Handling food waste in Stockholm

Comparison of a lifecycle assessment of two systems for handling food waste

AG2800 Life Cycle Assessment

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Group 7

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Abstract

Increasing the collection of food waste is of interest for City of Stockholm as it is an environmental goal and also due to the increasing demand for biofuel in Stockholm. The food waste that is collected is turned into biofuel and biofertilizer. To increase the collection of food waste, kitchen food-waste grinders has been installed in the new sustainable area of Stockholm, Stockholm Royal Seaport. The conventional system, used in many existing apartment buildings, is a system with paper bag collection.

The aim, of this study, is to provide City of Stockholm with a comparison of the alternatives for collection of food waste and information on which system that is the most environmentally preferable, when building new sustainable buildings. This is done by the use the Life Cycle Assessment (LCA) technic.

To do this this, three collection systems and a total of five scenarios are analyzed. Three of the scenarios consider the technical differences of the systems and two of the scenarios include people's behavior and the amount of food waste households actually sort within each of the different systems.

The result of the LCA is that Human toxicity (HT), terrestrial ecotoxicity (TE), freshwater eutrophication (FEu) and marine ecotoxicity (MT) were the major impact categories.

The paper bag system was found to be the most environmentally friendly system. Still, the system with kitchen food waste processors has a higher rate of sorted food waste and could therefore be of higher benefit. If the paper bag system is chosen, effort affecting household to sort out a higher fraction of food waste is needed.

Contents

1. Introduction

1.1 Managing food waste in Stockholm

In 2013 about 13% of the produced food waste from households, restaurants, caterers and shops in Stockholm was taken care of and sent to a biogas facility (Stockholm stad, 2014d). At the facility, the food waste is turned into biofertilizer and biogas (digester gas). The biogas is then upgraded in a process that generates biofuel (Stockholms Stad, 2012). Biofertilizers from digestion of food waste may be approved for KRAV-cultivation (organic farming) (Millers-Dalsjö et al., 2011). The goal for City of Stockholm is to take care of at least 50% of the produced food waste by 2018. This is an environmental goal and also a way to meet the huge future demand for biofuel in Stockholm. To achieve this goal the City of Stockholm has implemented three different techniques; increasing installations of kitchen food waste processors (KFWP), collection of food waste in paper bags and a system with green bags with food waste that is sorted and collected with the combustible waste and then optically sorted out (Stockholms Stad, 2012).

1.2 The aim of the study

The Stockholm Royal Seaport is a new built sustainable area with apartment buildings, where the construction is still ongoing. City of Stockholm is currently running an LCA study comparing the different food waste management systems. The KFWP system will be implemented in new apartment buildings. The reasons for carrying out this study are to explore if the chosen system for managing food waste is the most environmental friendly system to implement in sustainable buildings in Stockholm.

The question that this LCA is intended to answer is:

“What is the environmentally preferable choice between the two systems; KFWP and Paper bags?”

1.3 Intended application

The intended application is to provide a report for City of Stockholm (Stockholm Stad) for decision making regarding what system they should use when building new sustainable buildings. The intended audience is City of Stockholm, architects and governments of cities.

2. Scenarios and specific background

In chapter 2, the two chosen systems for handling food waste, will be explained in detail. Both systems contain two scenarios, one where the total amount of produced food waste is collected, and one scenario where only a certain percentage is collected and the rest is going to incineration with the household waste. In a third scenario, there is no collection of food waste at. All and every kilogram of food waste is going to incineration with the normal waste.

2.1 Kitchen food waste processor system

2.1.1. Kitchen food waste processors (KFWP) in Stockholm

As from 2008 any household (where it's possible) may install kitchen food waste grinders (Stockholm Vatten, 2014). Figure 2.1 shows a schematic picture of a grinder.

Figure 2.1: Food waste grinder installed in a sink (Waste King, 2014).

Kitchen food waste processors in Stockholm have two different collecting techniques: from the grinder to the sewage system and from the grinder to a local tank in the basement of the building (Stockholm Stad, 2012). The system where the food waste goes in the sewage system to a sewage plant can easily be implemented in existing buildings but it may generate two problems; sedimentation of fat and decomposition of organic matter. (Davidsson Å et al. 2011) The other system with tanks, placed in the basement of apartment buildings has the advantage that the decomposed food waste is transported directly to the biogas facility without having to be pre-treated. Problems known with this system is decomposition of organic matter in the tank and loss of nutrients and organic matter to the sewage system (Davidsson Å et al. 2011)

2.1.2 Managing food waste with KFWP in Stockholm Royal Seaport (Norra Djurgårdsstaden)

In the new sustainable area of Stockholm, Stockholm Royal Seaport, constructions of 12 000 apartments started 2011 and will be finished around 2025. City of Stockholm has ambitious environmental goals for the area and has developed recycling solutions for waste and water and aims to minimize waste and maximize recycling. As a part of this kitchen food waste grinders have been, and will be, installed in all the apartments in the area (Stockholms Stad, 2014a). So far only the collection technique with the grinder connected directly to the sewage system is in use. Two buildings will be built to try out the system where the food waste goes to a tank in the basement and then collected with a vacuum truck and sent to the biogas facility (Dolk M, 2014), described in figure 2.2. Both the collection of food waste via the sewage system and separate tank is/will be treated at Henriksdal, where the sewage plant is next to the biogas facility. (Dolk M, 2014; Nilsson J, 2014). In this study collection of the food waste using a local tank has been chosen.

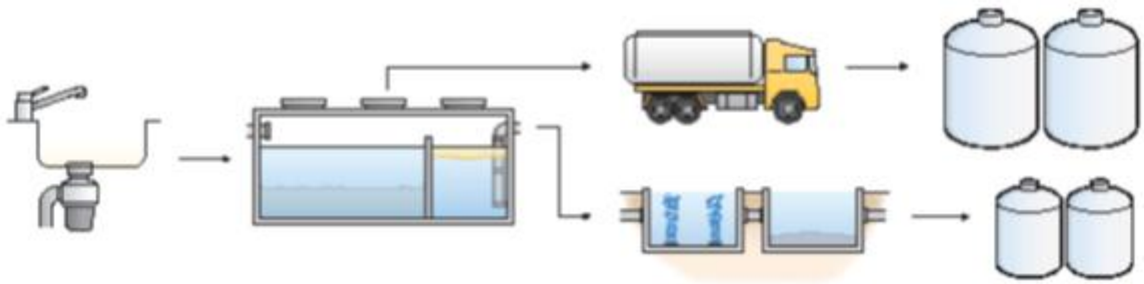


Figure 2.2: System drawing showing the path of the food waste from the grinder to tank, transportation with truck (and some overspill via the sewage system) to the biogas facility where it's turned into biogas (VA SYD referenced in Davidsson Å et al. 2012).

Random inspections have been conducted of the combustible waste in Stockholm Royal Seaport and the percentage of food waste that was left was about 13%. This is a remarkable low number compared to households with food waste sorted in separate containers where the combustible waste still consists of 30% food waste. In households with no sorting of food waste the combustible waste consists of 41% food waste (Stockholm stad, 2013).

2.1.3 Processes in the KFWP system

There are four processes included in the system (see figure 2.2). First, the production and installation of the equipment; the grinder, tank and pipes needs to be produced and installed in the apartments. Second, the collection of food waste which take place in the households. In this case, the food waste is grinded in the sink and flushed with water in pipes to a local tank. Third, the food waste slurry needs to be vacuumed from the tank and transported to the waste treatment facility. Fourth, the waste will be gasified into digester gas. Outside the system boundary is the upgrade of digester gas into biofuel. These steps are clarified by means of a flowchart in figure 2.3.

For the inputs in the food waste disposal phase the units; kitchen food waste processor, pipes and tank will all be included with their simplified life cycle analysis from cradle to grave and then divided by their lifetime to represent 1 year, as the functional unit is set to. The cradle to grave system of the grinder is shown in the flowchart as well, as it is the most interesting input to highlight.

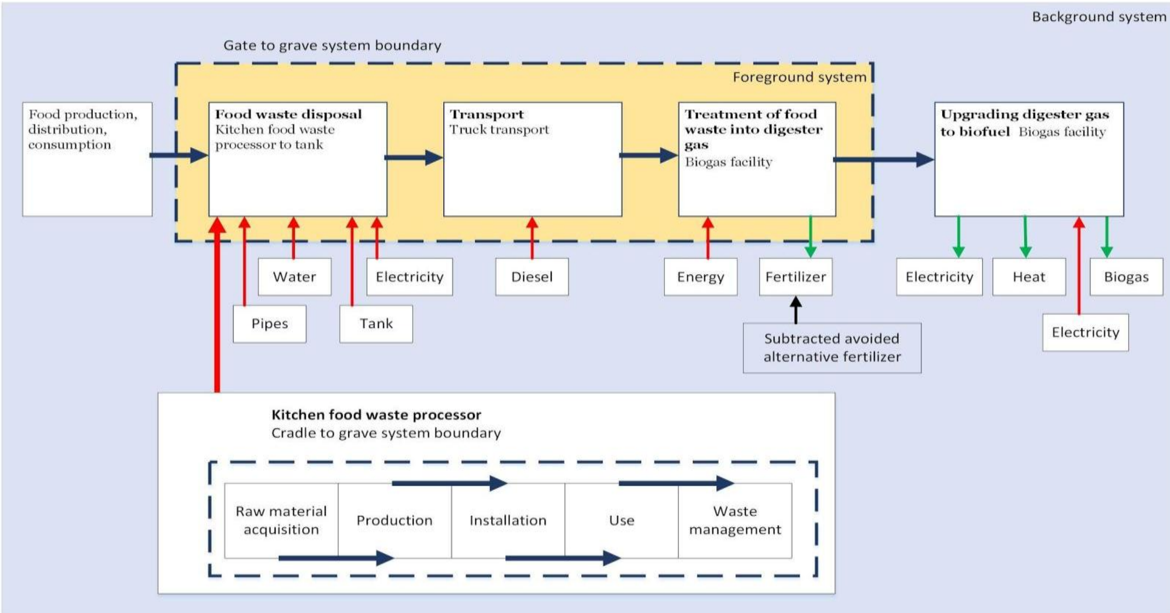


Figure 2.3: Flowchart presenting the KFWP system. The light blue area shows the background system and the yellow area is the foreground system. The dashed line represents the system boundaries. The boxes represent the different assemblies. The blue arrows represent movements between the different assemblies. The red arrows represent inputs and the green arrows are outputs.

2.1.4 Scenario 100% digestion

In the scenario "KFWP 100% digestion", it is assumed that 100% of the food waste is being treated in the kitchen food waste processor system. (A summary of the different scenarios is presented in Table 2.1.)

2.1.5 Scenario Digestion and incineration

In the scenario "KFWP digestion and incineration" it is assumed that 68% of the food waste is treated in the kitchen food waste processor system. It is assumed that the remaining 32% of the food waste are thrown in the combustible waste and sent to incineration. This assumption is based on actual studies on household waste in Stockholm Royal Seaport (Stockholm Stad 2013). (A summary of the different scenarios is presented in Table 2.1.)

2.2 Paper bag system

2.2.1 The paper bag system in Stockholm

Households living in houses and apartment buildings in Stockholm area are offered collection of food waste in paper bags. The paper bags are collected in a separate waste bin that tucks transport to a biogas facility, where it is converted into biogas and biofertilizer, described in figure 2.4.

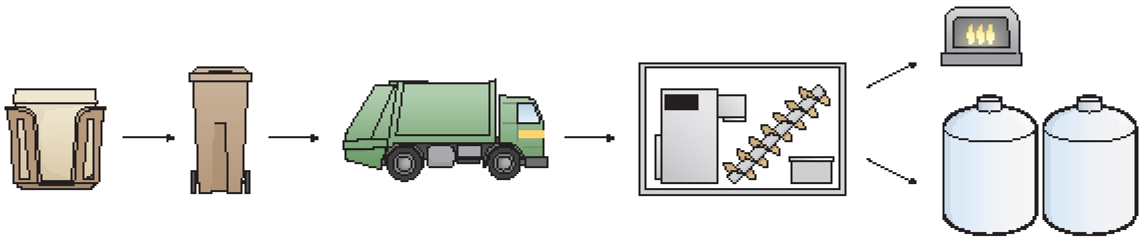


Figure 2.4: System drawing showing the path of the food waste from the small bin to big bin, transportation with truck to the biogas facility where it's pre-treated into a slurry and turned into biogas (VA SYD referenced in Davidsson Å et al. 2012).

For a good result it is important that the quality of the food waste is high and that there are no contaminations. As a financial incentive, this food waste collection is free of charge for the user and as the fee for residual waste is based on weight the total cost for waste collection is thereby reduced. Paper bags and bag holders are also distributed free of charge. In apartment buildings there are costs, for the property owners, due to appropriate solutions for the collection vessels (see figure 2.5). In apartment buildings the subvention of the waste rate is about 40%, compared to the waste tax for waste where the food-waste fraction is not separated (Stockholm Stad, 2014b; c) .

Figure 2.5: Example of vessel for food waste collection in paper bags used I apartment buildings. Photo: Kristin Stamyr

Solid food waste must be made into a preparation before digestion i.e. crushed and made into a "slurry" possible to pump. This is called pre-treatment and made in a step before the digester and is described in figure 2.6.

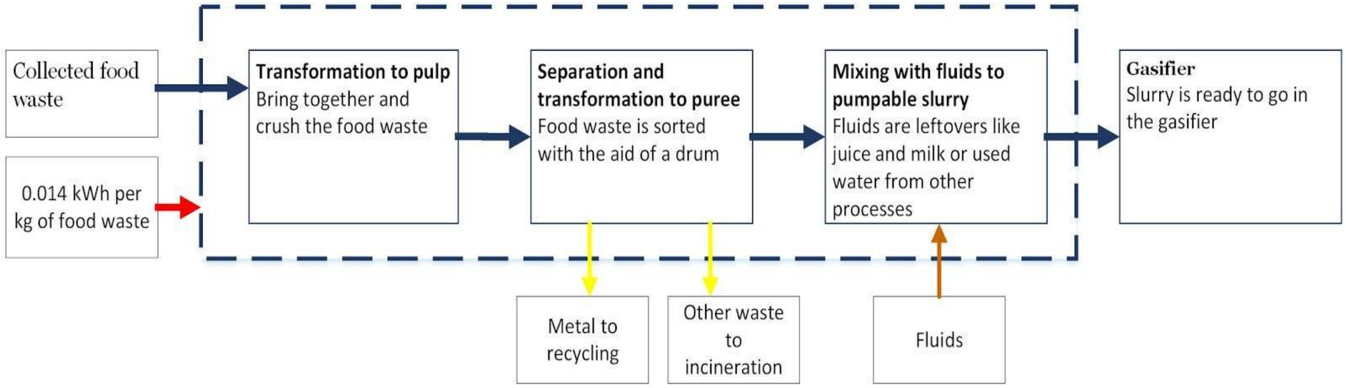


Figure 2.6: Description of the pre-treatment processes used at SRV-återvinning (Sedman C, 2014). First the collected food waste is crushed. Thereafter, it is "tumbled", the food is spun and pressed through small holes. Hence, the pureed waste is separated from residuals like plastic and metals (mainly forks and knifes). Now the organic puree is made into slurry by adding of fluids. The dashed line represents the system boundaries. The boxes represent the different assemblies. The blue arrows represent movements between the different assemblies. The red and orange arrows represent inputs and the yellow arrows are outputs.

2.1.2 Processes in the Paper bag system

There are four processes that are included in the system. First, the production and installation of the systems. For the paper bag system, special paper bags need to be produced, small bins (figure 2.7) for the apartments and a big bin needs to be produced and installed (figure 2.5). Second, the collection of food waste in the households. In this scenario the food waste is just thrown in the paper bags, no other step required. Third, the paper bags need to be collected and transported to the waste treatment facility. Fourth, the waste will be pre-treated and thereafter gasified into digester gas. Outside the system boundary is the upgrade of digester gas into biofuel. This is clarified, by means of a flowchart, in figure 2.8.

Figure 2.7: A paper bag placed in small bin. Photo: Kristin Stamyr

The inputs in the food-waste disposal-phase are the units; paper bag, small bin and big bin (see figure 2.8). They will all be included with their simplified life cycle analysis from cradle to grave and then divided (or multiplied with the yearly use of the paper bags) by their lifetime to present 1 year as the functional unit is set to be. (The functional unit is presented in paragraph 3.2.) The cradle to grave system of the paper bag is also shown in the flowchart as it is the most interesting input to highlight.

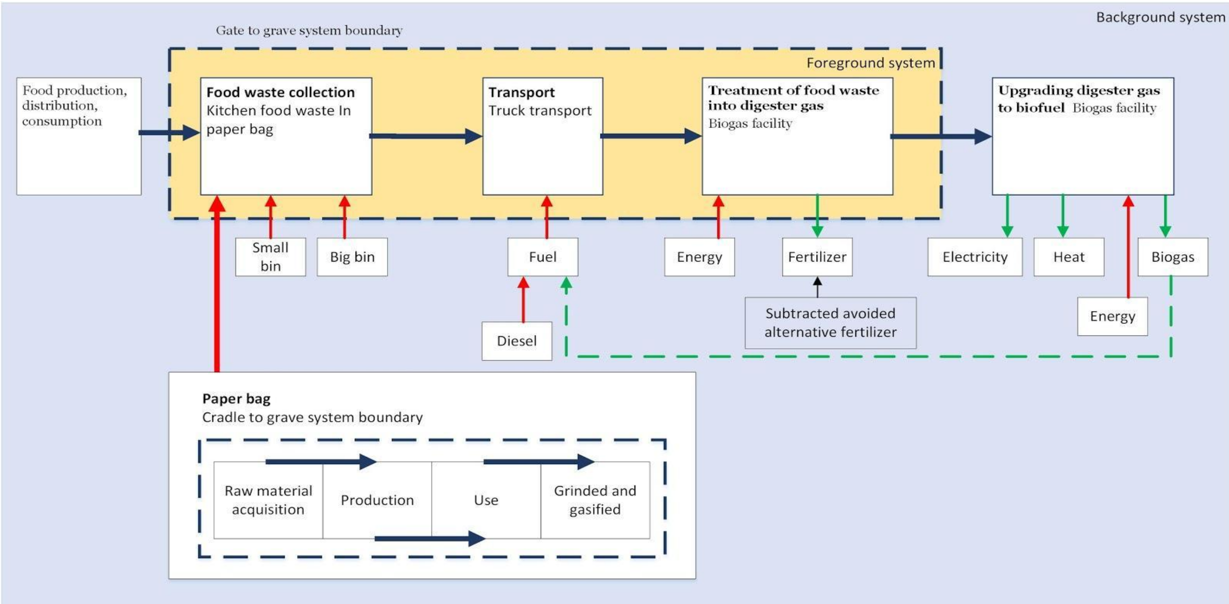


Figure 2.8: A flowchart presenting the paper bag system. The light blue area shows the background system and the yellow area is the foreground system. The dashed line represents the system boundaries. The boxes represent the different assemblies. The blue arrows represent movements between the different assemblies. The red arrows represent inputs and the green arrows are outputs. The dashed green line represents a possible loop back into the system.

2.1.3 Scenario 100% digestion

In the scenario "Paper bags 100% digestion" we assume that 100% of the functional unit (the treatment of 16560 kg food waste) is being sorted in paper bags and treated in the system. (The functional unit is presented in paragraph 3.2. A summary of the different scenarios is presented in Table 2.1.)

2.1.4 Scenario Digestion and incineration

In the scenario "Paper bags digestion and incineration" it is assumed that 27% of the produced food waste is being sorted in paper bags and treated in the system. This is a percentage that Stockholm Stad has used to compare the food waste collection in Stockholm Royal Seaport 2013 with and it's a percentage of the average food waste collected in apartment buildings in Sweden (Stockholm Stad, 2013). This ratio may be compared to numbers supplied by Familjebostäder where 66 apartments collected 815 kg of food waste during January - June 2013 (Lindeborg K and Wennerlund P, 2014). The remaining food waste (73%) is treated with the conventional waste. (A summary of the different scenarios is presented in Table 2.1.)

2.3 No food waste collection

As a comparison to the two chosen system for food waste collection a third system "No food waste collection" is presented. Even though, this is not in the main scope of the study it enables a better base for comparison and interpretation of the different scenarios.

2.3.1 100% incineration of plastic bags with household waste.

In the scenario "Plastic bags 100% incineration", it is assumed that 100% of the produced food waste is put in plastic bags and thrown in the combustible waste and sent to incineration. In this scenario it is assumed that no food waste collection system has been installed in the apartment buildings. Even though this scenario is not in the main scope of the study it may be interesting to have for comparison. (A summary of the different scenarios is presented in Table 2.1.)

2.4 Table of scenarios

Table 2.1 - A summary of the different scenarios The three systems of food waste collection are presented to the left and the distribution of digestion versus incineration is presented to the right under scenarios.

Systems	Scenarios
Kitchen food waste processor system	100% digestion 68% digestion and 32% incineration
Paper bag system	100% digestion 27% digestion and 73% incineration
No food waste collection (Plastic bag)	100% incineration

3 Goal and Scope

This study will be performed with the aid of a life cycle assessment (LCA). In this chapter, the goal and scope of the LCA study are determined. In paragraph 3.1 it will be explained what type of LCA this study is. Paragraph 3.2 defines the functional unit, which is the base for the comparison of the systems. Paragraph 3.3 sets the system boundaries in several dimensions. The last paragraphs, 3.4 to 3.6 explain the methodology.

3.1 Type of LCA

The study is an accounting comparative LCA because the treatments of food waste of two (three) different systems will be compared. On one hand, the “kitchen food waste processor (KFWP) system” and on the other hand, the “Paper bags system”.

3.2 Functional unit

The functional unit is the treatment of 16560 kg food waste. This is the average weight (kg) of produced food waste per year per apartment block (containing of 5 buildings with a total of 100 apartments). Each person generates 72 kg food waste per year (Jensen et al. 2011) and each apartment/household exists of an average of 2.3 persons, which is a Swedish average (Johansson T, 2014).

Food waste (left over food) that is recommended to put in the paper bags are remains of meat, seafood, pasta, rice, bread, egg shells, vegetables, fruit, tea leaves, coffee grounds, filters and uncolored paper-towels. The same type of waste may be putted in the grinder of the KFWP system except bones and big items like the peel of a banana.

3.3 System boundaries

3.3.1 Boundaries in relation to nature

There are several different ways to collect and disposal food waste. For this study, only two systems are considered important for City of Stockholm. This is because these systems are preferred by the City of Stockholm, to be implemented in new apartment buildings (Stockholm Stad, 2014e).

For the KFWP system there are two ways of collecting the food waste, one where the grinder is connected to pipes leading to a local tank (and the slurry is collected once a month by a vacuum truck) and the other where the grinder is directly connected to the sewage system (and treated in the sewage plant). Even though the second technique is the one in use in Stockholm Royal Seaport at the moment the technique with the tank is the one considered in this study. The reason for this decision is that the phases in this system are more alike the phases in the paper bag system and also this is the technique that is in the line to be tested by the City of Stockholm so it’s interesting to provide an analysis for it. Also, the “left overs” from biogas produced from food waste collected via the sewage system is contaminated by for example faeces and therefore a smaller value as a “biofertilizer”. (Dolk M., 2014.).

As shown in the flowcharts (figure 2.3 and 2.8), the two life cycles begin where the materials for the grinder, pipes and tank from the KFWP system, and the paper bags, small bin and big bin from the paper bag system are produced. They both end where the food waste is gasified into digester gas and biofertilizer. Table 3.1 shows the boundaries is a foreground and background system.

Table 3.1: Foreground and background systems.

Foreground system	Background system
Food waste disposal	Production of equipment
Food waste transport	Inputs of water, electricity and energy
Food waste treatment	

3.3.2 Geographical boundaries

This study will focus on the area Stockholm Royal Seaport in Stockholm, where new apartment buildings are currently built.When local data is not available data describing average in Sweden or parts there of have been priorotised.

3.3.3 Time horizon

This LCA uses current data and long term emissions of the systems are included. Concerning the future, the next developments that may happen are excluded: The amount of food waste may change in the future, electricity that is used by the grinder may consist of a different energy mix and the efficiency of the grinder, the trucks, the gasifier, the production of paper bags and de waste treatment of the materials may be improved.

3.4 Cut-off criteria

During the cycle of the two main processes there will be losses of material on the way from disposal to the digester gas production. These losses are not taken into account in the analysis. In the KFWP system there will be losses of material to the sewage system and decomposition in the tank and this will also lead to reduction of nutrients which might affect the quality or amount of biofertilizer negatively (Svenskt Gastekniskt Center 2011). In the paper bag system there will be losses of material in the pre-treatment process where the food waste is grinded and turned into slurry. Some food waste will be lost together with residues (Millers-Dalsjö D. et al. 2011).

3.5 Allocation procedures and assumption at system level

The allocation problems encountered in this project were overcome by considering avoided burdens and narrowing the system boundaries.

- In the process of treating the food waste slurry there is a multi-output allocation problem. The outputs are digester gas and biofertilizer. To deal with the allocation problem of the biofertilizer, avoided burdens of phosphorus, nitrogen and potassium was considered. To deal with the allocation problem of the digester gas avoided burdens of natural gas was considered.

- In the upgrade process for the digester gas into biofuel there is also a multi-output allocation. After the process at the biogas facility where the food waste slurry is made into digester gas, the gas goes in to an upgrade process where it's made into biofuel and some of the gas to heat and electricity. The aim was to include this process in the system but due to the lack of time to handle all the allocation problems with avoided burdens this allocation problem was handled by narrowing the system boundaries and not include this process.

- In the incineration process there is a multi-output allocation problem and to deal with this avoided burdens from heat and electricity was considered.

- In the recycling of metals, copper, aluminium and steel avoided burdens from production of virgin metals was considered.

- Average data is used in this accounting LCA in all the processes, including avoided processes.

- It is assumed that all plastic material is sent for incineration at the end of life.

3.6 Impact categories and impact assessment method

According to ISO 14040 1997, the three general impact categories to be considered in a LCA are: Resource use, human health and ecological consequences.

The impact assessment method used is ReCiPe Midpoint (Hierarchist) included in SimaPro. ReCiPe was created by RIVM, CML, PRé Consultants, and Radboud Universiteit Nijmegen. The ReCipe method is a help for the analysts to interpret the large amount of consumed resources and emissions that are listed after the calculation of the inventory result. This method was designed to reduce the long list of inventory results to a limited amount of mid and endpoint indicators. Midpoints results are more certain and numerous than endpoints indicators, but less easily interpreted. Typical examples of midpoints indicators are acidification, climate change, ecotoxicity, eutrophication, ozone depletion. The three endpoint indicators are damage to Human health, damage to ecosystems and damage to resource availability.

The hierarchist model, often considered as the default model of ReCipe, is the most relevant for scientific studies in comparison with the individualist and egalitarian models (respectively short term assuming that technology will solve some problems in the future and long term rather turned towards the precautionary principle way of thinking).

