methane bromotrifluoro- Halon 1301 and Methane bromotrifluoro- Halon 1211 are the main gases contributing to ODP. The details of substances contributing to this impact are presented in specification per substance of Kaja treatment system to ODP in Annex 8.

The impact category results are almost similar to that of Høyås farm WWT system. SO_x, NO_X and NH_3 emissions during construction phase are the main contributors to acidification impact and Total-N is the main element contributing to Eutrophication impact. Similarly, methane (CH_4) and carbon dioxide (CO_2) emission from septic tank during sludge accumulation contributes to GWP during operation phase and carbon dioxide emission during construction phase is the second factor contributing to GWP. ODP is contributed during the construction phase. Therefore, production process of Filtralite-P (expanded clay), pre-fabricated fibre glass components and PVC pipe during the construction phase is the major contributing factor for the **AP** and **ODP** and the process also have signifiant contribution to **GWP.**.

Table 4-5: Normalization of impacts of Kaja grey water treatment system.

Impact category	Construction	Operation	Sludge transport	Total
Acidification (AP)	2.74E-10	3.75E-14	2.41E-13	**2.74E-10**
Eutrophication (EP)	2.02E-11	1.39E-10	6.94E-14	**1.59E-10**
Global warming (GWP 100)	1.16E-10	9.35E-11	1.22E-13	**2.09E-10**
Ozone layer depletion (ODP)	2.74E-12	1.03E-15	4.92E-15	**2.74E-12**

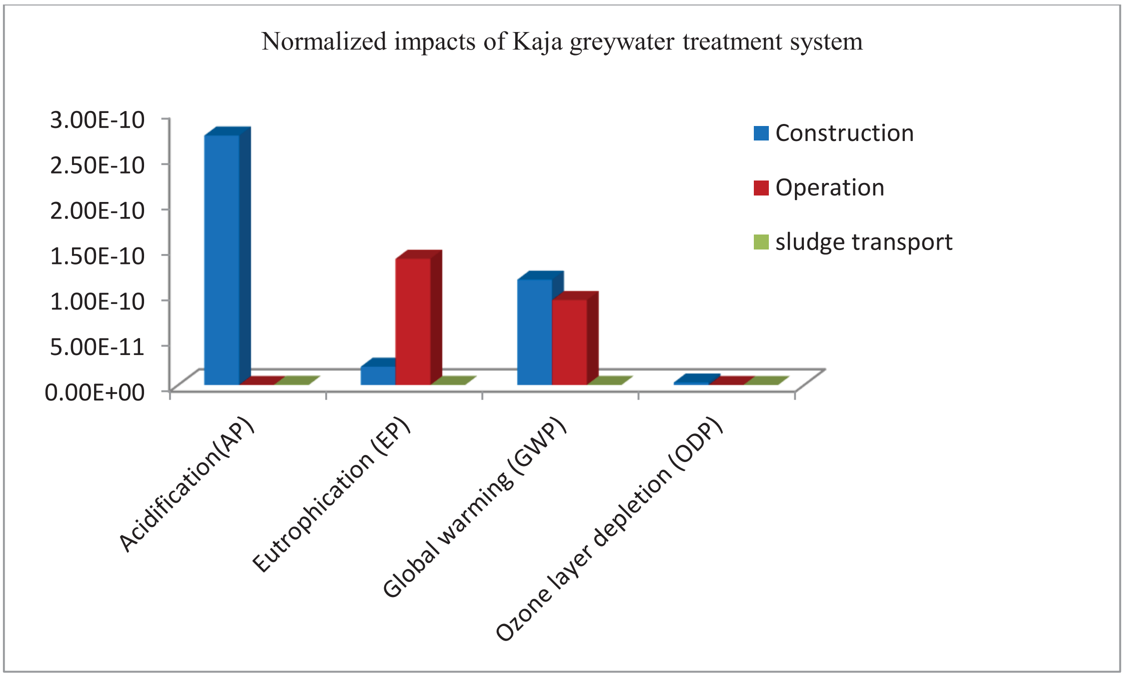


Fig. 4.4 Normalization of Impacts of Kaja grey water treatment system.

The normalized value of all the impacts considered in the study for Kaja grey water treatment system is presented above in Table 4-5 and is represented in above bar chart Fig. 4.4. The values to AP, EP, GWP and ODP are 2.74E-10, 1.59E-10, 2.09E-10 and 2.74E-12 respectively. As mentioned earlier, these values are the normalized impacts resulted by the treatment system, equivalent with the corresponding impacts of per capita per year. The normalized value show that acidification contributed during the construction phase is a significant impact followed by eutrophication during operation phase.

4.3. Results of Vidaråsen WWT system

Results in table 4-6 represented in fig. 4.5 below, show that **AP** (98.54%) and **ODP (**96.36%) are significant during construction phase and **EP** (98.04%) and **GWP** (98.58%) are significant during operation phase. Brief discussions on each environmental impact category are presented below:

Table 4-6: Impact Characterization of Vidaråsen WWT system

Impact category	Unit	Construction	Operation	Sludge transportation	Total
Acidification (AP)	kg SO_2 eq.	0.0879 **(98.54%)**	1.81E-5 (0.02%)	0.00135 (1.51%)	**0.0892**
Eutrophication (EP)	Kg PO_4^{-3} eq.	0.00536 (2.1%)	0.251 **(97.8%)**	0.000291 (0.11%)	**0.256**
Global warming (GWP 100)	kg CO_2 eq.	15.8 (1.12%)	1.39E3 **(98.58%)**	0.257 (0.02%)	**1.41E3**
Ozone layer depletion (ODP)	kg CFC-11 eq.	1.06E-6 **(96.3%)**	7.32E-10 (0.07%)	4.02E-8 (3.64%)	**1.1E-6**

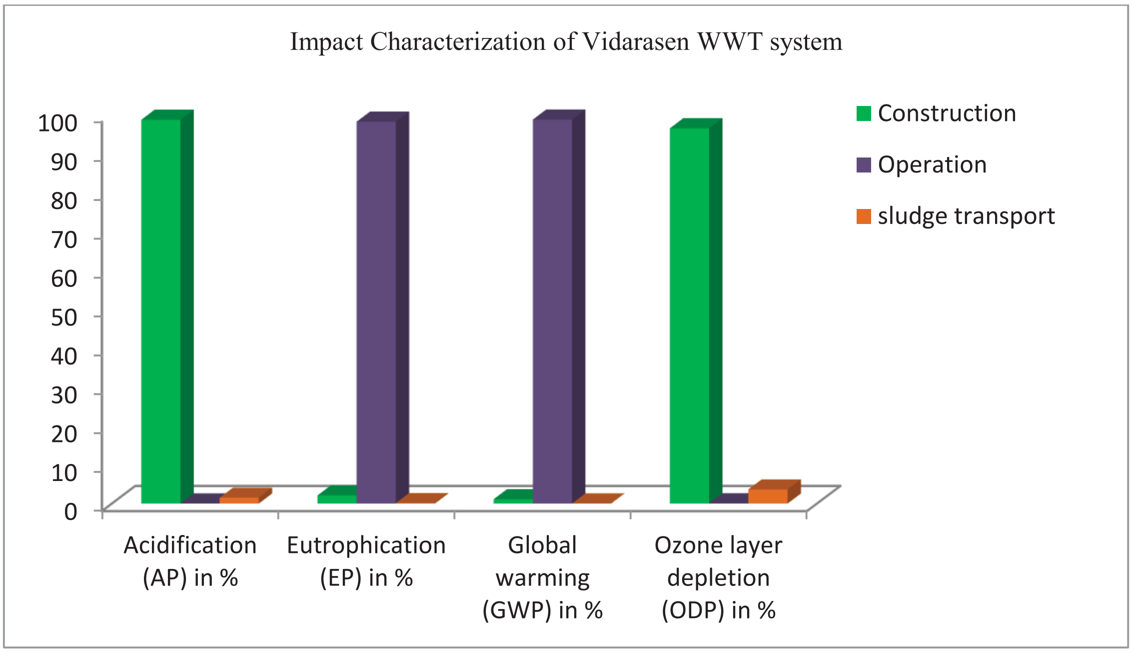


Fig.4.5. Impact Characterization of Vidaråsen WWT system.

AP: The total acidification impact values 0.0892 kg SO_2 equivalence, of which 98.54% is accounted during the construction phase (Table: 4-6). Production of Filtralite-P (61.3%), polystyrene foam (18.1%), PVC pipe (13.5%), polypropylene (2.85%) and fibre glass components (2.73%) contributes to the impact (details shown in assembly layout diagram of Vidaråsen system to AP in Annex 7). Sulphur dioxides (SO_X) have the highest contribution followed by Nitrogen oxides (NO_X) and Ammonia (NH_3) to the impact (details shown in specification per substance of Vidaråsen system to AP in Annex 8). There is a minor contribution of 1.51% to the impact during the sludge transport.

EP: The total eutrophication impact values 0.256 kg PO_4^{-3} eq. of which 98.04% is accounted during the operation phase (Table 4-6). The emission of Total-Nitrogen (0.168 kg PO_4^{-3} eq. i.e. 65.62% of total) and Total-Phosphorus (0.0827 kg PO_4^{-3} eq. i.e. 32.3% of total) in effluent water are the main contributors to the impact. The detail is presented in specification per substance of Vidaråsen system to EP in Annex 8.

GWP: The total global warming impact values 1.41E3 kg CO_2 eq. of which 98.58% is accounted during the operation phase (Table 4-6). Methane gas (CH_4,) emission has the highest contribution of 1.39E3 kg CO_2 eq. (almost 100%). The detail is presented in specification per substance of Vidaråsen system to GWP in Annex 8. The emissions of greenhouse gases resulting to GWP are during the sludge accumulation process in the septic tank, emissions from treatment units like pre-treatment filters, facultative pond and constructed wetlands.

ODP: The total ozone layer depletion impact values 1.1E-6 kg CFC-11 eq. of which 96.36% is accounted during the construction phase (Table 4-6). The operational phase has negligible effect to the impact and sludge transport results 3.64% to the impact. Production process of materials used in the treatment process has contributed to the ODP impact. Production of Filtralite-P (expanded clay) results 82.6% and polystyrene foam results 10.9% to the impact (detail shown in assembly layout diagram of Vidaråsen system to ODP in Annex 7). Emissions of substances (such as Methane bromotrifluro- Halon 1301, Methane bromotrifluro- HCFC-22, Methane bromotrifluro- Halon 1211 etc.), are the main contributors to the impact as presented in specification per substance of Vidaråsen system to ODP in Annex 8.

From the above discussions, it can be concluded that Sulphur oxides (SO_X) is more responsible than nitrogen oxides (NO_X) and ammonia (NH_3) to the AP and is resulted during the production process of construction materials used in the treatment system. Likewise, Total-N is the main contributing element for EP and methane gas (almost 100%) is the main contributor to GWP during the operational phase. Greenhouse gas emissions from septic tank, pre-treatment filters, facultative pond and constructed wetlands are the main treatment units resulting to the GWP. Similarly, production process of construction materials during construction phase is the key contributor to ODP.

Table 4-7 : Normalization of Impacts of Vidaråsen WWT system

Impact category	Construction	Operation	Sludge transportation	Total
Acidification (AP)	1.31E-10	2.7E-14	2.01E-12	**1.33E-10**
Eutrophication (EP)	1.07E-11	4.99E-10	5.79E-13	**5.1E-10**
Global warming (GWP 100)	6.26E-11	5.51E-9	1.02E-12	**5.57E-9**
Ozone layer depletion (ODP)	1.08E-12	7.47E-16	4.1E-14	**1.13E-12**

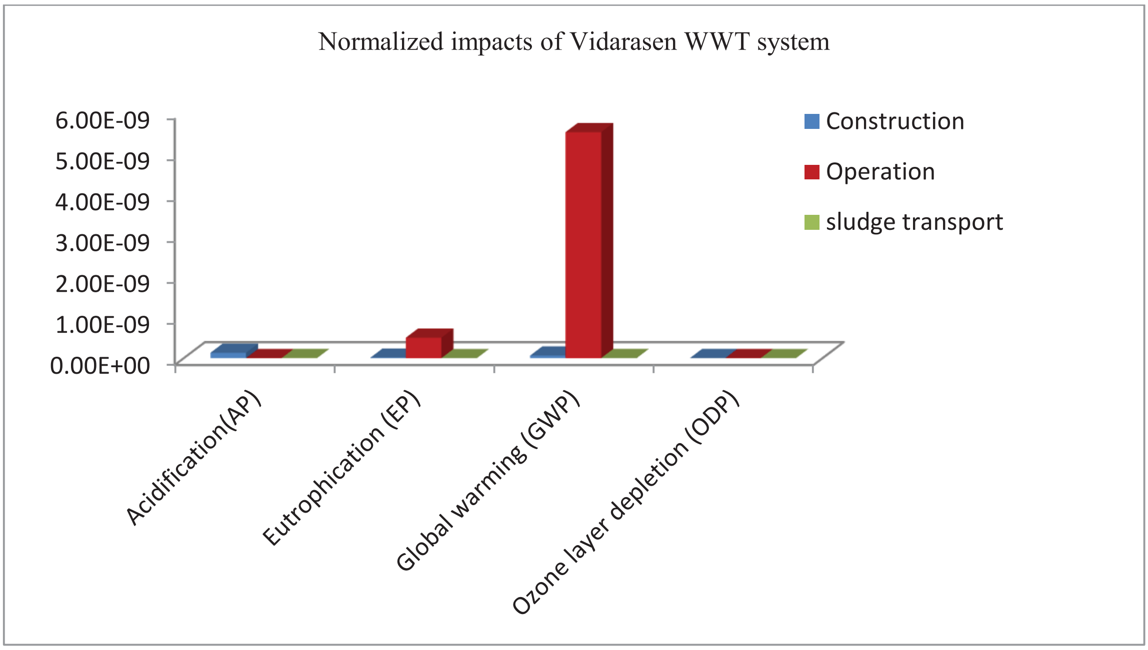


Fig. 4.6 Normalization of impacts of Vidaråsen WWT system.

The normalized value of all the impacts considered in the study for Vidaråsen WWT system is presented above in Table 4-7 and is represented in above bar chart Fig. 4.6. The values to AP, EP, GWP and ODP are 1.33E-10, 5.1E-10, 5.57E-9 and 1.13E-12 respectively. As mentioned earlier, these values are the normalized impacts resulted by the treatment system, equivalent with the corresponding impacts of per capita per year. The normalized values show that global warming contributed during operation phase is a significant impact followed by eutrophication impact during operation phase.

4.4. Overall discussions of the systems:

The comparative impact analysis of the three treatment systems show that acidification **(AP)** and Ozone layer depletion **(ODP)** are mainly resulted during the production process of construction materials. Filter material (Filtralite-P) has the highest contribution among the materials used in the treatment systems, though, the fact lies that Filtralite-P has been regarded as a high-quality filter media for phosphorous removal (ÁdÁm, et al., 2007). Norwegian Filtralite-P has P adsorption capacity of 12 gm P / kg (Jenssen, 2005). Results show that there is an effective control in Eutrophication impact (EP), but in other hand, Filtralite-P is the main contributor to **AP** and **ODP**. The production process also have significant contribution in **GWP**. Filtramar (shell-sand) has P adsorption capacity of 17 gm P

/ kg (Roseth, R., 2000; Adam, et al., 2007). Therefore, a sensitivity analysis can be carried out with alternative filter media like shell-sand or natural sand to analyse the environmental impacts of the on-site treatment systems under study.

On the other hand, when we look at the results of eutrophication **(EP)** impact resulted by all the treatment systems, presence of total nitrogen (Total-N) in the effluent is mainly responsible to the impact. Total-P has very less contribution in comparison to Total-N. Therefore, if removal of phosphorus content is the main requirement of the treatment system in order to reduce eutrophication impact, than using Filtralite-P as filter media is one of the best options because Filtralte-P saturated with phosphorus can be used as fertilizer in agricultural purpose after it has been proven safe to use in agriculture land . In a country like Norway, where removal of nutrients causing eutrophication of lakes, rivers and other receiving water bodies is the key priority of wastewater treatment systems, effective and sustainable control on this impact becomes the key necessity. As mentioned earlier, most of the municipalities in Norway have a strict requirement of effluent discharge with P concentration of 1 mg / litre (Jenssen, 2005).

Similarly, results show that Methane (CH_4) gas is the main contributing greenhouse gas emitted during the operational phase that has contributed to the Global Warming Impact (**GWP)** in all the three systems (60.12% in Høyås farm, 45% in Kaja system and 98.8% in Vidaråsen system). The methane emission occurs from treatment units like septic tank, facultative pond and constructed wetlands. Construction phase has also contributed to this impact category like in case of Høyås farm system and Kaja system where carbon dioxide (CO_2) has contributed 21.5% and 42.9% respectively to the impact and is resulted by the energy consumption during the production process of filter media, pre-fabricated fibre glass components and other construction materials. Replacement of such products (such as replacing the pre-fabricated fibreglass septic tank, phosphorus tanks with traditional reinforced cement concrete units or replacing Filtralite-P with shell-sand or natural sand) cannot be the effective solution unless we analyse the results from the replaced ones.

With regard to handling of the sludge, it is obvious that air emissions during lorry transport have remarkable contribution to environmental impacts. So question arises what if the sludge volume be reduced at the treatment sites so that the vehicular movements engaged in transport of the sludge also get reduced. There could be options for mitigating such issues.

Option 1:

Sludge drying reed-beds are successfully practiced over European countries like Denmark, France and Belgium since long time before (Cooper, et al., 2004). Danish experience show that anaerobically digested sludge containing 3-4% dry solids, achieved a total volume reduction of about 90% with a final dry-solids concentration up to 40%, after the sludge was been treated in a sludge drying reed- beds (Cooper, et al., 2004). Considering this study, if the sludge generated is treated on-site in sludge drying beds, there would be a considerable reduction in the sludge volume which would finally reduce the cost of sludge transport as well as environmental impacts associated with the transport.

For example, let's take the case of Vidaråsen WWT system.

Sludge accumulation rate per capita per year is 69.16 liters (Brandes, 1978). Therefore,

Total sludge volume produced = 69.16 liters per year * 200 persons = 13832 liters per year = 13.832 m^3 per year. i.e. Total Volume (V) = 13.832 m^3/yr

Taking % of dry solids = 4%

Then, volume of dry solid, V_s= 0.55328 m^3/yr

Taking total volume reduction = 90%

Net volume after reduction, V_N = 1.3832 m^3/yr

Multiplying this volume with the sludge density, 721 kg/m^3 we get,

Total mass of sludge, M_S = 1.3832 m^3/yr * 721 kg/m^3 = 997.3 kg/yr

There is a reduction of 10% in total mass of the sludge to be transported. This would finally reduce more likely in the same ratio the cost of transport as well as environmental impacts associated with the effluent gases emitted during transportation of sludge. In addition, it would also reduce the impacts related to emissions and energy consumption during the sludge treatment process, considering that less quantity of dry sludge would consume less energy resource than more quantity of wet sludge. Analysis should be done to find out the actual reduction in the environmental impacts and the transport cost for the reduced volume. So on-site sludge treatment with sludge drying reed-beds where there is sufficient area of land, could be an option to reduce the environmental impacts associated with the transport of sludge, despite the fact that on-site treatment of sludge would also contribute to some environmental impacts which is uncertain and needs expansion of the boundary condition of the system under study.

Option 2:

Reduction of sludge volume with anaerobic digestion process within the treatment system unit as in case of Vidaråsen WWT system also could be the other option. The Enhanced Faculative Pond (EFP) in Vidaråsen system has a deep pit in the center of the pond which are especially designed to avoid intrusion of oxygen (Oswald, 1990; Pandey, 2016). If the sludge accumulated in the septic tank is fed in batches into the anaerobic deep pit of the pond with a pipe directly connected from the septic tank bottom then anaerobic digestion of sludge occurs in the pit (Pandey, 2016). This mechanism will reduce the volume of sludge generated for disposal and hence reduce the disposal cost of sludge and its environmental impacts during transport. According to (Oswald, 1990), there are some systems in operation for up to 20 years without sludge removal from the pit bottom. Therefore, this mechanism could also be an option to reduce the vehicular movements for sludge transport and eventually reduce the environmental burdens associated with the sludge transport. But possibly there could be increase in environmental impacts associated with EFP if this option is practiced which is uncertain without any analysis.

4.5. Comparative impact assessment of three systems under study

Results presented in Table 4-8 represented by Fig. 4.7 presents the comparative contribution to impacts from the three systems. The comparative impact after normalization is presented in Fig. 4.8. The Høyås farm WWT system has highest contribution to **AP, EP** and **ODP** whereas the Vidaråsen WWT system has highest contribution to the **GWP**. The Kaja grey water treatment system has the least contribution to all impact categories considered. Higher contribution of Høyås farm WWT system to **AP, EP** and **ODP** is mainly due to use of filter media "Filtralite-P" and pre-fabricated fibre glass components. The **GWP** is higher in Vidaråsen WWT system because it has higher operational greenhouse gas emissions. This is mainly because of the area of CW which is the main contributing unit to greenhouse gases in Vidaråsen WWT system. In addition, the pond systems are also contributing to the greenhouse gases. In comparison to the other two systems, Vidaråsen WWT system however is a hybrid treatment system consisting of many treatment units occupying a large land area (around $10m^2$ per person). This shows that the scale of the system has significant influence on the impact categories. In addition, availability of land and the land value may constrain the replication of Vidaråsen system in urban settlements.

Table 4-8: Impact Characterization of three systems under study

Impact Category	Unit	Kaja treatment system	Høyås farm WWT system	Vidaråsen WWT system
Acidification (AP)	kg SO_2 eq.	0.184 (45.77%)	0.402 **(100%)**	0.0892 (22.19%)
Eutrophication (EP)	Kg PO_4^{-3} eq.	0.0798 (9.18%)	0.869 **(100%)**	0.256 (29.46%)
Global warming (GWP 100)	kg CO_2 eq.	52.9 (3.75%)	161 (11.42%)	1.41E3 **(100%)**
Ozone layer depletion (ODP)	kg CFC-11 eq.	2.69E-6 (61.27%)	4.39E-6 **(100%)**	1.1E-6 (25.05%)

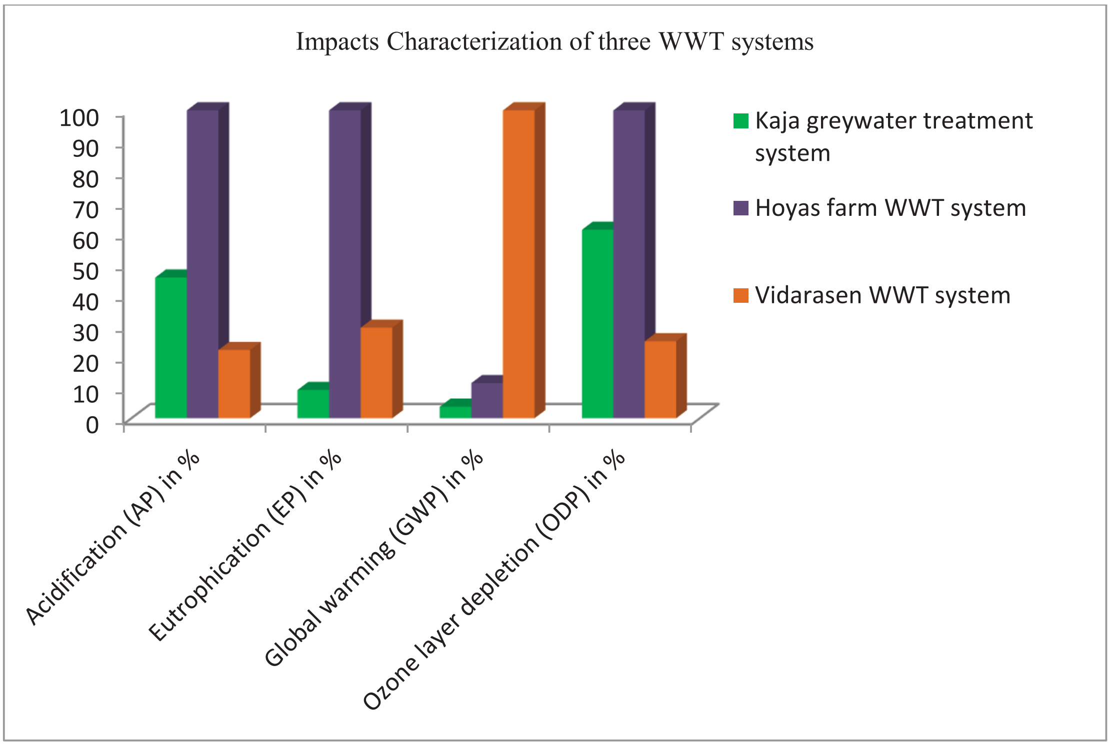


Fig.4.7. Impact Characterization of three systems under study

Table 4-9: Normalization of impacts of three systems under study

Impact Category	Kaja treatment system	Høyås farm WWT system	Vidaråsen WWT system
Acidification (AP)	2.74E-10	5.99E-10	1.33E-10
Eutrophication (EP)	1.59E-10	1.73E-9	5.1E-10
Global warming (GWP 100)	2.09E-10	6.37E-10	5.57E-9
Ozone layer depletion (ODP)	2.74E-12	4.48E-12	1.13E-12

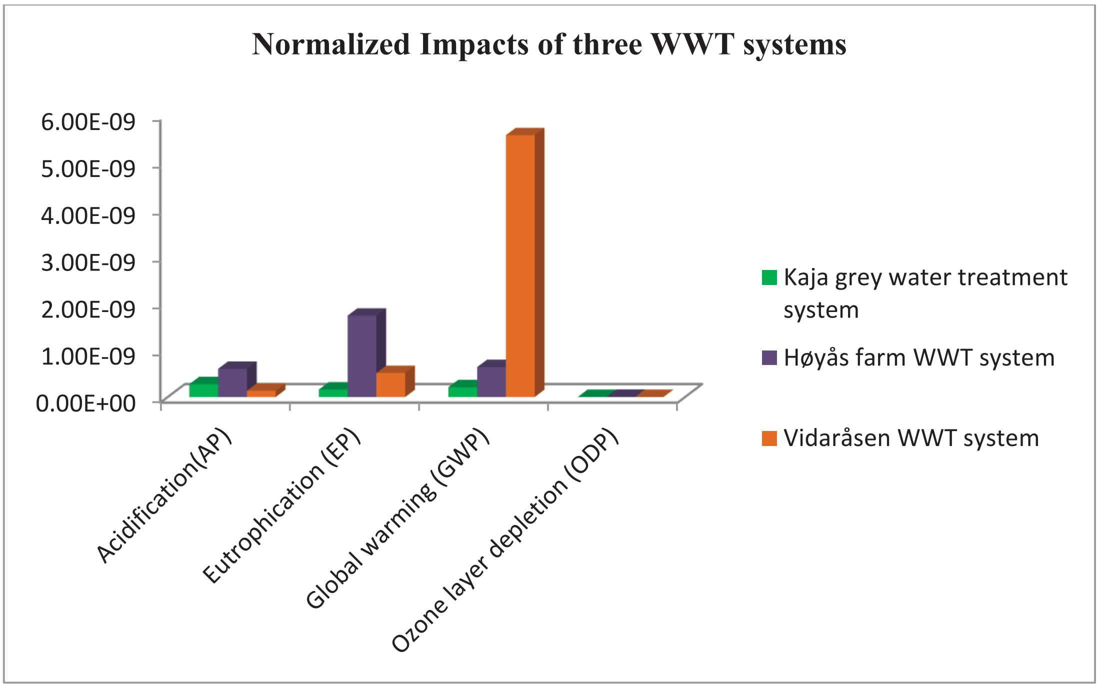


Fig.4.8 Normalization of Impacts of three systems under study.