ReCipe's modelling is based on environmental mechanisms, i.e. a serie of effects that globally have a damaging impact on the environment and human health (Recipe, 2014).

At this point in the project, we can assume that the environmental impacts we will be focusing on are the global warming potential (GWP: CO_2, CH_4, CFCs, fluorine components, etc.), the eutrophication potential (N-equiv., NO_x, NH_3, P, nitrates phosphates, etc.) and the acidification potential (H^+ equiv., SO_2, H_2SO_4, CO_2, NO_x, HCl, etc.).

3.7 Normalisation and weighting

Normalisation of the results are used and as the application of this LCA is decision making on a regional level on waste treatment strategies, the requirement on methodology is data representing regional averages, this is done in SimaPro.

Weighting is an optional step which will not be performed in this study because of its absence in ReCipe, our chosen impact assessment model. This is also a comparative LCA so according to ISO standards weighting is not allowed. This rule is due to the fact that weighting is subjective and may present different results depending on the weighing method which might lead to misinterpretations of the compared results (Baumann and Tillman, 2004).

4 Life cycle inventory analysis

This chapter will show and discuss every data that is used for this study. Paragraph 4.1 contains a table which present every data with the reference and database and gives a rough overview of the structure of the model. Paragraph 4.2 discusses the assumptions that are made for the specific data. These assumptions are made, due to data gaps and to simplify the model.

4.1 Data

All the processes and data are showed in table 4.1-4.3. The detailed calculations are shown in appendix A, B and C, as well as the detailed data about the transportation of the waste and the exact locations.

Table 4.1: Data and processes for the Paper bag system

Big bin	**Database**	**Amount**	**Unit**	**Reference**
Materials:				
Top of the bin: Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix,	ELCD v 2.00	75	kg	Gustafsson J, 2014
Underground chamber: Pre-cast concrete, min. reinf., prod. mix, concrete type C20/25, w/o consideration of casings	ELCD v 2.00	7.3	ton	Gustafsson J, 2014
Container: Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304	ELCD v 2.00	1	ton	Gustafsson J, 2014
Processes:				
Transportation of villiger from manufacturer in Switzerland to Stockholm: freight train	Ecoinvent v 2.2	15 351	tkm	Gustafsson J, 2014
Steel product manufacturing, average metal working	Ecoinvent v 2.2	75	kg	Gustafsson J, 2014
Small bin	**Database**	**Amount**	**Unit**	**Reference**
Materials:				
Polypropylene, granulate, at plant	Ecoinvent v 2.2	190	g	Appendix B
Steel, low-alloyed, at plant	Ecoinvent v 2.2	22	g	Appendix B
Processes:				
Transport from manufacturer to	Ecoinvent v 2.2	0.11	tkm	Appendix B

Stockholm, lorry >32t, EURO5				
Injection moulding	Ecoinvent v 2.2	190	g	Appendix B
Paper bag	**Database**	**Amount**	**Unit**	**Reference**
Materials:				
Craft paper, unbleached, at plant	Ecoinvent v 2.2	25	g	Kronström A, 2014; according to calculations in Appendix B
Processes:				
Transport of craft paper from manufacturer to manufacturer of bag: lorry >32t, EURO5	Ecoinvent v 2.2	0.03	tkm	Kronström A, 2014; Google maps, 2014
Transport of bag from manufacturer to Stockholm: lorry 16-32t, EURO4	Ecoinvent v 2.2	0.01	tkm	Kronström A, 2014; Google maps, 2014
Production of carton board boxes, gravure printing, at plant	Ecoinvent v 2.2 & assumption 20% recycling	20	g	according to calculations in Appendix B
Paper bags including zero-burden food waste	**Database**	**Amount**	**Unit**	**Reference**
Assemblies:				
Zero burden food waste		16 560	kg	Jensen et al., 2011 & Johansson, 2014
Paper bag		17 500	p	Sedman C, 2014
Waste scenario – Paper bags equipment	**Database**	**Amount**	**Unit**	**Reference**
Disposal, plastics, mixture, 15.3% water, to municipal incineration including avoided burdens	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Recycling steel and iron	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Disposal, concrete, 5% water, to inert material landfill	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Lifecycle Paper bag system 100%	**Database**	**Amount**	**Unit**	**Reference**

digested – Paper bags + food waste				
Processes:				
Waste transport to digestion, municipal waste collection, lorry 21t	Ecoinvent v 2.2	830	tkm	Nilsson J, 2014 & Holmström L, 2014
Waste transport to digestion, municipal waste collection, lorry 21tbiogas	Ecoinvent v 2.2 & NSCA, 2006	830	tkm	Nilsson J, 2014 & Holmström L, 2014
Bags waste scenario 100% paper and food waste to biogas – waste disposal scenario	**Database**	**Amount**	**Unit**	**Reference**
Disposal, biowaste, to anaerobic digestion/CH U including avoided burdens	Ecoinvent v 2.2	100	%	Nordenberg J, 2014
Disposal, biowaste, 60% H2O, to municipal incineration, allocation price/CH S incl heat and electricity	Ecoinvent v 2.2	0	%	Ecoinvent v 2.2
Lifecycle Paper bag system 27% digest 73% incineration – Paper bags + food waste	**Database**	**Amount**	**Unit**	**Reference**
Processes:				
Waste transport, municipal waste collection, lorry 21t	Ecoinvent v 2.2	685	tkm	Nilsson J, 2014 & Holmström L, 2014
Waste transport, municipal waste collection, lorry 21t biogas	Ecoinvent v 2.2 & NSCA, 2006	685	tkm	Nilsson J, 2014 & Holmström L, 2014
Bags waste scenario 27% paper and food waste to biogas 73% incineration – Waste scenario	**Database**	**Amount**	**Unit**	**Reference**
Disposal, biowaste, to anaerobic digestion/CH U including avoided burdens	Ecoinvent v 2.2	27	%	Jenny Nordenberg & Stockholm stad, 2013
Disposal, biowaste, 60% H2O, to municipal incineration, allocation price/CH S including heat and electricity	Ecoinvent v 2.2	73	%	Ecoinvent v 2.2

Table 4.2: Data and processes for the Kitchen food waste processor (KFWP) system

Grinder Waste King L2600 TC	Database	Amount	Unit	Reference
Materials:				
Iron, sand casted	USLCI	1.01	kg	Annerhall G, 2014
Aluminium, primary, at plant	Ecoinvent v 2.2	2.02	kg	Annerhall G, 2014
Copper, primary, at refinery	Ecoinvent v 2.2	2.02	kg	Annerhall G, 2014
Acrylonitrile-butadiene-styrene copolymer, ABS, at plant	Ecoinvent v 2.2	3.48	kg	Annerhall G, 2014
Stainless steel hot rolled coil, annealed & pickled, elec. arc furnace route, prod. mix, grade 304	ELCD v 2.00	1.57	kg	Annerhall G, 2014
Synthetic rubber, at plant	Ecoinvent v 2.2	0.11	kg	Annerhall G, 2014
Sanitary ceramics, at regional storage	Ecoinvent v 2.2	1.01	kg	Annerhall G, 2014
Tap water, at user	Ecoinvent v 2.2	32 800	kg	Avfall Sverige, 2011
Processes:				
Transport manufacturer to Stockholm: Container ship ocean, technology mix, 27.500 dwt pay load capacity	ELCD v 2.00	129 000	tkm	Annerhall G, 2014
Transport manufacturer to Stockholm: lorry >32t, EURO4	Ecoinvent v 2.2	50 500	tkm	Annerhall G, 2014
Container ship ocean, technology mix, 27.500 dwt pay load capacity	ELCD v 2.00	67 000	tkm	Annerhall G, 2014
Transport manufacturer to Stockholm: lorry 16-32t, EURO4	Ecoinvent v 2.2	5 500	tkm	Annerhall G, 2014
Metal product manufacturing	Ecoinvent v 2.2	6.5	kg	See data materials
Injection moulding	Ecoinvent v 2.2	3.5	kg	See data materials

Tank	Database	Amount	Unit	Reference
Materials/Assemblies:				
Glass fibre reinforced plastic, polyamide, injection moulding, at plant	Ecoinvent v 2.2	5 400	kg	Annerhall G, 2014; Bismont M, 2014; Uson c; The great soviet encyclopedia,

				1979
Processes:				
Injection moulding	Ecoinvent v 2.2	5 400	kg	Data materials
Transport, lorry 16-32t, EURO4	Ecoinvent v 2.2	16 200 000	kgkm	Annerhall G, 2014
Pipes KFWP	**Database**	**Amount**	**Unit**	**Reference**
Materials/Assemblies:				
PVC pipe	Industry data 2.0	480	kg	Annerhall G, 2014; The engineering toolbox, 2014; Uson Miljöteknik b
Processes:				
Transport from manufacturer to Stockholm, lorry 16-32t, EURO4	Ecoinvent v 2.2	144 000	tkm	Annerhall G, 2014
Injection moulding	Ecoinvent v 2.2	480	kg	See data materials
KFWP Food waste	**Database**	**Amount**	**Unit**	**Reference**
Materials/Assemblies:				
Zero burden food waste	Empty process	16 560	kg	Jensen et al., 2011 & Johansson, 2014
KFWP equipment waste scenario	**Database**	**Amount**	**Unit**	**Reference**
Recycling steel and iron including avoided burdens	Empty process	100	%	Ecoinvent v 2.2
Recycling steel and iron including avoided burdens	Empty process	100	%	Ecoinvent v 2.2
Disposal, plastics, mixture, 15.3% water, to municipal incineration including avoided burdens	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Disposal, plastics, mixture, 15.3% water, to municipal incineration including avoided burdens	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Recycling copper/ including avoided burdens	Empty process	100	%	Ecoinvent v 2.2

Disposal, inert waste, 5% water, to inert material landfill	Ecoinvent v 2.2	100	%	
Disposal, rubber, unspecified, 0% water, to municipal incineration including avoided burdens	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2
Recycling aluminium/ including avoided burdens	Empty process	100	%	Ecoinvent v 2.2
Lifecycle KFWP food waste 100% digested - KFWP food waste	**Database**	**Amount**	**Unit**	**Reference**
Processes:				
Electricity, low voltage, production SE, at grid/SE S	Ecoinvent v 2.2	400	kWh	Stockholm Vatten, 2008
Waste collection to digestion, municipal waste collection, lorry 21t/CH S	Ecoinvent v 2.2	2 200 000	kgkm	Ragn Sells Stockholm, 2014; Nordenberg J, 2014
KFWP food waste 100% digested waste scenario	**Database**	**Amount**	**Unit**	**Reference**
Disposal, biowaste, to anaerobic digestion including avoided burdens excluding pre treatment	Ecoinvent v 2.2	100	%	Nordenberg J, 2014 & Avfall, 2011
Disposal, biowaste, 60% H2O, to municipal incineration, allocation price including heat and electricity	Ecoinvent v 2.2	0	%	Ecoinvent v 2.2
Lifecycle KFWP food waste 68% digested 32% incinerated - KFWP food waste	**Database**	**Amount**	**Unit**	**Reference**
Processes:				
Electricity, low voltage, production SE, at grid	Ecoinvent v 2.2	400	kWh	Stockholm Vatten, 2008
Waste transport to digestion, municipal waste collection, lorry 21t	Ecoinvent v 2.2	1 500	tkm	Ragn Sells Stockholm, 2014; Nordenberg J, 2014
Waste transport to incineration, municipal waste collection, lorry 21t	Ecoinvent v 2.2	201	tkm	Nilsson J 2014 & Holmström L 2014

Waste transport to incineration, municipal waste collection, lorry 21 biogas	Ecoinvent v 2.2 & NSCA, 2006	201	tkm	Nilsson J 2014 & Holmström L 2014
KFWP food waste waste scenatio 68% digested 32% incinerated	**Database**	**Amount**	**Unit**	**Reference**
Disposal, biowaste, to anaerobic digestion/CH U including avoided burdens excluding pre treatment	Ecoinvent v 2.2	68	%	Nordenberg J, 2014 & Avfall, Sverige 2011
Disposal, biowaste, 60% H2O, to municipal incineration, allocation price/CH S including heat and electricity	Ecoinvent v 2.2	32	%	Ecoinvent v 2.2 & & Stockholm Stad, 2013

Table 4.3: Data and processes for the Plastic bag system

Lifecycle Plastic bag system 100% incineration - Plastic bag	**Database**	**Amount**	**Unit**	**Reference**
Materials/Assemblies:				
Polyethylene low density granulate (PE-LD), production mix, at plant	ELCD v 2.00	20	g	Assumption
Processes:				
Transport, lorry >32t, EURO5	Ecoinvent v 2.2	0.03	tkm	Appendix B
Transport, lorry 16-32t, EURO4	Ecoinvent v 2.2	0.01	tkm	Appendix B
Blow moulding	Ecoinvent v 2.2	20	g	Assumption
Lifecycle Plastic bag system 100% incineration - Plastic bags + waste	**Database**	**Amount**	**Unit**	**Reference**
Materials/Assemblies:				
Zero burden food waste	Empty process	16 560	kg	Jensen et al., 2011 & Johansson, 2014
Plastic bag		17 500	p	Assumption
Processes:				
Waste transport to incineration, municipal waste collection, lorry 21t	Ecoinvent v 2.2	631	tkm	Nilsson J, 2014 & Holmström L, 2014

Waste transport to incineration, municipal waste collection, lorry 21t biogas	Ecoinvent v 2.2 & NSCA, 2006	631	tkm	Nilsson J, 2014 & Holmström L, 2014
Plastic bags waste scenario 100% to incineration	**Database**	**Amount**	**Unit**	**Reference**
Disposal, biowaste, to anaerobic digestion including avoided burdens	Ecoinvent v 2.2	0	%	Nordenberg J, 2014
Disposal, biowaste, 60% H2O, to municipal incineration, allocation price including heat and electricity	Ecoinvent v 2.2	100	%	Ecoinvent v 2.2

4.2 Specific data assumptions

This subchapter will discuss every assumption that is done for this study on the specific data.

4.2.1 Paper bags

Paper bags of 20 g are assumed to be made from 25 g of unbleached craft paper produced in Sweden in an integrated paper mill. For the paper bag making process, the module production of carton board boxes was chosen as the most relevant one. This module does not include the production of carton board but does include the cutting, folding and printing steps and therefore ink, glues as well as electricity consumption. It was assumed that an excess of 20% of craft paper was necessary to produce craft paper bags. This excess was assumed to be recycled.

The craft paper was assumed to be produced at Mondi Dynäs AB in Väja, Sweden and transported by lorry to JD Stenqvist AB in Kvidinge, Sweden where the bags are produced (Kronström A, 2014).

4.2.2 Paper bags equipment

The paper bag equipment consists of 100 small bins and 1 big bin. Each small bin contains 22 g of low-alloyed steel and is moulded by injection of 190g of polypropylene. For simplification, it was assumed that they were produced at the same place as the paper bags and transported by lorry to Norra Djugårdstaden. The lifetime of a small bin was set at 10 years.

The "big bin" ensemble consists of a bin located above a buried tank. The lifetime of the whole ensemble was assumed to be 50 years. The bin located on the top consists of 75 kg of stainless steel whereas the buried tank is made of 7,3 tons of pre-cast concrete and 1 ton stainless steel. It was assumed that the components of this ensemble were produced in Küngoldingen, Switzerland by the company Viliger and transported by freight train to Norra Djugårdstaden. It was assumed that the plastic of the small bin was recycled/incinerated. Also the steel was recycled. Concerning the big bin, it was assumed that the pre-cast concrete part would be landfilled whereas the steel one would be recycled.

4.2.3 KFWP equipment

Grinder
It is assumed that the grinders in the apartments in Stockholm Royal Seaport are of the model Waste King L 2600 TC and that they use electricity produced in Sweden. The expected lifetime of the grinder is 15 to 20 years so it is assumed the lifetime is 16.5 year (Uson Miljöteknik a). The manufacturing company of the

grinder is located in Los Angeles (LA), but the production takes place in China. It is assumed this is in the city Hong Kong and that the transportation between these cities will be by an ocean container ship for technology mix with a 27 500 dwt pay load capacity. From LA to Stockholm, the transport to New York will be by truck running on diesel, by an ocean container ship for technology mix with a 27 500 dwt pay load capacity to Gothenburg and by truck running on diesel to Stockholm (Göran Annerhall, 2014; Google maps, 2014).

The retailer and installing company of the grinder, Uson miljöteknik, will disposal the grinder at the recycling for electronic products when they take care of an old grinder (Göran Annerhall, 2014). It is assumed that a private person would disposal the grinder in the same way at the end of the lifetime.

Tank
It is assumed the tank is transported from the production place to Stockholm by a truck running on diesel and at the end of the lifetime, the tank will be send to incineration.

The amount of material (kg) needed to build the tank is assumed to be 5400 kg based on the volume and dimensions of the tank.

Pipes
According to the schematic drawing of the tank, the diameter of the pipe is assumed to be 100 mm (Uson Miljöteknik b). It is assumed the average length of pipes that are installed in the whole block is 158 meter. Therefore it is assumed each floor is 2,5 meter high (including the ceiling) and the basement is 2 meter high. The assumptions for the distances between the buildings are shown in figure 4.1: map of apartment buildings in one block.

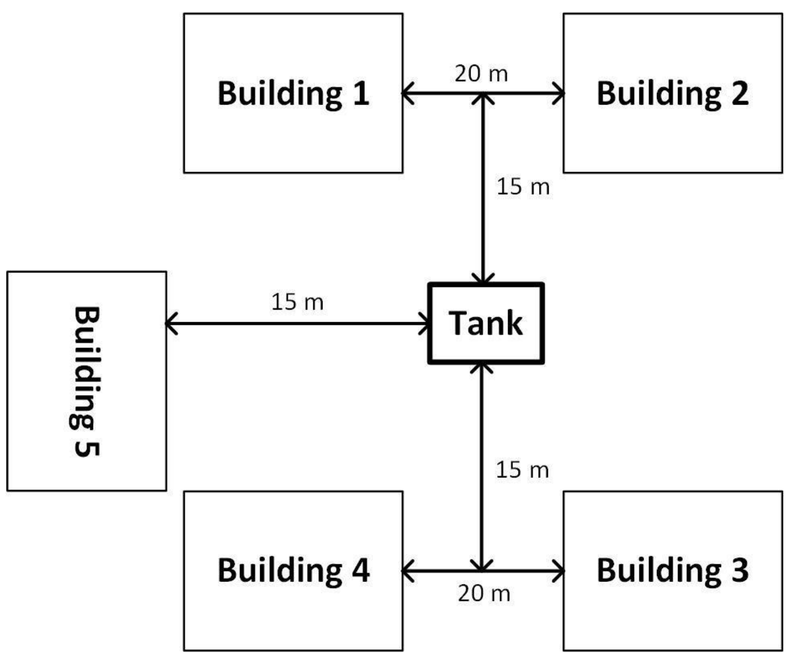


Figure 4.1: map of apartment buildings in one block

4.2.4 Plastic bags
It is assumed that the plastic bag is made of polyethylene, produced with the method blow moulding and

that it will weigh the same at the paper bag. Also, people will use the same amount of plastic bags, as they use paper bags.

4.2.5 Avoided burdens

Disposal scenario “anaerobic digestion of biowaste”. To include an avoided burdens to this process, natural gas was assumed to be the avoided product instead of digester gas.

4.2.6 Municipal waste collection ensured by trucks running on biogas

To create this transportation process, the Municipal waste collection process available in Simapro considering trucks running on diesel was edited. The following assumptions were made according to several sources. On one hand, the CO_2 emissions to air were reduced by 86%, the nitrogen oxides, CO as well as particulates emissions to air were reduced by 50%. On the other hand, hydrocarbons emissions to air were multiplied by 20. It was assumed that the fossil emissions to air were of fewer importance and were therefore removed. Finally, the comparison between the emissions of two passenger cars -one running on diesel, one running on methane from which 96% are coming from biogas- allowed to highlight methane emissions differences. It was assumed that the same ratios were applicable between the two trucks running on diesel and biogas to adjust the methane emissions of the biogas truck. (NSCA, 2006). See appendix C for the new process.

5 Life cycle results and interpretation

This chapter will discuss the most interesting results and interpret these results. Appendix D will show additional results.

5.1 Characterization results

5.1.1. KFWP System 100% digested

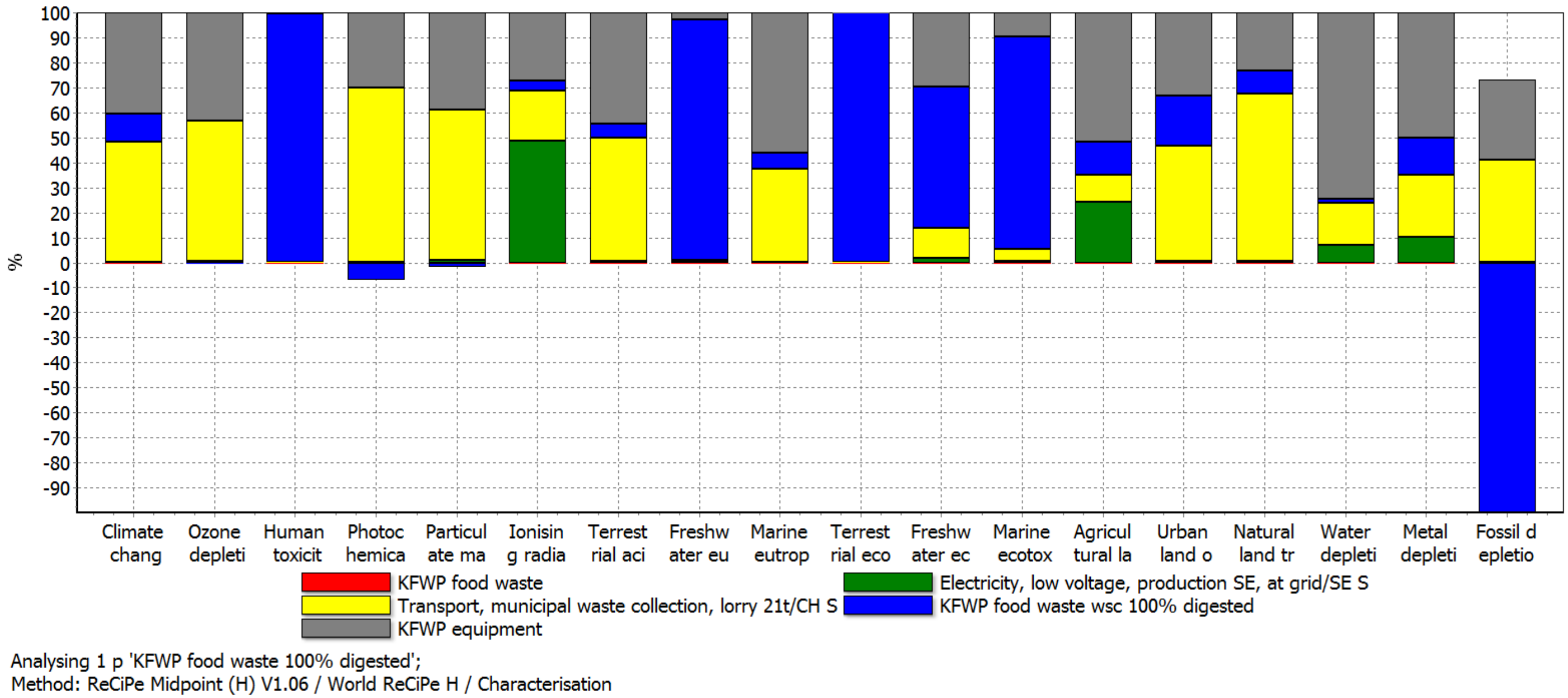


Figure 5.1 : Characterization results of the Kitchen food waste processor (KFWP) system with 100% food waste digested. The zero-burden food waste is represented in red, the municipal waste collection in yellow, the equipment for the KFWP in grey, use of electricity in green and the digestion of the food waste in blue.

Figure 5.1 highlights the impact of the municipal waste collection by lorry (in yellow in the chart) especially on photochemical oxidant formation (70%), natural land transformation (67%), particulate matter formation (60%), ozone depletion (56%), terrestrial acidification (49%), climate change potential (48%) and urban land occupation (46%).

The equipment (in grey in the chart) has greatest impacts on water depletion (74%), marine eutrophication (56%), agricultural land occupation (52%) and metal depletion (50%).

The digestion (in blue in the chart) represents 100% of the terrestrial ecotoxicity, 99.5% of the human toxicity impact of this system. It is also responsible of 96% of the freshwater eutrophication potential, 85% of the marine ecotoxicity and 50% of the freshwater toxicity. Concerning the fossil depletion, the digestion has a “positive” impact which is even over compensating the fossil depletion caused by transport and equipment subassemblies.

The electricity consumption represents 49% of the ionising radiation potential associated to this system.

The subassembly KFWP food waste (in red in the chart) is a zero-burden one which is therefore logically not contributing to any impact categories.

5.1.2 **Paper Bags System 100% digested**

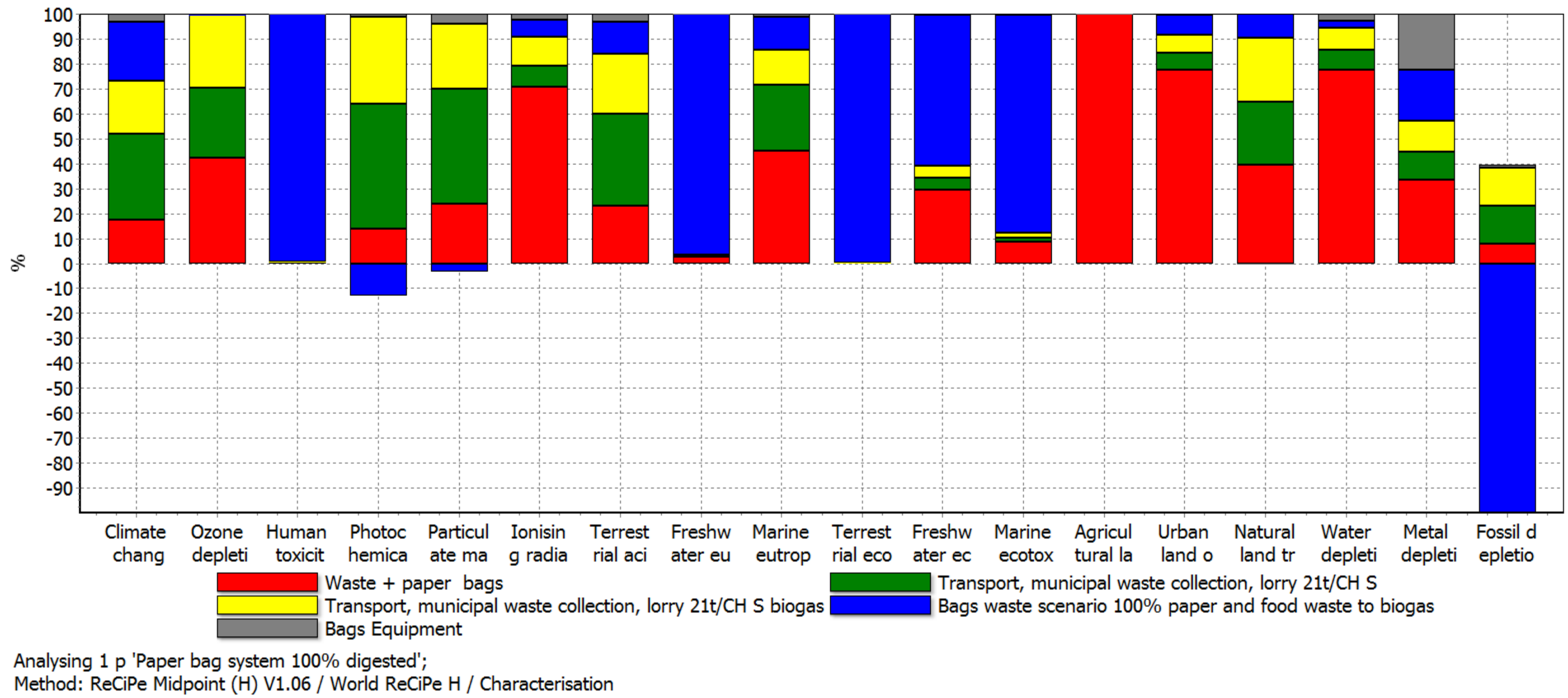


Figure 5.2: Characterization results of the Paper Bags system with 100% food waste digested. The effects of the zero-burden food waste in the paper bag is represented in red, the municipal waste collection by biogas trucks (50%) in yellow and trucks running on diesel in green (50%), the equipment required for the paper bag system in grey and the digestion of the paper bag including the food waste is represented in blue.

Figure 5.2 logically highlights different impacts than Figure 5.1 because of the differences of the systems KFWP and Paper Bags. However, it also shows similarities as 100% of the food waste is digested in those two systems.

The subassembly "Waste + paper bags" (in red in the chart) actually refers to the bags production out of craft paper as the food waste is a zero-burden assembly. This subassembly is responsible for 99.8% of the agricultural land occupation impact, 77% of the water depletion and urban land occupation impacts. 71% of the ionising radiation, 45% of the marine eutrophication, 42% of the ozone depletion and 40% of natural land transformation are due to the paper bags production.

The digestion (in blue in the chart) impact numbers are very similar to the previously observed numbers of the KFWP system since 100% of the food waste is also digested here. The waste scenario considering that 100% of the paper bags and the food waste are digested is fully responsible for the terrestrial ecotoxicity of the system. 99% of the human toxicity and 97% of the freshwater eutrophication impacts of the system are also due to the digestion process. It also has a “positive” impact on the fossil depletion.

The municipal waste collection by lorry running on diesel (in green in the chart) is less important in this system than in the KFWP 100% digested one. This is explained by the fact that only 50% of the municipal waste collection is made by trucks running on diesel in this system. However, it also has the greatest influence on photochemical oxidant formation, climate change, particulate matter formation and terrestrial acidification potentials.

The municipal waste collection ensured by lorries running on biogas has lower impacts than the one considering trucks running on diesel. However, it contributes to the same impact categories with quite close numbers. It is then possible to conclude that if 100% of the municipal waste collection was ensured by lorries running on biogas, the systems would have less environmental impacts. This is really easy to see in particular for the following impact categories: climate change, particulate matter formation, photochemical oxidant formation, terrestrial acidification and marine eutrophication.

The equipment subassembly of this system takes into account the municipal bins. It can be seen that they logically have a less important global environmental impact than the equipment subassembly of the KFWP system. Another remarkable difference between the two systems is the electricity consumption, completely absent in this Paper Bags system.

5.1.3 Plastic Bags system 100% incineration

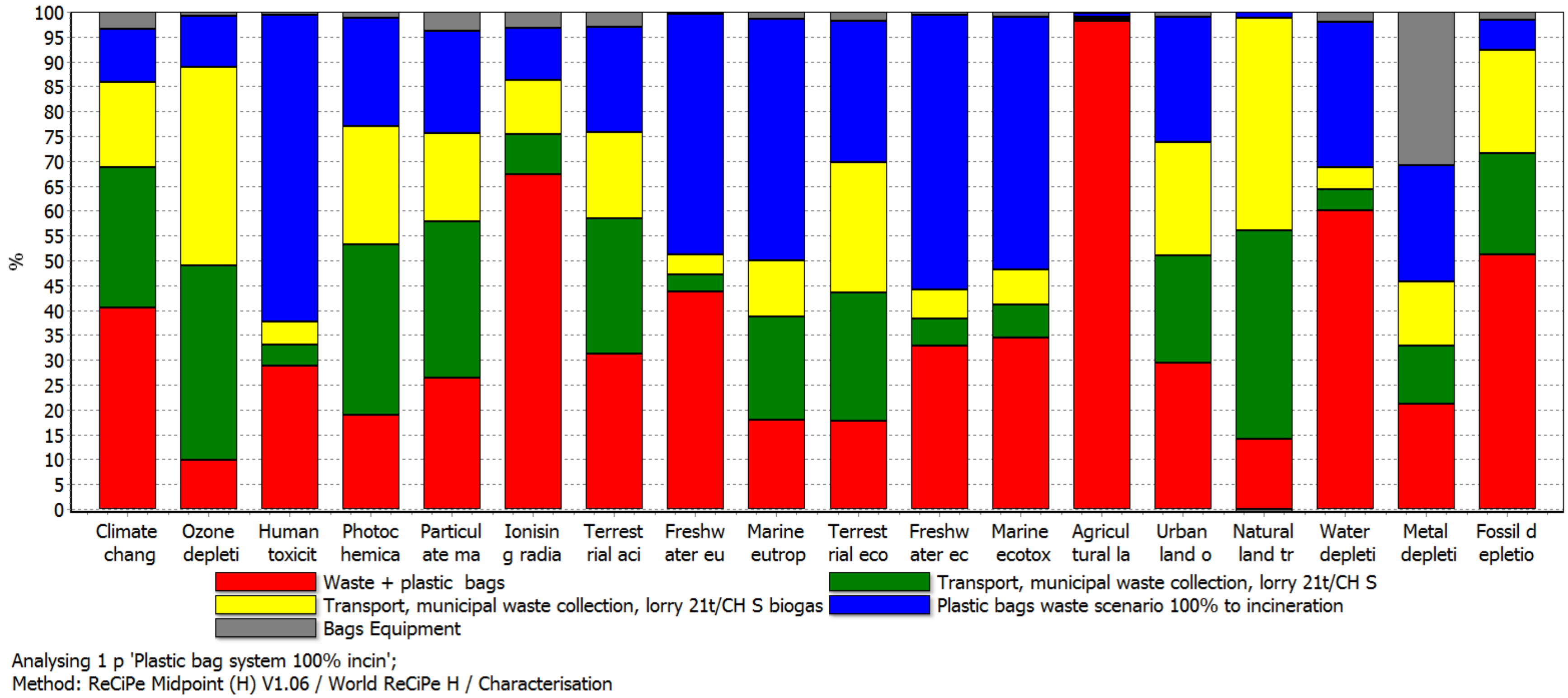


Figure 5.3: Characterization results of the Plastic Bags system with 100% food waste incinerated. The effects of the zero-burden food waste in the plastic bag is represented in red, the municipal waste collection by biogas trucks (50%) in yellow and trucks running on diesel in green (50%), the equipment required for the plastic bag system in grey and the incineration of the plastic bag including the food waste is represented in blue.

Figure 5.3 presents the characterized results of a hypothetical 100% incineration scenario managed with plastic bags. The first major difference with the two previous charts (considering 100% of the food waste digested), is that there is no "positive" impact or negative percentages in this chart due to the absence of digestion. The incineration, as the digestion, also engenders human toxicity, freshwater eutrophication, as well as terrestrial and marine ecotoxicity. The percentages are however globally lower than the digestion ones. Comparing figures 5.1 and 5.2 to figure 5.3 allow to highlight the highest influence of incineration compared to digestion on new impact categories. For example, in this system, the incineration process is responsible for approximately 50% of the marine eutrophication.

The subassembly “Waste + plastic bags” (in red in the chart) actually refers to the bags production out of low density Polyethylene. This subassembly is responsible for 98% of the agricultural land occupation impact, 67% of the ionising radiation and 60% of the water depletion impacts. 51% of the fossil depletion, 42% of the ozone depletion and 40% of natural land transformation are also due to the paper bags production.

The second most important subassembly in terms of responsibility on impact categories is the transport dedicated to the municipal waste collection. As the waste collection organisation for this system was considered identical to the Paper Bags system one (50% diesel-50% biogas), the same observations can be withdrawn from Figure 5.2 and 5.3.This scenario highlights a relatively less important impact of the bags equipment on the different impact categories except metal depletion.

5.1.4 KFWP System 68% digested 32% incinerated and Paper Bags System 27% digested 73% incinerated

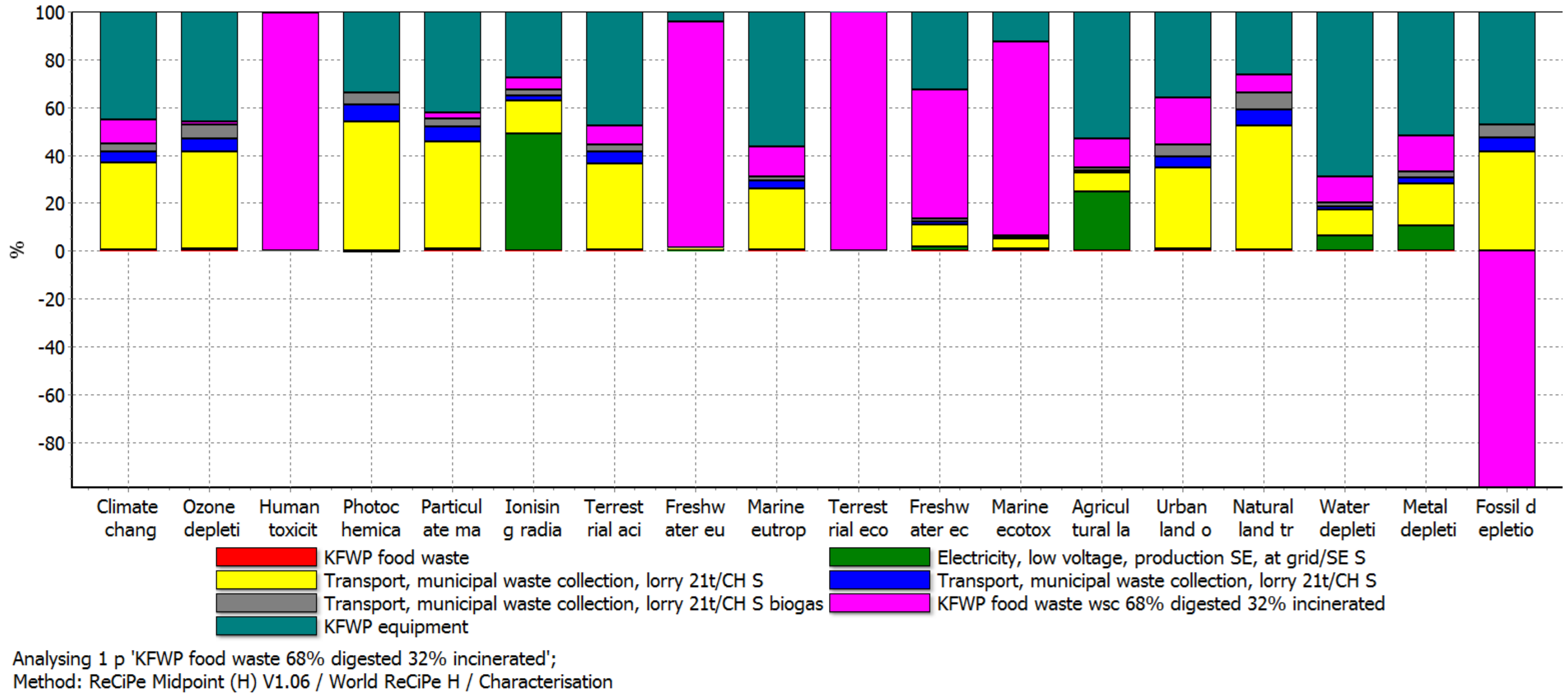


Figure 5.4: Characterization results of the Kitchen food waste processor (KFWP) system with 68% food waste digested and 32% incinerated. The effects of the zero-burden food waste is represented in red, the municipal waste collection by biogas trucks in yellow and trucks running on diesel in grey and blue, the equipment required for the KFWP system turquoise, electricity in green and effects of digestion in purpul.

The results presented in figure 5.4 for the KFWP System with 68% of food waste digested are similar to the results of figure 5.1 for the KFWP System with 100% digestion. The 32% of food waste incinerated have a relatively low influence on the different impact categories in front of the digestion.

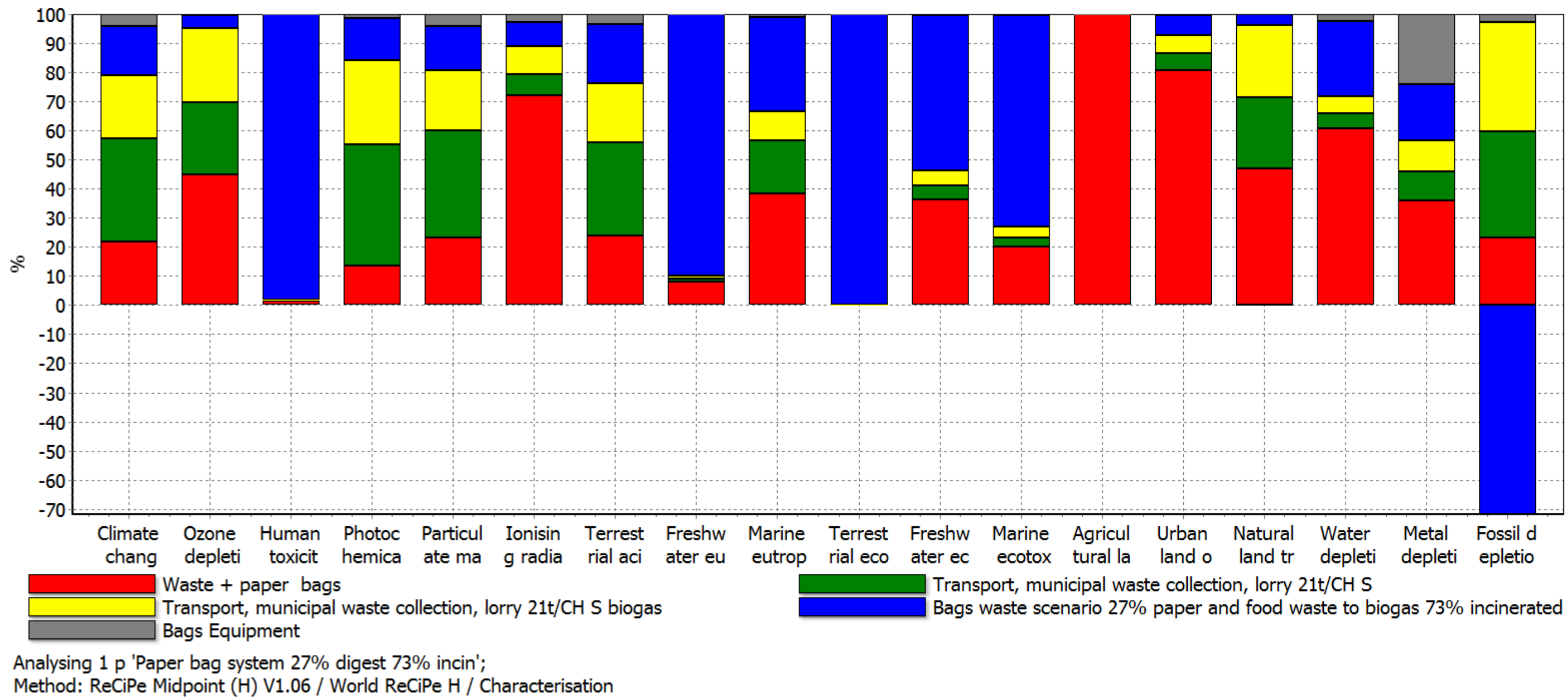
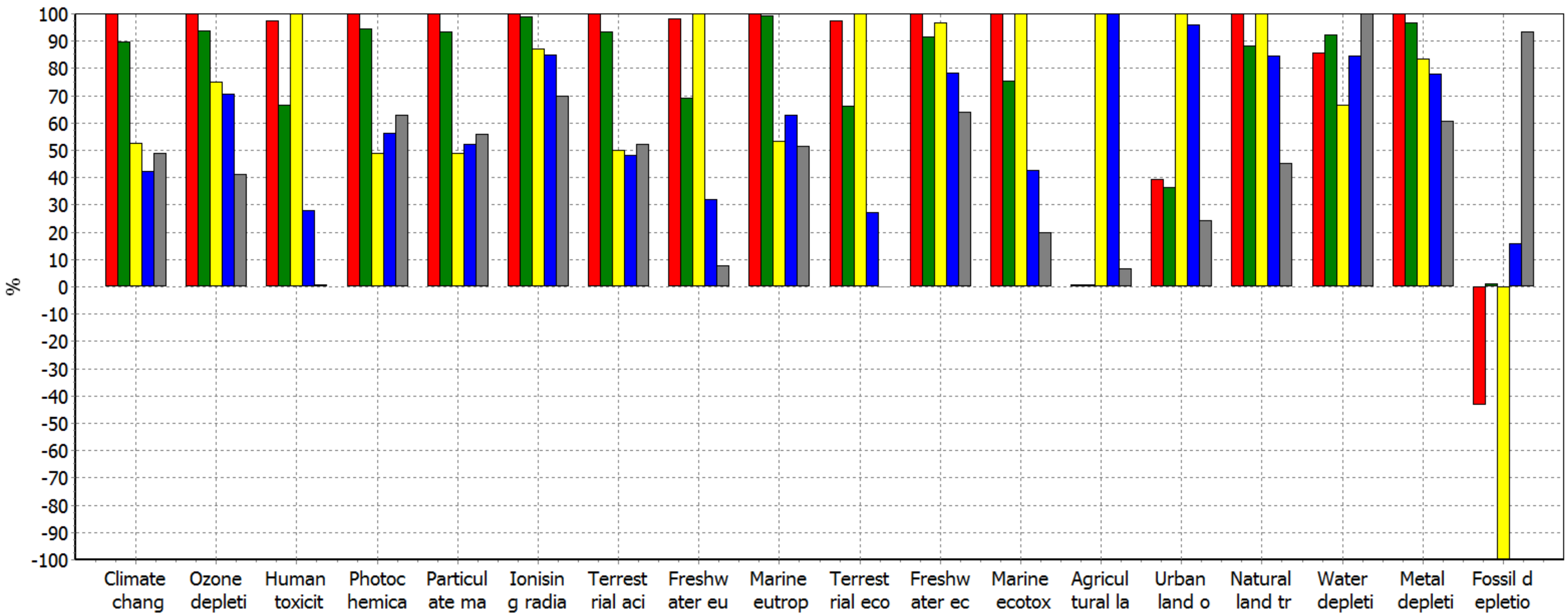


Figure 5.5 : Characterization results of the Paper Bags system with 27% food waste digested and 73% incinerated. The effects of the zero-burden food waste in the paper bag is represented in red, the municipal waste collection by biogas trucks in yellow and trucks running on diesel in green, the equipment required for the paper bag system in grey and the digestion of the paper bag including the food waste is represented in blue.

Once again, figure 5.5 highlights that the digestion process is given a much higher influence than incineration on Human Toxicity, Freshwater eutrophication, Terrestrial and marine Ecotoxicity as well as fossil depletion by SimaPro.

Regarding the other impact categories, figure 5.5 logically appears like a mix of figures 5.2 and 5.3 as the first system is a kind of combination of the two others. Figure 5.5 and 5.2 indeed show that the ionising radiation, agricultural and urban land occupation as well as the water depletion are mainly due to the paper bags production.

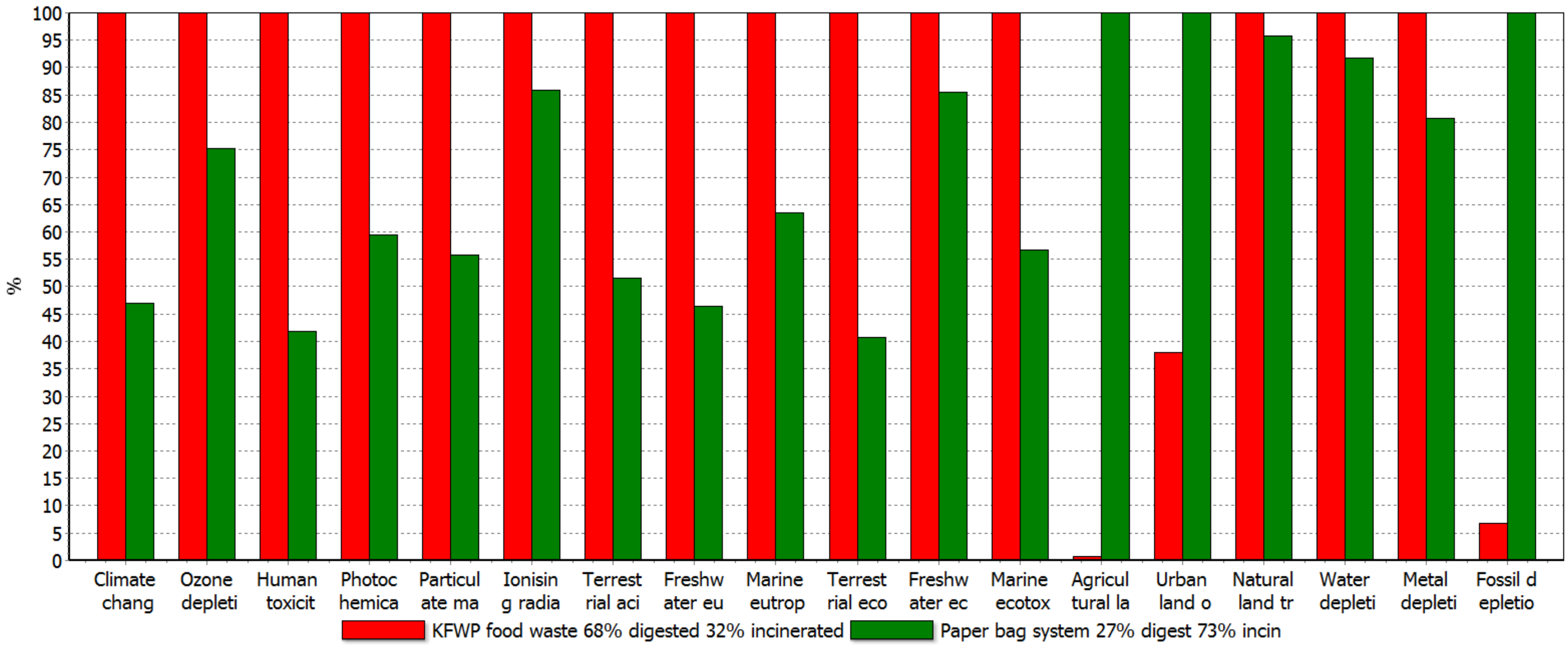
Comparing figures 5.4 and 5.5 show that despite the different waste scenarios of the two different considered systems, the waste scenarios have really similar influence on the same impact categories. Regarding the KFWP system, the equipment production has more importance than in the Paper Bags system, where the impact of the municipal waste collection ensured by lorries running on biogas and the production of the paper bags are of bigger concern.



Comparing product stages;
Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

Figure 5.6 : Comparison of the characterized results for the 5 scenarios. The Kitchen food waste processor (KFWP) system with 100% digestion in red, the KFWP system with 68% digestion and 32% incineration in green, the paper bag system with 100% digestion in yellow, the paperbag system with 27% digestion and 73% incineration in blue; and the system with collection in plastic bags and 100% incineration is represented in grey.

Figure 5.6 shows that the KFWP System (red and green bars) causes more climate change, ozone depletion, photochemical oxidant and particulate matter formation, ionising radiation, terrestrial acidification, marine eutrophication and metal depletion than the Plastic bags (grey) and the paper bags systems (yellow and blue). Regarding the fossil depletion, the difference is flagrant between the “positive” impact of the systems with a large part of digestion (appearing on figure 5.6 with negative percentages) and the highly negative impact of the plastic bags system combined with the 100% incineration scenario.



Comparing 1 p 'KFWP food waste 68% digested 32% incinerated' with 1 p 'Paper bag system 27% digest 73% incin';
Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

Figure 5.7 : Comparison of the characterization results for the two systems as they are currently running. Red represents the Kitchen food waste processor (KFWP) system with 68% digestion and 32% incineration. Green is representing the paper bag system with 27% digestion and 73% incineration.

Figure 5.7 enables conclusion to be drawn about the two systems as they are currently running. The paper bags system is preferable to the KFWP system except for the agricultural and urban land occupation or the fossil depletion. These results can be explained by the importance of the paper bags production requiring wood and therefore occupying more agricultural and urban lands. The much higher fossil depletion impact of the paper bags system is due to its percentage of incinerated food waste in opposition to the percentage of digested food waste for the KFWP system.

5.2 Significant impact categories of the total system and process contributions to them

According to the normalised results comparison (see Figure 5.7), the major impact categories decreasing in importance are human toxicity (HT), terrestrial ecotoxicity (TE), freshwater eutrophication (FEu) and marine ecotoxicity(MT) .