In conclusion, comparing the three systems, Kaja grey water treatment system could be the best option. Kaja grey water treatment system occupies very less area (2-3 m^2 surface area per person) with less numbers of treatment units (a septic tank, a bio-filter unit and a horizontal flow constructed wetland) and considers treatment of grey water from 48 persons. Since this system is based on source separation technique, black water is collected separately in separate tank and is trucked out once a month. The treatment performance is considered highly successful (Jenssen, et al., 2003). Another successful example of source separation system is the wastewater treatment system at Klosterenga, Oslo (33 apartments connected with 100 nos. of persons) and Torvetua (42 condominiums connected with 140 persons) having the very similar treatment performance with Kaja treatment system (Jenssen, et al., 2003). Results (Table: 4-8) of **EP** and **GWP** show that the environmental impacts from Kaja system is also minimal compared to other two systems under study. However, if the system boundary in the Kaja treatment system is expanded to include the vaccum toilet system and additional plumbing elements required to separate the black water and the grey water then the environmental impacts associated with these scenario could be different and possibly higher than the current boundary scenario.

Without valuation or weighing of environmental impacts, analysing the results with different alternative material replacement scenario and with the expansion of system boundary to include the vaccum toilets and plumbing elements, it would be difficult to predict that this system is better than the other treatment systems.

5.0 CONCLUSION AND RECOMMENDATIONS

5.1. Conclusion

This study compares the environmental performance of three small-scale wastewater treatment systems using the tool Life Cycle Analysis. The systems considered for this study are: A compact filter bed system consisting of bio-filter followed by two parallel beds consisting of Filtralite-P and Filtramar and sand filter as a final polishing unit (Høyås farm WWT system); a compact filter bed system treating grey water and consisting of bio-filter followed by horizontal flow bed with Filtralite-P (Kaja system) and a combination of wetland, pond system (Vidaråsen system).

The results show that the construction phase has significant contribution to acidification potential (**AP)** and ozone layer depletion **(ODP)** in all of the treatment systems under study. Production process of filter media, Filtralite-P (expanded clay), pre-fabricated fibre glass components, PVC pipe and polystyrene foam that are used in the treatment systems are the main contributing factor to these environmental burdens. In natural systems, like the ones considered for this study, there are opportunities to modify the systems using alternative media. For instance, Filtralite-P with Filtramar (shell-sand). But it would rather be uncertain and unjustified without any further analysis, to consider that the alternatives would give better environmental performance.

Eutrophication potential (EP) and Global Warming Potential (GWP) are contributed during the operational phase in every systems under study. Total-Nitrogen is the primary contributor to eutrophication potential in all the treatment systems under study. Total- P has very less contribution as comparison to Total-N. In the Norwegian context, where removal of nutrients (mainly phosphorus and nitrogen) causing eutrophication of effluent receiving water bodies is the key priority of wastewater treatment systems, effective and sustainable control on this impact becomes a key issue. Therefore, reduction and control in EP could be an achievement. The normalized value of EP is very less in all the systems. Hence, we can also conclude that Filtralite-P has very effective phosphorus adsorption capacity.

Similarly, results show that Methane (CH_4) gas is the main contributing greenhouse gas that has contributed to the Global Warming potential (**GWP)** in all the three systems and this methane emission is mainly occurred from septic tank and emissions from treatment units. Carbon dioxide has also significant contributions to GWP and originates from the construction phase during production process of pre-fabricated fibre glass components as well as the Filtralite-P as mentioned above.

While comparing the three different treatment systems, source separation (Kaja grey water treatment) system has the best results. Treating the grey water separately result in less environmental burdens and does not require sophisticated treatment units and large area. Kaja grey water treatment system requires only 2-3 m^2 surface area per person whereas Vidarasen WWT system requires almost 10 m^2 surface area per person. However, the environmental burdens from treatment of black water generated from the students at Kaja are not calculated. A separate analysis has to be carried out to identify the environmental burdens associated with black water treatment.

Another important finding from comparing the three systems is, it is more reliable and environment friendly to treat wastewater from a group of houses or clusters in a single on-site treatment system rather than building small treatment systems for a single household like in case of Høyås farm WWT system.

In addition, the environmental burdens as well as costs associated with the sludge disposal can be reduced if the sludge volume is reduced within the treatment site as in the Vidaråsen WWT system.

5.2. Recommendations:

Following recommendation are made from the LCA study:

1. Carry out LCA analysis replacing Filtralite-P (expanded clay) with alternative filter media “Filtramar” (shell-sand) in the on-site wastewater treatment systems in this study.
2. Perform a LCA study for environmental impacts associated with a centralized wastewater treatment system and compare the results with the decentralized wastewater treatment system.

REFERENCES:

1. Adam, K., Krogstad, T., Vråle, L., Søvik, A.K. and Jenssen, P.D., 2007. Phosphorus retention in the filter materials shellsand and Filtralite P®—Batch and column experiment with synthetic P solution and secondary wastewater. *Ecological Engineering*, *29*(2), pp.200-208.
2. ÁdÁm, K., Sovik, A.K., Krogstad, T. and Heistad, A., 2007. Phosphorous removal by the filter materials light-weight aggregates and shellsand-a review of processes and experimental set-ups for improved design of filter systems for wastewater treatment. *Vatten*, *63*(3), p.245.
3. Akwo, N.S., 2008. A Life Cycle Assessment of Sewage Sludge Treatment Options. *Unpublished MSc. Environmental Management Aalborg University, Aalborg*.
4. Al Nabelsi, S. and Ganesh, R., 2013. On-site wastewater treatment system in Høyås farm, Ås Norway.
5. Alanbari, M.A., Al-Ansari, N., Altaee, S.A. and Knutsson, S., 2014. Application of Simapro7 on Karbala Wastewater Treatment Plant, Iraq.*Journal of Earth Sciences and Geotechnical Engineering*, *4*(2), pp.55-68.
6. Almanza Ramirez, A., 2012. *Life cycle assessment for wastewater treatment in the chemical industry* (Doctoral dissertation, Agenda Ambiental).
7. Balkema, A.J., Preisig, H.A., Otterpohl, R. and Lambert, F.J., 2002. Indicators for the sustainability assessment of wastewater treatment systems. *Urban water*, *4*(2), pp.153-161.
8. Barjoveanu, G.E.O.R.G.E., Comandaru, I.M. and Teodosiu, C.A.R.M.E.N., 2010. Life cycle assessment of water and wastewater treatment systems: an overview. *Bulletin of the Politechnic Institute Iasi*, *56*, pp.73-86.
9. Belhani, M., Pons, M.N. and Alonso, D., 2008. SFGP 2007-The effects of sludge digester biogas recovery on WWTP ecological impacts and exergetic balance. *International Journal of Chemical Reactor Engineering*, *6*(1).
10. Bodenfilter.de (2016): About Constructed Wetlands. Available at: http://www.bodenfilter.de/engdef.htm (accessed: 16 August, 2016).
11. Bogner, J., Pipatti, R., Hashimoto, S., Diaz, C., Mareckova, K., Diaz, L., Kjeldsen, P., Monni, S., Faaij, A., Gao, Q. and Zhang, T., 2008. Mitigation of global greenhouse gas emissions from waste: conclusions and strategies from the

Intergovernmental Panel on Climate Change (IPCC) Fourth Assessment Report. Working Group III (Mitigation). *Waste Management & Research*, *26*(1), pp.11-32.

12. Brandes, M., 1978. Accumulation rate and characteristics of septic tank sludge and septage. *Journal (Water Pollution Control Federation)*, pp.936-943.
13. Brandes, M., 1978. Characteristics of effluents from gray and black water septic tanks. *Journal (Water Pollution Control Federation)*, pp.2547-2559.
14. Brix, H. and Arias, C.A., 2005. The use of vertical flow constructed wetlands for on-site treatment of domestic wastewater: New Danish guidelines.*Ecological engineering*, *25*(5), pp.491-500.
15. Burton, F.L. and Tchobanoglous, G., 1991. Wastewater Engineering, treatment, disposal, and resuse. Metcalf & Eddy, Inc.
16. Cooper, P., Willoughby, N. and Cooper, D., 2004. THE USE OF REED-BEDS FOR SLUDGE DRYING. *Water and Environment Journal*, *18*(2), pp.85-89.
17. Corominas, L., Foley, J., Guest, J.S., Hospido, A., Larsen, H.F., Morera, S. and Shaw, A., 2013. Life cycle assessment applied to wastewater treatment: state of the art. *Water research*, *47*(15), pp.5480-5492
18. Diaz-Valbuena, L.R., Leverenz, H.L., Cappa, C.D., Tchobanoglous, G., Horwath, W.R. and Darby, J.L., 2011. Methane, carbon dioxide, and nitrous oxide emissions from septic tank systems. *Environmental science & technology*, *45*(7), pp.2741-2747.
19. Dixon, A., Simon, M. and Burkitt, T., 2003. Assessing the environmental impact of two options for small-scale wastewater treatment: comparing a reedbed and an aerated biological filter using a life cycle approach.*Ecological Engineering*, *20*(4), pp.297-308.
20. Emmerson, R.H.C., Morse, G.K., Lester, J.N. and Edge, D.R., 1995. The Life-Cycle Analysis of Small-Scale Sewage-Treatment Processes. Water and Environment Journal, 9(3), pp.317-325.
21. En.wikipedia.org (2016): Wastewater treatment. Available at: https://en.wikipedia.org/wiki/Wastewater_treatment (accessed: 5 September, 2016).
22. Environment.no (2008): Municipal wastewater, Published 07.03.2008 by Norwegian Environment Agency. Available at:

http://www.environment.no/topics/marine-and-coastal-waters/eutrophication/municipal-waste-water/ (accessed: 13 September, 2016).

23. Fava, J., Consoli, F., Denison, R., Dickson, K., Mohin, T. and Vigon, B. eds., 1993. *A Conceptual Framework for Life-cycle Impact Assessment: Workshop Report February 1-7, 1992 Sandestin, Florida, USA*. SETAC Foundation for Environmental Education.
24. Finnveden, G., Johansson, J., Lind, P. and Moberg, Å., 2005. Life cycle assessment of energy from solid waste—part 1: general methodology and results. *Journal of Cleaner Production*, *13*(3), pp.213-229.
25. Fuchs, V.J., Mihelcic, J.R. and Gierke, J.S., 2011. Life cycle assessment of vertical and horizontal flow constructed wetlands for wastewater treatment considering nitrogen and carbon greenhouse gas emissions. *Water research*,*45*(5), pp.2073-2081
26. Fxbrowne.com (2005): Decentralized Wastewater: A Viable Option for Lakeshore Communities. Available at: http://www.fxbrowne.com/html/newsletters/March_2005/march05_feature.htm (accessed: 14 November, 2016).
27. Goedkoop, M., Schryver, A.D., Oele, M., Durksz, S. and de Roest, D., 2010. Introduction to LCA with SimaPro 7. Pré Consultants.
28. Grimstad.uia.no (2016): Life cycle assessment. Available at: http://grimstad.uia.no/puls/climatechange/nns05/13nns05a.htm (accessed: 21 August, 2016).
29. Haberl, R., Perfler, R. and Mayer, H., 1995. Constructed wetlands in Europe.*Water Science and Technology*, *32*(3), pp.305-315.
30. Hernandez-Paniagua, I.Y., Ramirez-Vargas, R., Ramos-Gomez, M.S., Dendooven, L., Avelar-Gonzalez, F.J. and Thalasso, F., 2014. Greenhouse gas emissions from stabilization ponds in subtropical climate. *Environmental technology*, *35*(6), pp.727-734.
31. Herrmann, I.T. and Moltesen, A., 2015. Does it matter which Life Cycle Assessment (LCA) tool you choose?–a comparative assessment of SimaPro and GaBi. *Journal of Cleaner Production*, *86*, pp.163-169.
32. Ho, G. and Anda, M., 2004. Centralised versus decentralised wastewater systems in an urban context: the sustainability dimension. In *Proceedings of the 2nd IWA leading-edge conference on sustainability*.

33. Hunger Notes (2016): 2016 World Hunger and Poverty Facts and Statistics. Available at: http://www.worldhunger.org/2015-world-hunger-and-poverty-facts-and-statistics/ (accessed: 11 August, 2016).
34. Iriarte, A., Gabarrell, X. and Rieradevall, J., 2009. LCA of selective waste collection systems in dense urban areas. *Waste Management*, *29*(2), pp.903-914.
35. ISO 14040:1997(E): Environmental management – Life cycle management – Principles and framework. Available at: http://web.stanford.edu/class/cee214/Readings/ISOLCA.pdf. (accessed: 22 August, 2016).
36.
37. ISO 14044:2006(en): Environmental management - Life cycle assessment – Principles and framework. Available at: https://www.iso.org/obp/ui/#iso:std:iso:14040:ed-2:v1:en (accessed: 19 August, 2016).
38. Jacquemin, L., Pontalier, P.Y. and Sablayrolles, C., 2012. Life cycle assessment (LCA) applied to the process industry: a review. *The International Journal of Life Cycle Assessment*, *17*(8), pp.1028-1041.
39. Jenssen, P.D. and Krogstad, T., 2003. Design of constructed wetlands using phosphorus sorbing lightweight aggregate(LWA). *Advances in Ecological Sciences*, *11*, pp.259-272
40. Jenssen, P.D. and Siegrist, R.L., 1990. Technology assessment of wastewater treatment by soil infiltration systems. *Water science and technology*, *22*(3-4), pp.83-92.
41. Jenssen, P.D. and Vråle, L., 2003, April. Greywater treatment in combined biofilter/constructed wetlands in cold climate. In *C. Werner et al (2003) Ecosan–closing the loop, 2nd int. symp. Ecological sanitation, Lübeck, Germany, GTZ.*
42. Jenssen, P.D., 2002. Design and performance of ecological sanitation systems in Norway. *EcoSanRes http://greywater-action. org/sites/default/files/laura/Sep09/ecosan-norway-jenssen. pdf [Accessed 2013.10. 20]*.
43. Jenssen, P.D., 2005. A complete recycling (ecosan) system at student dormitories in Norway.
44. Jenssen, P.D., Jonasson, S.A. and Heistad, A., 2006. Naturbasert rensing av avløpsvann-en kunnskapssammenstilling med hovedvekt på norske er-faringer.

45. Jenssen, P.D., Krogstad, T., Paruch, A.M., Mæhlum, T., Adam, K., Arias, C.A., Heistad, A., Jonsson, L., Hellström, D., Brix, H. and Yli-Halla, M., 2010. Filter bed systems treating domestic wastewater in the Nordic countries–performance and reuse of filter media. *Ecological engineering*,*36*(12), pp.1651-1659.
46. Jenssen, P.D., Mæhlum, T., Krogstad, T. and Vråle, L., 2005. High performance constructed wetlands for cold climates. *Journal of Environmental Science and Health*, *40*(6-7), pp.1343-1353.
47. Jenssen, P.D., Vråle, L. and Lindholm, O., 2007, November. Sustainable wastewater treatment. In *Proceedings of International Conference on Natural Resources and Environmental Management and Environmetal Safety and Health, Kuching, Malaysia* (Vol. 2729).
48. Jhansi, S.C. and Mishra, S.K., 2013. Wastewater treatment and reuse: Sustainability options. *Consilience: The Journal of Sustainable Development*,*10*(1), pp.1-15.
49. JOHANNESSEN, E. 2012. *Optimizing phosphorous removal in on-site wastewater treatment facilities,* Ås, Universitetet, UMB.
50. Källqvist, T., Molvær, J., Oug, E., Berge, D., Tjomsland, T. and Stene-Johansen, S., 2002. Implementation of the Urban Waste Water Treatment Directive in Norway-An evaluation of the Norwegian Approach regarding wastewater treatment.
51. Kivaisi, A.K., 2001. The potential for constructed wetlands for wastewater treatment and reuse in developing countries: a review. *Ecological engineering*, *16*(4), pp.545-560.
52. Kujawa-Roeleveld, K. and Zeeman, G., 2006. Anaerobic treatment in decentralised and source-separation-based sanitation concepts. *Reviews in Environmental Science and Bio/Technology*, *5*(1), pp.115-139.
53. Leverenz, H.L., Tchobanoglous, G. and Darby, J.L., 2010. *Evaluation of greenhouse gas emissions from septic systems*. Alexandria, VA: Water Environment Research Foundation.
54. Libralato, G., Ghirardini, A.V. and Avezzù, F., 2012. To centralise or to decentralise: An overview of the most recent trends in wastewater treatment management. *Journal of Environmental Management*, *94*(1), pp.61-68.

55. Lundin, M. and Morrison, G.M., 2002. A life cycle assessment based procedure for development of environmental sustainability indicators for urban water systems. *Urban water*, *4*(2), pp.145-152.
56. Lundin, M., Bengtsson, M. and Molander, S., 2000. Life cycle assessment of wastewater systems: influence of system boundaries and scale on calculated environmental loads. *Environmental Science & Technology*, *34*(1), pp.180-186.
57. Mæhlum, T., 1998. *Cold-climate constructed wetlands: aerobic pre-treatment and horizontal subsurface flow systems for domestic sewage and landfill leachate purification*. Norges Landbrukshoegskole.
58. Massoud, M.A., Tarhini, A. and Nasr, J.A., 2009. Decentralized approaches to wastewater treatment and management: Applicability in developing countries. *Journal of environmental management*, *90*(1), pp.652-659.
59. Mcengr.com (2016): Wastewater Options Explained to the Public, On-site septic systems. Available at: http://www.mcengr.com/homeowner/infiltrator.html (accessed: 6 November, 2016).
60. Mironga, F.D., 2014. Small Scale Wastewater Treatment System at Høyås Farm in Ås, Norway
61. Moberg, Å., Finnveden, G., Johansson, J. and Lind, P., 2005. Life cycle assessment of energy from solid waste—part 2: landfilling compared to other treatment methods. *Journal of Cleaner Production*, *13*(3), pp.231-240.
62. Muga, H.E. and Mihelcic, J.R., 2008. Sustainability of wastewater treatment technologies. *Journal of environmental management*, *88*(3), pp.437-447.
63. Muñoz Ortiz, I., 2006. Life cycle assessment as a tool for green chemistry: application to different advanced oxidation processes for wastewater treatment.
64. Negelah, S., 2008. *A Life Cycle Assessment of Sewage Sludge Treatment Options* (Doctoral dissertation, Msc, thesis, Aalborg University, Denmark).
65. Norskeutslipp.no (2016): Wastewater treatment plants. The Norwegian PRTR – Pollutants to air and water and generated transfers of waste. Available at: http://www.norskeutslipp.no/en/Wastewater-treatment-plants-/?SectorID=100 (accessed: 13 September, 2016).
66. NORVAR & NKF 2001. Våtmarkfiltre. *VA/Miljø-blad.*
67. Oswald, W.J., 1990, November. Advanced integrated wastewater pond systems. In *Proceedings of the ASCE convention: Supplying water and saving the environment for six billion people* (pp. 73-80).

68. Palme, U., Lundin, M., Tillman, A.M. and Molander, S., 2005. Sustainable development indicators for wastewater systems–researchers and indicator users in a co-operative case study. *Resources, Conservation and Recycling*,*43*(3), pp.293-311.

69. Pan, T., Zhu, X.D. and Ye, Y.P., 2011. Estimate of life-cycle greenhouse gas emissions from a vertical subsurface flow constructed wetland and conventional wastewater treatment plants: A case study in China. *Ecological Engineering*, *37*(2), pp.248-254.

70. Pandey, B., 2016. A long-term performance evaluation of a hybrid natural wastewater treatment system at Vidaråsen Camphill, Andebu Norway.

71. Pandey, M.K., Jenssen, P.D., Krogstad, T. and Jonasson, S., 2013. Comparison of vertical and horizontal flow planted and unplanted subsurface flow wetlands treating municipal wastewater. *Water Science and Technology*,*68*(1), pp.117-123.

72. Paruch, A.M., Mæhlum, T., Haarstad, K., Blankenberg, A.G.B. and Hensel, G., 2016. Performance of Constructed Wetlands Treating Domestic Wastewater in Norway Over a Quarter of a Century–Options for Nutrient Removal and Recycling. In *Natural and Constructed Wetlands* (pp. 41-55). Springer International Publishing.

73. Paruch, A.M., Mæhlum, T., Obarska-Pempkowiak, H., Gajewska, M., Wojciechowska, E. and Ostojski, A., 2011. Rural domestic wastewater treatment in Norway and Poland: experiences, cooperation and concepts on the improvement of constructed wetland technology. *Water Science and Technology*, *63*(4), pp.776-781.

74. Pasqualino, J.C., Meneses, M., Abella, M. and Castells, F., 2009. LCA as a decision support tool for the environmental improvement of the operation of a municipal wastewater treatment plant. *Environmental science & technology*,*43*(9), pp.3300-3307.

75. Picek, T., Čížková, H. and Dušek, J., 2007. Greenhouse gas emissions from a constructed wetland—plants as important sources of carbon. *Ecological engineering*, *31*(2), pp.98-106.

76. Pillay, S.D., 2006. *An environmental life cycle assessment of the provision of recycled water in Durban* (Doctoral dissertation, University of Kwazulu-Natal, Durban).

77. Plumbing Connection (2016): Norway's innovative wastewater treatments. Available at: http://plumbingconnection.com.au/norways-innovative-wastewater-treatments/ (accessed: 14 September, 2016).
78. Pré Consultants (2008). SimaPro 7, Amersfoort, The Netherlands.
79. Pré Consultants, B.V., 2008. SimaPro 7 user's manual. *The Netherlands*.
80. Renou, S., Thomas, J.S., Aoustin, E. and Pons, M.N., 2008. Influence of impact assessment methods in wastewater treatment LCA. *Journal of Cleaner Production*, *16*(10), pp.1098-1105
81. Roseth, R., 2000. Shell sand: a new filter medium for constructed wetlands and wastewater treatment. *Journal of Environmental Science & Health Part A*, *35*(8), pp.1335-1355.
82. Roy, P., Nei, D., Orikasa, T., Xu, Q., Okadome, H., Nakamura, N. and Shiina, T., 2009. A review of life cycle assessment (LCA) on some food products. *Journal of food engineering*, *90*(1), pp.1-10.
83. Scholzel, H., 1999. Small scale wastewater treatment plant project: Report of visit to the Republic of the Marshall Islands: 3-10 June 1999. *SOPAC Prelim. Rep.*, (114), p.31.
84. Schultz, T.E., 2005. Biological wastewater treatment. *Chem. Eng*, *112*(10), pp.44-48.
85. Seidenstat, P., 2003. Global Challenges of Providing Water and Wastewater Services. *World Economics*, *4*(1), pp.133-152.
86. SINGH, V.P., DASS, P., KAUR, K., Billore, S.K., Gupta, P.K. and Parashar, D.C., 2005. Nitrous oxide fluxes in a tropical shallow urban pond under influencing factors. *Current science*, *88*(3), pp.478-483.
87. Sonnemann, G., Castells, F., Schuhmacher, M. and Hauschild, M., 2004. Integrated life-cycle and risk assessment for industrial processes. *The International Journal of Life Cycle Assessment*, *9*(3), pp.206-207.
88. Søvik, A.K. and Kløve, B., 2005. Phosphorus retention processes in shell sand filter systems treating municipal wastewater. *Ecological engineering*,*25*(2), pp.168-182.
89. Søvik, A.K., Augustin, J., Heikkinen, K., Huttunen, J.T., Necki, J.M., Karjalainen, S.M., Kløve, B., Liikanen, A., Mander, Ü., Puustinen, M. and Teiter, S., 2006. Emission of the greenhouse gases nitrous oxide and methane from constructed wetlands in Europe. *Journal of environmental quality*, *35*(6), pp.2360-2373.