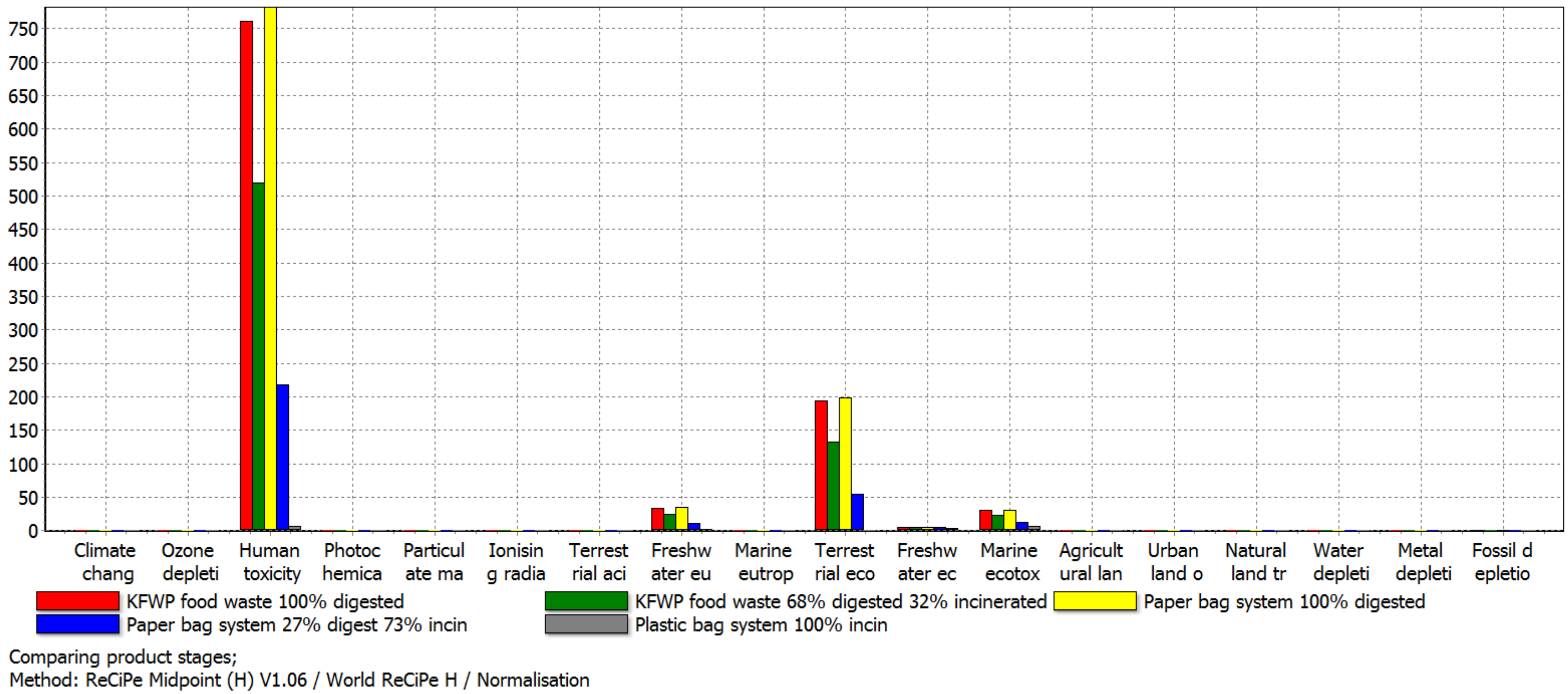


Figure 5.8: Comparison of the normalised impact assessment for the five different systems. Red represents the Kitchen food waste processor (KFWP) system with 100% digestion, green the KFWP system with 68% digestion and 32% incineration, blue is representing the paper bag system with 27% digestion and 73% incineration, yellow the Paper bag system with 100% digestion; and grey the Plastic bag system with 100% incineration.

Figure 5.8 highlights that the paper bag system with 100% of food waste digested has higher environmental impacts than the KFWP system with 100% of food waste digested, followed by the KFWP System with 68% of food waste digested and the Paper Bag System with 27% of food waste digested. The plastic bag system with 100% of food waste incinerated shows the lowest environmental impacts.

Both the KFWP 100% digested and the Paper Bag 100% digested systems are leading to the same kind of environmental impact and their results are close (see figure 5.9). When the total functional unit is considered digested, the KFWP treatment system appears to be more environmentally friendly than the paper bag system.

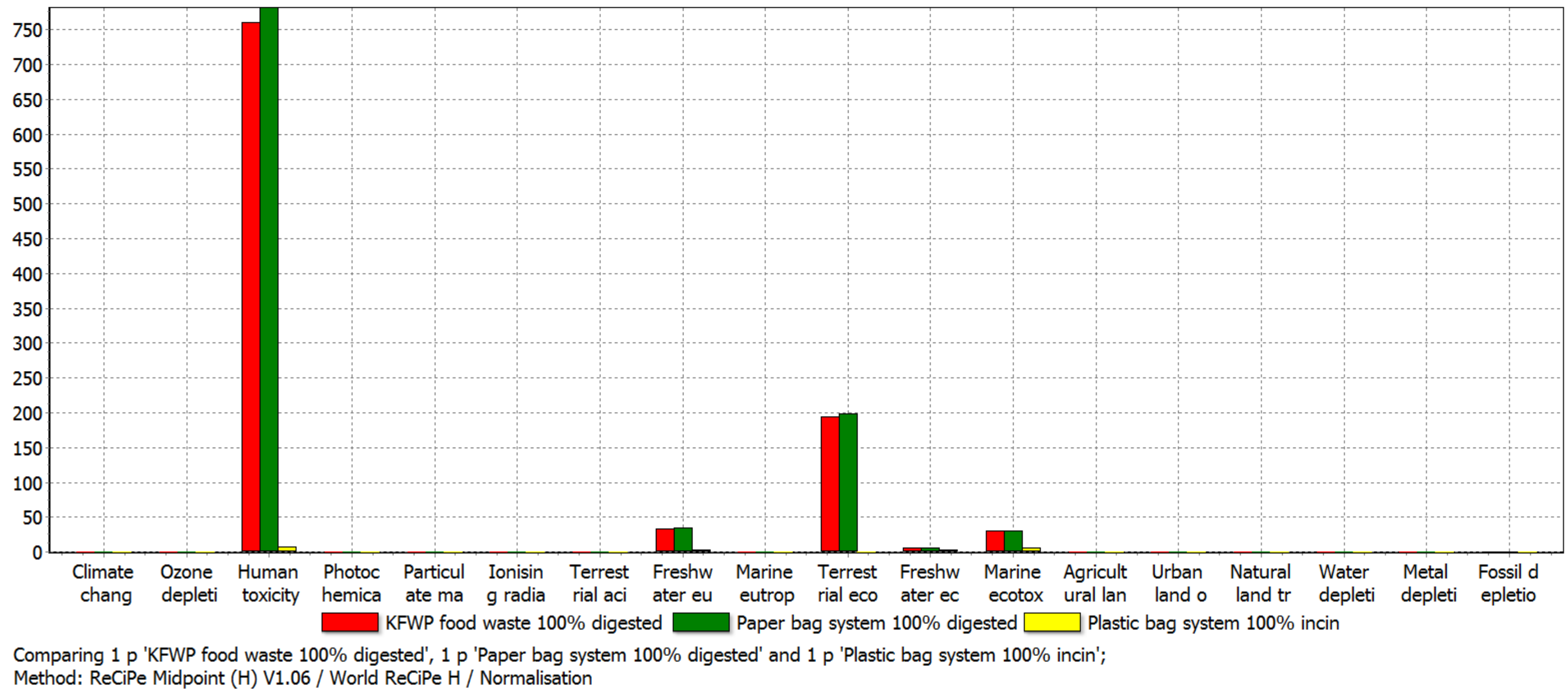


Figure 5.9: Comparison of 100% of the functional unit treated in the three different systems, normalised results.

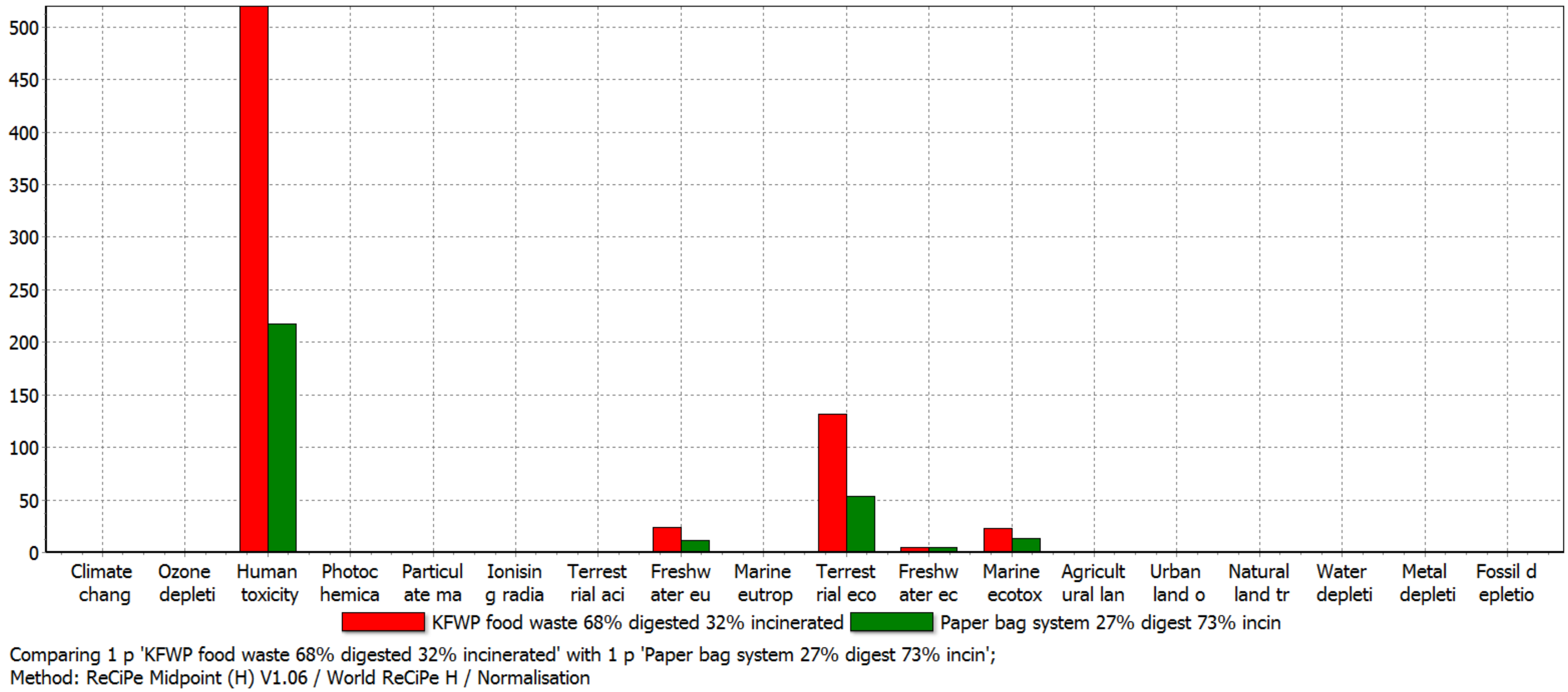


Figure 5.10: *Comparison of the current percentage of the functional unit treated in the two different collection systems with KFWP and paper bags.*

Figure 5.10 presents the comparison of the normalised environmental impacts for the paper bag and KFWP systems in function of the current percentage of food waste going to anaerobic digestion and incineration. The same impact categories appear to play a major role in the environmental impact of these systems: human toxicity is the most important. The impacts associated with the KFWP system are more than twice as important as the ones linked to the Paper bag system. It is therefore possible to conclude that the Paper Bag system is more environmentally friendly than the KFWP system if we consider the current ratios digestion/incineration. These results combined with the process contribution charts (see Figures 5.9, 5.10) underline the important contribution of the anaerobic digestion process to the four main impact categories. Figure 5.11 presents p*rocess contribution to Human toxicity for the KFWP system with 68% of food waste digested*.

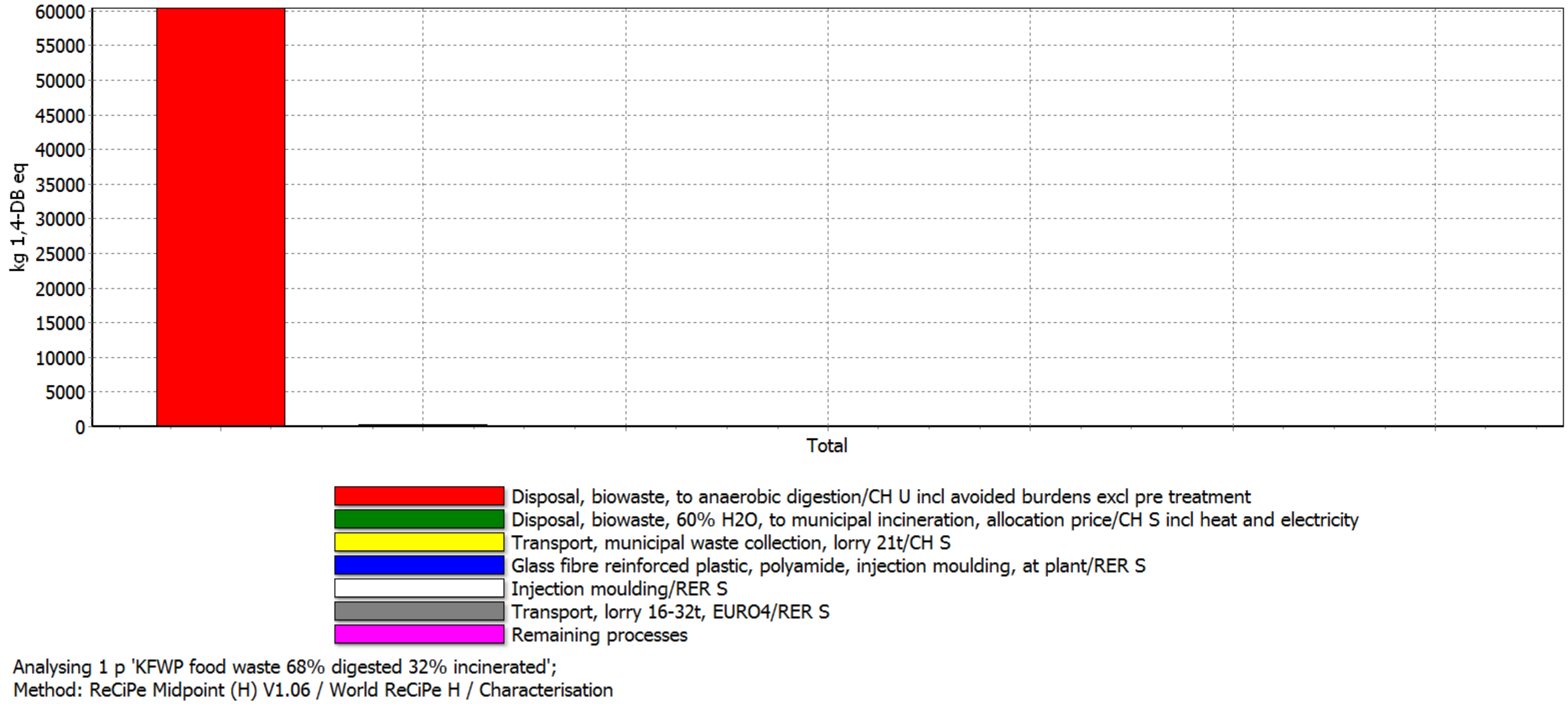


Figure 5.11: Process contribution to Human toxicity for the KFWP system with 68% of food waste digested.

5.2.1 Expected important impact categories and contribution of the processes to them

Compared to the environmental impact categories listed above, the environmental impacts considered in the goal and scope definition like climate change can be considered of less importance. Although, it seems like SimaPro is giving a lot more value to the human toxicity category than to the others. It can therefore be interesting to still consider climate change, freshwater eutrophication and fossil depletion for example, especially when thinking about Stockholm's goals. Considering the process contribution for climate change for the paper bag system with 27% of the food waste digested (see Figure 5.11 and 5.12), the municipal waste collection by lorry running on diesel is the most important. Then comes the anaerobic digestion process, the municipal waste collection by lorry running on biogas, the municipal incineration process and finally the production of the craft paper.

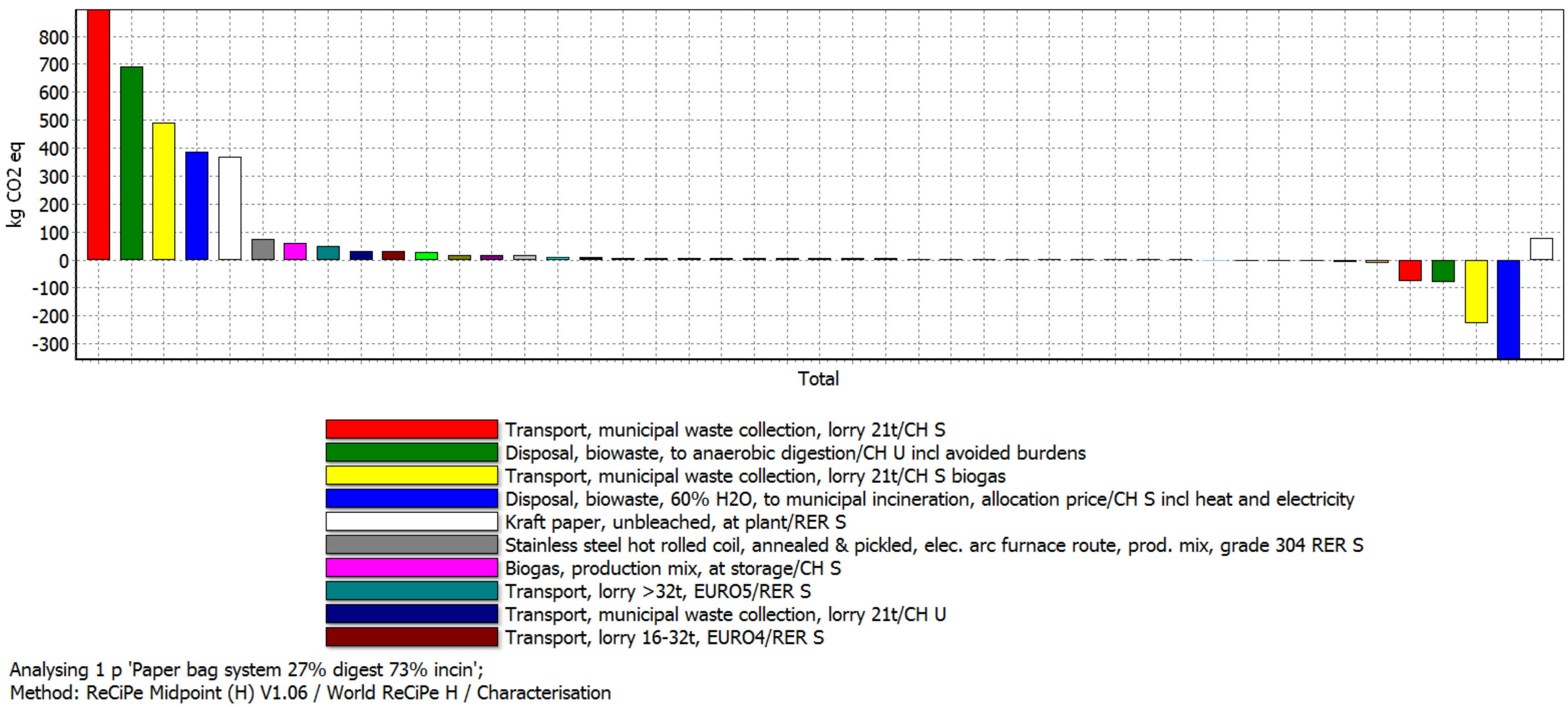


Figure 5.12: Process contribution to Climate change for the paper bag system with 27% of the food waste digested.

The analysis of the process contribution to climate change for the KFWP system with 68% of the food waste digested (see figure 5.13) reveals that the injection moulding of the tank has quite an impact on the climate change potential of this system.

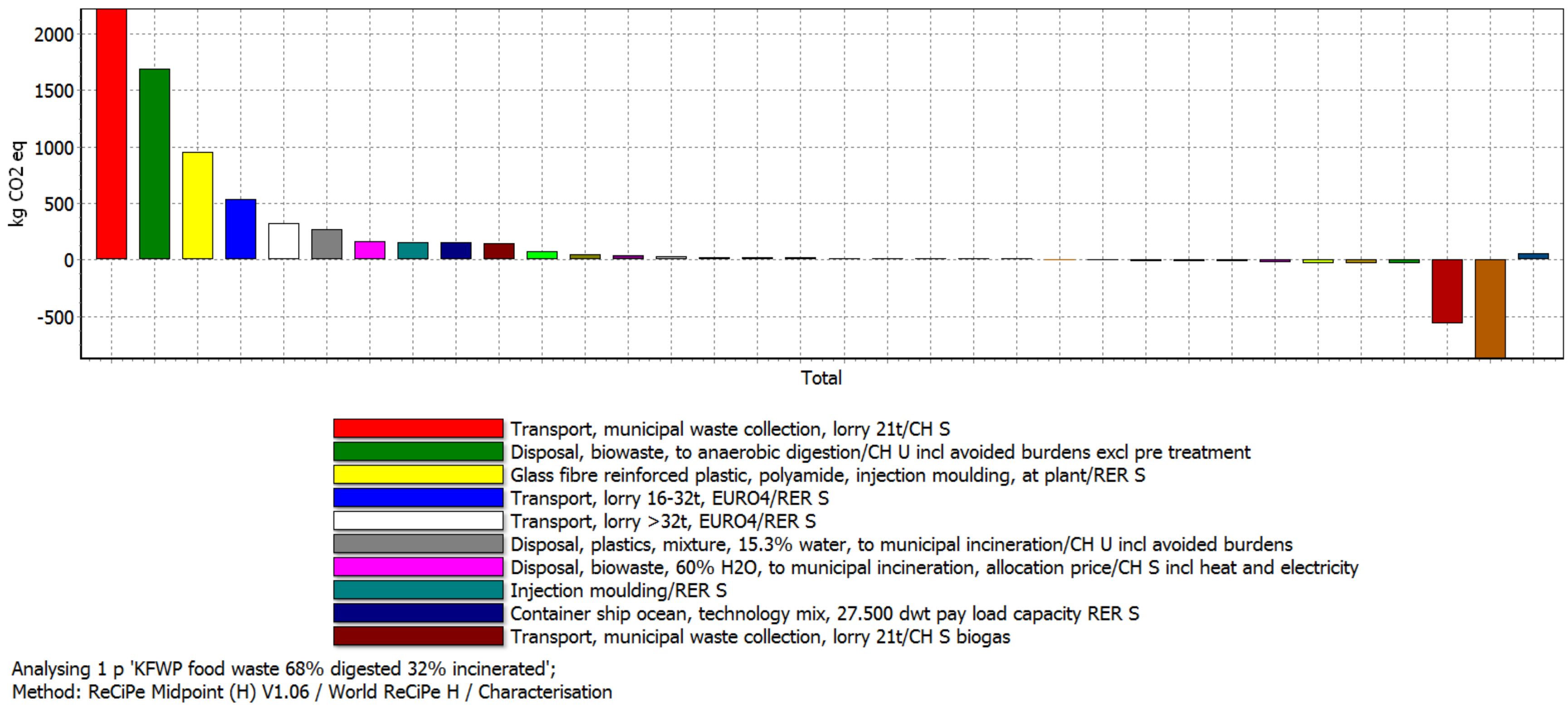


Figure 5.13: Process contribution to Climate change for the KFWP system with 68% of the food waste digested.

5.3 Significant life cycle stages/processes

The study of the process contribution charts of the main impact categories highlights that for the four main impact category mentioned above (HT, FEu, MT and TE), the process which contributes the most is the disposal of biowaste to anaerobic digestion or to municipal incineration.

Human toxicity is calculated in function of the emissions of toxic substances for human whereas ecotoxicity takes into account consequences of chemical outputs on nonhuman organisms.

According to the table 5.1, the emission of phosphorus to soil is the main cause of the high human toxicity impact of the waste scenario 100% digestion in Paper bags.

Table 5.1: Characterization inventory results for human toxicity of the system Paper bags with 100% food waste digested

Human toxicity Paper bag system 100% digestion									
No.	Substance	Compartment	Unit	Total	Waste + paper bags	Transport. municipal waste collection. lorry 21t/CH S	Transport. municipal waste collection. lorry 21t/CH S biogas	Bags waste scenario 100% paper and food waste to biogas	Bags Equipment
	Total		kg 1.4-DB eq	918	429	46.5	51.3	913	4.65.
	Remaining substances		kg 1.4-DB eq	320	146	23.2	25.5.	123	2.66
1	Phosphorus	Soil	kg 1.4-DB eq	90 700	4.05	3.39	3.44	90700	0.0226
2	Manganese	Water	kg 1.4-DB eq	374	279	19.8	22.4	51.2	1.97
3	Zinc	Soil	kg 1.4-DB eq	219	0.124	0.00289	0.00303	219	0.000276
4	Cadmium	Soil	kg 1.4-DB eq	112	0.215	0.00388	0.00410	112	0.000226
5	Lead	Soil	kg 1.4-DB eq	94.6	0.00480	0.000121	0.000128	94.6	0.0000288

The release of toxic chemicals such as ammonia, hydrogen sulphide, heavy metal ions and carbon dioxide by anaerobic digestion of biowaste (The Microbiology of Anaerobic Digesters, 2003) could also be part of the human toxicity impact calculations of the process.

The main causes of the human toxicity impact of incineration are listed in the table 5.2. Incineration leads to a lot less of phosphorus emissions to soil than anaerobic digestion. Incineration also engenders to the release of heavy metal ions visible in table 5.2.

Table 5.2: Characterization inventory results for human toxicity of the system Plastic bags with 100% food waste incinerated

Human toxicity Plastic bag system 100% incineration									
No	Substance	Compartment	Unit	Total	Waste + plastic bags	Transport, municipal waste collection, lorry 21t/CH S	Transport. municipal waste collection. lorry 21t/CH S biogas	Plastic bags waste scenario 100% to incineration	Bags Equipment
	Total		kg 1,4-DB eq	824	237	35.3	39.0	508	4.65.
	Remaining substances		kg 1,4-DB eq	5.35	2.05.	0.574	0.633	1.45.	0.648
1	Manganese	Water	kg 1,4-DB eq	256	171	15.1	17.0	51.4	1.97
2	Arsenic, ion	Water	kg 1,4-DB eq	256	23.2	3.03	3.49	226	0.425.
3	Phosphorus	Air	kg 1,4-DB eq	154	2.24	0.0545	0.0884	152	0.0163
4	Selenium	Water	kg 1,4-DB eq	52.6	10.6	1.05	1.20	39.6	0.137
5	Mercury	Air	kg 1,4-DB eq	26.3	4.22	3.02	3.28	15	0.717
6	Barium	Water	kg 1,4-DB eq	15.4	5.64	4.05.	4.18	1.48	0.0888
7	Phosphorus	Soil	kg 1,4-DB eq	7.34	1.49	2.58	2.61	0.632	0.0226
8	Arsenic	Air	kg 1,4-DB eq	7.32	3.74	0.941	1.14	1.35	0.142
9	Lead	Air	kg 1,4-DB eq	7.08	2.77	1.18	1.31	1.58	0.245.
10	Molybdenum	Water	kg 1,4-DB eq	6.74	2.14	0.205	0.237	4.08	0.0778
11	Dioxin, 2,3,7,8 Tetrachlorodibenzo-p-	Air	kg 1,4-DB eq	5.50.	0.0258	0.00462	0.00609	5.45	0.00566
12	Vanadium	Air	kg 1,4-DB eq	4.84	2.34	0.774	0.788	0.900	0.0286
13	Vanadium, ion	Water	kg 1,4-DB eq	3.88	0.920	0.146	0.163	2.63	0.0203

14	Mercury	Water	kg 1,4-DB eq	3.82	2.16	0.186	0.215.	1.24	0.0308
15	Zinc	Air	kg 1,4-DB eq	2.82	0.262	1.14	1.15	0.247	0.0138
16	Lead	Water	kg 1,4-DB eq	2.80	0.262	0.0397	0.116	2.36	0.0201
17	Zinc, ion	Water	kg 1,4-DB eq	2.76	1.34	0.355.	0.400	0.649	0.0213
18	Cadmium	Air	kg 1,4-DB eq	1.86	0.518	0.477	0.509	0.337	0.0179
19	Barium	Soil	kg 1,4-DB eq	1.06	0.0834	0.442	0.446	0.0885.	0.00227

The incineration of biowaste allows the carbon confined in biowaste to be emitted to the atmosphere under the form of carbon dioxide and methane, although the results do not show that these emissions are important when compared to the toxic substances emitted to the environment.

The results globally show that the systems with more digestion are less environmentally friendly because of their higher normalized environmental impacts. However, as mentioned earlier, the comparison of the characterization results of the five systems (see figure 5.2 underlines that the choice on the more environmentally friendly system depends to a large extent to the impact category considered.

6 Conclusions and recommendations

The goal of City of Stockholm is to build sustainable apartment buildings, so they choose environmentally friendly systems. The results show that the most environmental friendly system is the paper bag system. This means, it had the lowest impact on the environment. This system is not taken into account that the demand for biogas is growing rapidly because all buses in Stockholm are running on biogas. Therefore another goal of City of Stockholm is to produce more biogas to fulfil this demand. Considering this goal, the KFWP system would be a better choice because you get more biogas per 1 kg food waste.

Systems allowing more digestion will obviously allow more biogas to be produced. This could be satisfying for the city of Stockholm which set environmental goals concerning the collection of food waste by 2018 (Waste management plan for Stockholm 2013-2016).

One way to meet the goals of the increased food waste collection for 2018 could be to install more KFWP systems in new apartment buildings since this leads to more food waste collected than the installation of the paper bag system. Although more information and awareness about the importance of sorting food waste could increase the food waste collection in the paper bag system.

In this analysis the assumption that the grinder is connected to a tank might influence the results. The tank needs to be produced, transported and installed in the building block and transportation is needed to vacuum the slurry and transport it to the biogas facility. The other collection system, which is the one used today in Stockholm Royal Seaport the food waste goes in the sewage system and there is no need of a tank or transportation. Although this system leads to other processes such as treatment at the sewage plant.

It could be interesting to see if the second collection system would lead to less or greater environmental impacts compared to the paper bag system. As the equipment of the KFWP system is shown to have a high impact it might be interesting to investigate options here.

The aim of this LCA is also to give answer to environmental impact caused by these processes. It would therefore be interesting to expand the study to include a back loop off biofuel decreasing the dependence on diesel. To be fair it would be interesting to investigate the possibility of having a lorry running on biofuel operating the KFWP system.

Taking into account the emissions of pollutants to air avoided by vehicles running on biogas instead of diesel would reduce consequently the environmental impact of the systems with the highest percentages of digestion.

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Appendix A Data KFWP system

The system includes:

Manufacturing phase: Processor, tank, pipes
Usage phase: Water consumption, electricity consumption
Transportation: Vacuum truck (diesel)
Waste scenario: Biogas facility producing digester gas from food waste slurry.

Manufacturing phase

Grinder
Product: Waste King L 2600 TC
Expected life time: 15 to 20 years (Uson Miljöteknik a). The lifetime of both the tank and the pipes are 50 years and for this time period we would need 3 grinders. Therefor we calculate the lifetime of the grinder as 50/3= 16.5 years.
Shipping weight: 11.22 kg (Waste King, 2014)

Materials and amounts of materials:

*Tabel 1 (*Annerhall G, 2014*)*

Material	Amount
Iron (II,III) oxide synonymous C.I. Pigment Black 11	9%
Aluminium, Al	18%
Copper	18%
ABS plastic	31%
Steel STS 304 (stainless)	14%
Rubber, (Unspecified	1%
Ceramic	9%

Manufacturer: Anaheim Manufacturing Company, located in Los Angeles, California (USA) (Annerhall G, 2014).

Production country: China (Annerhall G, 2014)

Transports: From China (assumption Hong Kong) to Los Angeles by container shipping boat: 129000 tkm. From LA to New York by big truck (assumption): 50500 tkm. From NY to Gothenburg by container shipping boat (assumption): 67000 tkm. From Gothenburg to Stockholm by truck (assumption): 500 km (Annerhall G, 2014; Google maps, 2014).

Tank
Expected life time: 50 years (Bismont M, 2014)
Material: Glass fiber reinforced plastic (Annerhall G, 2014)
Amount: The size of the tank is 4 cubic meter (Bismont M, 2014) and the dimensions can be seen in the drawing (Uson Miljöteknik b) Calculation of amount of material: 6.5 (length) * 1.4 (height) * 0.8 (width) = 7.3 m^3. 7 - 4 = 3 m^3 material.
3 m^3 * 1800 kg/m^3 (the density of glass fiber reinforced plastic)=5400 kg (The great soviet encyclopedia, 1979)

Manufacturer: LK systems (Annerhall G, 2014)
Production country: Sweden (Ulricehamn or Gävle) (Annerhall G, 2014)
Transport: Truck (assumption), approximately 300 km (average km between Ulricehamn and Gävle to Stockholm) (Google maps, 2014)

Waste disposal: Incineration (assumption)

Pipes
Expected life time: 50 years (Bismont M, 2014)
Material: PVC (Annerhall G, 2014)

Amount: (assumptions) Calculation of the average distance of pipes from five 5-floor buildings sharing one tank placed in the basement (see Plan of block) giving the amount of material in kg:

Length of pipes for one of four buildings (1-4): 2.5 m (each floor) *5 + 2 m (basement) + 10 m (distance to pipe connection with other building) + 7.5 m (half the distance to tank) = 32 m. Length of pipes for building (5): 2.5 m (each floor) *5 + 2 m (basement) + 15 m (distance to tank) = 29.5. Total length of pipes: 32 * 4 + 29.5 = 157.5 m.
Diameter of pipe (assumption from looking at the inflow at the drawing of the tank): 100 mm. Weight of 100 mm (4 inch) PVC pipes = 2.01(lb/ft) =2.01 (0.4536 kg / 0.3048m) = 2.99 kg/m (The engineering toolbox, 2014). 158*3 = 474 kg.

Manufacturer: LK systems (Annerhall G, 2014)
Production country: Sweden (Ulricehamn or Gävle) (Annerhall G, 2014)
Transport: Truck (assumption), approximately 300 km (average km between Ulricehamn and Gävle to Stockholm) (Google maps, 2014)

Waste disposal: Incineration (assumption)

Use phase KFWP

<u>Water consumption</u>
To flush down the food waste in the sink 12 liters of water per kg food waste is used (Avfall Sverige, 2011).

<u>Electricity consumption</u>
Electricity use for a 500 W motor is 5-6 kWh per household/apartment per year (considering that the KFWP runs a few minutes per day) (Stockholm Vatten, 2008). The motor in Waste King L 2600 TC is 1/5 hp = 370 W so with the same ratio it would be a range between 3.2-4.5kWh and average 3.85 kWh. So for 100 apartments for one year it would be approximately 400 kWh.

Transportation

<u>Transportation from tank to biogas facility</u>

Company responsible for collection and transportation: Ragn Sells (Ragn Sells Stockholm, 2014)

Vehicle: Vacuum truck, 11 cubic meters = 3 tanks (Ragn Sells Stockholm, 2014)

Fuel: Diesel (testing for biogas on some garbage trucks but not for vacuum trucks) (Ragn Sells Stockholm, 2014)

Frequency of emptying tanks: 1 time / month (Ragn Sells Stockholm, 2014)

Distance: Ragn Sells Länna à Stockholm Royal Seaport (Taxgatan 7) à Henriksdals biogas facility à Ragn Sells Länna (Ragn Sells Stockholm, 2014). = 47 km (Google maps, 2014).

Transport (tkm) for scenario of KFWP 100% digestion:

1 Truck can handle 3 tanks, in total 11 m3. Food waste slurry is 90% water (Nordenberg J, 2014) , so we assume is has the same density as water. 11 m3 water = 11000 liter water = 11000 kg food waste slurry for 1 full truck. 11000 / 3 = 3666 kg food waste in 1 full tank. Pick up is every month so yearly: 3666*12 = 44000 kg total weight functional unit after grinded.

50*44000 = 2 200 000 kgkm = *2200 tkm*

Transport (tkm) for scenario of KFWP 68% digestion and 32% incineration:

68% of 2200 = *1500 tkm* to digestion

32% of 16560 = 5300 kg to incineration

5300 * 76 = 402800 kgkm = *402.8 tkm*

Vacuuming: For the compressor to run the truck has to be on while the tank is being emptied, this takes about 10-20 minutes. Emissions are coming out from both the compressor and the truck during this time. The truck can take 3 tanks, so the total time would be an average of 45 min (Ragn Sells Stockholm, 2014). The truck used in the SimaPro model is a truck for collection of municipal waste that includes for example stopping for collection so this specific data for the vacuuming truck is not taken into account.

Waste scenario

Biogas facility
Digester gas production facility: Henriksdals avloppsreningsverk, Stockholm Vatten
Inputs: Food waste slurry
Outputs: Digester gas + biofertilizer
Biofertilizer allocation data:
1 kg of food waste contains:
Phosphor (P): 0.3 * 2.5 g
Nitrogen (N): 0.3 * 30.4 g
Potassium (K): 0.3 * 4.8 g
(Avfall Sverige, 2011)
0.3 * 1 kg food waste = the dry weight (Nordenberg J, 2014).

1 ton food waste à 70-110 Nm3 (normal cubic meter) vehicle biogas. (Aronsson P, 2014)
Average 90 Nm3
Vehicle gas consist of approximately 97% CH_4 and 3% CO_2 (Nordenberg J, 2014)
Digester gas consist of approximately 60% CH_4 and 40% CO_2 (Nordenberg J, 2014)
Since Nm3 is used as a unit pressure and temperature is constant and a simplified version of the common gas law may be used.

→ 90Nm3 vehicle gas corresponds to 87.3 Nm3 pure CH_4 (0.97*90 Nm3) and 2.7 Nm3 pure CO_2 (0.03*90Nm3)

This correspond to 152.25 Nm3 of digester gas (87.3/0.6+2.7/0.4)

→ 0.15225 Nm3/kg food waste

Appendix B Data paper bag system

The system includes:

Manufacturing phase: Paper bag, Small bin, Big bin
Usage phase: N.A.
Transportation: Waste trucks (50% diesel, 50% biofuels (Holmström L 2014))
Waste scenario: Biogas facility producing digester gas from solid food waste.

Manufacturing phase

Paper bag

Product: Bag suitable for food waste.
Raw material: Made of water-resistant kraft-paper. 70g/m². Made at Mondi Dynäs AB in Väja, Sweden.
Due to high quality demands the paper is currently made of virgin materials.

Production of bag: The bag is manufactured by JD Stenqvist AB in Kvidinge, Sweden.
The bag is made according to EN13432.(Kronström A, 2014)

Transports:
From Monid Dynäs AB in Väja to JD Stenqvist AB in Kvidinge transport by lorry is assumed. Distance: 1000 km (Google maps, 2014)

From JD Stenqvist AB in Kvidinge to Stockholm transport by lorry is assumed. Distance: 500 km (Google maps, 2014)

The weight of the bag was measured
80 bags had a total weight of 1582 g → 20g /bag.

The chosen process in SimaPro stated a required surplus of 20% → manufacturing of a bag requires 25 g of craft paper.

Small bin

Product: Small bin used in the kitchen to hold the paper bag.
Materials: 190 g polypropylene and 22 g steel-alloy, based on weighing and inspection.
Estimated life-time: 10 years (assumption)

An assumption was made that the bin was manufactured at the same location as the paper bags. Kvidinge to Stockholm transport by lorry is assumed.

Distance: 500 km (Google maps, 2014)

Big bin

Product: Collection vessel for paper bag holding food waste.
Villiger, Balero form Sansac was chosen.

Materials: Top (Balero) is made of stainless steel. Underground shaimber is made of 7,3 ton concrete and the container is made from 1 ton of stainless steel. (Gustafsson, 2014)

Estimated life-time: 50 years (assumption)

The Villiger system is made in Switzerland. And transportation from Küngoldingen, Switzerland to Stockholm, Sweden by train (Gustafsson J, 2014) is estimated to be 1800 km (Google maps, 2014).

Use phase

Paper bag

Number of bag required:
175 bags per household * 100 households /year =17 500 bags
150-200 bags per household estimated by Sedman C (2014) → 175 on average

Small bin

No extra input is required during the use phase. 1 small bin per household is required → 100 small bins.

Big bin

The big bin holds 1500 l of waste and is emptied every second week (assumption).
The waste is transported by garbage trucks run by SITA (Nilsson J, 2014).

The fleet of garbage trucks consist of 50% trucks that run on biofuels and 50% of trucks that run on diesel (Holmström L, 2014). The trucks have their garage in Sollentuna (Holmström L, 2014), pick up the food waste in Royal Seaport of Stockholm. There after it is transported to SRV Återvinning in Huddinge for treatment. After this the trucks return to the garage in Sollentuna (Holmström L, 2014; Nilsson J, 2014).

Waste scenario

Paper bag

The paper bags are treated together with the food waste.

Small bin

The plastic in the small bin is recycled and the metal is incinerated (assumption).

Big bin

The stainless steel is recycled and the concrete is sent to landfill.

Biogas facility
Digester gas production facility: SRV-återvinning (is currently performing the pre-treatment. However, from 2015 will be able to handle the whole process.) (Sedman C, 2014)

Inputs: Food waste

Outputs: Digester gas + biofertilizer
Biofertilizer allocation data:
1 kg of food waste contains:
Phosphor (P): 0.3 * 2.5 g
Nitrogen (N): 0.3 * 30.4 g
Potassium (K): 0.3 * 4.8 g
(Avfall Sverige, 2011)
0.3 * 1 kg food waste = the dry weight (Nordenberg J, 2014).

1 ton food waste à 70-110 Nm3 (normal cubic meter) vehicle biogas. (Aronsson P, 2014)
Average 90 Nm3
Vehicle gas consist of approximately 97% CH_4 and 3% CO_2 (Nordenberg J, 2014)
Digester gas consist of approximately 60% CH_4 and 40% CO_2 (Nordenberg J, 2014)
Since Nm3 is used as a unit pressure and temperature is constant and a simplified version of the common gas law may be used.
→ 90Nm3 vehicle gas corresponds to 87.3 Nm3 pure CH_4 (0.97*90 Nm3) and 2.7 Nm3 pure CO_2 (0.03*90Nm3)
This correspond to 152.25 Nm3 of digester gas (87.3/0.6+2.7/0.4)
→ 0.15225 Nm3/kg food waste

Appendix C New process data sheet in SimaPro

A new process for transportation of municipal waste collection running on biogas was created. The process for transportation of municipal waste collection running on diesel was modified and due to the large amounts of emissions in the data sheet only the modified parts of the data sheet is presented in the appendix. The full unmodified data sheet can be seen in Ecoinvent database.
Ecoinvent system processes
Name: transport, municipal waste collection, lorry 21t/tkm/CH
Category: transport
Date (created on): 2010-06-03
Process identifier: EIN_SYSX06573801965

New process

Name: Transport, municipal waste collection, lorry 21t/CH S biogas
Category type: transport
Date (created on): 2014-11-28

Process identifier: Standard20555900005

Modified data from SimaPro:

Transport, municipal waste collection, lorry 21t/CH S biogas	**1**	**tkm**		
Materials/fuels				
Biogas, production mix, at storage/CH S	0.15	m3		0.15 m3 biogas/tkm truck consumption (Biogas Technology, AvB. T. Nijaguna p. 259)
Carbon dioxide, biogenic	high. pop.	0.000160384	kg	CO2 emissions reduced by 86% (NSCA Biogas as a road transport fuel, 2006)
				0.0011456*0.14=0,000160384
				0,00020566*0.14=0,0000287924
				0,00011244*0.14=0,0000157416
				1.1371*0.14=0,159194
				0.093674*0.14=0.0131

				1436
				0.00000003265*0.14=0,00 0000004571
				0.024066*0.14=0.003 36924
Carbon monoxide, fossil	high. pop.	0.001 3769	kg	CO emissions reduced by 50% (NSCA)
				0.0027538*0.5=0.0013 769
				0.00013898*0.5=0.00 006949
				0.00000000003835*0.5=0- 000000000019175
				0.00023687*0.5=0.00 0118435
Hydrocarbons, aliphatic, alkanes, cyclic	high. pop.	2.350 28E-09	kg	Hydrocarbons emissions multiplied by 20 (NSCA)
				0.00000000076309*20= 0.00000000235028
				0.0000000000058757*20=0.00 0000000117514
				0.00000063808*20=0.000 0127616
				0.00000013446*20=0.000 0026892
				0.0000010225*20=0.0 0002045
				0.000000034642*20=0.00 000069284
				0.000000050529*20=0.00 000101058
				0.000000000000000023*20=0

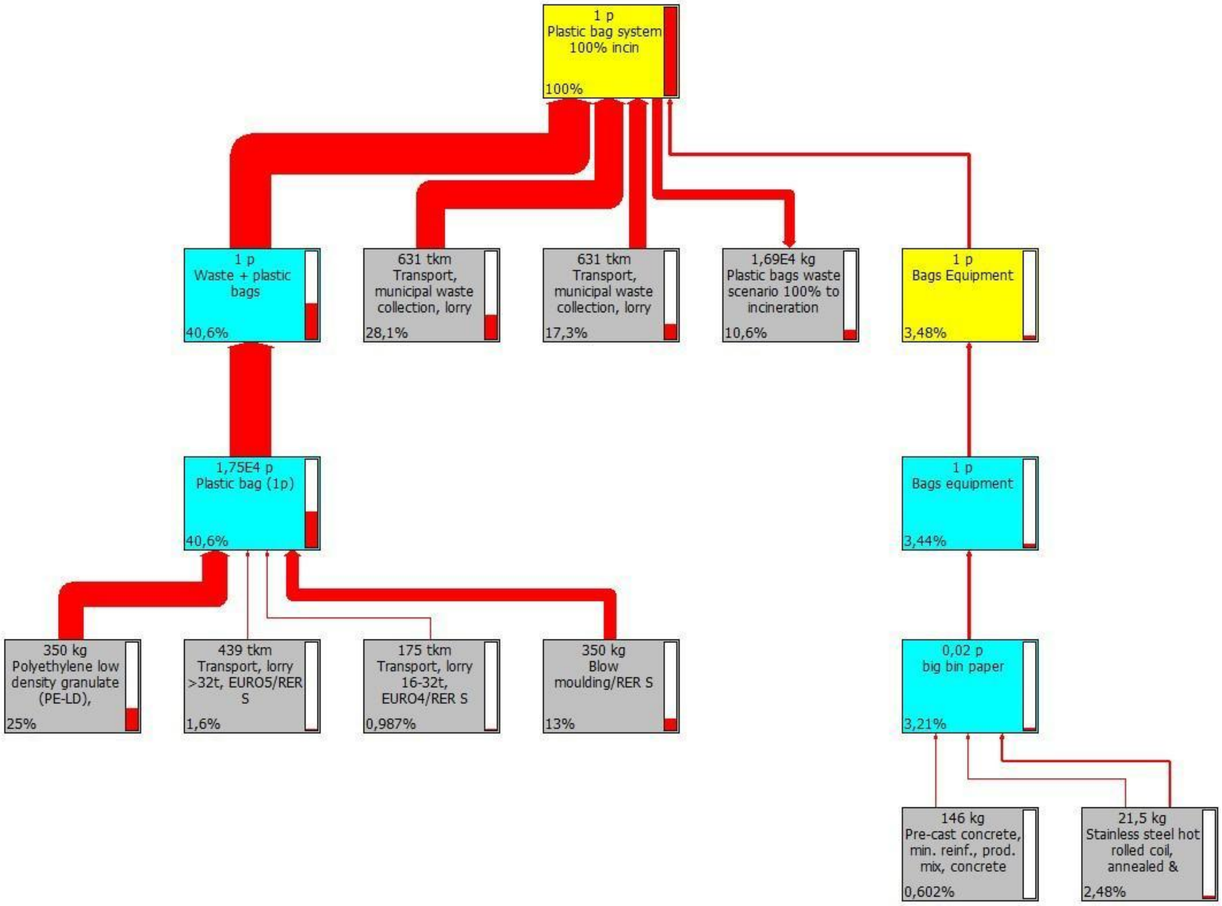
				.00000000000000046
				0.000000059006*20=0.00 000118012
				0.000000045484*20=0.00 000090968
				0.00000024124*20=0.000 0048248
				0.00000000033782*20=0. 0000000067564
				0.000000000002059*20=0.000 00000004118
				0.0000000022603*20=0.0 00000045206
Methane, biogenic	high. pop.	0.000 06511 4	kg	*1000
				ratio deduced from the comparison of methane emissions to the air
				by passenger cars running on diesel (euro3) and methane (96% from biogas):
				big differences concerning biogenic methane emissions but not the others > not modified
				*10000
				*10000
Nitrogen oxides	high. pop.	0.003 8414	kg	NOx emissions reduced by 50% (NSCA)
				0.0076828*0.5=0.003 8414
				0.00054781*0.5=0.00 0273905
				0.00000000014511*0.5=0.0000 00000072555
				0.0001921*0.5=0.000

				09605
PAH, polycyclic aromatic hydrocarbons	high. pop.	3.6008E-08	kg	hydrocarbons emissions multiplied by 20 (NSCA)
				0.0000000018004*20=0.000000036008
				0.0000000068587*20=0.000000137174
				0.000000017988*20=0.00000035976
				particulate matter reduced by 50% (NSCA)
				0.00062993*0.5=0.000314965
				0.000039603*0.5=0.0000198015
				0.00000061407*0.5=0.000000307035
				0.0000000000039387*0.5=0.0000000000001969
				0.00001179*0.5=0.000005895
				0.00018216*0.5=0.00009108
				0.000062596*0.5=0.000031298
				0.0000015352*0.5=0.0000007676
				0.0000041432*0.5=0.0000020716
				0.00010723*0,5=0.000053615
				0.000027883*0.5=0.0000139415

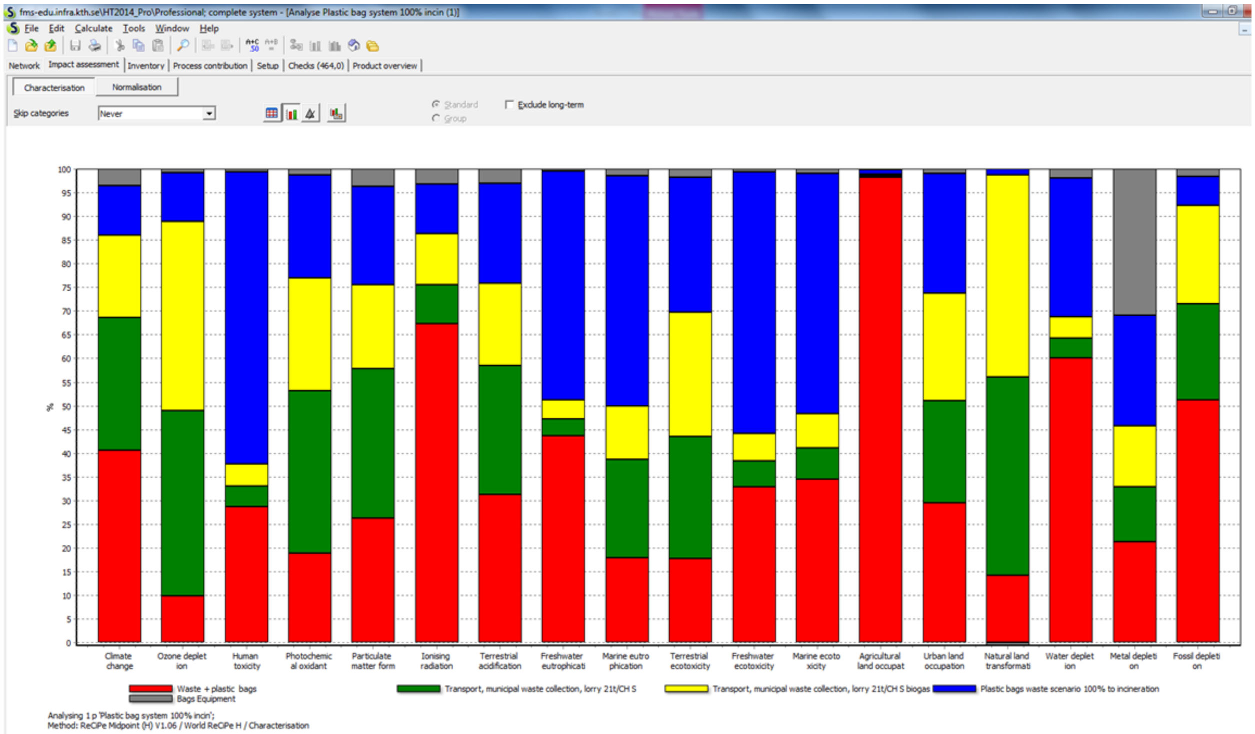
	0,0000009211*0,5=0,0000 0046055
	0.0000029656*0.5=0.0000 014828