90. Stadmark, J. and Leonardson, L., 2005. Emissions of greenhouse gases from ponds constructed for nitrogen removal. *Ecological Engineering*, *25*(5), pp.542-551.
91. Stranddorf, H.K., Hoffmann, L. and Schmidt, A., 2005. LCA technical report: impact categories, normalization and weighting in LCA. Update on selected EDIP97-data.
92. Svanström, M., Fröling, M., Modell, M., Peters, W.A. and Tester, J., 2004. Environmental assessment of supercritical water oxidation of sewage sludge. *Resources, conservation and recycling*, *41*(4), pp.321-338.
93. Tchobanoglous, G. and Burton, F.L., 1991. Wastewater engineering. Management, 7, pp.1-4.
94. Teiter, S. and Mander, Ü., 2005. Emission of N 2 O, N 2, CH 4, and CO 2 from constructed wetlands for wastewater treatment and from riparian buffer zones. *Ecological Engineering*, *25*(5), pp.528-541.
95. Tillman, A.M., Svingby, M. and Lundström, H., 1998. Life cycle assessment of municipal waste water systems. *The international journal of life cycle assessment*, *3*(3), pp.145-157.
96. UN.org (2014): Water and food security / International Decade for Action "Water for Life" 2005-2015. Available at: http://www.un.org/waterforlifedecade/food_security.shtml (accessed: 23 July, 2016).
97. Wendland, C. and Albold, A., 2010. Sustainable and cost-effective wastewater systems for rural and peri-urban communities up to 10,000 population equivalents: guidance paper. *Munich: WECF*.
98. Wilderer, P.A. and Schreff, D., 2000. Decentralized and centralized wastewater management: a challenge for technology developers. *Water Science and Technology*, *41*(1), pp.1-8.
99. Zaman, A.U., 2010. Comparative study of municipal solid waste treatment technologies using life cycle assessment method. *International Journal of Environmental Science & Technology*, *7*(2), pp.225-234.
100. Zhu, T., Mæhlum, T., Krogstad, T. and Jenssen, P.D., 1997. Fate of phosphorus i light-weight aggregate (LWA) wastewater treatment wetland.*Zhu, T. Phosphorus and nitrogen removal in light-weight aggregate (LWA) constructed wetlands and intermittent filter systems. Doctor Scientiarum Thesis*, *16*

ANNEX 1: TREATMENT PERFORMANCE OF WASTEWATER TREATMENT SYSTEMS UNDER STUDY.

Table: 1

Average treatment performance of Kaja system. Built year 1997 (Jenssen, et al., 2003)

Parameters	unit	Effluent			% removal		Total removal %	Average total removal % from studies by Jenssen, et al., 2003)
		septic tank	prefilter	wetland	biofilter	wetland		
TP	mg P/l	0.97	0.32	0.07	67	78.1	92.8	94
TN	mg N/l	8.2	5	2.5	39	50	69.5	70
BOD7	mg O/l	130.7	38.2	6.9	70.8	81.9	94.7	94

Table: 2

Average treatment performance of Hoyas farm (study period October 2012 to January 2013) (Al Nabelsi, et al., 2013) Built year September 2012.

Parameters	unit	Outlet						% removal					Final effluent % removal
		septic tank	biofilter	PFFM	PFFP	SFFM	SFFP	biofilter	PFFM	PFFP	SFFM	SFFP	
TP	mg P/l	12.19	6.38	0.688	0.333	0.262	0.276	47.66	94.36	97.26	97.85	97.74	97.79
BOD5	mg O/l	357.7	36.8	19.44	13	45.1	23.82	89.7	94.57	96.37	87.39	93.34	90.36
COD	mg O/l	685	237.5	141.4	275	145.8	186.4	65.33	79.36	59.85	78.72	72.79	75.75

Table: 3

Average treatment performance of Hoyas farm (study period June 2013 to March 2014) (Mironga, 2014)

Parameters	unit	outlet						% removal					Final effluent % removal
		septic tank	biofilter	PFFM	PFFP	SFFM	SFFP	biofilter	PFFM	PFFP	SFFM	SFFP	
TP	mg P/l	16.56	10.4	1.68	1.19	0.95	0.61	37.2	89.85	92.81	94.26	96.32	95.29
TN	mg N/l	112.55	72.75	55.23	62.26	43.75	51.73	35.54	50.93	44.68	61.13	54.04	57.58
BOD5	mg O/l	254.18	10.59	4.58	5.17	3.83	3.11	95.83	98.2	97.96	98.5	98.77	98.63

Table: 4

Average treatment performance of Hoyas farm from Table 2 & 3 of Annex 1.

Parameters	Final % removal
TP	96.54
TN	57.58
BOD5	94.495

Table 5

Treatment performance of Vidareson treatement system (study period 2004-2014, designed for 200 Pe, Pandey, 2016)

Parameters	unit	outlet septic tank	outlet pre-filter	% removal in pre-filter	outlet AFP	% removal in AFP	outlet stabilization ponds	% removal in stabilization ponds	Average final effluent (outlet of CW)	Overall treatment % of the system
TP	mg P/l	5.75							0.32	94.43
TN	mg N/l	49	28.42	42	19.89	59.41			4.7	90.4
BOD	mg/l	203	44.66	78	39.3	80.64			2	99

Table 6

Treatment performance of first five years of operation of Vidareson treatement system (Browne, et al., 2005)

Parameters	STE	Pre-filters	% removal	EFP	% removal	Pond 1	% removal	Pond 2 + 3	% removal	CW	% removal
Total - P	6.8	3.6	47.06	2.16	68.23	0.88	87.06	0.52	92.35	0.25	96.32
Total - N	49.1	28.2	42.57	13.7	72.1	6.51	86.74	4.42	91	4.07	91.71

Table 7

Average treatment performance of Vidarasen treatment system taken from Table 5 & 6 of Annex 1.

Parameters	% removal
Total - P	95.375
Total - N	91.055
BOD	99

ANNEX 2 : Water emissions and sludge quantity from wastewater treatment systems under study.

Table: 1

Percentage of P, N, BOD5, COD a person produces per day (Yri, et al., 2007)		**conversion**
Parameters	The amount produced g/pe.d	kg/p.e./year
Total-P	1.6	0.5824
Total-N	12	4.368
BOD5	40	14.56
BOD7	46	16.744
COD	94	34.216

Table: 2

Water effluent in Hoyas farm treatment system referring Table 4 of Annex 1 and Table 1 of Annex 2		
Parameters	% removal by system	Emissions from 1 person (kg /p.e./yr)
Total - P	96.54	0.02015104
Total - N	57.58	1.8529056
BOD 5	94.494	0.8016736

Table: 3

Sludge accumulation in the septic tank of Hoyas farm wastewater treatment system		**Reference**	
Sludge accumulation rate in wastewater =	69.16 litres / person / year	(Brandes, 1978)	
	0.06916 m3 /p.e./year		
Density of sludge =	721 kg / m3	http://www.aqua-calc.com/page/density-table/substance/sewage-coma-and-blank-sludge	
Therefore, Mass of sludge =	0.06916 * 721		
i.e.	49.87 kg /p.e./ year.		
Mass of sludge generated =	**0.05 tons/p.e./year**		

Table: 4

Grey water compositions in Kaja system measured in STE (Jenssen, et al., 2003; Jenssen, 2002).				
Parameters	Concentration	Mass		Reference
	in mg/L	in g/pe and year	in kg/p.e./year	
Total - P	0.97	56	0.056	(Jenssen, et al., 2003)
Total - N	8.2	470	0.47	
BOD	87	3642	3.642	(Jenssen, 2005)

Table: 5

Water effluent from Kaja grey water treatment system referring Table 1 of Annex 1 and Table 4 of Annex 2		
Parameters	% removal by system	Emissions from 1 person (kg /p.e./yr)
Total - P	94	0.00336
Total - N	70	0.141
BOD	94	0.21852

Table: 6

Sludge accumulation in the septic tank of Kaja greywater treatment system		**Reference**	
Sludge accumulation rate in grey water =	8.3 litres / person / year	(Brandes, 1978)	
	8.3E-3 m3 /p.e./year	http://www.aqua-calc.com/page/density-table/substance/sewage-coma-and-blank-sludge	
Density of sludge =	721 kg / m3		
Therefore, Mass of sludge =	8.3E-3 * 721		
i.e.	5.98 kg /p.e./ year.		
Mass of sludge generated =	**5.98 E-3 tons/p.e./ year**		

Table: 7

Water effluent from Vidarasen WWT system referring Table 11 of Annex 1 and Table 1 of Annex 2.		
Parameters	% removal by system	Emissions from 1 person (kg / p.e. / yr)
Total - P	95.375	0.026936
Total - N	91.055	0.3907176
BOD	99	0.1456

Table: 8

Sludge accumulation in the septic tank of Vidarasen wastewater treatment system		**Reference**	
Sludge accumulation rate in wastewater =	69.16 litres / person / year	(Brandes, 1978)	
	69.16E-3 m3 /p.e./year	http://www.aqua-calc.com/page/density-table/substance/sewage-coma-and-blank-sludge	
Density of sludge =	721 kg / m3		
Therefore, Mass of sludge =	69.16E-3 * 721		
i.e.	49.86 kg /p.e./ year.		
Mass of sludge generated =	**0.05 tons per person per year**		

ANNEX 3: AIR EMISSIONS FROM WASTEWATER TREATMENT SYSTEMS UNDER STUDY.

Table: 1

Green house gas emissions from constructed wetlands (Fuchs, et al., 2011)

S.N.	Gases emissions	Unit	Emission rate in constructed wetland	
			HSSFW	VSSFW
1	Methane (CH4)	mg / m2 / day	96.5	77.4
2	Carbon diooxide (CO2)	mg / m2 / day	1301	5200
3	Nitrous oxide (N2O)	mg / m2 / day	2.9	10.8

(where, HSSFW = horizontal sub surface flow wetland, VSSFW = vertical sub surface flow wetland)

Table: 2

Green house gas emissions from Septic tank (Diaz-Valbuena, et al., 2011)

S.N.	Gases emissions	Unit	Emission rate in Septic tank
1	Methane (CH4)	g / person/ day	11.0
2	Carbon diooxide (CO2)	g / person/ day	33.3
3	Nitrous oxide (N2O)	g / person/ day	0.005

Table: 3

Green house gas emissions from Natural pond system (Hernandez-Paniagua, et al., 2014; SINGH, et al., 2005)

S.N.	Gases emissions	Unit	Emission rate	Source
1	Methane (CH4)	g / m2 / day	86.0	Hernandez-Paniagua, et al., 2014
2	Carbon diooxide (CO2)	g / m2 / day	85.0	
3	Nitrous oxide (N2O)	mg / m2 / day	0.51	SINGH, et al., 2005

Table: 4

Air emissions from septic tank of Hoyas farm WWT system referring Table 2 of Annex 3

S.N.	Gases emissions	Unit	Emission rate from septic tank
1	Methane (CH4)	kg/p.e./year	4.004
2	Carbon diooxide (CO2)	kg/p.e./year	12.1212
3	Nitrous oxide (N2O)	kg/p.e./year	0.00182

Table: 5

Air emissions from septic tank and constructed wetland of Kaja grey water treatment system referring Table 1 & 2 of Annex 3

S.N.	Gases emissions	Unit	Emission rate from system units		Total
			Septic tank	HSSFW (s.a. = 100 m2)	
1	Methane (CH4)	kg/p.e./year	1.001	0.0182947917	1.0192947917
2	Carbon diooxide (CO2)	kg/p.e./year			
3	Nitrous oxide (N2O)	kg/p.e./year	0.0001978261	0.0002390399	0.0004368659

(where, HSSFW = horizontal sub surface flow wetland, s.a. = surface area)

Table: 6

Air emissions from ST, PTF 1, PTF 2, EFP, CW 1 & CW 2 of Vidarasen WWT system referring Table1, 2 & 3 of Annex 3.

S.N.	System units	Unit	Emission rate			Remarks
			CH4	CO2	N2O	
1	Settling tank	kg/p.e./year	4.004	12.12	0.00182	
2	Pre-treatment filter 1	kg/p.e./year	0.04	0.47	0.0010556	HSSFW with s.a. = 200 m2
3	Pre-treatment filter 2	kg/p.e./year	0.01	0.95	0.0019656	VSSFW with s.a. = 100 m2
4	Enhanced Faculative Pond	kg/p.e./year	56.35	55.69	0.000334152	s.a. = 360 m2
5	Stabilization ponds 1,2 & 3	kg/p.e./year				s.a. = 1050 m2
6	Constructed wetland 1	kg/p.e./year	0.02	0.21	0.00047502	HSSFW with s.a. = 90 m2
7	Constructed wetland 2	kg/p.e./year	0.02	0.24	0.0005278	HSSFW with s.a. = 100 m2
	Total	kg/p.e./year	**60.43**	**69.68**	**0.006178**	

(where, HSSFW = horizontal sub surface flow wetland, VSSFW = vertical sub surface flow wetland, s.a. = surface area, PTF = primary treatment filter, EFP = Enhanced Faculative Pond and CW = Constructed wetland)

ANNEX 4: SUMMARY OF CONSTRUCTION MATERIALS, EMISSIONS, SLUDGE & ENERGY.

Summary of construction materials and emissions during operation phase.

S.N.	Phases	Unit	Kaja	Vidaråsen	Høyås farm	Remarks
1	**Construction**					Data's for Kaja system from Table 4 of Annex 5.
	Sand	kg /p.e./yr	29.2	80.33	280.28	
	Gravel (fine)	kg /p.e./yr	13.24	87	238.15	
	Gravel (coarse)	kg /p.e./yr		18.92		Data's for Vidarasen system from Table 6 of Annex 5.
	Filtralite- P (HC 2.5 - 5mm)	kg /p.e./yr	63		59.13	
	Filtralite- P (HC 0.5 - 4mm)	kg /p.e./yr		23.75	12.5	
	Filtramar (shell sand)	kg /p.e./yr			22	
	Styrofoam	kg /p.e./yr	2.06	1.25		Data's for Hoyas farm system from Table 2 of Annex 5.
	PVC film 1mm	kg /p.e./yr	0.05		0.03	
	Fibre glass	kg /p.e./yr	0.51	0.16	8.28	
	Geo-membrane 0.75mm	kg /p.e./yr		0.52	0.64	
	PVC pipe (lb)	lb/p.e./yr	1.16	1.81	15.73	

2.0	**Operation Phase**					
2.1	**Emissions in water**					reference: Table 2, 5 & 7 of Annex 2.
	Total - P	kg /p.e./yr	0.00336	0.026936	0.02015104	
	Total - N	kg /p.e./yr	0.141	0.3907176	1.8529056	
	BOD 5	kg /p.e./yr	0.21852	0.1456	0.8016736	
2.2	**Air emissions**					reference: Table 4, 5 & 6 of Annex 3.
	Methane (CH4)	kg /p.e./yr	1.02	60.43	4.004	
	Carbon dioxide (CO2)	kg /p.e./yr		69.68	12.1212	
	Nitrous oxide (N2O)	kg /p.e./yr	0.00044	0.00618	0.00182	
2.3	**Sludge accumulation in septic tank**	tons /p.e./yr	5.98E-03	0.05	0.05	reference: Table 3, 6 & 8 of Annex 2.
	Sludge transportation to a distance of 20 kilometers	tons km/p.e./yr	1.20E-01	1	1	
3.0	**Energy consumption**	kWh / yr	144.83	434.48	144.83	
	Energy consumption	kWh/p.e./yr	3.017291667	2.1724	18.10375	
(Energy consumption during pumping of wastewater = 0.397875 kWh / day (Mironga, 2014).						

ANNEX 5: QUANTITY ESTIMATION SHEET OF CONSTRUCTION MATERIALS OF WASTEWATER TREATMENT SYSTEMS UNDER STUDY.

Table 1

HOYAS farm (designed for average 8 persons)

Elements	Nos	length	Width	Area	Height	volume	Qty	gravel qty (m3)	sand (m3)	Filtralite P (m3)	Filtramar (shell sand)	PVC pipe (m)	geo-membrane (m2)	PVC film 1mm
Septic tank (9m3)	dia. 2m, L=3.7, H = 2.7m Fibre glass specification of VA/Miljo blad. Nr 48. Manufacturer : Bokn Plast AS. Weight : 380 kg													
E/W excav	1	4.1	2.4		2.9		28.536							
gravel filled														
long wall	2	4.1	0.2		2.7			4.428						
short wall	2	2	0.2		2.7			2.16						
base	1	3.7	2		0.2			0.4						
Geo-membrane (0.75mm) in all sides	1	13	2.9	37.7									37.7	
Geo-membrane (0.75mm) in base	1	4.1	2.4	9.84									9.84	
total							**28.54**	**6.99**					47.54	
Pumping chambers (1nos.) and inspection and sampling chamber (2nos.)	pumping chamber made of fibre glass (mass 210 kg) and sampling chamber of concrete circular ring													
E/W excav	3	1.40	1.40		2.90		17.05							
gravel filled														
long wall	6	1.40	0.20		2.70			4.54						
short wall	6	1.00	0.20		2.70			3.24						
base	3	1.00	1.00		0.20			0.60						
pipe dia. 50mm	1	10.00										10.00		
geo-membrane in sides	3	10.80	1.40	45.36									45.36	
geo-membrane in base	3	1.40	1.40	5.88									5.88	
total							**17.05**	**8.38**				**10.00**	**51.24**	
Biofilter	domes 3 nos., dia. = 2.3, mass of 1 dome = 210/2 = 105 kg													
E/W excav	1	7.3	2.7		0.6		11.826							
Filtralite-P (HC 2.5-5mm)	1	7.3	2.7		0.6					11.826				
pipe dia. 20mm	1	8										8		
pipe dia. 100mm	1	5										5		
PVC film 1mm	1	7.3	2.5											18.25
geo-membrane (0.75mm)	1	7.3	2.5										18.25	
total							**11.826**			**11.826**		**13**	**18.25**	**18.25**
Phosphorous filter tank (2nos.)	Fibre glasstank (2 nos.) of dia. 2m, VA Miljo blad nr. 49 (mass 210 kg each). Therefore total mass of fibre glass = 420kg													
E/W excav	1	4.80	2.40		1.70		19.58							
Filtralite-P (HC 2-4mm)	1					4.00				4.00				
Filtramar (shell sand)	1					4.00					4.00			
gravel filled														
long wall	2	4.80	0.20		1.70			3.26						
short wall	3	2.00	0.20		1.70			2.04						
base	1	4.00	2.00		0.20			1.60						
pipe dia. 50mm	2	10.00										20.00		
geo-membrane in sides	1	14.40	1.70	24.48									24.48	
geo-membrane in base	1	4.80	2.40	11.52									11.52	
total							**19.58**	**6.90**		**4.00**	**4.00**	**20.00**	**36.00**	
Sand filter tank														
E/W excav	1	10	2.8		1.1		30.8							
sand layer	1	10	2.8		0.8				22.4					
gravel layer	1	10	2.8		0.1			2.8						
pipe dia. 100mm	2	20										40		
pipe dia. 100mm	1	10										10		
geo-membrane in sides	1	25.6	1.1	28.16									28.16	
geo-membrane in base	1	10	2.8	28									28	
total							**30.8**	**2.8**	**22.4**			**50**	**56.16**	

Table 2

Summary of HOYAS Farm (designed for average 8 persons and maximum of 25 persons)

Members	Unit	E/W soil (kg)	sand (kg)	Gravel (kg)	Filtralite-P (HC 2.5-5mm) in kg	Filtramar (shell sand) in kg	Filtralite-P (HC 0.5-4mm) in kg	Fibre glass (kg)	PVC Pipe (lb) 50-100mm	geo-membrane (kg)	PVC film (1mm) in kg
Septic tank	kg			10622				380	271	34	
Pumping and Inspection chamber	kg			12732				210		36	
Bio filter	kg				9461			315	352		2
Phosphorous filter tank	kg			10494		3520	2000	420	541	13	
Sand filter trench	kg		44845	4256					1353	40	
Total (kg)			44845	38103	9461	3520	2000	1325	2517	122	2
Total kg/p.e./20 yrs			**280.28**	**238.15**	**59.13**	**22.00**	**12.50**	**8.28**	**15.73**	**0.76**	**0.015**

Table 3

KAJA grey water treatment system, AS

Elements	Nos	length	Width	Height	E/W Qty.	Gravel (m3)	PVC pipe (m)	Filtralite-P HC 2.5-5mm (m3)	PVC film 1mm (liner) (m2)	sand (m3)	Styrofoam insulation (m2)
Septic tank (10m3)	L = 3.88 m, H = 2.7 m, dia. = 2m, Wt. = 380 Fibre glass specification of VA/Miljo blad. Nr 48. Manufacturer : Bokn Plast AS										
E/W excav	1	4.3	2.4	2.9	29.93						
gravel filled											
long wall	2	4.3	0.2	2.7		4.64					
short wall	2	2	0.2	2.7		2.16					
base	1	3.9	2	0.2		1.56					
PVC film (liner)in sides	1	13.4	2.9						38.86		
PVC film (liner) in base	1	4.3	2.4						10.32		
Total					**29.93**	**8.36**			**49.18**		
Bio-filter (1nos.)	dome 1 nos., dia. = 2.3m, mass = 210/2 = 105kg										
E/W filling(base) levelling	1	8	7	0.2	11.2						
E/W filling around embankment	1	28	0.5	0.9	12.6						
E/W filling(above filtralite)											
PVC film 1 mm in sides	1	30	0.9						27		
PVC film 1 mm in base	1	8	7						56		
Filtralite- P (HC 2.5 - 5mm)	1	8	7	0.6				33.6			
PVC pipe	1						29				
Total					**23.8**		**29**	**33.6**	**83**		
Constructed wetland	size (14*5*1m)										
E/W excav	1	14	5	1	70						
sand filling	1	14	5	0.2						14	
PVC film 1 mm in sides	1	38	1						38		
PVC film 1 mm in base	1	14	5						70		
Styrofoam 5cm thickness insulation @ 4 sides	2	19		1							38
PVC pipe	1						12				
Filtralite- P (HC 2.5 - 5mm)	1	14	5	0.6				42			
PVC film 1 mm (above filtralite)	1	14	5						70		
soil filling (above PVC film)	1	14	5	0.2	14						
Total					**84**		**12**	**42**	**178**	**14**	**38**

Table 7: Densities of materials

Properties		
soil density =	1600	(kg/m3)
sand (fine) density =	2002	(kg/m3)
gravel (fine) density =	1520	(kg/m3)
Filtralite- P (HC 2.5-5mm) density =	800	(kg/m3)
Filtralite- P (HC 0.5-4mm) density =	500	(kg/m3)
Filtramar (coarse) density =	880	(kg/m3)
Filtramar (fine) density =	950	(kg/m3)
PVC pipe density =	1300 - 1450	(kg/m3)
PVC film (1mm) density =	128	(kg/m3)
0.1016 m PVC pipe (110mm) in lb =	2.75	lb
1 m PVC pipe (110mm) in lb =	27.067	lb
geo-membrane thickness =	0.75	mm
geo-membrane density =	940	(kg/m3)
Gravel (coarse) density, dry 1/4 to 2 inch =	1682	(kg/m3)
Styrofoam 5cm thickness (Polystyrene) density =	1040	(kg/m3)

Table 4

Summary of Kaja grey water treatment (48 students)									
	Elements								
Members	Unit	E/W soil (kg)	sand (kg)	gravel (kg)	Filtralite-P (HC 2.5-5mm) in kg	PVC pipe (lb)	PVC film 1mm (kg)	Styrofoam (kg) Polystyrene foam slab 5cm	Fibre glass (kg)
Septic tank	kg			12713.28			6		380
Bio-filter	kg				26880	785	11		105
Constructed wetland	kg		28028		33600	325	23	1976	
Total (kg)			28028.00	12713.28	60480.00	1109.75	39.70	1976	485
Total kg/p.e./20 yrs			**29.20**	**13.24**	**63.00**	**1.16**	**0.04**	**2.06**	**0.51**