Appendix D Results

Plastic Bags System 100% incineration



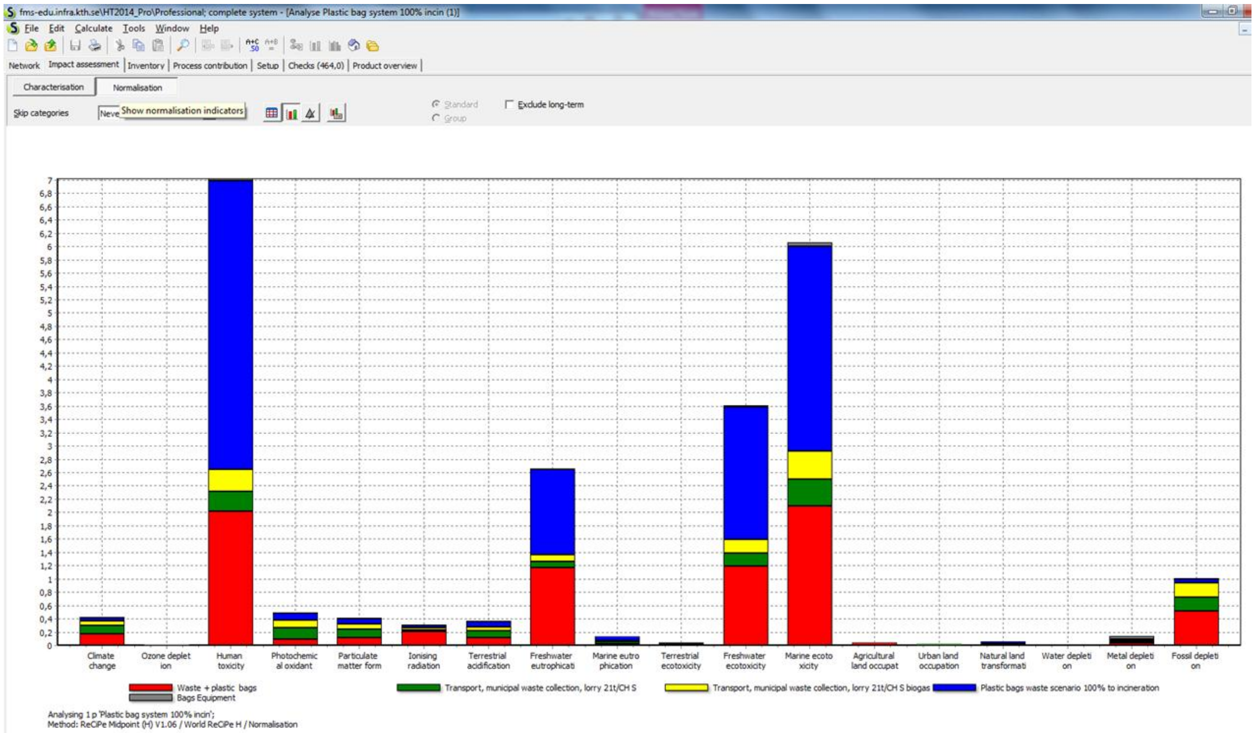
Plastic Bags System 100% incineration Characterisation Inventory



fms-edu.infra.kth.se\HT2014_Pro\Professional; complete system - [Analyse Plastic bag system 100% incin (1)]

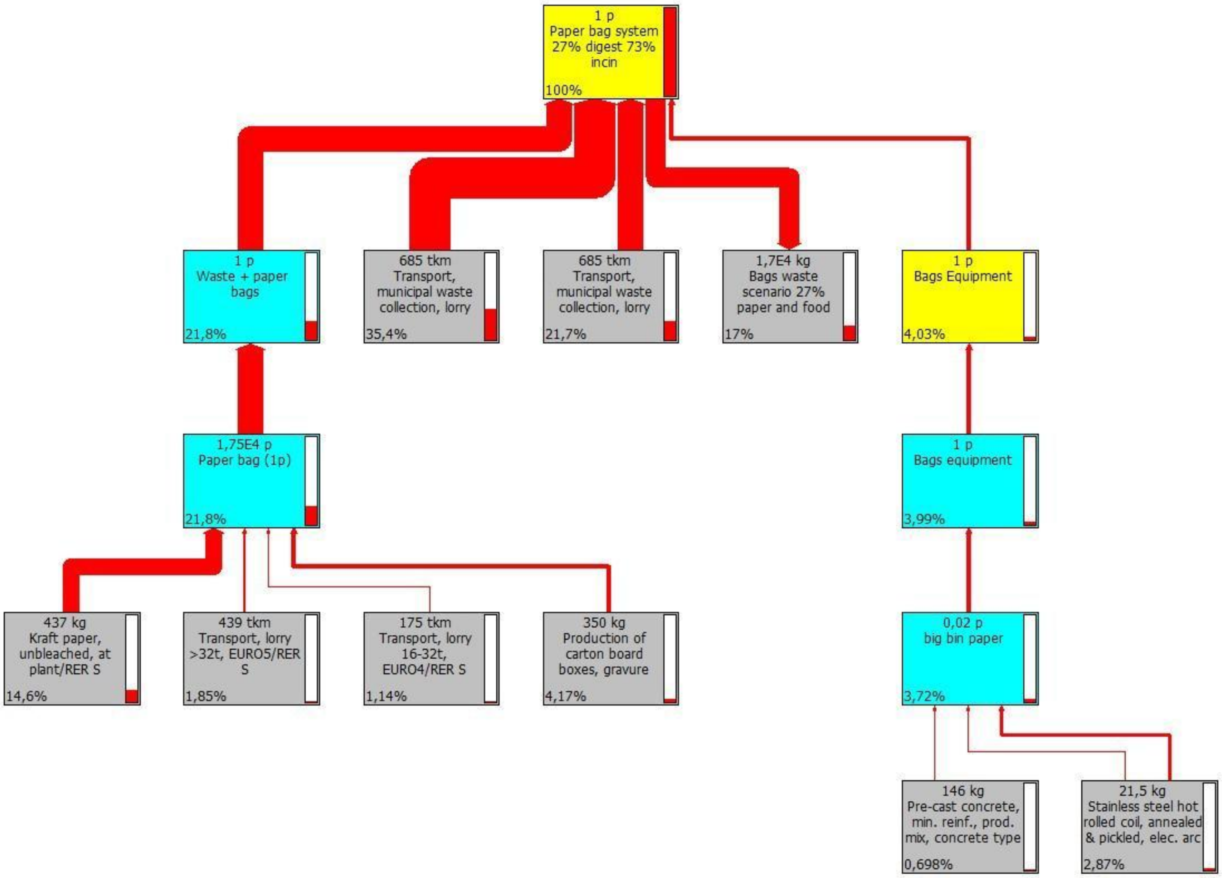
Sel	Impact category	Unit	Total	Waste + plastic bags	Transport, municipal waste	Transport, municipal waste	Plastic bags waste scenario 100% to	Bags Equipment
☑	Climate change	kg CO2 eq	2,93E3	1,19E3	825	506	310	102
☑	Ozone depletion	kg CFC-11 eq	0,000317	3,12E-5	0,000124	0,000127	3,23E-5	2,75E-6
☑	Human toxicity	kg 1,4-DB eq	824	237	35,3	39	508	4,65
☑	Photochemical oxidant formation	kg NMVOC	23,9	4,52	8,18	5,68	5,21	0,289
☑	Particulate matter formation	kg PM10 eq	5,86	1,54	1,85	1,04	1,21	0,22
☑	Ionising radiation	kg U235 eq	400	269	32,8	43,2	42,1	13
☑	Terrestrial acidification	kg SO2 eq	14	4,39	3,81	2,44	2,95	0,432
☑	Freshwater eutrophication	kg P eq	0,771	0,337	0,0274	0,0301	0,373	0,00385
☑	Marine eutrophication	kg N eq	1,04	0,186	0,216	0,118	0,507	0,0149
☑	Terrestrial ecotoxicity	kg 1,4-DB eq	0,265	0,0472	0,0684	0,0694	0,0757	0,00464
☑	Freshwater ecotoxicity	kg 1,4-DB eq	15,6	5,14	0,847	0,92	8,63	0,0947
☑	Marine ecotoxicity	kg 1,4-DB eq	14,6	5,05	0,968	1,05	7,42	0,151
☑	Agricultural land occupation	m2a	259	254	0,86	0,927	2,39	0,36
☑	Urban land occupation	m2a	21	6,18	4,54	4,77	5,28	0,214
☑	Natural land transformation	m2	0,696	0,0991	0,294	0,298	0,00883	-0,00428
☑	Water depletion	m3	30	18	1,25	1,34	8,79	0,584
☑	Metal depletion	kg Fe eq	62,4	13,2	7,26	8,05	14,6	19,2
☑	Fossil depletion	kg oil eq	1,39E3	714	281	289	85,9	21,8

Plastic Bags System 100% incineration Normalisation Inventory

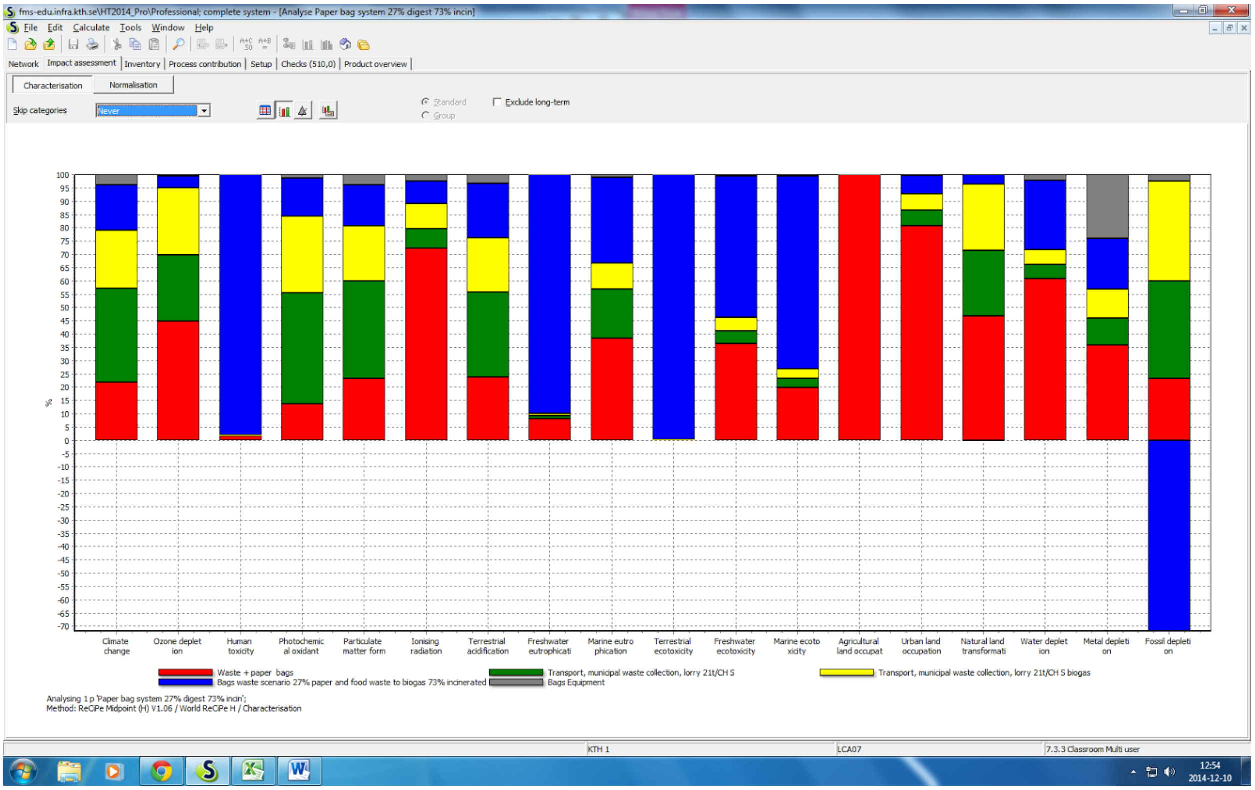


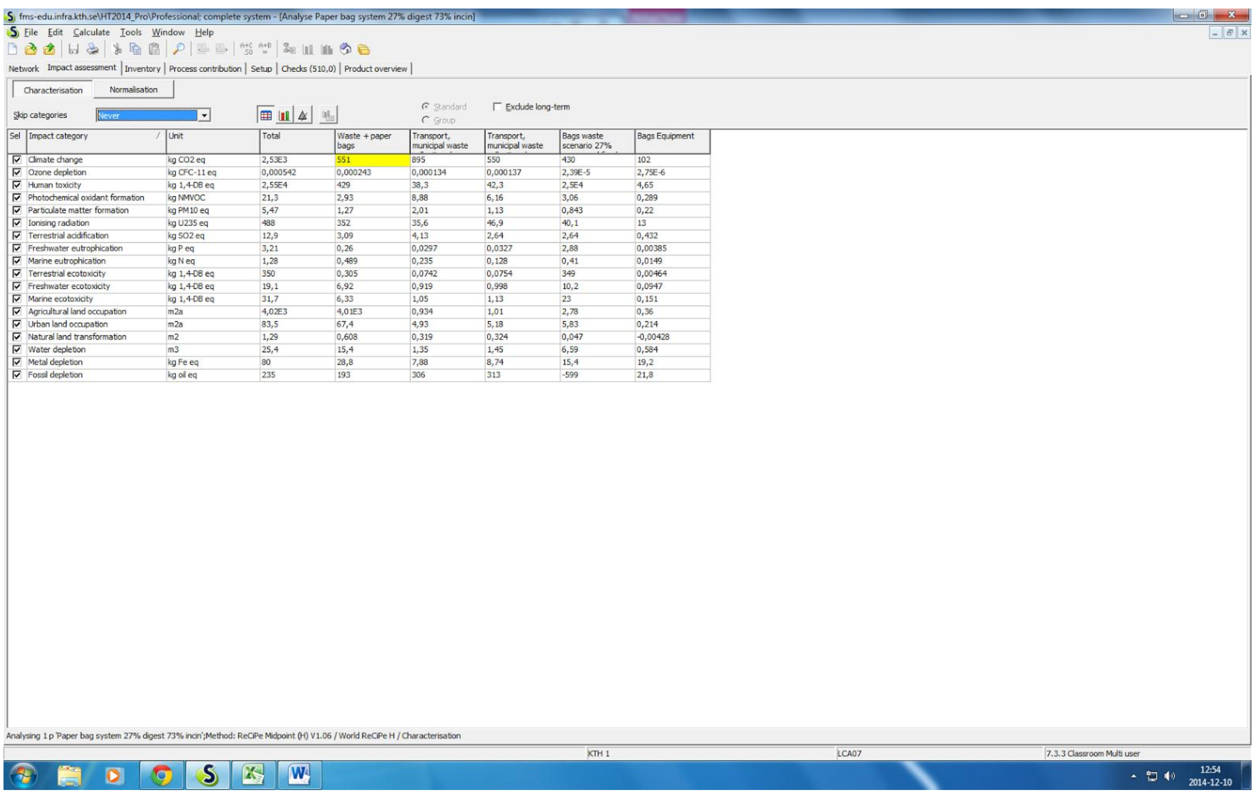
Sel	Impact category	Unit	Total	Waste + plastic bags	Transport, municipal waste	Transport, municipal waste	Plastic bags waste scenario 100% to	Bags Equipment
☑	Climate change		0,425	0,173	0,12	0,0735	0,0449	0,0148
☑	Ozone depletion		0,00841	0,000829	0,00329	0,00336	0,000858	7,3E-5
☑	Human toxicity		7,02	2,02	0,301	0,332	4,33	0,0396
☑	Photochemical oxidant formation		0,488	0,0924	0,167	0,116	0,106	0,00591
☑	Particulate matter formation		0,417	0,11	0,132	0,0738	0,0862	0,0156
☑	Ionising radiation		0,304	0,205	0,0249	0,0328	0,032	0,00986
☑	Terrestrial acidification		0,367	0,115	0,0997	0,0638	0,0774	0,0113
☑	Freshwater eutrophication		2,66	1,16	0,0944	0,104	1,29	0,0133
☑	Marine eutrophication		0,142	0,0253	0,0295	0,016	0,0691	0,00203
☑	Terrestrial ecotoxicity		0,0408	0,00727	0,0105	0,0107	0,0117	0,000714
☑	Freshwater ecotoxicity		3,61	1,19	0,195	0,212	1,99	0,0218
☑	Marine ecotoxicity		6,06	2,09	0,401	0,433	3,08	0,0625
☑	Agricultural land occupation		0,0477	0,0469	0,000159	0,000171	0,000441	6,63E-5
☑	Urban land occupation		0,0271	0,00798	0,00586	0,00616	0,00681	0,000277
☑	Natural land transformation		0,0578	0,00824	0,0244	0,0248	0,000734	-0,000356
☑	Water depletion		0	0	0	0	0	0
☑	Metal depletion		0,14	0,0297	0,0163	0,0181	0,0327	0,0432
☑	Fossil depletion		1,01	0,519	0,205	0,21	0,0626	0,0159

Paper Bags system 27% digestion 73% incineration



Paper Bags system 27% digestion 73% incineration Characterisation Inventory

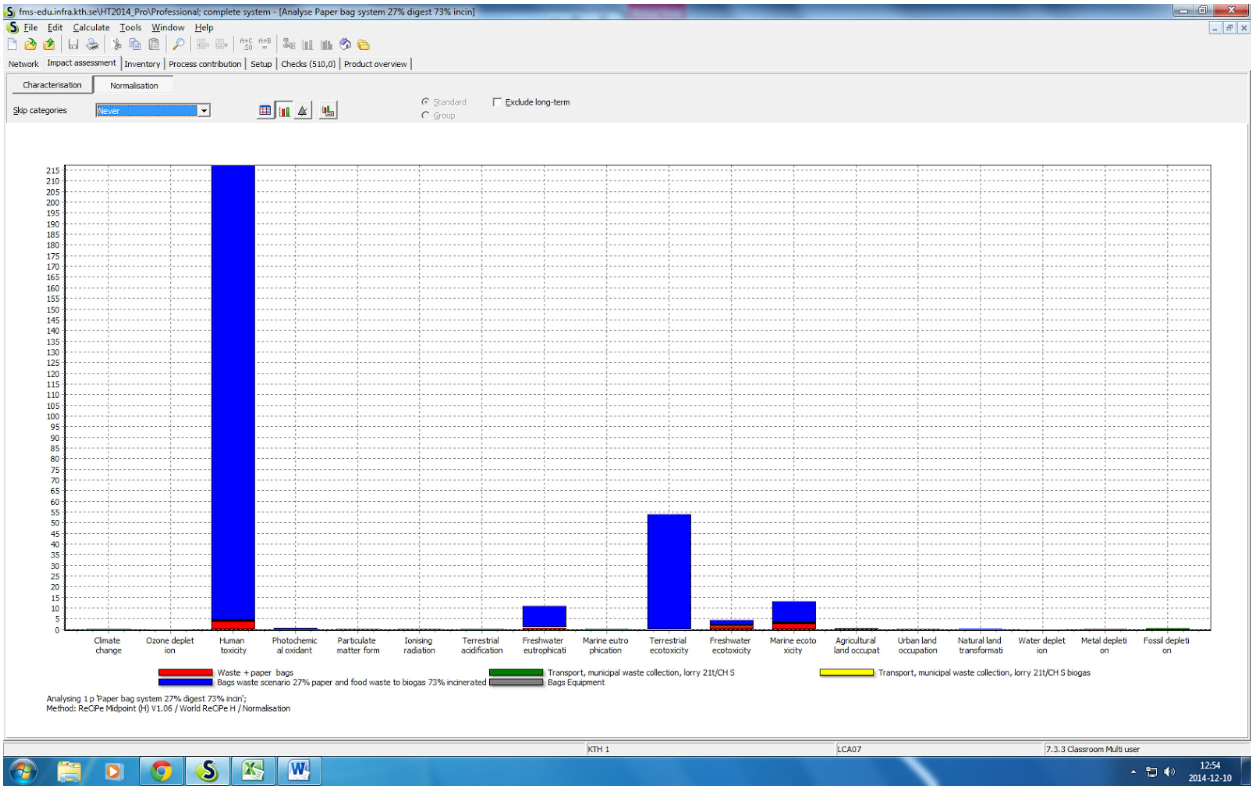


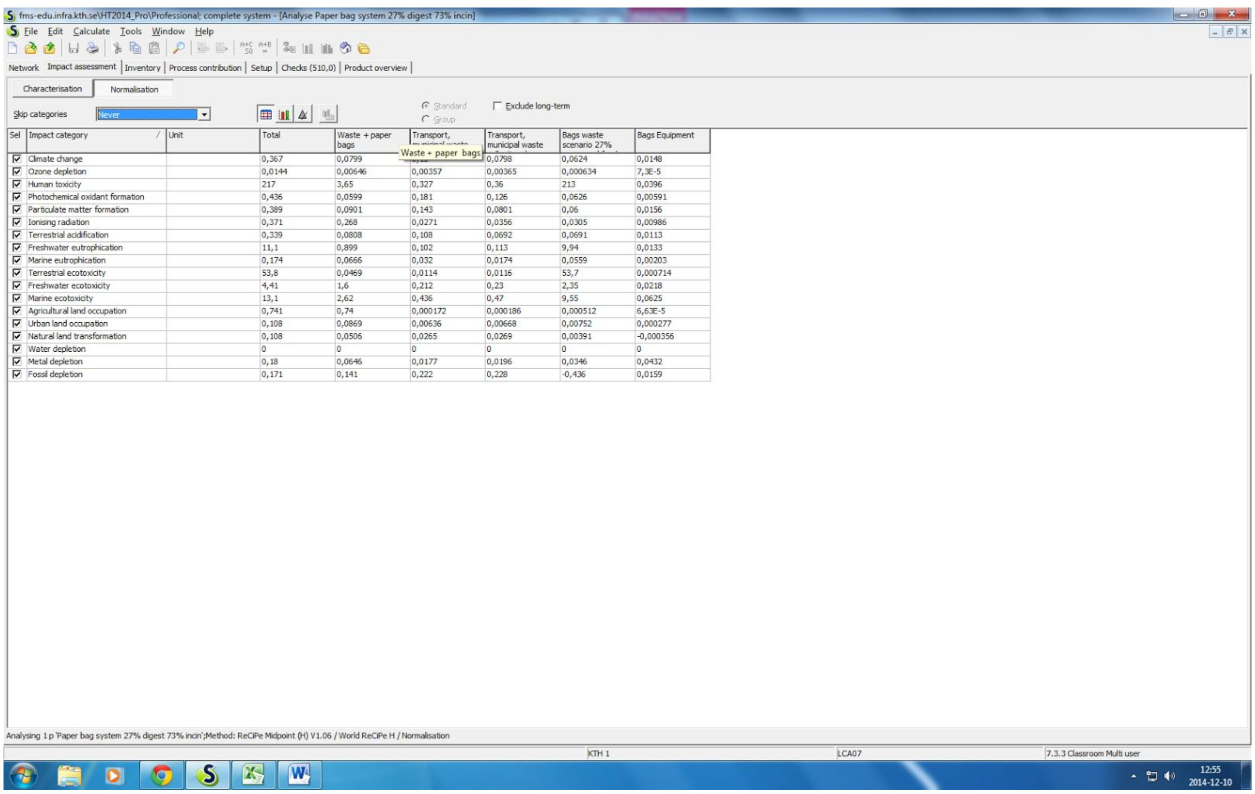


Sel	Impact category	Unit	Total	Waste + paper bags	Transport, municipal waste	Transport, municipal waste	Bags waste scenario 27%	Bags Equipment
☑	Climate change	kg CO2 eq	2,53E3	551	895	550	430	102
☑	Ozone depletion	kg CFC-11 eq	0,000542	0,000243	0,000134	0,000137	2,39E-5	2,75E-6
☑	Human toxicity	kg 1,4-DB eq	2,55E4	429	38,3	42,3	2,5E4	4,65
☑	Photochemical oxidant formation	kg NMVOC	21,3	2,93	8,88	6,16	3,06	0,289
☑	Particulate matter formation	kg PM10 eq	5,47	1,27	2,01	1,13	0,843	0,22
☑	Ionising radiation	kg U235 eq	488	352	35,6	46,9	40,1	13
☑	Terrestrial acidification	kg SO2 eq	12,9	3,09	4,13	2,64	2,64	0,432
☑	Freshwater eutrophication	kg P eq	3,21	0,26	0,0297	0,0327	2,88	0,00385
☑	Marine eutrophication	kg N eq	1,28	0,489	0,235	0,128	0,41	0,0149
☑	Terrestrial ecotoxicity	kg 1,4-DB eq	350	0,305	0,0742	0,0754	349	0,00464
☑	Freshwater ecotoxicity	kg 1,4-DB eq	19,1	6,92	0,919	0,998	10,2	0,0947
☑	Marine ecotoxicity	kg 1,4-DB eq	31,7	6,33	1,05	1,13	23	0,151
☑	Agricultural land occupation	m2a	4,02E3	4,01E3	0,934	1,01	2,78	0,36
☑	Urban land occupation	m2a	83,5	67,4	4,93	5,18	5,83	0,214
☑	Natural land transformation	m2	1,29	0,608	0,319	0,324	0,047	-0,00428
☑	Water depletion	m3	25,4	15,4	1,35	1,45	6,59	0,584
☑	Metal depletion	kg Fe eq	80	28,8	7,88	8,74	15,4	19,2
☑	Fossil depletion	kg oil eq	235	193	306	313	-599	21,8

Analysing 1 p 'Paper bag system 27% digest 73% incin';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