Table 5

Vidarasen Camphill, 3158 Andebu, Norway														
Elements	**Nos**	**length**	**Width**	**Height**	**Area**	**volume**	**Qty of Excav.**	**sand (m3)**	**Gravel (fine) (m3)**	**Gravel (coarse) (m3)**	**geo-membrane (0.75mm) m2**	**Styro foam insulation (m2)**	**Filtralite-P (HC 0.5 - 4mm) (kg)**	**PVC pipe (m)**
Septic tank	dia. = 2m, L = 4.6, H = 2.7, volume = 11m3, Wt. = 650kg (for 12m3). Fibre glass specification of VA/Miljo blad. Nr 48. Manufacturer : Bokn Plast AS.													
E/W excavation	1	5	2.4	2.9			34.8							
Gravel filling														
long wall	2	5	0.2	2.9					5.80					
short wall	2	2	0.2	2.9					2.32					
base	1	4.6	2	0.2					1.84					
geo-membrane in sides	1	14.8	2.9		42.92						42.92			
geo-membrane in base	1	5	2.4		12						12.0			
PVC pipe	1	30												30
Total							**34.8**		**9.96**		**54.92**			**30**
Pre-treatment filter 1	surface area = 200 m2													
E/W excavation	1			1.10	200		220							
Gravel (coarse) bed	1			0.15	200				30					
Gravel (fine) bed	1			0.15	200					30				
Fine sand	1			0.30	200			60						
geo-membrane in base	1	20	10		200						200			
geo-membrane in sides	1	60	1.1		66						66			
PVC pipe														35
Total							**220**	**60**	**30**	**30**	**266**			**35**
Pre-treatment filter 2	surface area = 100 m2													
E/W excavation	1			1.3	100		130							
Gravel (coarse) bed	1			0.15	100				15					
Gravel (fine) bed	1			0.15	100					15				
Fine sand	1			0.50	100			50						
geo-membrane in base	1	10	10		100						100			
geo-membrane in sides	1	40	1.3		52						52			
PVC pipe														25
Total							**130**	**50**	**15**	**15**	**152**			**25**
Enhanced Faculative pond	surface area = 360 m2													
E/W excav. (circular portion)	1			1.50	360.00		540.00							
E/W excav. (square portion)	1					100.00	100.00							
Gravel filled all around	1			1.00	174.00				174.00					
geo-membrane in base	1				360.00						360.00			
geo-membrane in sides	1	67.24	1.5		100.86						100.86			
PVC pipe														70.00
Flowform cascades (Vortex model)	5													
Pump	1													
Total							**640**		**174**		**460.86**			**70**

Stabilization Pond 1	Surface area = 600 m2, depth = 1.2 m													
E/W excav.	1			1.2	600		720							
geo-membrane in base	1				600						600			
geo-membrane in sides	1	140	1.2		168						168			
PVC pipe	1													40
Stabilization Pond 2	Surface area = 250 m2, depth = 1.5 m													
E/W excav.	1			1.5	250		375							
geo-membrane in base	1				250						250.00			
geo-membrane in sides	1	55.93	1.5		83.9						83.89			
PVC pipe														10
Stabilization Pond 3	Surface area = 320 m2, depth = 1.5 m													
E/W excav.	1			1.5	320		480							
geo-membrane in base	1				320						320			
geo-membrane in sides	1	60	1.5		90						90			
PVC pipe														10
Sand (fine) filter	1			0.35	90			31.5						
Total							**1575**	**31.5**			**911.89**			**60**
Constructed wetland 1	L = 5m, W = 18 m, H = 1m, A = 90 m2													
E/W excav.	1	5	18	1.2			108.00							
sand filling	1	5	18	0.1				9.00						
geo-membrane in base	1	5	18		90						90			
geo-membrane in sides	1	46	1.2		55.2						55.2			
Styrofoam 5cm thickness insulation @ 4 sides	2		23	1								46		
PVC pipe														38.00
Filtralite- P (HC 0.5 - 4mm)	1	5	18	1									90	
Geo membrane (above filtralite)	1	5	18		90						90			
soil filling (above geo-membrane)	1	5	18	0.1			9.00							
Total							**117.00**	**9.00**			**235.2**	**46**	**90**	**38.00**
Constructed wetland 2	L = 20 m, W = 5 m, H = 1m, A = 100 m2													
E/W excav.	1	20	5	1.2			120							
sand filling	1	20	5	0.1				10						
geo-membrane in base	1	20	5		100						100			
geo-membrane in sides	1	50	1.2		60						60			
Styrofoam 5cm thickness insulation @ 4 sides	2	25		1								50		
PVC pipe														10
Filtralite- P (HC 0.5 - 4mm)	1	20	5	1									100	
Geo membrane (above filtralite)	1	20	5		100						100			
soil filling (above geo-membrane)	1	20	5	0.1			10							
Total							**130**	**10**			**260**	**50**	**100**	**10**

Table 6

Summary of Vidarasen camphill (200 Pe)										
		Elements								
Members	**Unit**	**E/W soil (kg)**	**Sand (kg)**	**Gravel (fine) kg**	**Gravel (coarse) kg**	**Filtralite- P (HC 0.5 - 4mm) in kg**	**PVC pipe (lb)**	**Geo-membrane 0.75mm (kg) Polyproplene**	**Styrofoam (Polystyrene foam slab 5cm) insulation @ 4 sides**	Glass fibre (kg)
Septic tank				15139			812	39		650
Pre-treatment filter 1			120120	45600	50460		947	188		
Pre-treatment filter 2			100100	22800	25230		677	107		
Enhanced Faculative pond				264480			1895	325		
Stabilization Ponds 1,2 & 3			63063				1624	643		
Constructed wetland 1			18018			45000	1029	166	2392	
Constructed wetland 2			20020			50000	271	183	2600	
Total (kg)			321321	348019	75690	95000	7254	1650	4992	650
Total kg/p.e./20 yrs			**80.33**	**87.00**	**18.92**	**23.75**	**1.81**	**0.41**	**1.248**	**0.16**

ANNEX 6:

Cross sections of treatment units, product specification of Filtralite filter media, individual summary of construction materials used at Hoyas farm WWT system, Kaja grey water treatment system and Vidarasen WWT system.

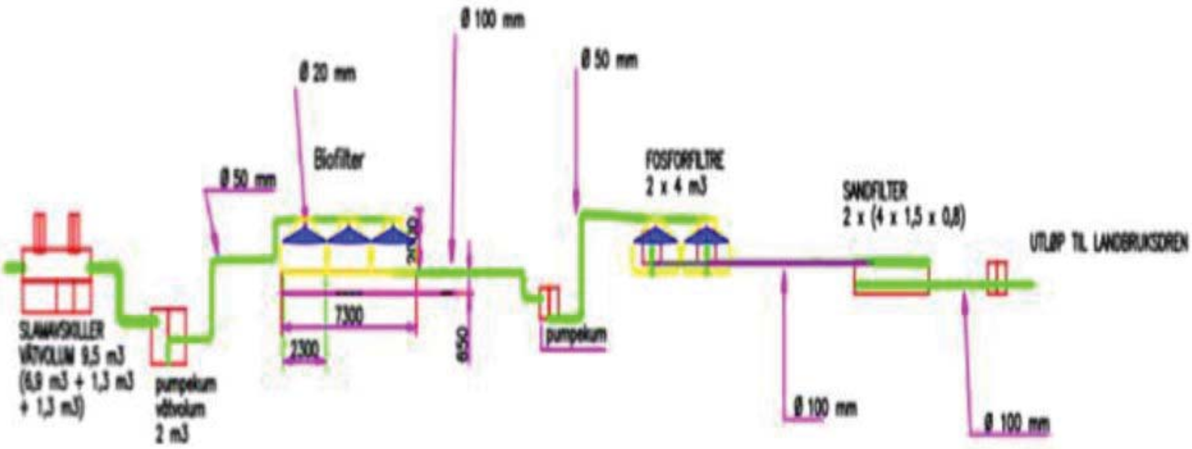


Fig. (i) Cross-section of WWT system in Hoyas farm (source: Al Nabelsi, et al., 2013).

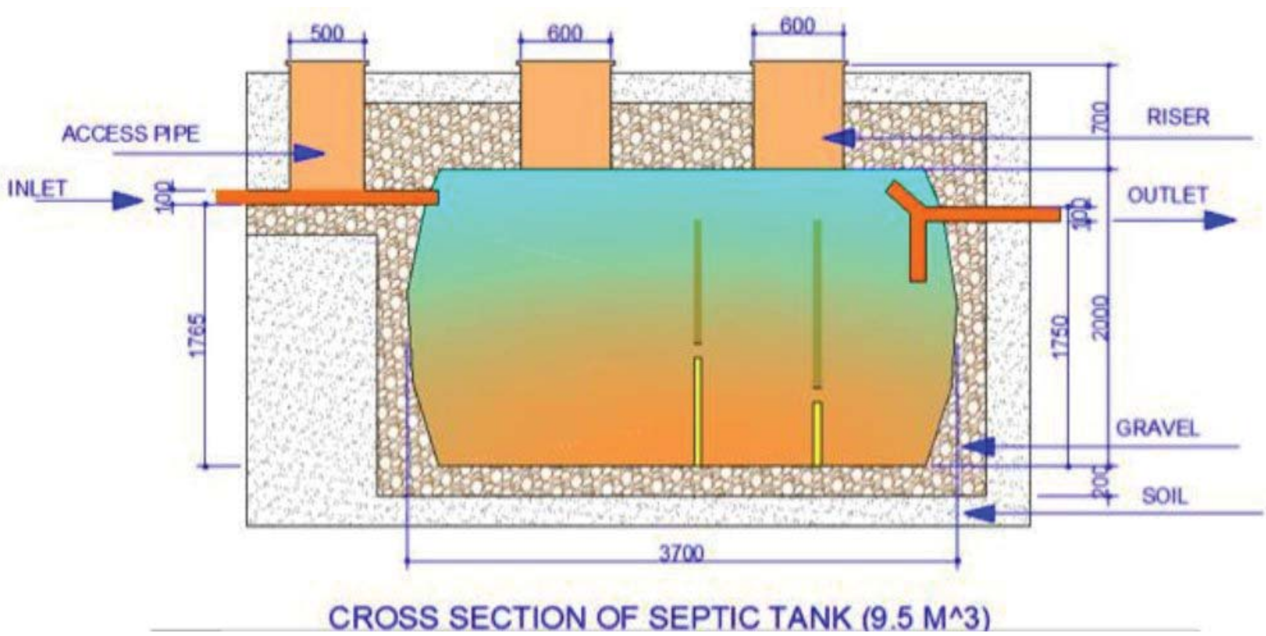


Fig. (ii) Cross section of Septic Tank (source: Al Nabelsi, et al., 2013).

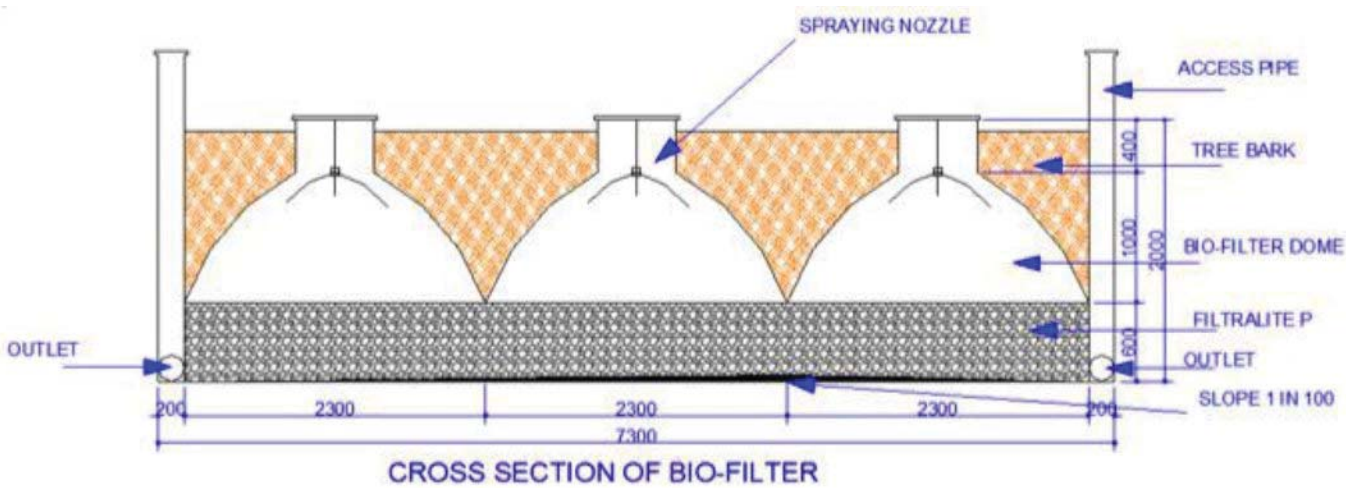


Fig. (iii) Cross section of Bio-filter of Hoyas farm (source: Al Nabelsi, et al., 2013).

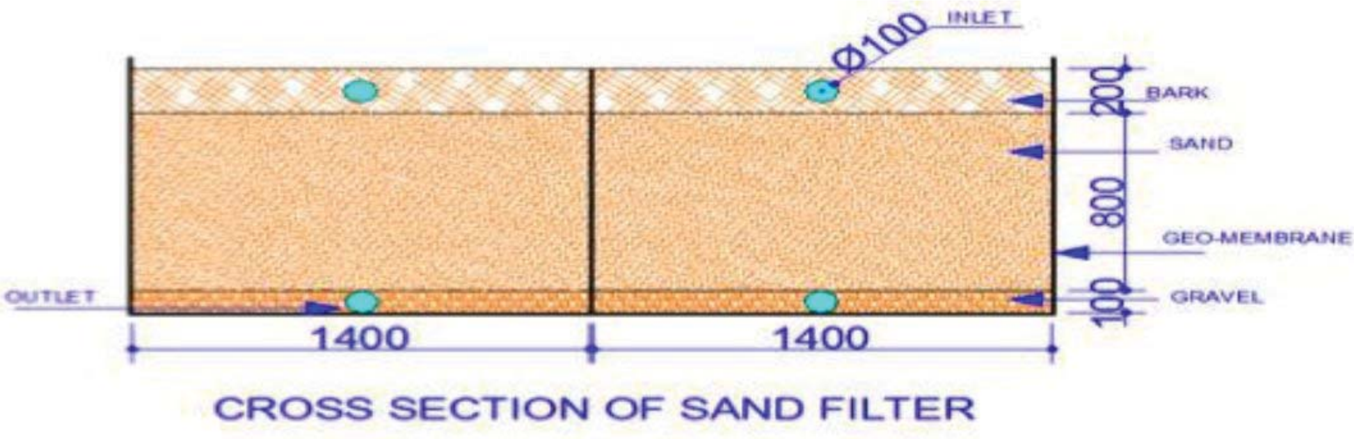


Fig. (iv) Cross section of Sand Filter of Hoyas farm (source: Al Nabelsi, et al., 2013).

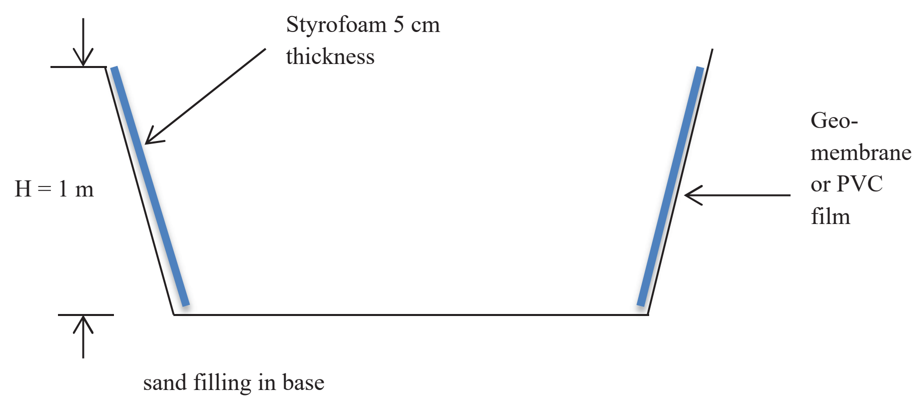


Fig. (v) Cross section of constructed wetland

Table (i) Summary of construction materials used at Hoyas farm WWT system,

S.N.	Items	Unit	System units					Total
			ST	PC	BF	PF	SF	
1.	Sand	kg/p.e./yr					280.28	**280.28**
2.	Gravel	kg/p.e./yr	66.38	79.57		65.58	26.60	**238.15**
3.	Filtralite-P (2.5-5mm)	kg/p.e./yr			59.13			**59.13**
4.	Filtralite-P (0.5-4mm)	kg/p.e./yr				12.50		**12.50**
5.	Filtrammer	kg/p.e./yr				22.00		**22.00**
6.	Fibre glass	kg/p.e./yr	2.37	1.31	1.97	2.62		**8.28**
7.	PVC pipe	lb/p.e./yr	1.7		2.2	3.38	8.45	**15.73**
8.	Geo-membrane	kg/p.e./yr	0.21	0.225		0.081	0.25	**0.76**
9.	PVC film	kg/p.e./yr			0.015			**0.015**

(where, ST = septic tank, PC = pumping chamber, BF = bio-filter, PF = phosphorous filter and SF = sand filter).

Table (ii): Summary of materials used for construction of Kaja grey water treatment system:

S.N.	Items	Unit	System units			Total
			ST	BF	CW	
1.	Sand	kg/p.e./yr			29.20	**29.20**
2.	Gravel	kg/p.e./yr	13.24			**13.24**
3.	Filtralite-P (2.5-5mm)	kg/p.e./yr		28.00	35.00	**63.00**
4.	Fibre glass	kg/p.e./yr	0.4	0.11		**0.51**
5.	PVC film	kg/p.e./yr	0.0062	0.0115	0.024	**0.04**
6.	Styrofoam	kg/p.e./yr			2.06	**2.06**
7.	PVC pipe	lb/p.e./yr		0.82	0.34	**1.16**

(where, ST = septic tank, BF = bio-filter and CW = constructed wetland).

Table (iii): Summary of materials used for construction of Vidaråsen WWT system:

S.N.	Items	Unit	System units							Total
			ST	PTF 1	PTF 2	EFP	SP 1,2,3	CW 1	CW2	
1.	Sand	kg/p.e./yr		30.03	25.03		15.77	4.5	5.0	**80.33**
2.	Gravel (fine)	kg/p.e./yr	3.78	11.4	5.7	66.12				**87.00**
3.	Gravel (coarse)	kg/p.e./yr		12.61	6.31					**18.92**
4.	Filtralite P(0.5-4mm)	kg/p.e./yr						11.25	12.5	**23.75**
5.	Glass fibre	kg/p.e./yr	0.16							**0.16**
6.	Geo-membrane	kg/p.e./yr	0.009	0.047	0.026	0.081	0.16	0.041	0.045	**0.41**
7.	Styrofoam	kg/p.e./yr						0.6	0.65	**1.25**
8.	PVC pipe	lb/p.e./yr	0.203	0.236	0.17	0.473	0.406	0.257	0.068	**1.81**

(where, ST = septic tank, PTF 1 = pre-treatment filter 1, PTF 2 = pre-treatment filter 2, EFP = enhanced facultative pond, SP 1,2,3 = stabilization ponds 1,2 and 3, CW1 = constructed wetland 1 and CW2 = constructed wetland 2).

Calculation of greenhouse gases methane (CH_4) and nitrous oxide (N_2O) emission ratio from septic tank and constructed wetland of Kaja grey water treatment system:

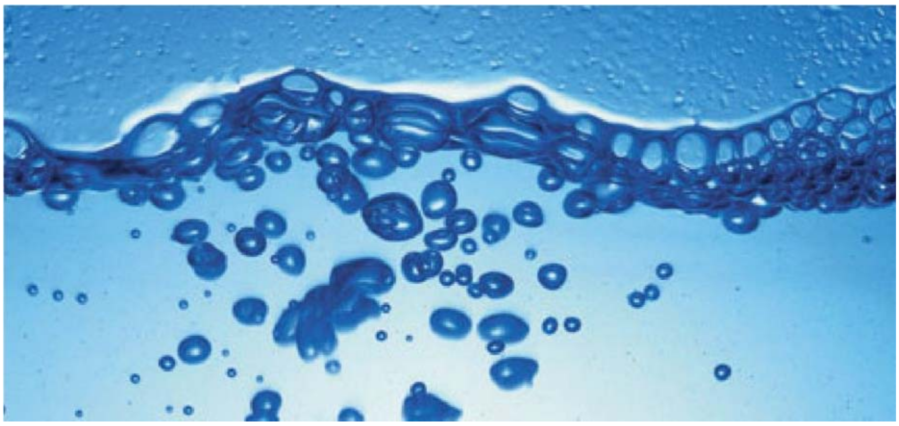
BOD concentration at septic tank effluent of Kaja grey water treatment system = 87 mg / L (i.e. 87 g/m^3) (Jenssen, 2005.) with average daily grey water production of 115 liters per student. So total grey water flow is 5.52 m^3/day (i.e. 115 liters * 48 students per day = 5520 litres day = 5.52 m^3/day). Therefore, mass of BOD in Kaja system = 87 g/m^3 * 5.52 m^3/day =

480.24 g/day. Converting this value to person equivalent = (480.24 g/day) / 48 persons = **10 g / p.e. /day.**

BOD produced by 1 person per day measured at septic tank effluent considering both black water and grey water is **40 g/p.e./day (**Yri et al., 2007). Therefore, the ratio of BOD content in grey water and BOD content in wastewater = 10 / 40 =1/4. So the Ratio is **1:4**

Similarly, same procedure has been adopted for N_2O emission at Kaya grey water system. Total-N produced in Kaja grey water treatment system = 470 g / p.e. / year (Jenssen, and Vråle, 2003). This value equals to **1.3 g / p.e. / day (**i.e. 470/364 = 1.3). As mentioned by (Yri et al., 2007), Total-N produced by 1 person per day measured at septic tank effluent considering both black and grey water is **12 g / p.e. / day** (Yri et al., 2007), as mentioned in Annex 8. Therefore, the ratio of Total-N in grey water and Total-N in wastewater is = 1.3 / 12 = 1 / 9.2. So the Ratio is **1:9.2**

FILTRALITE® P 0-4



Product description

PRODUCT

Filtralite® is high quality filter media, manufactured from a unique expanded clay material.

ADVANTAGES

Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.

EXPLANATIONS

N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round

Product specification

Commercial name	FILTRALITE® P 0-4
Density	Bulk density, loose : 500 kg/m^3
Type of material	Expanded clay
Appearance	Porous surface with white particles
Manufactured by	Leca Rælingen (Saint-Gobain Group), Norway
Version	8

Size and weight	Value	Deviation	Comments
Particle size range	0-4 mm	> 4 mm max. 10 %	EN 12905
Bulk density, dry, loose	500 kg/m^3	± 75 kg/m^3	EN 1097-3

Other properties	Value	Comments
Voids	~ 60 %	EN 1097-3, approximate value
pH	~ 12	Leca norm
Alkalinity	~ 35 mekv/l	NS 4754, approximate value
Hydraulic conductivity K K dim	 100 m/d 25 m/d	Approximate value 9 °C, clean water 9 °C, filter media with wetland plants, pre-treatment in septic tank and aerobic biofilter or equivalent system

The sewage water has to be pre-treated in septic tank and aerobic biofilter (or equivalent system) before the Filtralite P filter bed. Recommended loading of pre-filtrated municipal wastewater: 7-10 m^3 Filtralite P / p.e, (p.e. = 0,6 kg P /year). The material will leak some lime during the start-up period. (All values are based on the assumption of using the filter material in a saturated reed bed / constructed wetlands with long retention time and exposed to typical municipal wastewater.) We strongly recommend use of consultants or system suppliers for dimensioning and design of wetland systems. This material shall not be pumped.

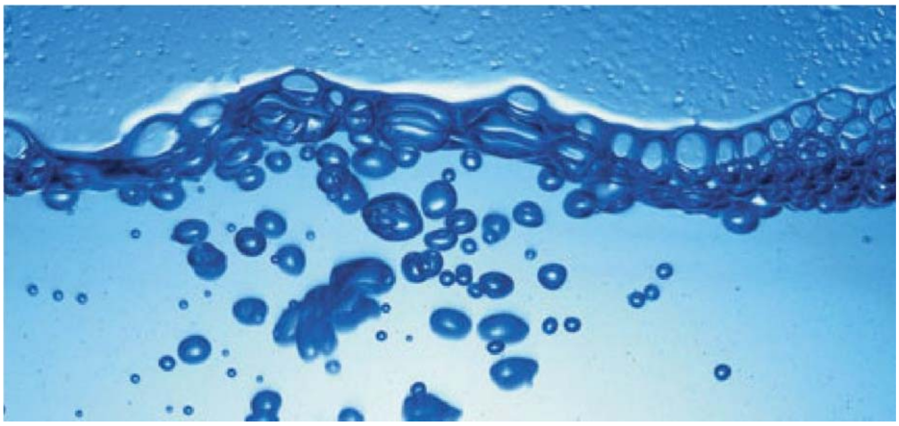
FILTRALITE® P 0-4

Disclaimer

The information provided in this data sheet is based on our current knowledge and experience. All the above information must be considered as guidelines. It is the user's responsibility to ensure that the product is suitable for the intended use and perform self-monitoring. The user is responsible if the product is used for purposes other than those recommended, or improper execution. We are available for consultation in the use of our products.

Saint-Gobain Byggevarer as
Brobekkveien 84
Postboks 216 Alnabru
0614 Oslo
Phone: +47 22 88 77 00
www.filtralite.com

FILTRALITE® P 0,5-4



Product description

PRODUCT

Filtralite® is high quality filter media, manufactured from a unique expanded clay material.

ADVANTAGES

Filtralite® media, with its highly porous structure, enables improved filter efficiency by reduced backwash frequency and improved water velocity. Filtralite® media generate substantial savings by both improved filter capacity, and reduced operational costs.

EXPLANATIONS

N = Normal density, M = Medium density, H = High density, C = Crushed, R = Round

Product specification

Commercial name	**FILTRALITE® P 0,5-4**
Density	Bulk density, loose : 370 kg/m^3
Type of material	Expanded clay
Appearance	Porous surface with white particles
Manufactured by	Leca Rælingen (Saint-Gobain Group), Norway
Version	7

Size and weight	**Value**	**Deviation**	**Comments**
Particle size range	0,5-4 mm	> 4 mm max. 10 % < 0,5 mm max. 10 %	EN 12905
Bulk density, dry, loose	370 kg/m^3	± 75 kg/m^3	EN 1097-3
Particle density, apparent	850 kg/m^3	± 200 kg/m^3	EN 1097-6: Annex E

Other properties	**Value**	**Comments**
Voids	~ 60 %	EN 1097-3, approximate value
pH	~ 12	Leca norm
Alkalinity	~ 35 mekv/l	NS 4754, approximate value

The sewage water has to be pre-treated in septic tank and aerobic biofilter (or equivalent system) before the Filtralite P filter bed. Recommended loading of pre-filtrated municipal wastewater: 7-10 m^3 Filtralite P / p.e, (p.e. = 0,6 kg P /year). The material will leak some lime during the start-up period. (All values are based on the assumption of using the filter material in a saturated reed bed / constructed wetlands with long retention time and exposed to typical municipal wastewater.) We strongly recommend use of consultants or system suppliers for dimensioning and design of wetland systems. This material shall not be pumped.

FILTRALITE® P 0,5-4

Disclaimer

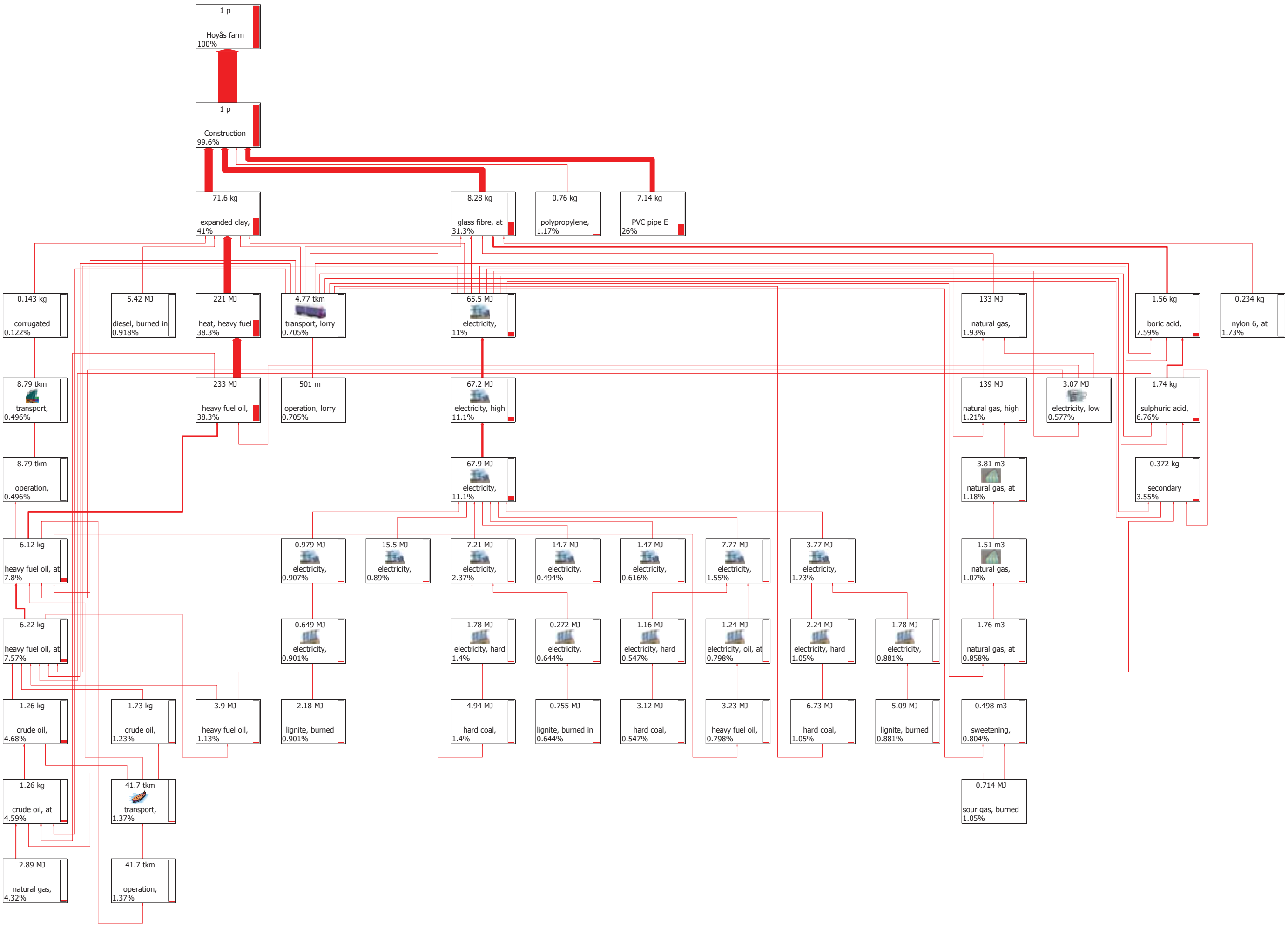
The information provided in this data sheet is based on our current knowledge and experience. All the above information must be considered as guidelines. It is the user's responsibility to ensure that the product is suitable for the intended use and perform self-monitoring. The user is responsible if the product is used for purposes other than those recommended, or improper execution. We are available for consultation in the use of our products.

Saint-Gobain Byggevarer as
Brobekkveien 84
Postboks 216 Alnabru
0614 Oslo
Phone: +47 22 88 77 00
www.filtralite.com

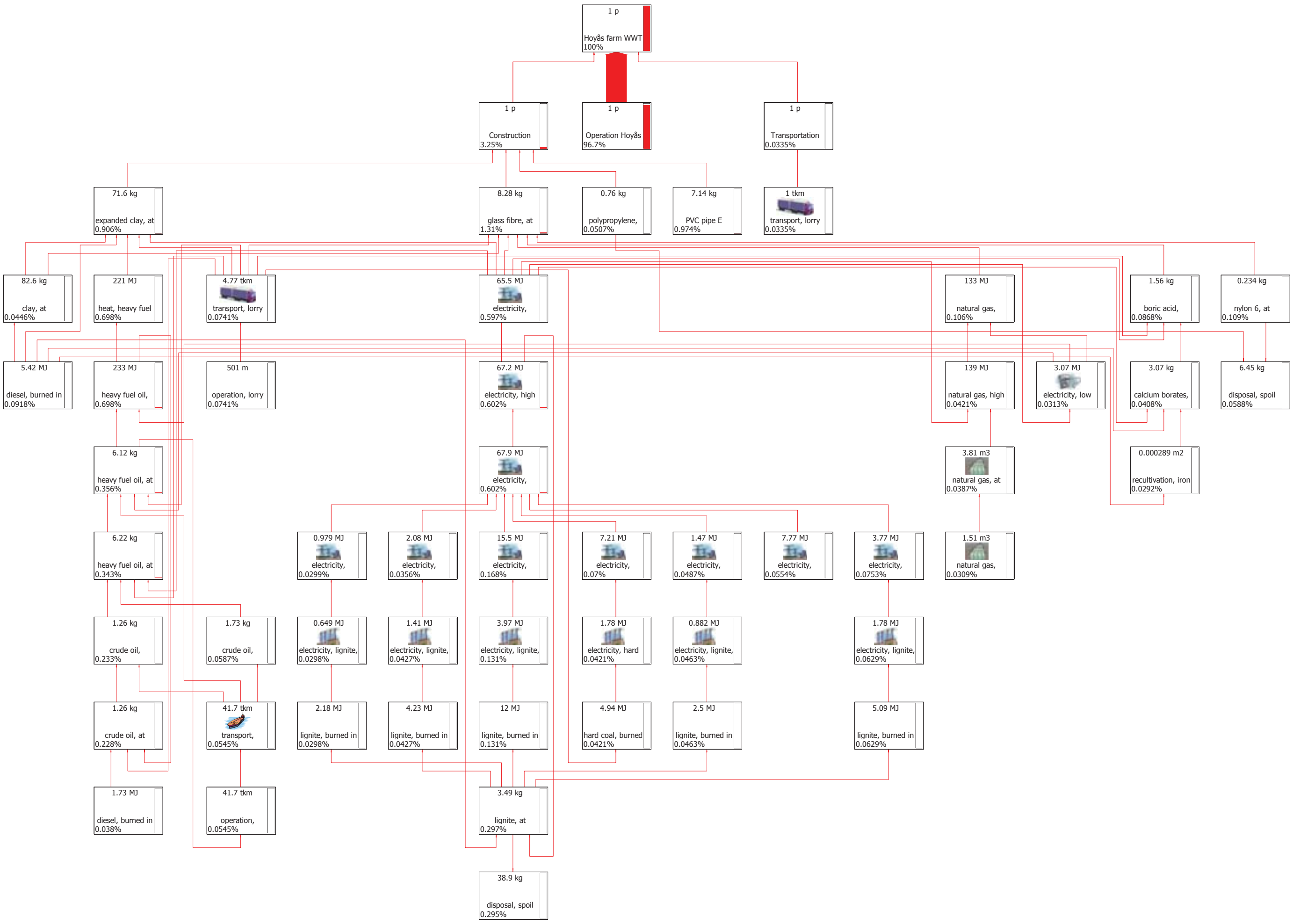
ANNEX 7:

Assembly layout diagrams of AP, EP, GWP & ODP of WWT systems under study.

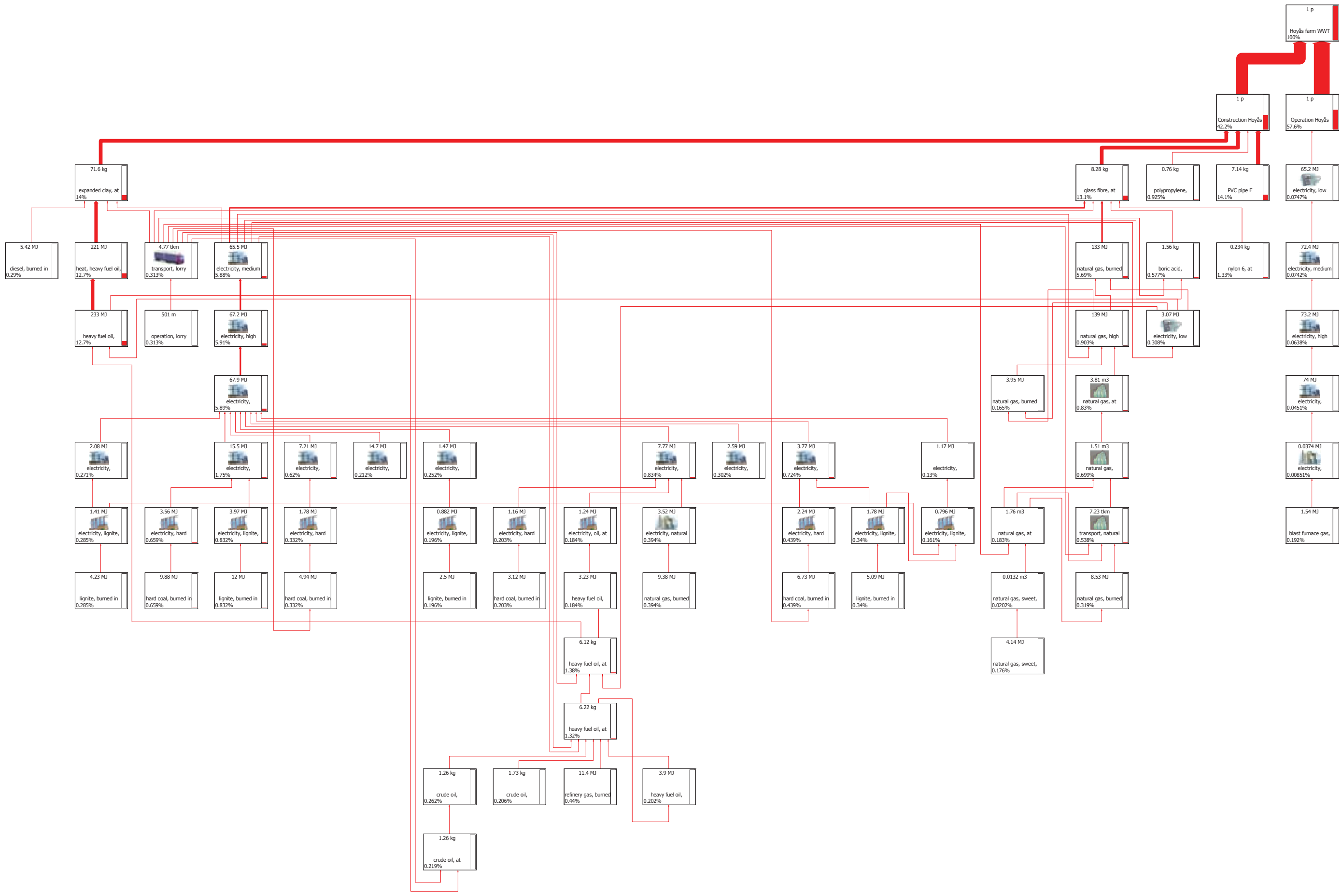
Product:	Hoyås farm WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Acidification (kg SO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.49%
Flow cut-off:	0%



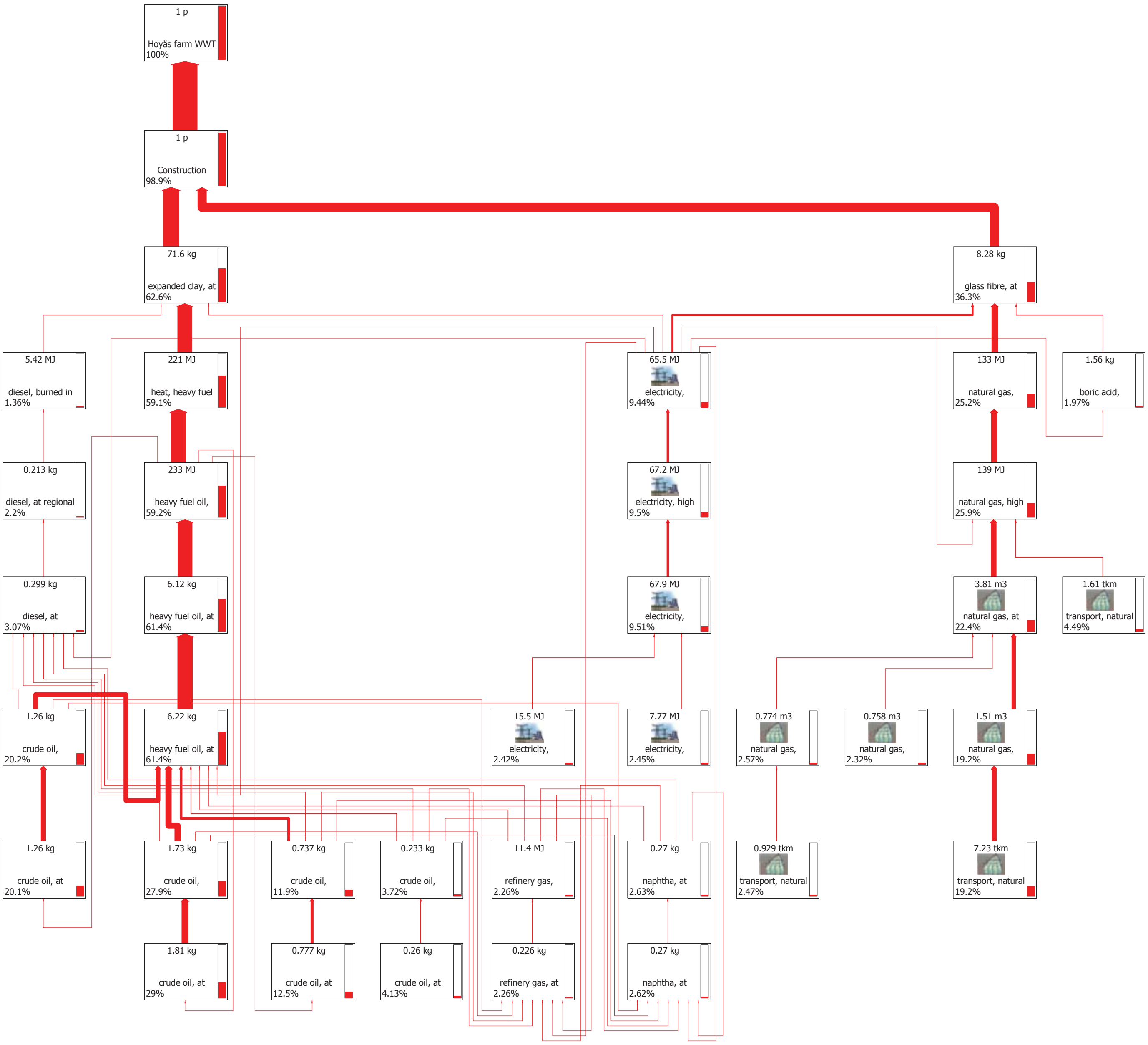
Product:	Hoyås farm WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Eutrophication (kg PO4--- eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.028%
Flow cut-off:	0%



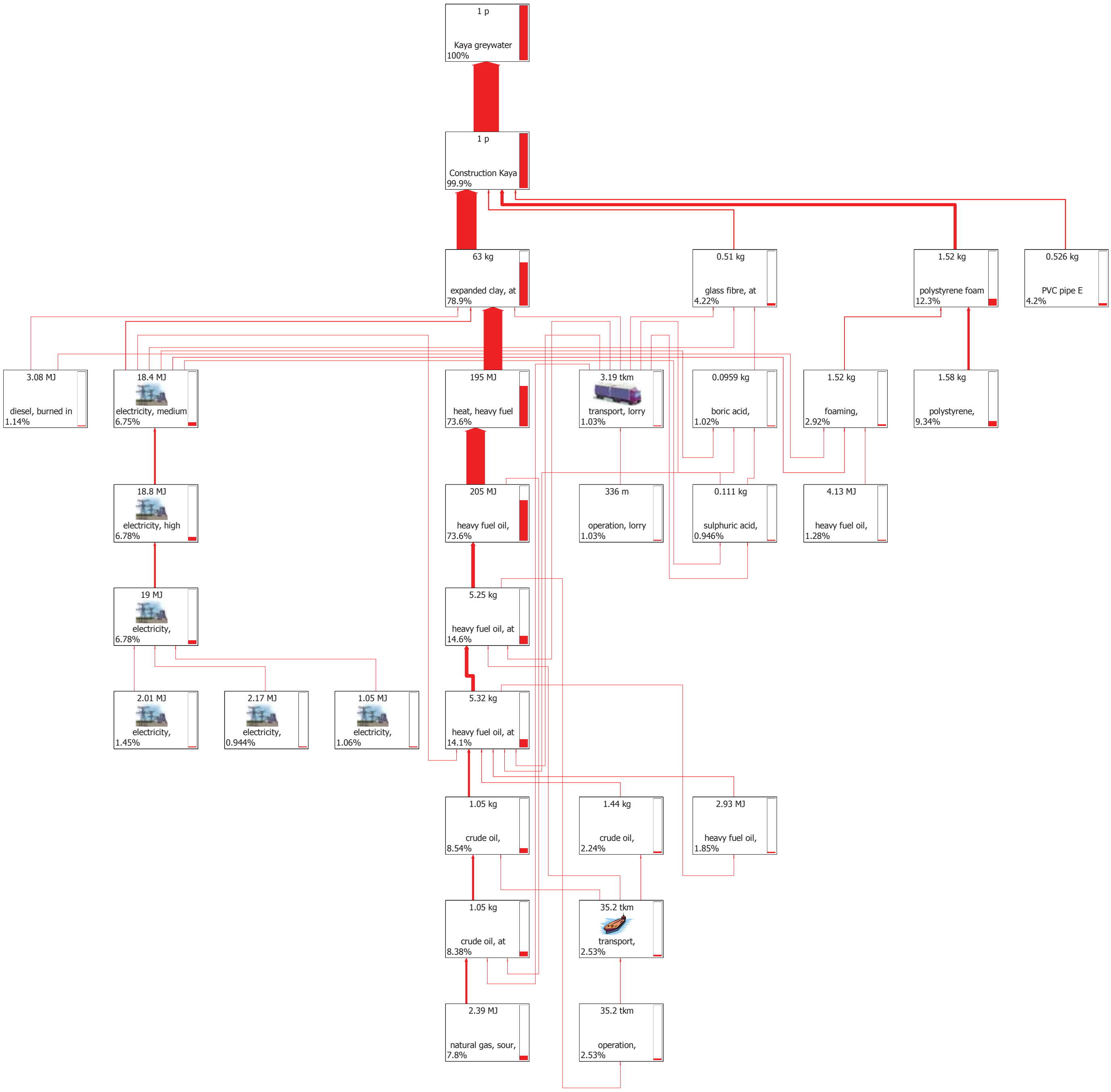
Product:	Hoyås farm WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Global warming (GWP100) (kg CO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.16%
Flow cut-off:	0%



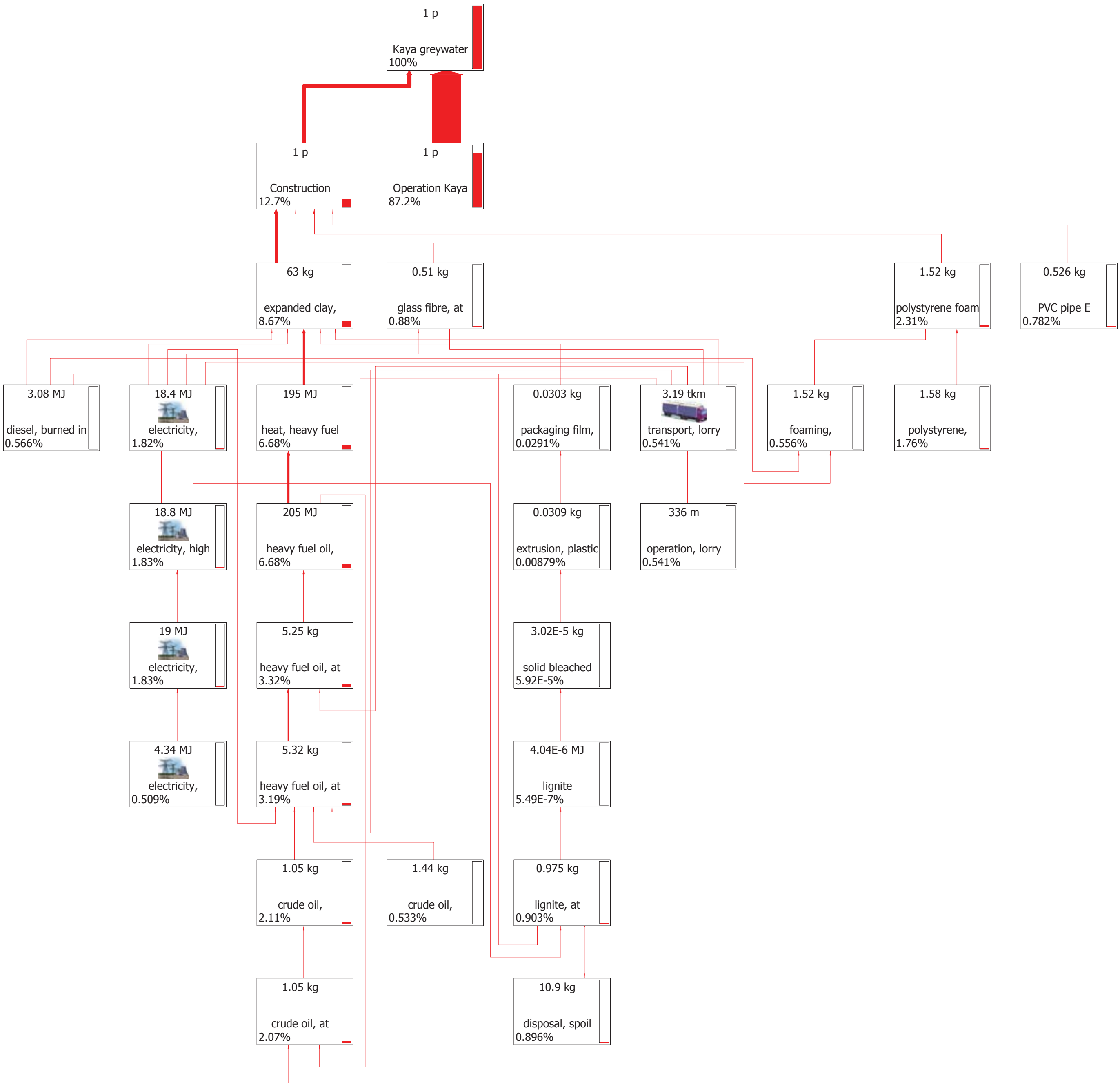
Product:	Hoyås farm WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Ozone layer depletion (ODP) (kg CFC-11 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	1.9%
Flow cut-off:	0%