Paper Bags system 27% digestion 73% incineration Normalisation Inventory

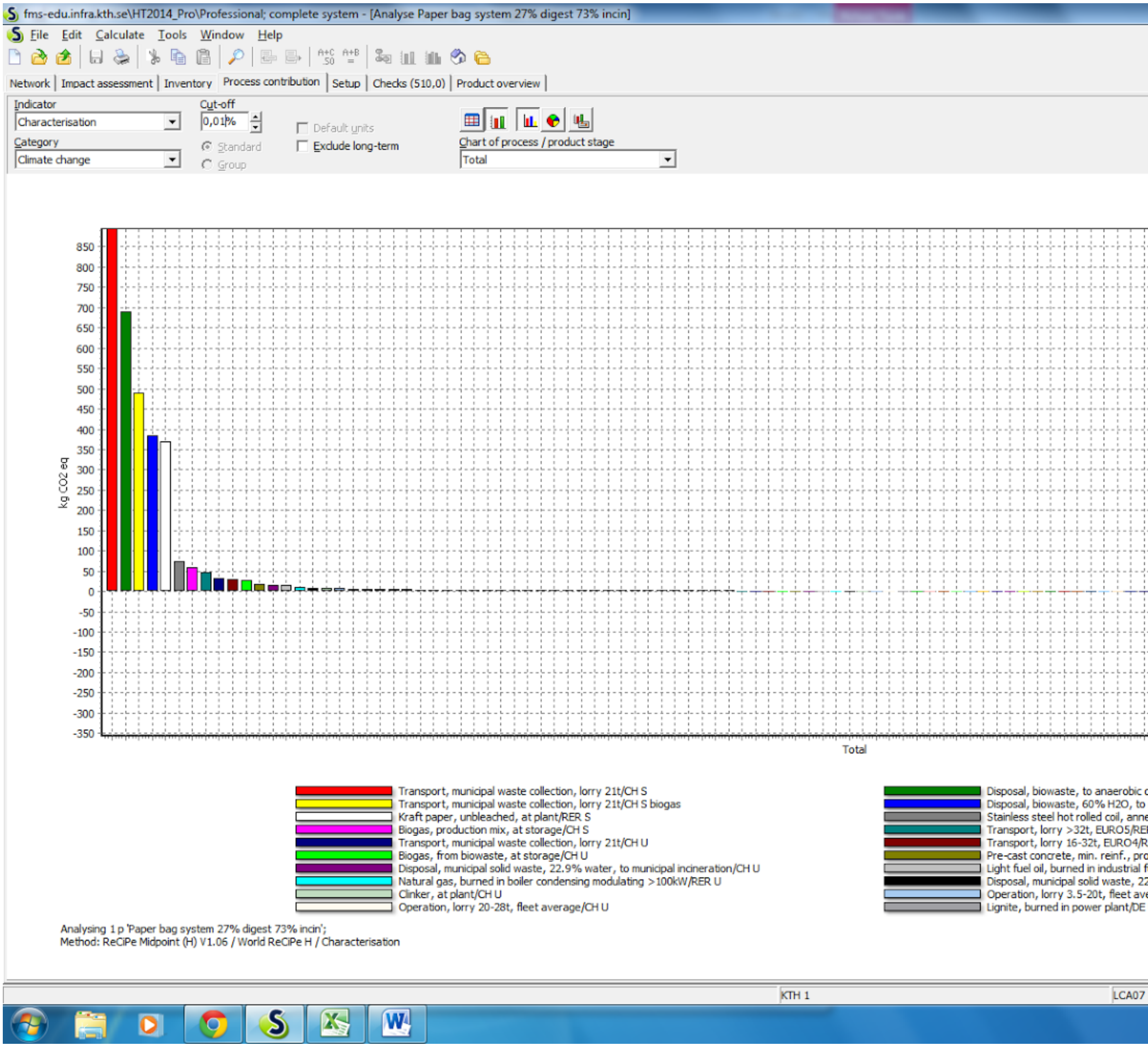




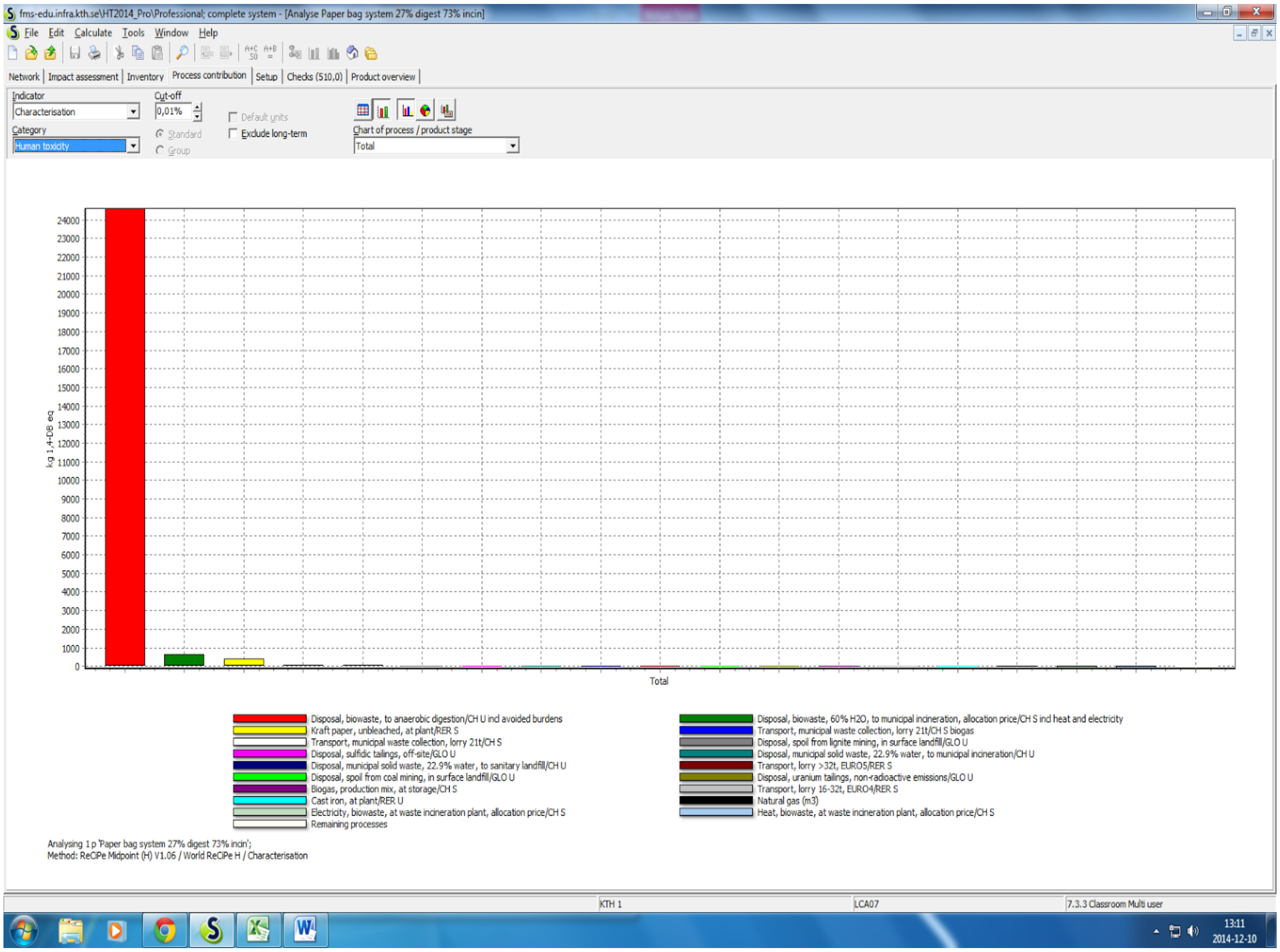
Sel	Impact category	Unit	Total	Waste + paper bags	Transport, municipal waste ...	Transport, municipal waste ...	Bags waste scenario 27% ...	Bags Equipment
☑	Climate change		0,367	0,0799	[illegible]	0,0798	0,0624	0,0148
☑	Ozone depletion		0,0144	0,00646	0,00357	0,00365	0,000634	7,3E-5
☑	Human toxicity		217	3,65	0,327	0,36	213	0,0396
☑	Photochemical oxidant formation		0,436	0,0599	0,181	0,126	0,0626	0,00591
☑	Particulate matter formation		0,389	0,0901	0,143	0,0801	0,06	0,0156
☑	Ionising radiation		0,371	0,268	0,0271	0,0356	0,0305	0,00986
☑	Terrestrial acidification		0,339	0,0808	0,108	0,0692	0,0691	0,0113
☑	Freshwater eutrophication		11,1	0,899	0,102	0,113	9,94	0,0133
☑	Marine eutrophication		0,174	0,0666	0,032	0,0174	0,0559	0,00203
☑	Terrestrial ecotoxicity		53,8	0,0469	0,0114	0,0116	53,7	0,000714
☑	Freshwater ecotoxicity		4,41	1,6	0,212	0,23	2,35	0,0218
☑	Marine ecotoxicity		13,1	2,62	0,436	0,47	9,55	0,0625
☑	Agricultural land occupation		0,741	0,74	0,000172	0,000186	0,000512	6,63E-5
☑	Urban land occupation		0,108	0,0869	0,00636	0,00668	0,00752	0,000277
☑	Natural land transformation		0,108	0,0506	0,0265	0,0269	0,00391	-0,000356
☑	Water depletion		0	0	0	0	0	0
☑	Metal depletion		0,18	0,0646	0,0177	0,0196	0,0346	0,0432
☑	Fossil depletion		0,171	0,141	0,222	0,228	-0,436	0,0159

Analysing 1 p 'Paper bag system 27% digest 73% incin';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Normalisation

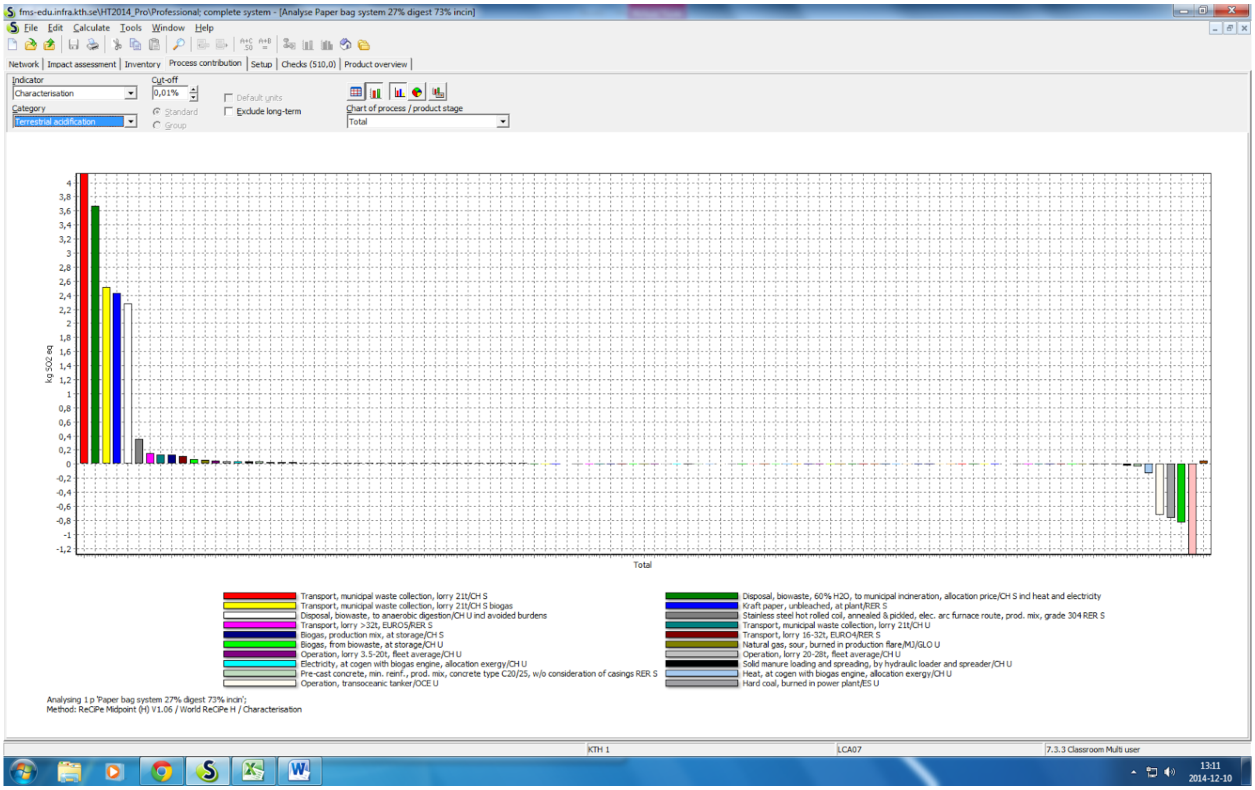
Paper Bags system 27% digestion 73% incineration Characterisation Process contribution to Climate change



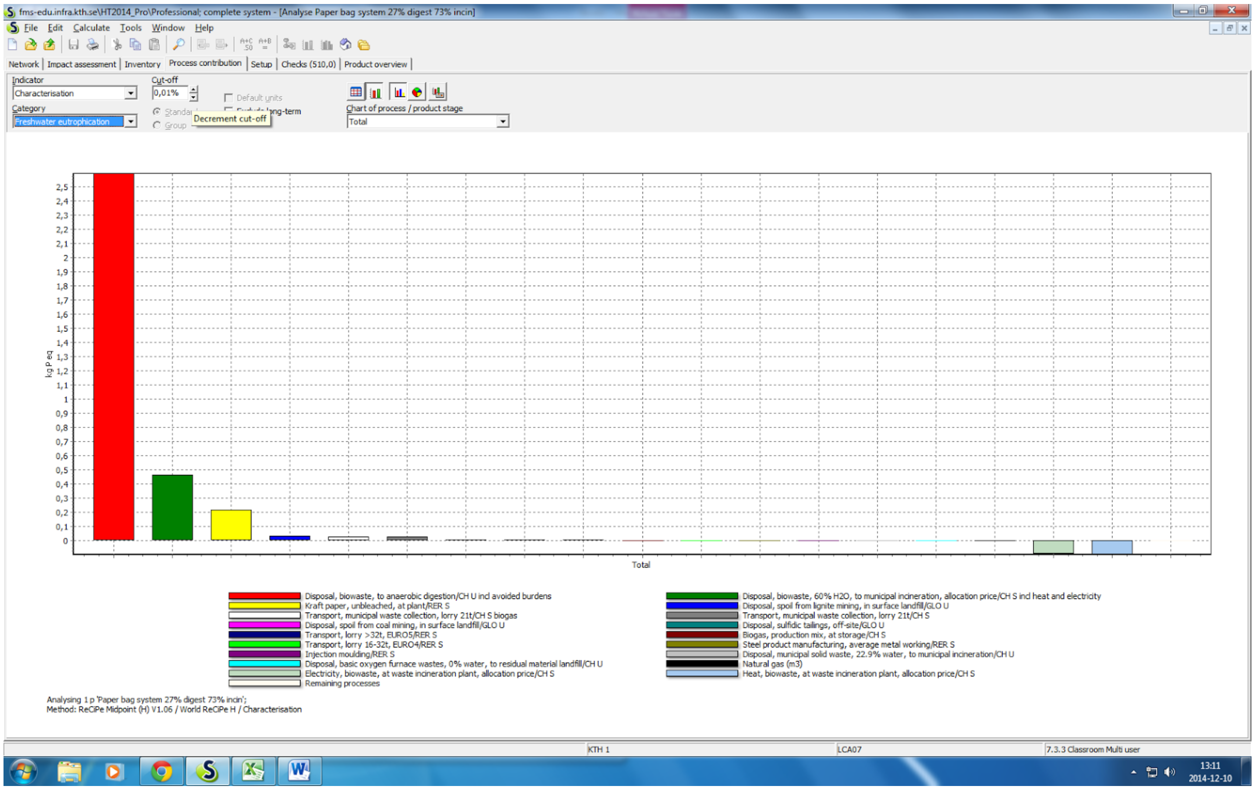
Paper Bags system 27% digestion 73% incineration Characterisation Process contribution to Human tox



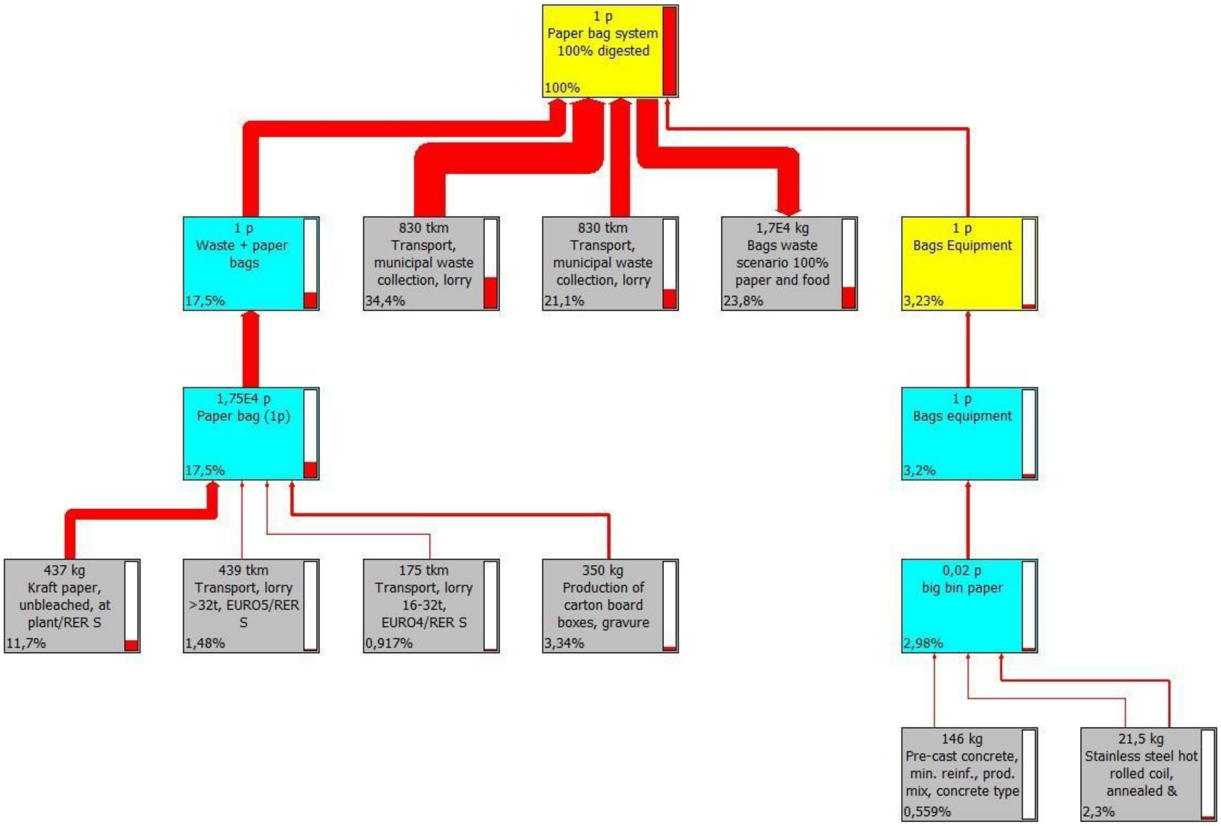
Paper Bags system 27% digestion 73% incineration Characterisation Process contribution to Climate change to Terrestrial acidif



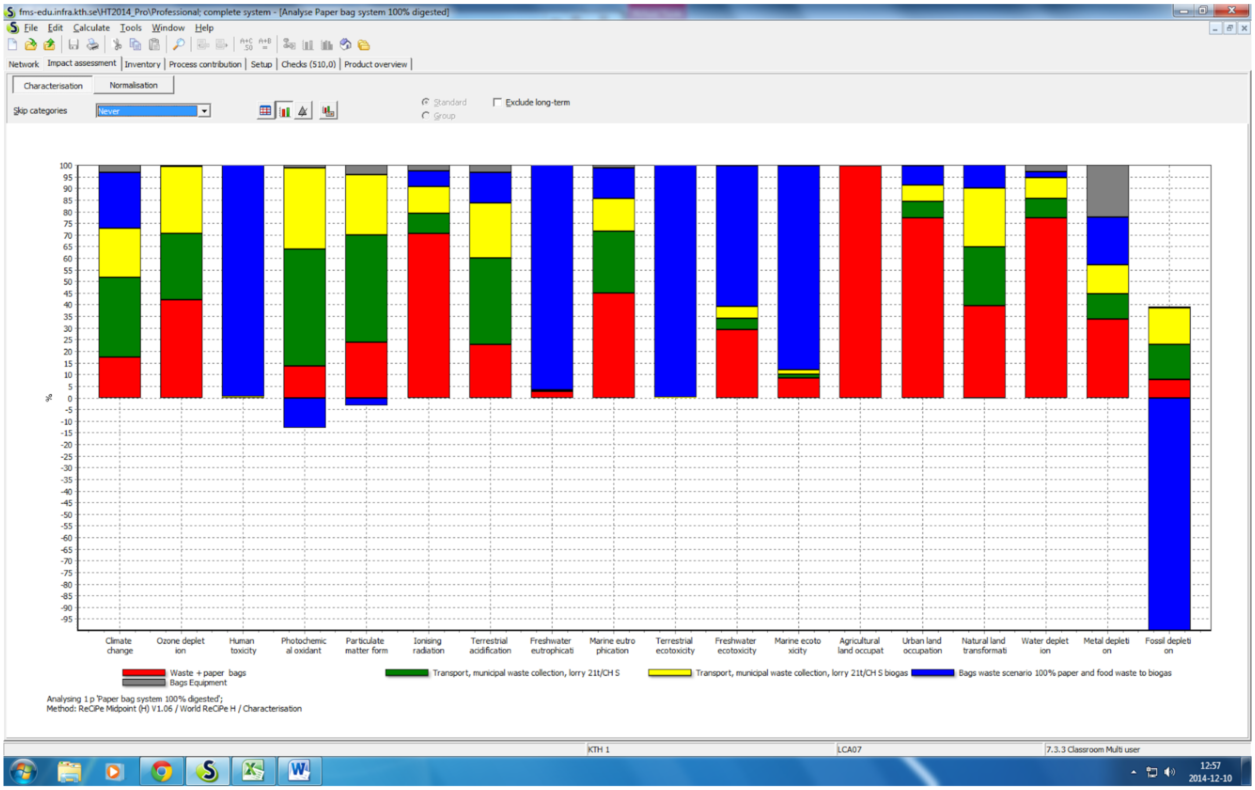
Paper Bags system 27% digestion 73% incineration Characterisation Process contribution to Climate change to Freshwater eutrophication