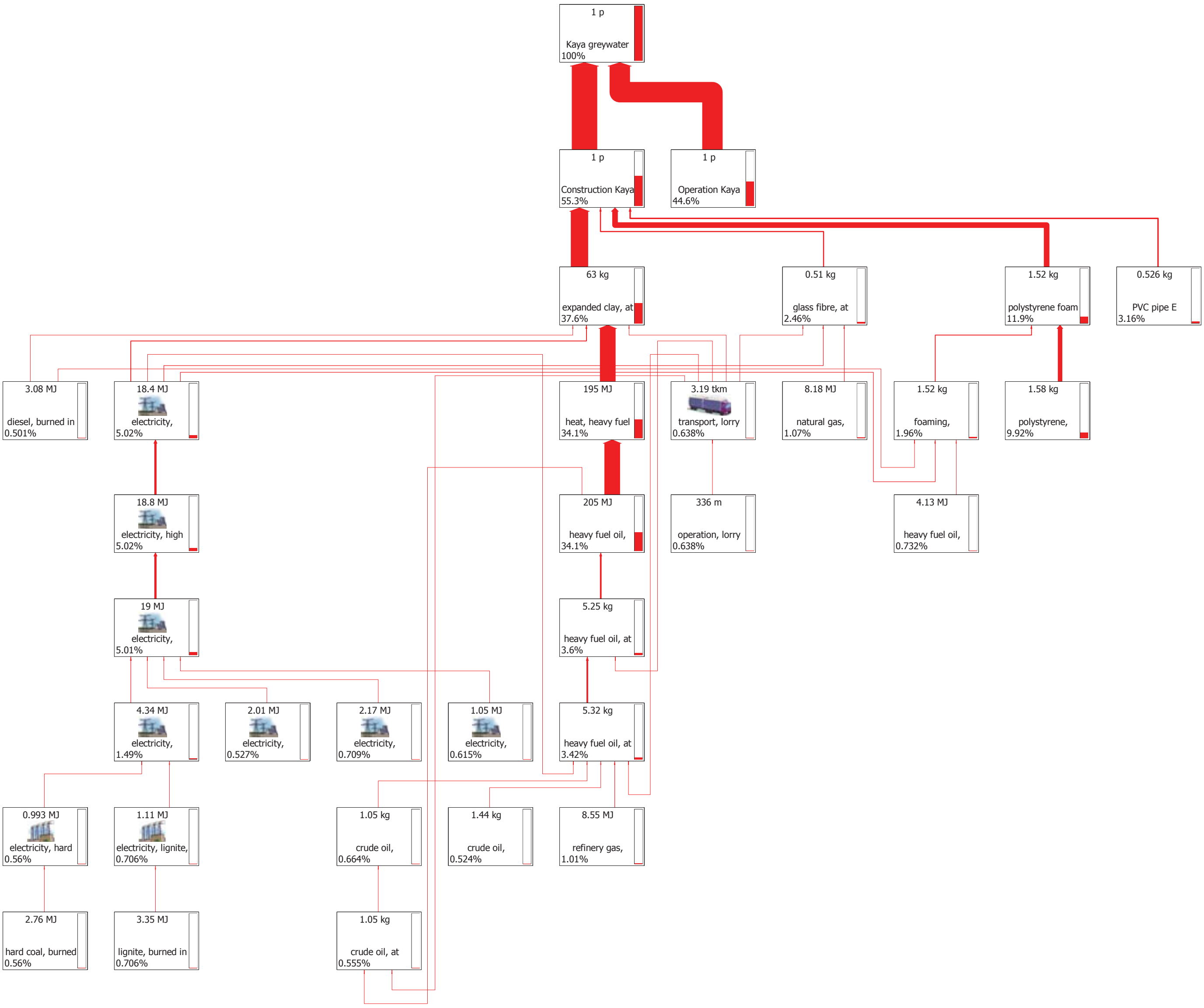
Product:	Kaya greywater treatment system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Acidification (kg SO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.88%
Flow cut-off:	0%



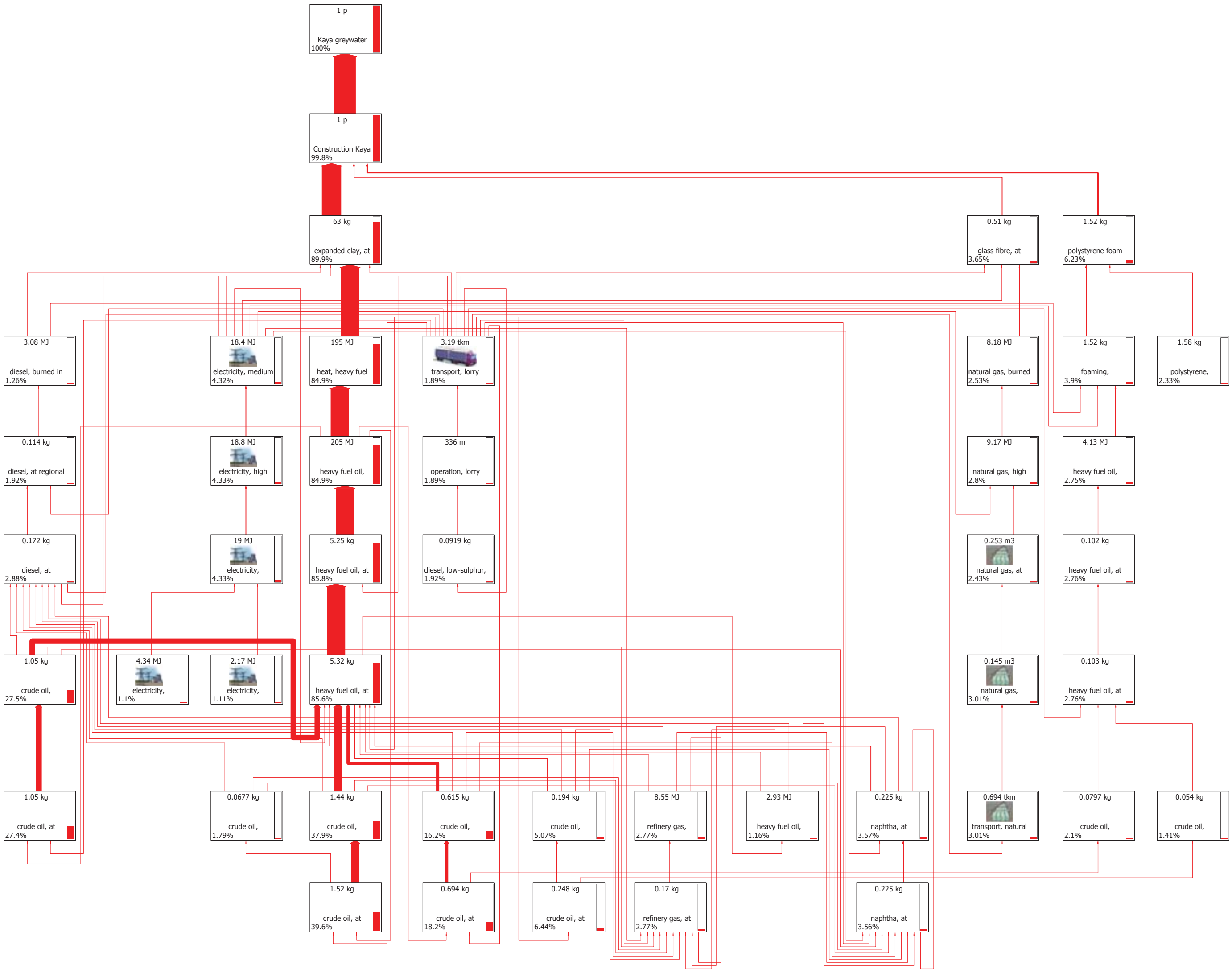
Product:	Kaya greywater treatment system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Eutrophication (kg PO4--- eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.5%
Flow cut-off:	0%



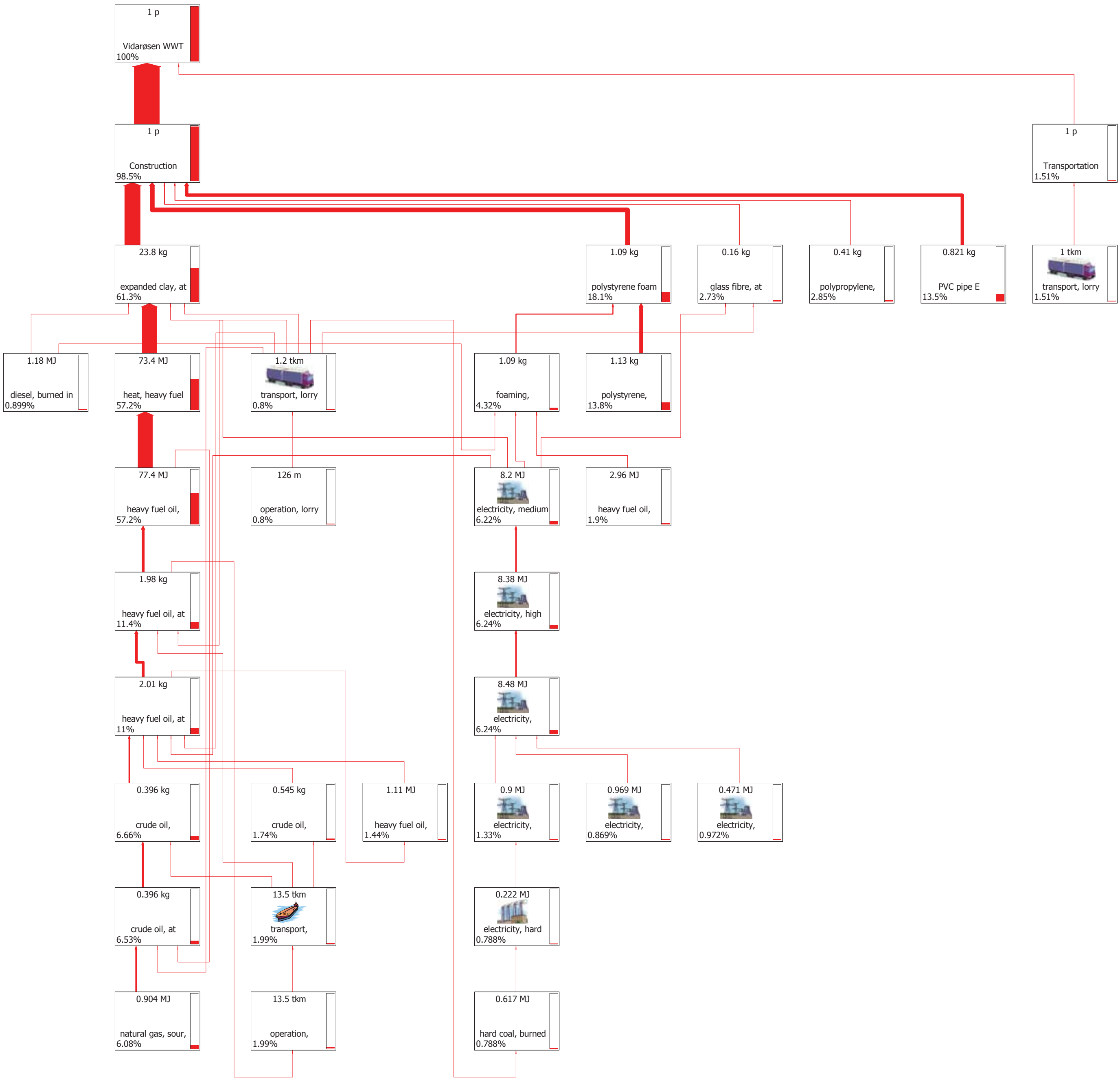
Product:	Kaya greywater treatment system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Global warming (GWP100) (kg CO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.5%
Flow cut-off:	0%



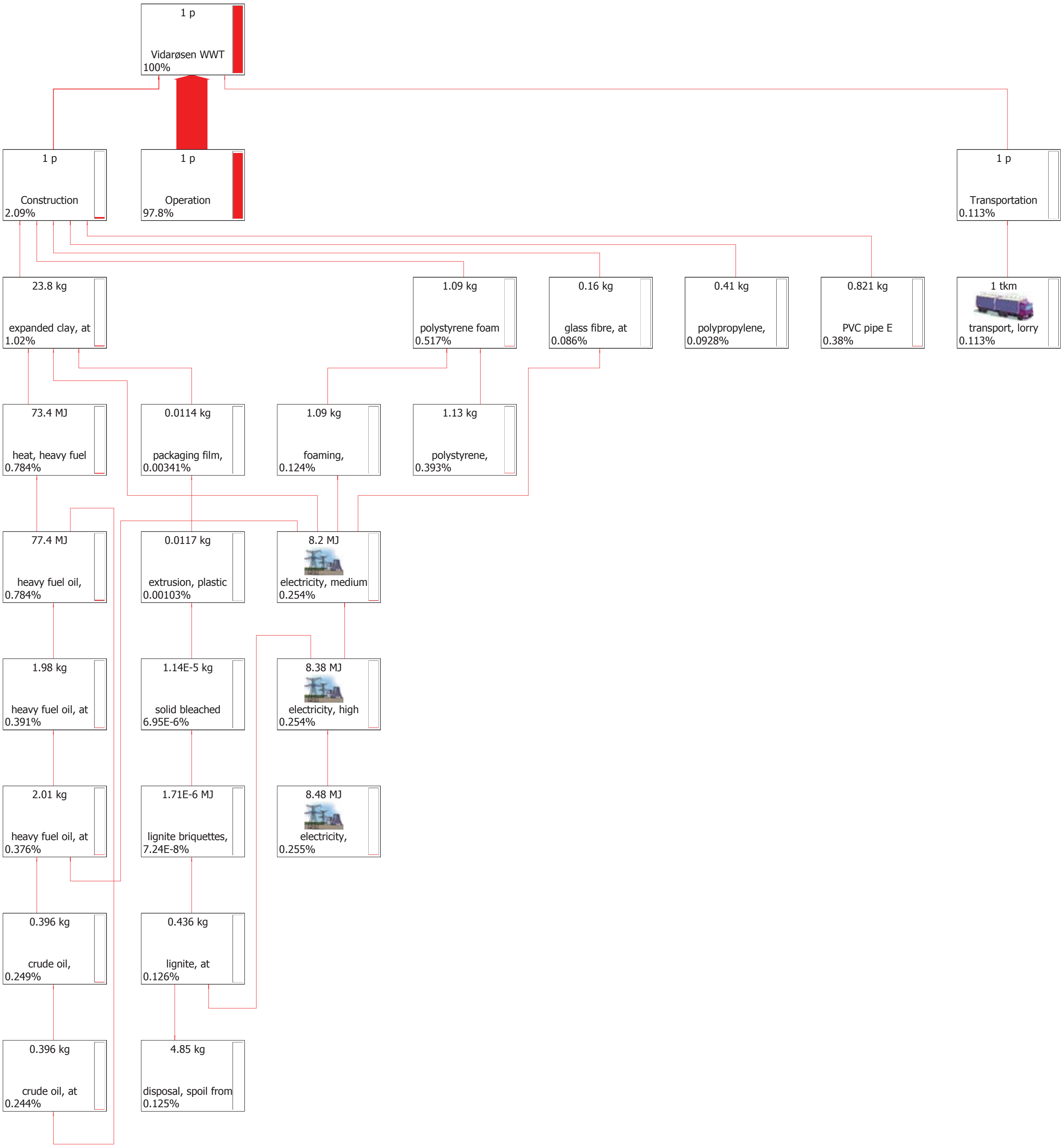
Product:	Kaya greywater treatment system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Ozone layer depletion (ODP) (kg CFC-11 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	1%
Flow cut-off:	0%



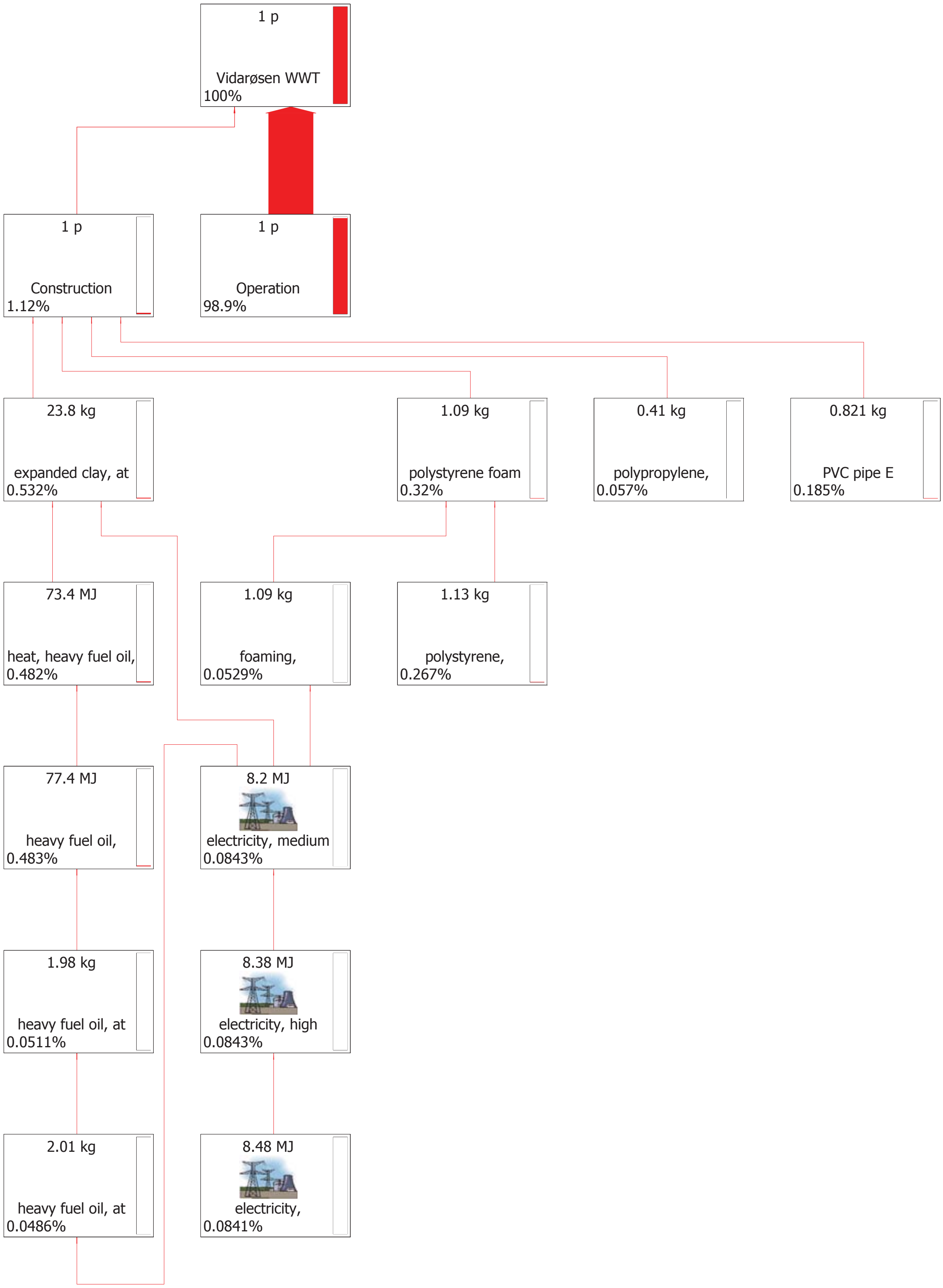
Product:	Vidarøsen WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Acidification (kg SO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.73%
Flow cut-off:	0%



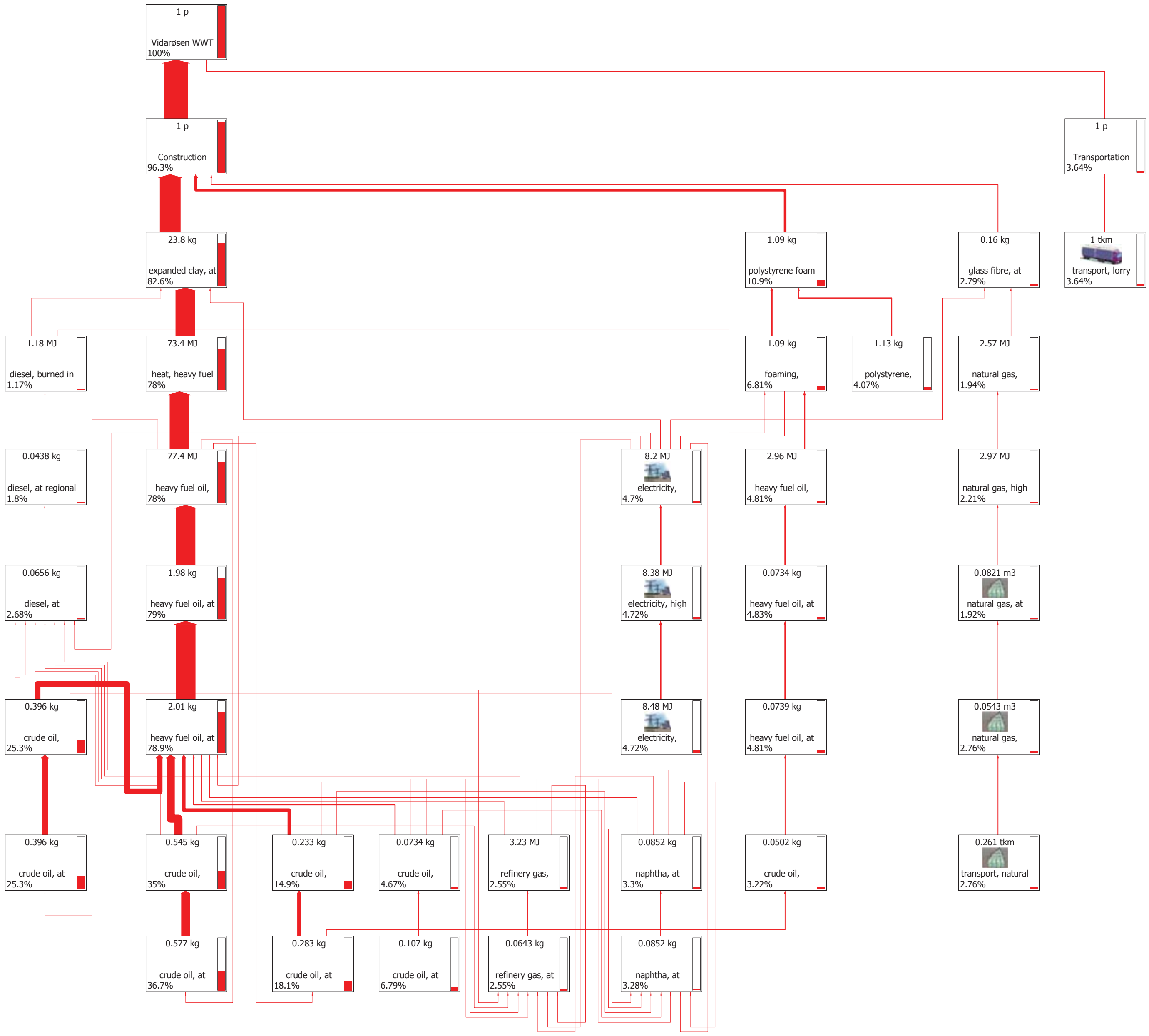
Product: Vidarøsen WWT system
Project: Wastewater treatment Norge_2
Category: Assembly\Others
Method: CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator: Characterisation, Eutrophication (kg PO4--- eq)
Indicator mode: Cumulated indicator
Exclude long-term emissions: Yes
Node cut-off: 0.08%
Flow cut-off: 0%



Product:	Vidarøsen WWT system
Project:	Wastewater treatment Norge_2
Category:	Assembly\Others
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator:	Characterisation, Global warming (GWP100) (kg CO2 eq)
Indicator mode:	Cumulated indicator
Exclude long-term emissions:	Yes
Node cut-off:	0.03%
Flow cut-off:	0%



Product: Vidarøsen WWT system
Project: Wastewater treatment Norge_2
Category: Assembly\Others
Method: CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Selected indicator: Characterisation, Ozone layer depletion (ODP) (kg CFC-11 eq)
Indicator mode: Cumulated indicator
Exclude long-term emissions: Yes
Node cut-off: 2.5%
Flow cut-off: 0%



Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Hoyås farm WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Acidification
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Hoyå	Operation Hoyås	Transportation Ho
	Total of all compartments			kg SO2 eq	0.402	0.4	0.000151	0.00135
1	Ammonia	Air		kg SO2 eq	0.000355	0.000348	1.97E-7	6.7E-6
2	Ammonia	Air	high. pop.	kg SO2 eq	0.000104	0.000101	2.81E-6	2.88E-7
3	Ammonia	Air	low. pop.	kg SO2 eq	8.92E-5	8.85E-5	1.17E-7	5.94E-7
4	Nitrogen oxides	Air		kg SO2 eq	0.0279	0.027	4.72E-6	0.000923
5	Nitrogen oxides	Air	high. pop.	kg SO2 eq	0.0385	0.0384	8.03E-5	1.64E-5
6	Nitrogen oxides	Air	low. pop.	kg SO2 eq	0.00876	0.00869	6.61E-6	6.33E-5
7	Nitrogen oxides	Air	stratosphere + tr	kg SO2 eq	2.43E-10	1.56E-10	2.62E-14	8.74E-11
8	Sulfur dioxide	Air		kg SO2 eq	0.0835	0.0835	6.95E-8	2.44E-5
9	Sulfur dioxide	Air	high. pop.	kg SO2 eq	0.186	0.186	1.86E-5	8.32E-5
10	Sulfur dioxide	Air	low. pop.	kg SO2 eq	0.0568	0.0566	3.73E-5	0.00023
11	Sulfur dioxide	Air	stratosphere + tr	kg SO2 eq	4.17E-11	2.67E-11	4.49E-15	1.5E-11

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Hoyås farm WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Eutrophication
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Descending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Hoyå	Operation Hoyås	Transportation Ho
	Total of all compartments			kg PO4--- eq	0.869	0.0282	0.84	0.000291
1	Phosphorus, total	Water		kg PO4--- eq	0.0625	0.000696	0.0618	x
2	Phosphorus	Soil	industrial	kg PO4--- eq	2.44E-7	7.31E-10	1.27E-12	2.43E-7
3	Phosphorus	Soil	agricultural	kg PO4--- eq	1.29E-5	8.92E-6	3.97E-6	2E-8
4	Phosphorus	Water	river	kg PO4--- eq	0.000194	0.000194	2.32E-9	8.58E-8
5	Phosphorus	Water	ocean	kg PO4--- eq	3.8E-6	3.78E-6	5.36E-10	2.29E-8
6	Phosphorus	Water	groundwater	kg PO4--- eq	3.7E-9	3.64E-9	8.48E-14	5.83E-11
7	Phosphorus	Water		kg PO4--- eq	1.88E-7	1.87E-7	4.66E-11	1.06E-9
8	Phosphorus	Air	low. pop.	kg PO4--- eq	3.76E-8	3.64E-8	1.43E-10	1.07E-9
9	Phosphorus	Air	high. pop.	kg PO4--- eq	3.31E-6	2.38E-6	9.22E-7	6.16E-9
10	Phosphorus	Air		kg PO4--- eq	5.95E-11	2.66E-11	2.53E-14	3.29E-11
11	Phosphate	Water	river	kg PO4--- eq	3.72E-6	3.56E-6	1.68E-8	1.43E-7
12	Phosphate	Water	ocean	kg PO4--- eq	1.84E-6	1.8E-6	3.22E-9	4.12E-8
13	Phosphate	Water	groundwater	kg PO4--- eq	0.00308	0.00306	1.56E-6	1.26E-5
14	Nitrogen, total	Water		kg PO4--- eq	0.778	4.37E-5	0.778	x
15	Nitrogen oxides	Air	stratosphere + tr	kg PO4--- eq	6.32E-11	4.04E-11	6.8E-15	2.27E-11
16	Nitrogen oxides	Air	low. pop.	kg PO4--- eq	0.00228	0.00226	1.72E-6	1.65E-5
17	Nitrogen oxides	Air	high. pop.	kg PO4--- eq	0.01	0.01	2.09E-5	4.26E-6
18	Nitrogen oxides	Air		kg PO4--- eq	0.00726	0.00702	1.23E-6	0.00024
19	Nitrogen	Water	river	kg PO4--- eq	0.00022	0.00022	6.35E-8	1.22E-7
20	Nitrogen	Water	ocean	kg PO4--- eq	2.77E-7	2.75E-7	3.56E-11	1.7E-9
21	Nitrite	Water	river	kg PO4--- eq	2.94E-8	2.78E-8	6.65E-11	1.54E-9
22	Nitrite	Water	ocean	kg PO4--- eq	6.4E-8	6.37E-8	6.92E-11	2.58E-10
23	Nitrate	Water	river	kg PO4--- eq	0.00013	0.000129	2.39E-8	1.6E-7
24	Nitrate	Water	ocean	kg PO4--- eq	5.69E-6	5.66E-6	3.68E-9	2.82E-8
25	Nitrate	Water	groundwater	kg PO4--- eq	2.13E-5	2.1E-5	2.95E-8	2.06E-7
26	Nitrate	Water		kg PO4--- eq	4.45E-6	4.45E-6	x	x
27	Nitrate	Air	low. pop.	kg PO4--- eq	3.43E-8	3.41E-8	3.87E-11	1.77E-10
28	Nitrate	Air	high. pop.	kg PO4--- eq	1.37E-9	1.36E-9	1.29E-12	1.2E-11
29	COD, Chemical Oxygen Demand	Water	river	kg PO4--- eq	0.00185	0.00184	2.49E-7	1.16E-5
30	COD, Chemical Oxygen Demand	Water	ocean	kg PO4--- eq	0.000328	0.000326	4.64E-8	2.68E-6

31	COD, Chemical Oxygen Demand	Water	groundwater	kg PO4--- eq	6.17E-9	6.12E-9	1.97E-11	3.1E-11
32	COD, Chemical Oxygen Demand	Water		kg PO4--- eq	0.00211	0.00211	1.85E-11	2.99E-8
33	Ammonium, ion	Water	river	kg PO4--- eq	8.3E-5	8.28E-5	1.53E-8	1.83E-7
34	Ammonium, ion	Water	ocean	kg PO4--- eq	3.64E-6	3.6E-6	6.71E-10	4.12E-8
35	Ammonium, ion	Water	groundwater	kg PO4--- eq	4.63E-7	4.59E-7	1.48E-9	2.35E-9
36	Ammonium, ion	Water		kg PO4--- eq	4.32E-5	4.32E-5	2.07E-14	7.23E-11
37	Ammonium carbonate	Air	high. pop.	kg PO4--- eq	8.36E-11	8E-11	2E-14	3.6E-12
38	Ammonia	Air	low. pop.	kg PO4--- eq	1.95E-5	1.94E-5	2.55E-8	1.3E-7
39	Ammonia	Air	high. pop.	kg PO4--- eq	2.28E-5	2.21E-5	6.16E-7	6.3E-8
40	Ammonia	Air		kg PO4--- eq	7.76E-5	7.61E-5	4.3E-8	1.47E-6

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Hoyås farm WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Global warming (GWP100)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Hoyå	Operation Hoyås	Transportation Hc
	Total of all compartments			kg CO2 eq	161	68	92.8	0.257
1	Carbon dioxide	Air		kg CO2 eq	18	18	x	x
2	Carbon dioxide, fossil	Air		kg CO2 eq	1.06	0.867	0.000812	0.188
3	Carbon dioxide, fossil	Air	high. pop.	kg CO2 eq	34.6	34.5	0.0504	0.0272
4	Carbon dioxide, fossil	Air	low. pop.	kg CO2 eq	7.43	7.4	0.0096	0.0264
5	Carbon dioxide, fossil	Air	stratosphere + tr	kg CO2 eq	1.09E-7	7E-8	1.18E-11	3.93E-8
6	Carbon dioxide, land transformation	Air	low. pop.	kg CO2 eq	0.00138	0.000796	0.000584	2.94E-6
7	Carbon monoxide	Air		kg CO2 eq	0.0343	0.0343	x	x
8	Carbon monoxide, fossil	Air		kg CO2 eq	0.0052	0.00417	3.19E-6	0.00102
9	Carbon monoxide, fossil	Air	high. pop.	kg CO2 eq	0.0185	0.0185	1.45E-5	2.34E-5
10	Carbon monoxide, fossil	Air	low. pop.	kg CO2 eq	0.00582	0.00573	3.23E-5	5.49E-5
11	Carbon monoxide, fossil	Air	stratosphere + tr	kg CO2 eq	2.02E-10	1.29E-10	2.17E-14	7.25E-11
12	Chloroform	Air		kg CO2 eq	5.37E-17	2.19E-17	9.1E-21	3.18E-17
13	Chloroform	Air	high. pop.	kg CO2 eq	8.46E-8	8.2E-8	9.11E-11	2.55E-9
14	Chloroform	Air	low. pop.	kg CO2 eq	3.3E-9	3.27E-9	4.4E-12	2.68E-11
15	Dinitrogen monoxide	Air		kg CO2 eq	0.612	0.0387	0.569	0.00412
16	Dinitrogen monoxide	Air	high. pop.	kg CO2 eq	0.742	0.741	0.0011	0.000153
17	Dinitrogen monoxide	Air	low. pop.	kg CO2 eq	0.0383	0.0376	0.000561	0.000144
18	Dinitrogen monoxide	Air	stratosphere + tr	kg CO2 eq	3.08E-10	1.97E-10	3.32E-14	1.11E-10
19	Ethane, 1,1-difluoro-, HFC-152a	Air	high. pop.	kg CO2 eq	3.29E-9	4.13E-11	6.36E-14	3.25E-9
20	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CO2 eq	4.63E-16	1.89E-16	7.86E-20	2.75E-16
21	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CO2 eq	3.14E-9	3.11E-9	4.19E-12	2.56E-11
22	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air		kg CO2 eq	0.00285	0.00152	2.67E-6	0.00132
23	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	high. pop.	kg CO2 eq	2.62E-8	1.59E-8	1.05E-13	1.03E-8
24	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	low. pop.	kg CO2 eq	7.65E-6	7.59E-6	1.23E-8	4.4E-8
25	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CO2 eq	2.05E-8	1.72E-10	2.04E-13	2.03E-8
26	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CO2 eq	0.000996	0.000988	1.33E-6	6.42E-6
27	Ethane, hexafluoro-, HFC-116	Air		kg CO2 eq	8.34E-5	3.85E-5	3.72E-8	4.49E-5
28	Ethane, hexafluoro-, HFC-116	Air	high. pop.	kg CO2 eq	2.81E-6	2.36E-8	2.81E-11	2.79E-6
29	Methane	Air		kg CO2 eq	96.8	4.75	92.1	x
30	Methane, biogenic	Air		kg CO2 eq	0.00641	0.00639	4.74E-6	1.96E-5

31	Methane, biogenic	Air	high. pop.	kg CO2 eq	0.00114	0.00113	8.74E-6	1.68E-6
32	Methane, biogenic	Air	low. pop.	kg CO2 eq	0.00992	0.00421	0.0057	8.14E-6
33	Methane, bromo-, Halon 1001	Air		kg CO2 eq	2.42E-17	9.88E-18	4.11E-21	1.44E-17
34	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CO2 eq	0.000338	0.000336	1.36E-6	2.3E-7
35	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CO2 eq	1.24E-10	1.58E-11	1.81E-14	1.09E-10
36	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CO2 eq	0.00167	0.00165	2.6E-7	2.21E-5
37	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CO2 eq	5E-7	2.95E-7	2.05E-12	2.04E-7
38	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CO2 eq	0.00163	0.00162	9.6E-6	1.2E-6
39	Methane, dichloro-, HCC-30	Air		kg CO2 eq	2.24E-5	2.24E-5	x	x
40	Methane, dichloro-, HCC-30	Air	high. pop.	kg CO2 eq	2.34E-9	2.31E-9	1.37E-12	3.22E-11
41	Methane, dichloro-, HCC-30	Air	low. pop.	kg CO2 eq	3.25E-9	3.22E-9	4.34E-12	2.65E-11
42	Methane, dichlorodifluoro-, CFC-12	Air		kg CO2 eq	3.42E-14	1.39E-14	5.8E-18	2.03E-14
43	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CO2 eq	0.000218	0.000218	4.6E-11	9.34E-8
44	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CO2 eq	9.52E-6	9.51E-6	4.49E-10	7.52E-9
45	Methane, dichlorofluoro-, HCFC-21	Air	high. pop.	kg CO2 eq	1.2E-11	7.32E-12	4.82E-17	4.72E-12
46	Methane, fossil	Air		kg CO2 eq	0.00194	0.00167	4.99E-7	0.000268
47	Methane, fossil	Air	high. pop.	kg CO2 eq	0.514	0.513	2.6E-5	0.000356
48	Methane, fossil	Air	low. pop.	kg CO2 eq	1.09	1.07	0.00354	0.00717
49	Methane, fossil	Air	stratosphere + tr	kg CO2 eq	3.99E-11	2.56E-11	4.3E-15	1.44E-11
50	Methane, monochloro-, R-40	Air	high. pop.	kg CO2 eq	4.38E-6	4.38E-6	3.27E-17	2.95E-12
51	Methane, monochloro-, R-40	Air	low. pop.	kg CO2 eq	9.5E-9	9.41E-9	1.27E-11	7.73E-11
52	Methane, tetrachloro-, CFC-10	Air		kg CO2 eq	2.6E-12	1.06E-12	4.4E-16	1.54E-12
53	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CO2 eq	1.06E-5	1.03E-5	8.62E-9	2.63E-7
54	Methane, tetrafluoro-, CFC-14	Air		kg CO2 eq	0.00036	0.000166	1.61E-7	0.000194
55	Methane, tetrafluoro-, CFC-14	Air	high. pop.	kg CO2 eq	8.04E-9	1.01E-10	1.55E-13	7.94E-9
56	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CO2 eq	4.28E-10	2.6E-10	1.71E-15	1.68E-10
57	Methane, trifluoro-, HFC-23	Air	high. pop.	kg CO2 eq	2.19E-7	1.33E-7	8.76E-13	8.57E-8
58	Sulfur hexafluoride	Air		kg CO2 eq	0.0455	0.0278	0.0176	7.42E-5
59	Sulfur hexafluoride	Air	low. pop.	kg CO2 eq	1.76E-7	6.25E-8	8.37E-11	1.13E-7

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Hoyås farm WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Ozone layer depletion (ODP)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Hoyå	Operation Hoyås	Transportation Ho
	Total of all compartments			kg CFC-11 eq	4.39E-6	4.34E-6	6.08E-9	4.02E-8
1	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CFC-11 eq	3.64E-19	1.48E-19	6.17E-23	2.16E-19
2	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CFC-11 eq	2.47E-12	2.44E-12	3.29E-15	2.01E-14
3	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CFC-11 eq	3.07E-12	2.58E-14	3.07E-17	3.05E-12
4	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CFC-11 eq	8.64E-8	8.57E-8	1.15E-10	5.56E-10
5	Methane, bromo-, Halon 1001	Air		kg CFC-11 eq	1.79E-18	7.31E-19	3.04E-22	1.06E-18
6	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CFC-11 eq	1.33E-6	1.32E-6	5.32E-9	9.03E-10
7	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CFC-11 eq	2.16E-13	2.74E-14	3.15E-17	1.89E-13
8	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CFC-11 eq	2.91E-6	2.87E-6	4.52E-10	3.85E-8
9	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CFC-11 eq	9.99E-12	5.91E-12	4.1E-17	4.08E-12
10	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CFC-11 eq	3.26E-8	3.23E-8	1.92E-10	2.4E-11
11	Methane, dichlorodifluoro-, CFC-12	Air		kg CFC-11 eq	2.64E-18	1.08E-18	4.48E-22	1.57E-18
12	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CFC-11 eq	1.69E-8	1.69E-8	3.56E-15	7.23E-12
13	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CFC-11 eq	7.36E-10	7.36E-10	3.48E-14	5.82E-13
14	Methane, monochloro-, R-40	Air	high. pop.	kg CFC-11 eq	5.48E-9	5.48E-9	4.09E-20	3.69E-15
15	Methane, monochloro-, R-40	Air	low. pop.	kg CFC-11 eq	1.19E-11	1.18E-11	1.58E-14	9.67E-14
16	Methane, tetrachloro-, CFC-10	Air		kg CFC-11 eq	1.73E-15	7.05E-16	2.93E-19	1.03E-15
17	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CFC-11 eq	7.04E-9	6.86E-9	5.75E-12	1.75E-10
18	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CFC-11 eq	9.3E-14	5.66E-14	3.72E-19	3.65E-14

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Kaya greywater treatment system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Acidification
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Kaya	Operation Kaya g	Transportation Ka
	Total of all compartments			kg SO2 eq	0.184	0.184	2.51E-5	0.000162
1	Ammonia	Air		kg SO2 eq	5.06E-5	4.97E-5	3.28E-8	8.04E-7
2	Ammonia	Air	high. pop.	kg SO2 eq	1.77E-5	1.72E-5	4.69E-7	3.46E-8
3	Ammonia	Air	low. pop.	kg SO2 eq	4.82E-5	4.81E-5	1.94E-8	7.13E-8
4	Nitrogen oxides	Air		kg SO2 eq	0.005	0.00489	7.87E-7	0.000111
5	Nitrogen oxides	Air	high. pop.	kg SO2 eq	0.017	0.0169	1.34E-5	1.97E-6
6	Nitrogen oxides	Air	low. pop.	kg SO2 eq	0.00412	0.00411	1.1E-6	7.6E-6
7	Nitrogen oxides	Air	stratosphere + tr	kg SO2 eq	1.38E-10	1.28E-10	4.37E-15	1.05E-11
8	Sulfur dioxide	Air		kg SO2 eq	0.0067	0.00669	1.16E-8	2.92E-6
9	Sulfur dioxide	Air	high. pop.	kg SO2 eq	0.124	0.124	3.11E-6	9.99E-6
10	Sulfur dioxide	Air	low. pop.	kg SO2 eq	0.0274	0.0274	6.22E-6	2.76E-5
11	Sulfur dioxide	Air	stratosphere + tr	kg SO2 eq	2.37E-11	2.19E-11	7.48E-16	1.8E-12

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Kaya greywater treatment system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Eutrophication
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Kaya	Operation Kaya g	Transportation Ka
	Total of all compartments			kg PO4--- eq	0.0798	0.0101	0.0696	3.49E-5
1	Ammonia	Air		kg PO4--- eq	1.11E-5	1.09E-5	7.18E-9	1.76E-7
2	Ammonia	Air	high. pop.	kg PO4--- eq	3.88E-6	3.77E-6	1.03E-7	7.56E-9
3	Ammonia	Air	low. pop.	kg PO4--- eq	1.05E-5	1.05E-5	4.25E-9	1.56E-8
4	Ammonium carbonate	Air	high. pop.	kg PO4--- eq	9.43E-12	8.99E-12	3.33E-15	4.32E-13
5	Ammonium, ion	Water		kg PO4--- eq	3.43E-6	3.43E-6	3.45E-15	8.68E-12
6	Ammonium, ion	Water	groundwater	kg PO4--- eq	1.29E-7	1.29E-7	2.47E-10	2.82E-10
7	Ammonium, ion	Water	ocean	kg PO4--- eq	2.82E-6	2.81E-6	1.12E-10	4.94E-9
8	Ammonium, ion	Water	river	kg PO4--- eq	2.56E-5	2.56E-5	2.55E-9	2.2E-8
9	COD, Chemical Oxygen Demand	Water		kg PO4--- eq	0.000167	0.000167	3.09E-12	3.59E-9
10	COD, Chemical Oxygen Demand	Water	groundwater	kg PO4--- eq	1.72E-9	1.71E-9	3.29E-12	3.72E-12
11	COD, Chemical Oxygen Demand	Water	ocean	kg PO4--- eq	0.00027	0.00027	7.74E-9	3.22E-7
12	COD, Chemical Oxygen Demand	Water	river	kg PO4--- eq	0.00158	0.00157	4.15E-8	1.4E-6
13	Nitrate	Air	high. pop.	kg PO4--- eq	2.17E-10	2.15E-10	2.15E-13	1.44E-12
14	Nitrate	Air	low. pop.	kg PO4--- eq	9.58E-9	9.55E-9	6.46E-12	2.12E-11
15	Nitrate	Water		kg PO4--- eq	3.53E-7	3.53E-7	x	x
16	Nitrate	Water	groundwater	kg PO4--- eq	1.12E-5	1.12E-5	4.92E-9	2.47E-8
17	Nitrate	Water	ocean	kg PO4--- eq	2.93E-6	2.92E-6	6.13E-10	3.39E-9
18	Nitrate	Water	river	kg PO4--- eq	1.47E-5	1.47E-5	3.98E-9	1.92E-8
19	Nitrite	Water	ocean	kg PO4--- eq	1.79E-8	1.79E-8	1.15E-11	3.1E-11
20	Nitrite	Water	river	kg PO4--- eq	1.85E-8	1.84E-8	1.11E-11	1.85E-10
21	Nitrogen	Water	ocean	kg PO4--- eq	2.1E-7	2.1E-7	5.94E-12	2.04E-10
22	Nitrogen	Water	river	kg PO4--- eq	4.04E-5	4.03E-5	1.06E-8	1.46E-8
23	Nitrogen oxides	Air		kg PO4--- eq	0.0013	0.00127	2.05E-7	2.88E-5
24	Nitrogen oxides	Air	high. pop.	kg PO4--- eq	0.00441	0.0044	3.48E-6	5.11E-7
25	Nitrogen oxides	Air	low. pop.	kg PO4--- eq	0.00107	0.00107	2.87E-7	1.98E-6
26	Nitrogen oxides	Air	stratosphere + tr	kg PO4--- eq	3.59E-11	3.32E-11	1.13E-15	2.73E-12
27	Nitrogen, total	Water		kg PO4--- eq	0.0592	3.47E-6	0.0592	x
28	Phosphate	Water	groundwater	kg PO4--- eq	0.000863	0.000861	2.6E-7	1.52E-6
29	Phosphate	Water	ocean	kg PO4--- eq	7.64E-7	7.58E-7	5.38E-10	4.94E-9
30	Phosphate	Water	river	kg PO4--- eq	3.31E-6	3.29E-6	2.8E-9	1.72E-8

31	Phosphorus	Air		kg PO4--- eq	8.21E-12	4.26E-12	4.22E-15	3.94E-12
32	Phosphorus	Air	high. pop.	kg PO4--- eq	1.14E-6	9.88E-7	1.54E-7	7.39E-10
33	Phosphorus	Air	low. pop.	kg PO4--- eq	1.03E-8	1.01E-8	2.38E-11	1.28E-10
34	Phosphorus	Water		kg PO4--- eq	2.12E-8	2.1E-8	7.78E-12	1.27E-10
35	Phosphorus	Water	groundwater	kg PO4--- eq	3.17E-9	3.17E-9	1.41E-14	7E-12
36	Phosphorus	Water	ocean	kg PO4--- eq	2.99E-6	2.99E-6	8.94E-11	2.75E-9
37	Phosphorus	Water	river	kg PO4--- eq	0.000326	0.000326	3.87E-10	1.03E-8
38	Phosphorus	Soil	agricultural	kg PO4--- eq	3.3E-6	2.63E-6	6.63E-7	2.41E-9
39	Phosphorus	Soil	industrial	kg PO4--- eq	2.95E-8	3.53E-10	2.12E-13	2.92E-8
40	Phosphorus, total	Water		kg PO4--- eq	0.0105	5.52E-5	0.0104	x

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Kaya greywater treatment system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Global warming (GWP100)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Kaya	Operation Kaya g	Transportation Ka
	Total of all compartments			kg CO2 eq	52.9	29.3	23.6	0.0308
1	Carbon dioxide	Air		kg CO2 eq	1.42	1.42	x	x
2	Carbon dioxide, fossil	Air		kg CO2 eq	0.553	0.53	0.000135	0.0226
3	Carbon dioxide, fossil	Air	high. pop.	kg CO2 eq	22.7	22.7	0.00841	0.00327
4	Carbon dioxide, fossil	Air	low. pop.	kg CO2 eq	2.51	2.5	0.0016	0.00317
5	Carbon dioxide, fossil	Air	stratosphere + tr	kg CO2 eq	6.22E-8	5.74E-8	1.96E-12	4.72E-9
6	Carbon dioxide, land transformation	Air	low. pop.	kg CO2 eq	0.000382	0.000284	9.73E-5	3.53E-7
7	Carbon monoxide	Air		kg CO2 eq	0.00276	0.00276	x	x
8	Carbon monoxide, fossil	Air		kg CO2 eq	0.00244	0.00232	5.33E-7	0.000123
9	Carbon monoxide, fossil	Air	high. pop.	kg CO2 eq	0.0128	0.0128	2.42E-6	2.81E-6
10	Carbon monoxide, fossil	Air	low. pop.	kg CO2 eq	0.00286	0.00285	5.38E-6	6.59E-6
11	Carbon monoxide, fossil	Air	stratosphere + tr	kg CO2 eq	1.15E-10	1.06E-10	3.62E-15	8.7E-12
12	Chloroform	Air		kg CO2 eq	1.88E-17	1.49E-17	1.52E-21	3.82E-18
13	Chloroform	Air	high. pop.	kg CO2 eq	2.53E-8	2.5E-8	1.52E-11	3.06E-10
14	Chloroform	Air	low. pop.	kg CO2 eq	9.21E-10	9.17E-10	7.33E-13	3.22E-12
15	Dinitrogen monoxide	Air		kg CO2 eq	0.15	0.0139	0.135	0.000495
16	Dinitrogen monoxide	Air	high. pop.	kg CO2 eq	0.144	0.144	0.000183	1.83E-5
17	Dinitrogen monoxide	Air	low. pop.	kg CO2 eq	0.0133	0.0132	9.36E-5	1.73E-5
18	Dinitrogen monoxide	Air	stratosphere + tr	kg CO2 eq	1.75E-10	1.62E-10	5.54E-15	1.33E-11
19	Ethane, 1,1-difluoro-, HFC-152a	Air	high. pop.	kg CO2 eq	4.12E-10	2.18E-11	1.06E-14	3.9E-10
20	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CO2 eq	1.62E-16	1.29E-16	1.31E-20	3.29E-17
21	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CO2 eq	8.77E-10	8.74E-10	6.98E-13	3.07E-12
22	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air		kg CO2 eq	0.00118	0.00102	4.45E-7	0.000159
23	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	high. pop.	kg CO2 eq	2.26E-9	1.03E-9	1.75E-14	1.23E-9
24	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	low. pop.	kg CO2 eq	2.14E-6	2.13E-6	2.05E-9	5.28E-9
25	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CO2 eq	2.54E-9	1.05E-10	3.41E-14	2.44E-9
26	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CO2 eq	0.000278	0.000277	2.22E-7	7.7E-7
27	Ethane, hexafluoro-, HFC-116	Air		kg CO2 eq	1.18E-5	6.44E-6	6.21E-9	5.39E-6
28	Ethane, hexafluoro-, HFC-116	Air	high. pop.	kg CO2 eq	3.49E-7	1.44E-8	4.69E-12	3.34E-7
29	Methane	Air		kg CO2 eq	23.8	0.373	23.5	x
30	Methane, biogenic	Air		kg CO2 eq	0.00179	0.00179	7.91E-7	2.35E-6

31	Methane, biogenic	Air	high. pop.	kg CO2 eq	0.00209	0.00209	1.46E-6	2.01E-7
32	Methane, biogenic	Air	low. pop.	kg CO2 eq	0.00222	0.00126	0.000952	9.76E-7
33	Methane, bromo-, Halon 1001	Air		kg CO2 eq	8.47E-18	6.75E-18	6.86E-22	1.72E-18
34	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CO2 eq	3.49E-5	3.46E-5	2.26E-7	2.76E-8
35	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CO2 eq	1.75E-11	4.43E-12	3.02E-15	1.3E-11
36	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CO2 eq	0.00141	0.00141	4.34E-8	2.66E-6
37	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CO2 eq	0.00302	0.00302	3.42E-13	2.45E-8
38	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CO2 eq	0.000186	0.000184	1.6E-6	1.44E-7
39	Methane, dichloro-, HCC-30	Air		kg CO2 eq	1.77E-6	1.77E-6	x	x
40	Methane, dichloro-, HCC-30	Air	high. pop.	kg CO2 eq	4.86E-8	4.86E-8	2.29E-13	3.87E-12
41	Methane, dichloro-, HCC-30	Air	low. pop.	kg CO2 eq	9.09E-10	9.05E-10	7.23E-13	3.18E-12
42	Methane, dichlorodifluoro-, CFC-12	Air		kg CO2 eq	1.19E-14	9.51E-15	9.67E-19	2.43E-15
43	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CO2 eq	1.35E-5	1.35E-5	7.67E-12	1.12E-8
44	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CO2 eq	1.11E-6	1.11E-6	7.5E-11	9.02E-10
45	Methane, dichlorofluoro-, HCFC-21	Air	high. pop.	kg CO2 eq	1.04E-12	4.73E-13	8.04E-18	5.66E-13
46	Methane, fossil	Air		kg CO2 eq	0.000934	0.000902	8.32E-8	3.22E-5
47	Methane, fossil	Air	high. pop.	kg CO2 eq	1.19	1.19	4.33E-6	4.27E-5
48	Methane, fossil	Air	low. pop.	kg CO2 eq	0.338	0.337	0.00059	0.00086
49	Methane, fossil	Air	stratosphere + tr	kg CO2 eq	2.27E-11	2.1E-11	7.17E-16	1.72E-12
50	Methane, monochloro-, R-40	Air	high. pop.	kg CO2 eq	2.7E-7	2.7E-7	5.46E-18	3.55E-13
51	Methane, monochloro-, R-40	Air	low. pop.	kg CO2 eq	2.66E-9	2.64E-9	2.11E-12	9.28E-12
52	Methane, tetrachloro-, CFC-10	Air		kg CO2 eq	9.07E-13	7.22E-13	7.34E-17	1.85E-13
53	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CO2 eq	3.4E-6	3.37E-6	1.44E-9	3.16E-8
54	Methane, tetrafluoro-, CFC-14	Air		kg CO2 eq	5.1E-5	2.78E-5	2.68E-8	2.32E-5
55	Methane, tetrafluoro-, CFC-14	Air	high. pop.	kg CO2 eq	1.01E-9	5.33E-11	2.59E-14	9.53E-10
56	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CO2 eq	3.69E-11	1.68E-11	2.86E-16	2.01E-11
57	Methane, trifluoro-, HFC-23	Air	high. pop.	kg CO2 eq	1.89E-8	8.59E-9	1.46E-13	1.03E-8
58	Sulfur hexafluoride	Air		kg CO2 eq	0.0107	0.00779	0.00294	8.91E-6
59	Sulfur hexafluoride	Air	low. pop.	kg CO2 eq	3.17E-8	1.81E-8	1.4E-11	1.36E-8

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Kaya greywater treatment system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Ozone layer depletion (ODP)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Descending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Kaya	Operation Kaya g	Transportation Ka
	Total of all compartments			kg CFC-11 eq	2.69E-6	2.68E-6	1.01E-9	4.82E-9
1	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CFC-11 eq	8.03E-15	3.65E-15	6.21E-20	4.37E-15
2	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CFC-11 eq	2.27E-9	2.25E-9	9.59E-13	2.11E-11
3	Methane, tetrachloro-, CFC-10	Air		kg CFC-11 eq	6.04E-16	4.81E-16	4.89E-20	1.23E-16
4	Methane, monochloro-, R-40	Air	low. pop.	kg CFC-11 eq	3.32E-12	3.31E-12	2.64E-15	1.16E-14
5	Methane, monochloro-, R-40	Air	high. pop.	kg CFC-11 eq	3.37E-10	3.37E-10	6.83E-21	4.43E-16
6	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CFC-11 eq	8.62E-11	8.62E-11	5.8E-15	6.98E-14
7	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CFC-11 eq	1.05E-9	1.05E-9	5.94E-16	8.67E-13
8	Methane, dichlorodifluoro-, CFC-12	Air		kg CFC-11 eq	9.24E-19	7.36E-19	7.48E-23	1.88E-19
9	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CFC-11 eq	3.72E-9	3.68E-9	3.2E-11	2.88E-12
10	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CFC-11 eq	6.04E-8	6.04E-8	6.83E-18	4.9E-13
11	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CFC-11 eq	2.46E-6	2.46E-6	7.54E-11	4.62E-9
12	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CFC-11 eq	3.04E-14	7.7E-15	5.26E-18	2.27E-14
13	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CFC-11 eq	1.37E-7	1.36E-7	8.87E-10	1.08E-10
14	Methane, bromo-, Halon 1001	Air		kg CFC-11 eq	6.27E-19	4.99E-19	5.08E-23	1.28E-19
15	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CFC-11 eq	2.41E-8	2.4E-8	1.93E-11	6.68E-11
16	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CFC-11 eq	3.82E-13	1.58E-14	5.12E-18	3.66E-13
17	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CFC-11 eq	6.89E-13	6.86E-13	5.49E-16	2.41E-15
18	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CFC-11 eq	1.27E-19	1.01E-19	1.03E-23	2.59E-20

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Vidarøsen WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Acidification
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Vida	Operation Vidarøs	Transportation Vi
	Total of all compartments			kg SO2 eq	0.0892	0.0879	1.81E-5	0.00135
1	Ammonia	Air		kg SO2 eq	3.89E-5	3.22E-5	2.37E-8	6.7E-6
2	Ammonia	Air	high. pop.	kg SO2 eq	7.75E-6	7.13E-6	3.39E-7	2.88E-7
3	Ammonia	Air	low. pop.	kg SO2 eq	1.97E-5	1.91E-5	1.4E-8	5.94E-7
4	Nitrogen oxides	Air		kg SO2 eq	0.0046	0.00368	5.68E-7	0.000923
5	Nitrogen oxides	Air	high. pop.	kg SO2 eq	0.00842	0.0084	9.67E-6	1.64E-5
6	Nitrogen oxides	Air	low. pop.	kg SO2 eq	0.00174	0.00168	7.96E-7	6.33E-5
7	Nitrogen oxides	Air	stratosphere + tr	kg SO2 eq	1.36E-10	4.84E-11	3.15E-15	8.74E-11
8	Sulfur dioxide	Air		kg SO2 eq	0.00963	0.00961	8.37E-9	2.44E-5
9	Sulfur dioxide	Air	high. pop.	kg SO2 eq	0.0536	0.0535	2.24E-6	8.32E-5
10	Sulfur dioxide	Air	low. pop.	kg SO2 eq	0.0112	0.0109	4.49E-6	0.00023
11	Sulfur dioxide	Air	stratosphere + tr	kg SO2 eq	2.33E-11	8.29E-12	5.4E-16	1.5E-11

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Vidarøsen WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Eutrophication
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Descending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Vida	Operation Vidarøs	Transportation Vi
	Total of all compartments			kg PO4--- eq	0.256	0.00536	0.251	0.000291
1	Phosphorus, total	Water		kg PO4--- eq	0.0827	7.99E-5	0.0826	x
2	Phosphorus	Soil	industrial	kg PO4--- eq	2.43E-7	1.45E-10	1.53E-13	2.43E-7
3	Phosphorus	Soil	agricultural	kg PO4--- eq	1.66E-6	1.16E-6	4.78E-7	2E-8
4	Phosphorus	Water	river	kg PO4--- eq	0.000279	0.000279	2.79E-10	8.58E-8
5	Phosphorus	Water	ocean	kg PO4--- eq	1.15E-6	1.13E-6	6.45E-11	2.29E-8
6	Phosphorus	Water	groundwater	kg PO4--- eq	1.25E-9	1.2E-9	1.02E-14	5.83E-11
7	Phosphorus	Water		kg PO4--- eq	8.43E-9	7.36E-9	5.62E-12	1.06E-9
8	Phosphorus	Air	low. pop.	kg PO4--- eq	5.61E-9	4.52E-9	1.72E-11	1.07E-9
9	Phosphorus	Air	high. pop.	kg PO4--- eq	6.1E-7	4.92E-7	1.11E-7	6.16E-9
10	Phosphorus	Air		kg PO4--- eq	3.46E-11	1.78E-12	3.05E-15	3.29E-11
11	Phosphate	Water	river	kg PO4--- eq	2.35E-6	2.2E-6	2.02E-9	1.43E-7
12	Phosphate	Water	ocean	kg PO4--- eq	3.34E-7	2.92E-7	3.88E-10	4.12E-8
13	Phosphate	Water	groundwater	kg PO4--- eq	0.000399	0.000387	1.88E-7	1.26E-5
14	Nitrogen, total	Water		kg PO4--- eq	0.168	5.02E-6	0.168	x
15	Nitrogen oxides	Air	stratosphere + tr	kg PO4--- eq	3.53E-11	1.26E-11	8.19E-16	2.27E-11
16	Nitrogen oxides	Air	low. pop.	kg PO4--- eq	0.000454	0.000437	2.07E-7	1.65E-5
17	Nitrogen oxides	Air	high. pop.	kg PO4--- eq	0.00219	0.00218	2.51E-6	4.26E-6
18	Nitrogen oxides	Air		kg PO4--- eq	0.0012	0.000957	1.48E-7	0.00024
19	Nitrogen	Water	river	kg PO4--- eq	1.61E-5	1.6E-5	7.65E-9	1.22E-7
20	Nitrogen	Water	ocean	kg PO4--- eq	8.1E-8	7.93E-8	4.29E-12	1.7E-9
21	Nitrite	Water	river	kg PO4--- eq	8.86E-9	7.31E-9	8.01E-12	1.54E-9
22	Nitrite	Water	ocean	kg PO4--- eq	8.24E-9	7.97E-9	8.34E-12	2.58E-10
23	Nitrate	Water	river	kg PO4--- eq	1.1E-5	1.08E-5	2.88E-9	1.6E-7
24	Nitrate	Water	ocean	kg PO4--- eq	1.19E-6	1.16E-6	4.43E-10	2.82E-8
25	Nitrate	Water	groundwater	kg PO4--- eq	4.67E-6	4.46E-6	3.55E-9	2.06E-7
26	Nitrate	Water		kg PO4--- eq	5.11E-7	5.11E-7	x	x
27	Nitrate	Air	low. pop.	kg PO4--- eq	4.45E-9	4.27E-9	4.66E-12	1.77E-10
28	Nitrate	Air	high. pop.	kg PO4--- eq	1.02E-10	9E-11	1.55E-13	1.2E-11
29	COD, Chemical Oxygen Demand	Water	river	kg PO4--- eq	0.000632	0.000621	2.99E-8	1.16E-5
30	COD, Chemical Oxygen Demand	Water	ocean	kg PO4--- eq	0.000106	0.000103	5.59E-9	2.68E-6

31	COD, Chemical Oxygen Demand	Water	groundwater	kg PO4--- eq	7.97E-10	7.64E-10	2.38E-12	3.1E-11
32	COD, Chemical Oxygen Demand	Water		kg PO4--- eq	0.000242	0.000242	2.23E-12	2.99E-8
33	Ammonium, ion	Water	river	kg PO4--- eq	1.54E-5	1.52E-5	1.84E-9	1.83E-7
34	Ammonium, ion	Water	ocean	kg PO4--- eq	1.11E-6	1.07E-6	8.08E-11	4.12E-8
35	Ammonium, ion	Water	groundwater	kg PO4--- eq	6E-8	5.74E-8	1.79E-10	2.35E-9
36	Ammonium, ion	Water		kg PO4--- eq	4.97E-6	4.97E-6	2.49E-15	7.23E-11
37	Ammonium carbonate	Air	high. pop.	kg PO4--- eq	6.75E-12	3.15E-12	2.4E-15	3.6E-12
38	Ammonia	Air	low. pop.	kg PO4--- eq	4.32E-6	4.18E-6	3.07E-9	1.3E-7
39	Ammonia	Air	high. pop.	kg PO4--- eq	1.7E-6	1.56E-6	7.41E-8	6.3E-8
40	Ammonia	Air		kg PO4--- eq	8.51E-6	7.04E-6	5.18E-9	1.47E-6

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Vidarøsen WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Global warming (GWP100)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Vida	Operation Vidarøs	Transportation Vi
	Total of all compartments			kg CO2 eq	1.41E3	15.8	1.39E3	0.257
1	Carbon dioxide	Air		kg CO2 eq	2.06	2.06	x	x
2	Carbon dioxide, fossil	Air		kg CO2 eq	0.394	0.206	9.78E-5	0.188
3	Carbon dioxide, fossil	Air	high. pop.	kg CO2 eq	10.8	10.8	0.00607	0.0272
4	Carbon dioxide, fossil	Air	low. pop.	kg CO2 eq	1.1	1.08	0.00116	0.0264
5	Carbon dioxide, fossil	Air	stratosphere + tr	kg CO2 eq	6.11E-8	2.18E-8	1.42E-12	3.93E-8
6	Carbon dioxide, land transformation	Air	low. pop.	kg CO2 eq	0.000194	0.000121	7.03E-5	2.94E-6
7	Carbon monoxide	Air		kg CO2 eq	0.00394	0.00394	x	x
8	Carbon monoxide, fossil	Air		kg CO2 eq	0.00191	0.000889	3.85E-7	0.00102
9	Carbon monoxide, fossil	Air	high. pop.	kg CO2 eq	0.0119	0.0119	1.75E-6	2.34E-5
10	Carbon monoxide, fossil	Air	low. pop.	kg CO2 eq	0.0012	0.00114	3.88E-6	5.49E-5
11	Carbon monoxide, fossil	Air	stratosphere + tr	kg CO2 eq	1.13E-10	4.02E-11	2.62E-15	7.25E-11
12	Chloroform	Air		kg CO2 eq	3.76E-17	5.76E-18	1.1E-21	3.18E-17
13	Chloroform	Air	high. pop.	kg CO2 eq	1.35E-8	1.09E-8	1.1E-11	2.55E-9
14	Chloroform	Air	low. pop.	kg CO2 eq	4.37E-10	4.1E-10	5.29E-13	2.68E-11
15	Dinitrogen monoxide	Air		kg CO2 eq	1.85	0.00582	1.84	0.00412
16	Dinitrogen monoxide	Air	high. pop.	kg CO2 eq	0.0532	0.0529	0.000132	0.000153
17	Dinitrogen monoxide	Air	low. pop.	kg CO2 eq	0.00584	0.00563	6.76E-5	0.000144
18	Dinitrogen monoxide	Air	stratosphere + tr	kg CO2 eq	1.72E-10	6.14E-11	4E-15	1.11E-10
19	Ethane, 1,1-difluoro-, HFC-152a	Air	high. pop.	kg CO2 eq	3.26E-9	8.87E-12	7.66E-15	3.25E-9
20	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CO2 eq	3.24E-16	4.97E-17	9.46E-21	2.75E-16
21	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CO2 eq	4.16E-10	3.9E-10	5.04E-13	2.56E-11
22	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air		kg CO2 eq	0.00171	0.000388	3.21E-7	0.00132
23	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	high. pop.	kg CO2 eq	1.06E-8	3.27E-10	1.26E-14	1.03E-8
24	Ethane, 1,1,1,2-tetrafluoro-, HFC-134a	Air	low. pop.	kg CO2 eq	9.98E-7	9.53E-7	1.48E-9	4.4E-8
25	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CO2 eq	2.04E-8	4.19E-11	2.46E-14	2.03E-8
26	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CO2 eq	0.00013	0.000124	1.6E-7	6.42E-6
27	Ethane, hexafluoro-, HFC-116	Air		kg CO2 eq	4.76E-5	2.71E-6	4.48E-9	4.49E-5
28	Ethane, hexafluoro-, HFC-116	Air	high. pop.	kg CO2 eq	2.79E-6	5.75E-9	3.38E-12	2.79E-6
29	Methane	Air		kg CO2 eq	1.39E3	0.545	1.39E3	x
30	Methane, biogenic	Air		kg CO2 eq	0.000818	0.000798	5.71E-7	1.96E-5

31	Methane, biogenic	Air	high. pop.	kg CO2 eq	0.00186	0.00186	1.05E-6	1.68E-6
32	Methane, biogenic	Air	low. pop.	kg CO2 eq	0.00121	0.00052	0.000687	8.14E-6
33	Methane, bromo-, Halon 1001	Air		kg CO2 eq	1.7E-17	2.6E-18	4.95E-22	1.44E-17
34	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CO2 eq	1.35E-5	1.31E-5	1.63E-7	2.3E-7
35	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CO2 eq	1.11E-10	1.98E-12	2.18E-15	1.09E-10
36	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CO2 eq	0.000571	0.000549	3.13E-8	2.21E-5
37	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CO2 eq	0.00217	0.00217	2.47E-13	2.04E-7
38	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CO2 eq	7.4E-5	7.17E-5	1.16E-6	1.2E-6
39	Methane, dichloro-, HCC-30	Air		kg CO2 eq	2.57E-6	2.57E-6	x	x
40	Methane, dichloro-, HCC-30	Air	high. pop.	kg CO2 eq	3.46E-8	3.45E-8	1.65E-13	3.22E-11
41	Methane, dichloro-, HCC-30	Air	low. pop.	kg CO2 eq	4.31E-10	4.04E-10	5.22E-13	2.65E-11
42	Methane, dichlorodifluoro-, CFC-12	Air		kg CO2 eq	2.39E-14	3.67E-15	6.98E-19	2.03E-14
43	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CO2 eq	4.35E-6	4.25E-6	5.54E-12	9.34E-8
44	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CO2 eq	4.28E-7	4.2E-7	5.41E-11	7.52E-9
45	Methane, dichlorofluoro-, HCFC-21	Air	high. pop.	kg CO2 eq	4.87E-12	1.5E-13	5.8E-18	4.72E-12
46	Methane, fossil	Air		kg CO2 eq	0.000609	0.000341	6.01E-8	0.000268
47	Methane, fossil	Air	high. pop.	kg CO2 eq	0.944	0.944	3.13E-6	0.000356
48	Methane, fossil	Air	low. pop.	kg CO2 eq	0.145	0.137	0.000426	0.00717
49	Methane, fossil	Air	stratosphere + tr	kg CO2 eq	2.23E-11	7.95E-12	5.18E-16	1.44E-11
50	Methane, monochloro-, R-40	Air	high. pop.	kg CO2 eq	8.47E-8	8.47E-8	3.94E-18	2.95E-12
51	Methane, monochloro-, R-40	Air	low. pop.	kg CO2 eq	1.26E-9	1.18E-9	1.53E-12	7.73E-11
52	Methane, tetrachloro-, CFC-10	Air		kg CO2 eq	1.82E-12	2.78E-13	5.3E-17	1.54E-12
53	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CO2 eq	1.69E-6	1.42E-6	1.04E-9	2.63E-7
54	Methane, tetrafluoro-, CFC-14	Air		kg CO2 eq	0.000205	1.17E-5	1.93E-8	0.000194
55	Methane, tetrafluoro-, CFC-14	Air	high. pop.	kg CO2 eq	7.96E-9	2.17E-11	1.87E-14	7.94E-9
56	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CO2 eq	1.73E-10	5.35E-12	2.06E-16	1.68E-10
57	Methane, trifluoro-, HFC-23	Air	high. pop.	kg CO2 eq	8.85E-8	2.73E-9	1.05E-13	8.57E-8
58	Sulfur hexafluoride	Air		kg CO2 eq	0.00567	0.00348	0.00212	7.42E-5
59	Sulfur hexafluoride	Air	low. pop.	kg CO2 eq	1.21E-7	8.04E-9	1.01E-11	1.13E-7

Calculation:	Analyse
Results:	Specification per substance
Product:	1 p Vidarøsen WWT system (of project Wastewater treatment Norge_2)
Method:	CML 2 baseline 2000 V2.05 / the Netherlands, 1997
Indicator:	Characterisation
Compartment:	All compartments
Per sub-compartment:	Yes
Skip unused:	Yes
Category:	Ozone layer depletion (ODP)
Cut-off:	0%
Exclude infrastructure processes:	Yes
Exclude long-term emissions:	Yes
Sorted on item:	Substance
Sort order:	Ascending

No	Substance	Compartment	Sub-compartment	Unit	Total	Construction Vida	Operation Vidarøs	Transportation Vi
	Total of all compartments			kg CFC-11 eq	1.1E-6	1.06E-6	7.32E-10	4.02E-8
1	Ethane, 1,1,1-trichloro-, HCFC-140	Air		kg CFC-11 eq	2.55E-19	3.91E-20	7.43E-24	2.16E-19
2	Ethane, 1,1,1-trichloro-, HCFC-140	Air	low. pop.	kg CFC-11 eq	3.27E-13	3.06E-13	3.96E-16	2.01E-14
3	Ethane, 1,1,2-trichloro-1,2,2-trifluoro-, CFC-113	Air	high. pop.	kg CFC-11 eq	3.06E-12	6.28E-15	3.69E-18	3.05E-12
4	Ethane, 1,2-dichloro-1,1,2,2-tetrafluoro-, CFC-114	Air	low. pop.	kg CFC-11 eq	1.13E-8	1.07E-8	1.39E-11	5.56E-10
5	Methane, bromo-, Halon 1001	Air		kg CFC-11 eq	1.26E-18	1.93E-19	3.66E-23	1.06E-18
6	Methane, bromochlorodifluoro-, Halon 1211	Air	low. pop.	kg CFC-11 eq	5.28E-8	5.13E-8	6.4E-10	9.03E-10
7	Methane, bromotrifluoro-, Halon 1301	Air	high. pop.	kg CFC-11 eq	1.92E-13	3.44E-15	3.79E-18	1.89E-13
8	Methane, bromotrifluoro-, Halon 1301	Air	low. pop.	kg CFC-11 eq	9.93E-7	9.54E-7	5.44E-11	3.85E-8
9	Methane, chlorodifluoro-, HCFC-22	Air	high. pop.	kg CFC-11 eq	4.33E-8	4.33E-8	4.93E-18	4.08E-12
10	Methane, chlorodifluoro-, HCFC-22	Air	low. pop.	kg CFC-11 eq	1.48E-9	1.43E-9	2.31E-11	2.4E-11
11	Methane, dichlorodifluoro-, CFC-12	Air		kg CFC-11 eq	1.85E-18	2.84E-19	5.4E-23	1.57E-18
12	Methane, dichlorodifluoro-, CFC-12	Air	high. pop.	kg CFC-11 eq	3.36E-10	3.29E-10	4.28E-16	7.23E-12
13	Methane, dichlorodifluoro-, CFC-12	Air	low. pop.	kg CFC-11 eq	3.31E-11	3.25E-11	4.19E-15	5.82E-13
14	Methane, monochloro-, R-40	Air	high. pop.	kg CFC-11 eq	1.06E-10	1.06E-10	4.93E-21	3.69E-15
15	Methane, monochloro-, R-40	Air	low. pop.	kg CFC-11 eq	1.57E-12	1.48E-12	1.91E-15	9.67E-14
16	Methane, tetrachloro-, CFC-10	Air		kg CFC-11 eq	1.21E-15	1.86E-16	3.53E-20	1.03E-15
17	Methane, tetrachloro-, CFC-10	Air	high. pop.	kg CFC-11 eq	1.12E-9	9.48E-10	6.92E-13	1.75E-10
18	Methane, trichlorofluoro-, CFC-11	Air	high. pop.	kg CFC-11 eq	3.76E-14	1.16E-15	4.48E-20	3.65E-14

Norges miljø- og biovitenskapelig universitet
Noregs miljø- og biovitskapelege universitet
Norwegian University of Life Sciences

Postboks 5003
NO-1432 Ås
Norway