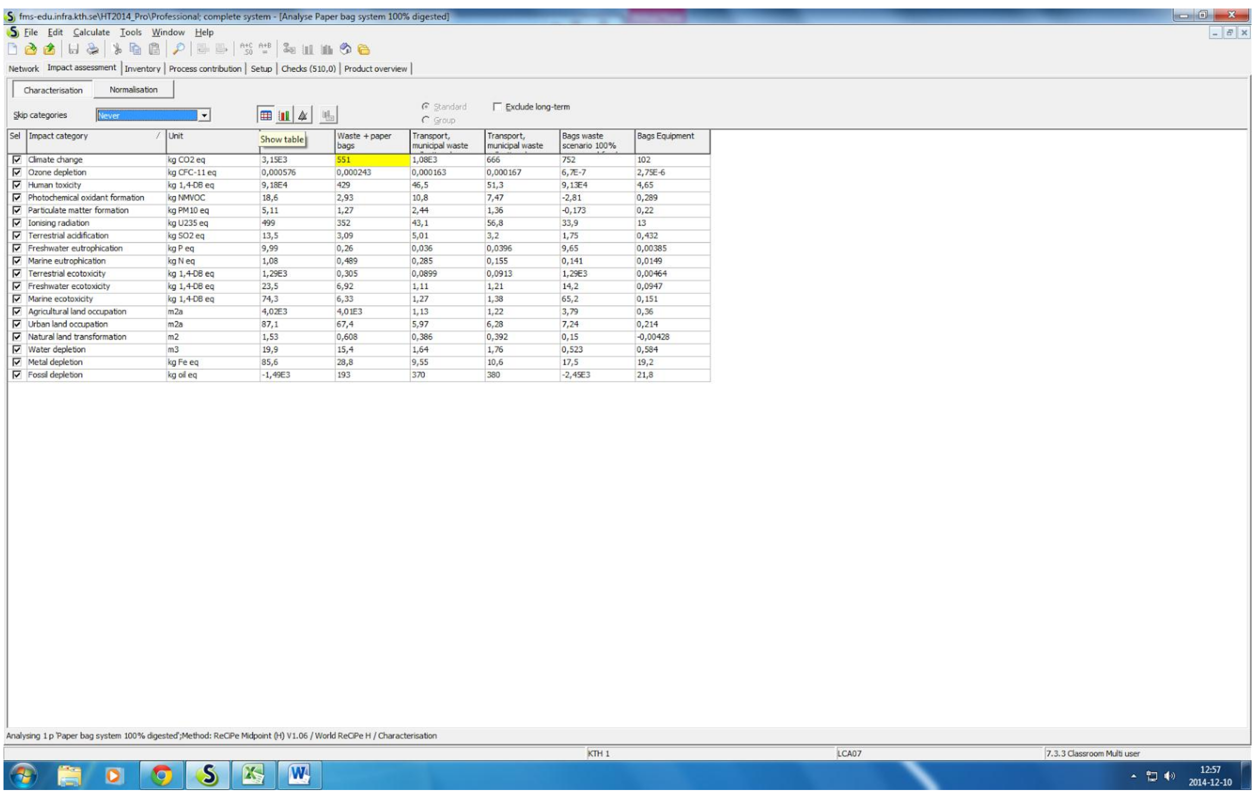


Paper Bags 100% digestion



Paper Bags 100% digestion Characterisation Inventory

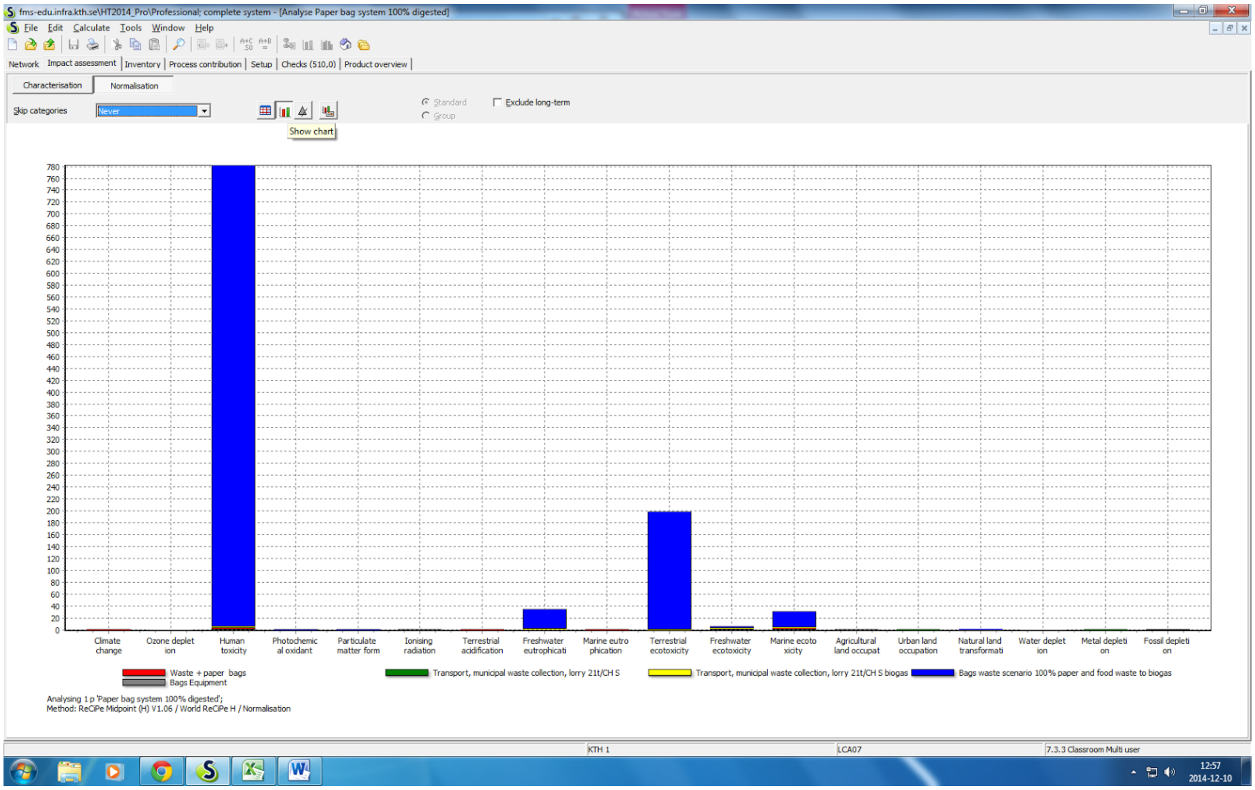


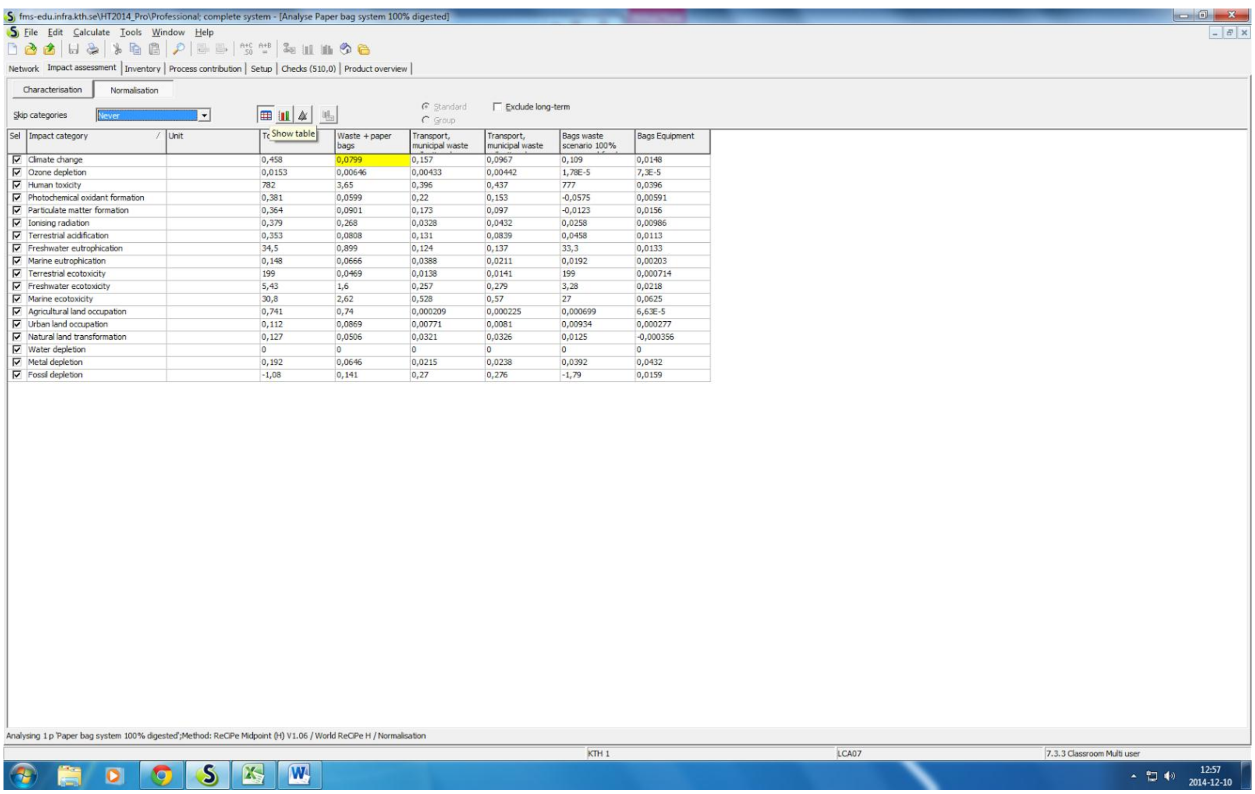


Sel	Impact category	Unit		Waste + paper bags	Transport, municipal waste	Transport, municipal waste	Bags waste scenario 100%	Bags Equipment
☑	Climate change	kg CO2 eq	3,15E3	551	1,08E3	666	752	102
☑	Ozone depletion	kg CFC-11 eq	0,000576	0,000243	0,000163	0,000167	6,7E-7	2,75E-6
☑	Human toxicity	kg 1,4-DB eq	9,18E4	429	46,5	51,3	9,13E4	4,65
☑	Photochemical oxidant formation	kg NMVOC	18,6	2,93	10,8	7,47	-2,81	0,289
☑	Particulate matter formation	kg PM10 eq	5,11	1,27	2,44	1,36	-0,173	0,22
☑	Ionising radiation	kg U235 eq	499	352	43,1	56,8	33,9	13
☑	Terrestrial acidification	kg SO2 eq	13,5	3,09	5,01	3,2	1,75	0,432
☑	Freshwater eutrophication	kg P eq	9,99	0,26	0,036	0,0396	9,65	0,00385
☑	Marine eutrophication	kg N eq	1,08	0,489	0,285	0,155	0,141	0,0149
☑	Terrestrial ecotoxicity	kg 1,4-DB eq	1,29E3	0,305	0,0899	0,0913	1,29E3	0,00464
☑	Freshwater ecotoxicity	kg 1,4-DB eq	23,5	6,92	1,11	1,21	14,2	0,0947
☑	Marine ecotoxicity	kg 1,4-DB eq	74,3	6,33	1,27	1,38	65,2	0,151
☑	Agricultural land occupation	m2a	4,02E3	4,01E3	1,13	1,22	3,79	0,36
☑	Urban land occupation	m2a	87,1	67,4	5,97	6,28	7,24	0,214
☑	Natural land transformation	m2	1,53	0,608	0,386	0,392	0,15	-0,00428
☑	Water depletion	m3	19,9	15,4	1,64	1,76	0,523	0,584
☑	Metal depletion	kg Fe eq	85,6	28,8	9,55	10,6	17,5	19,2
☑	Fossil depletion	kg oil eq	-1,49E3	193	370	380	-2,45E3	21,8

Analysing 1 p 'Paper bag system 100% digested';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

Paper Bags 100% digestion Normalisation Inventory

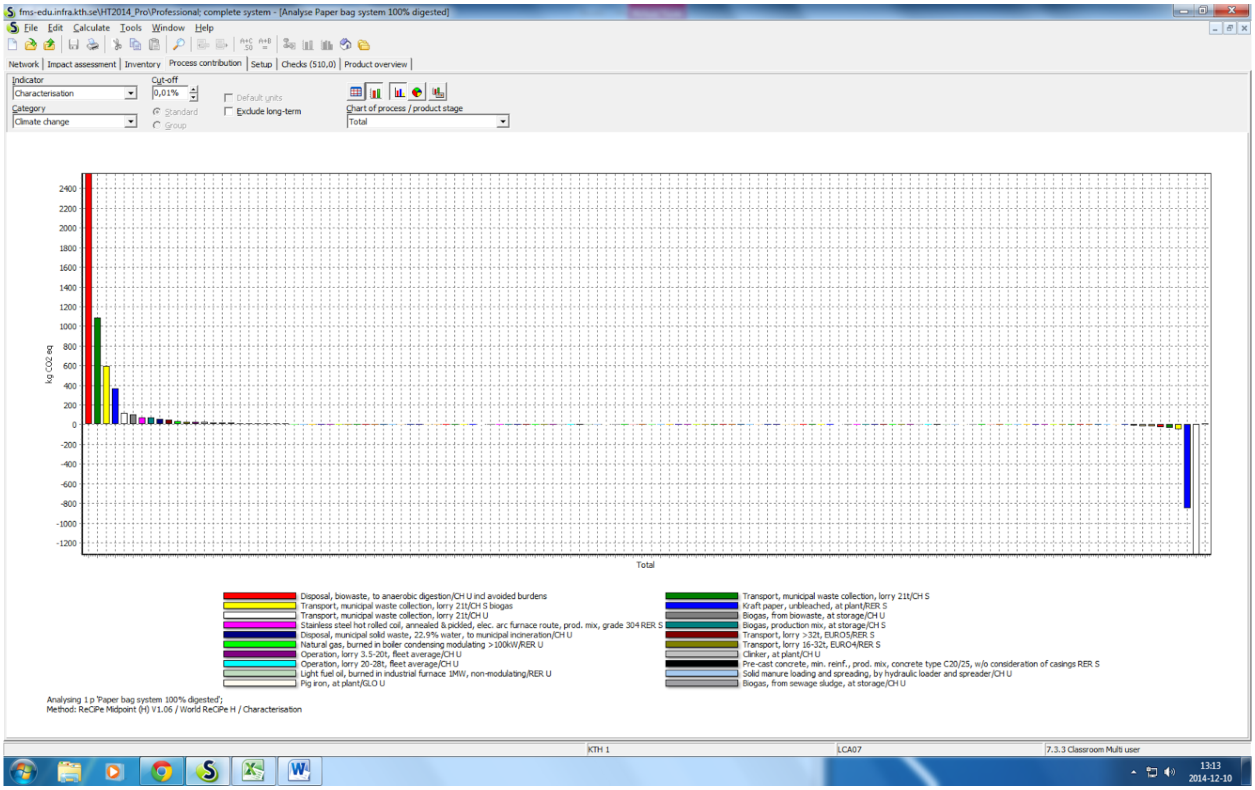




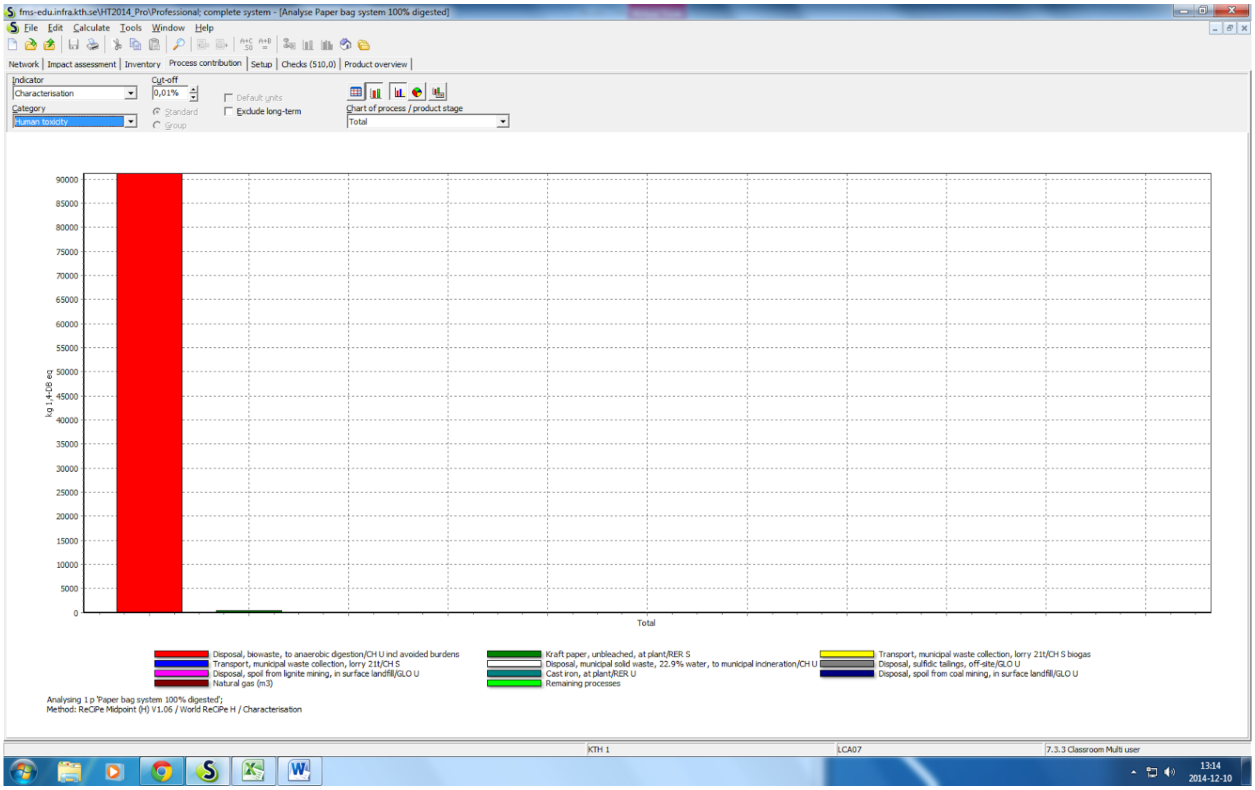
Sel	Impact category	Unit	Tc Show table	Waste + paper bags	Transport, municipal waste	Transport, municipal waste	Bags waste scenario 100%	Bags Equipment
☑	Climate change		0,458	0,0799	0,157	0,0967	0,109	0,0148
☑	Ozone depletion		0,0153	0,00646	0,00433	0,00442	1,78E-5	7,3E-5
☑	Human toxicity		782	3,65	0,396	0,437	777	0,0396
☑	Photochemical oxidant formation		0,381	0,0599	0,22	0,153	-0,0575	0,00591
☑	Particulate matter formation		0,364	0,0901	0,173	0,097	-0,0123	0,0156
☑	Ionising radiation		0,379	0,268	0,0328	0,0432	0,0258	0,00986
☑	Terrestrial acidification		0,353	0,0808	0,131	0,0839	0,0458	0,0113
☑	Freshwater eutrophication		34,5	0,899	0,124	0,137	33,3	0,0133
☑	Marine eutrophication		0,148	0,0666	0,0388	0,0211	0,0192	0,00203
☑	Terrestrial ecotoxicity		199	0,0469	0,0138	0,0141	199	0,000714
☑	Freshwater ecotoxicity		5,43	1,6	0,257	0,279	3,28	0,0218
☑	Marine ecotoxicity		30,8	2,62	0,528	0,57	27	0,0625
☑	Agricultural land occupation		0,741	0,74	0,000209	0,000225	0,000699	6,63E-5
☑	Urban land occupation		0,112	0,0869	0,00771	0,0081	0,00934	0,000277
☑	Natural land transformation		0,127	0,0506	0,0321	0,0326	0,0125	-0,000356
☑	Water depletion		0	0	0	0	0	0
☑	Metal depletion		0,192	0,0646	0,0215	0,0238	0,0392	0,0432
☑	Fossil depletion		-1,08	0,141	0,27	0,276	-1,79	0,0159

Analysing 1 p 'Paper bag system 100% digested';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Normalisation

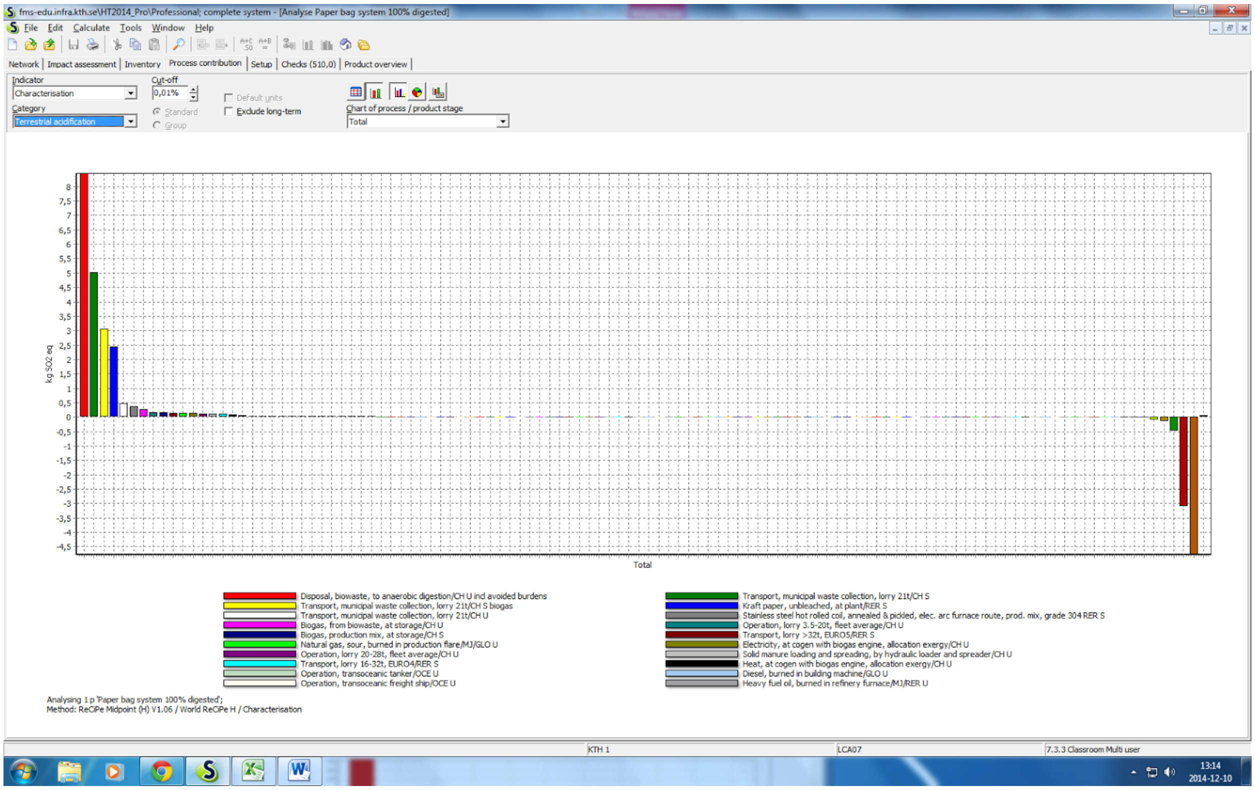
Paper Bags 100% digestion Characterisation process contrib to Climate change



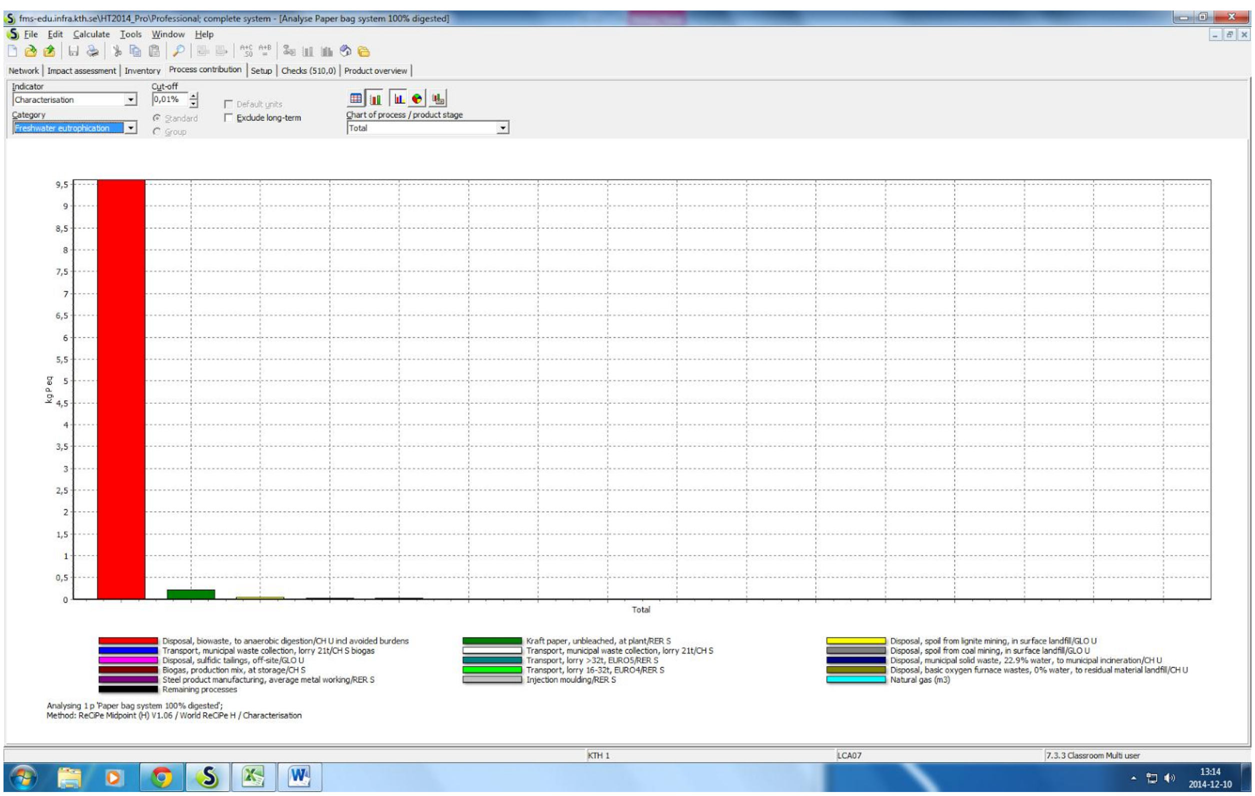
Paper Bags 100% digestion Characterisation process contrib to Human tox



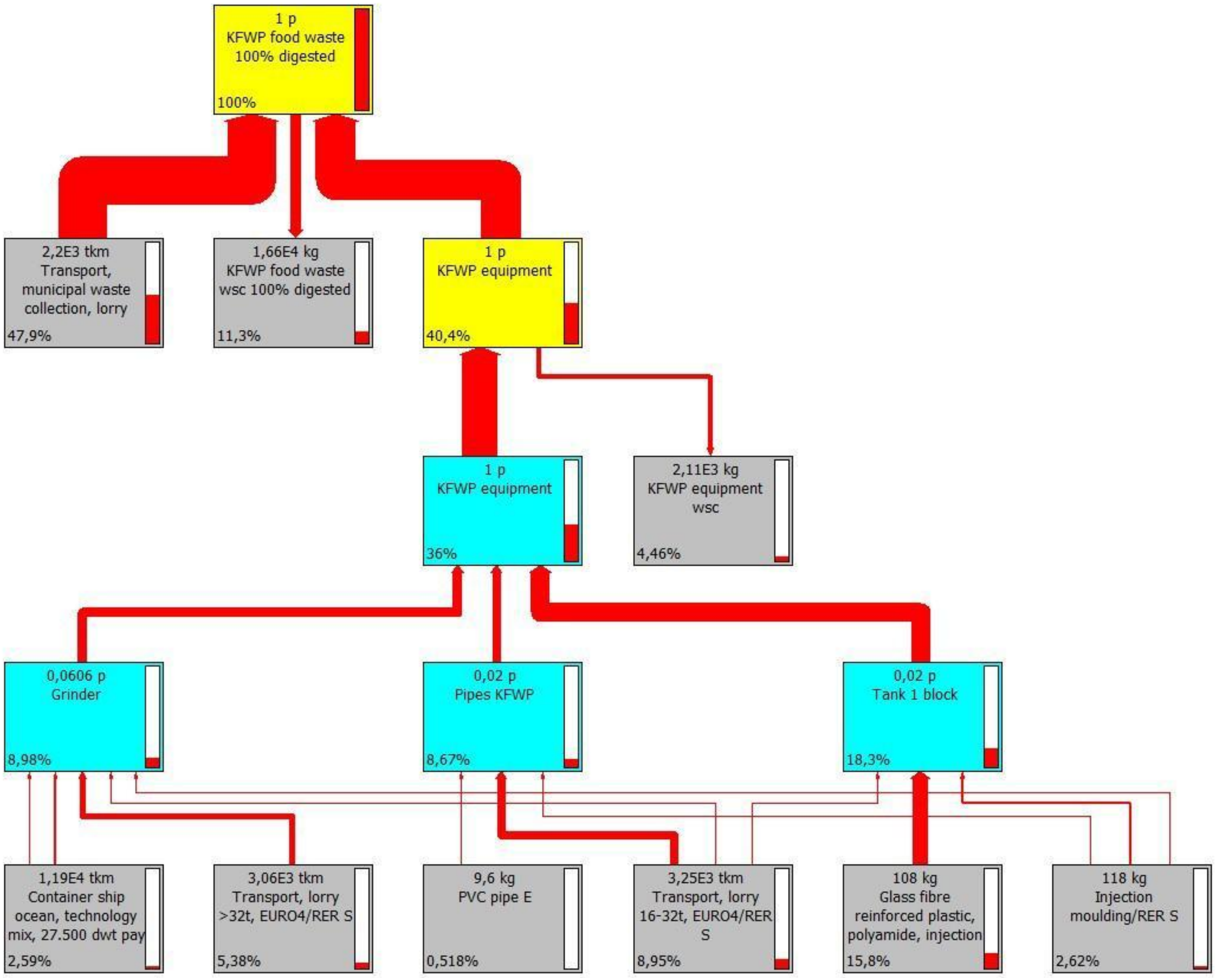
Paper Bags 100% digestion Characterisation process contrib to Terrestrial acidif



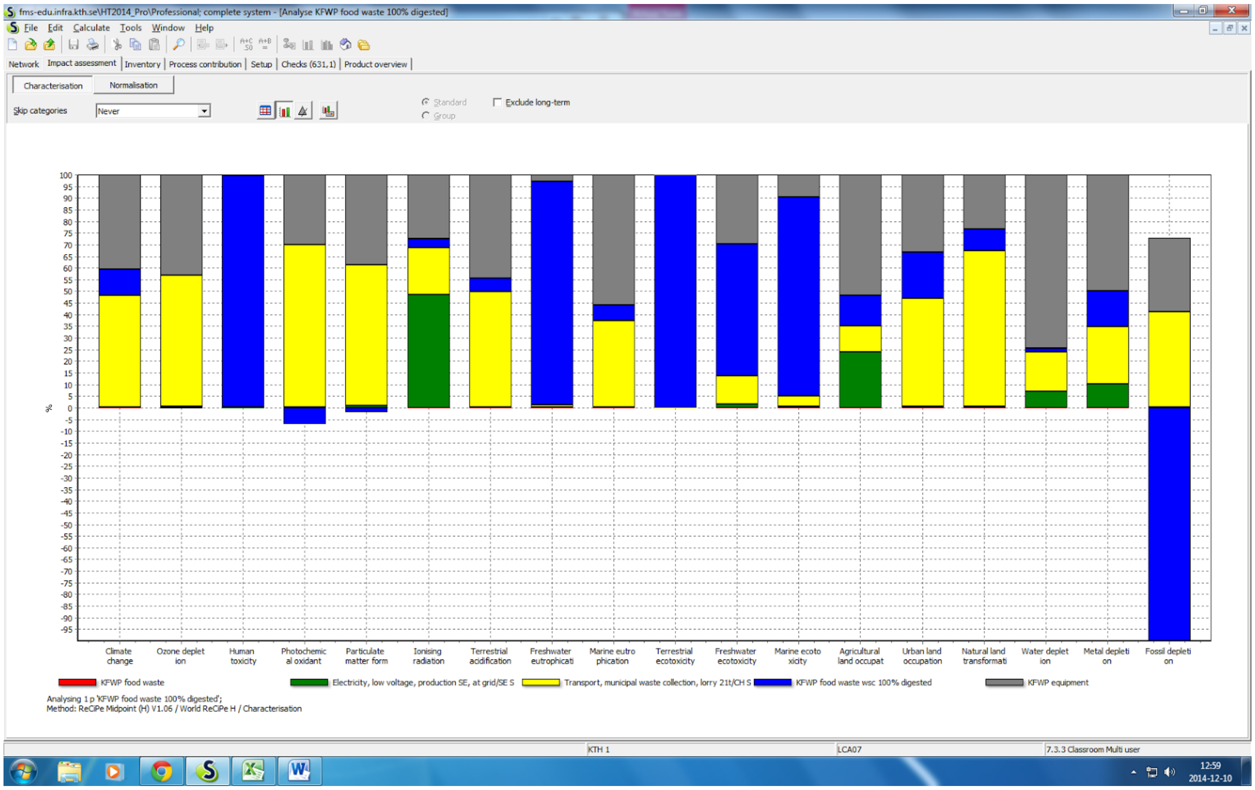
Paper Bags 100% digestion Characterisation process contrib to freshwater eutroph



KFWP System 100% digestion



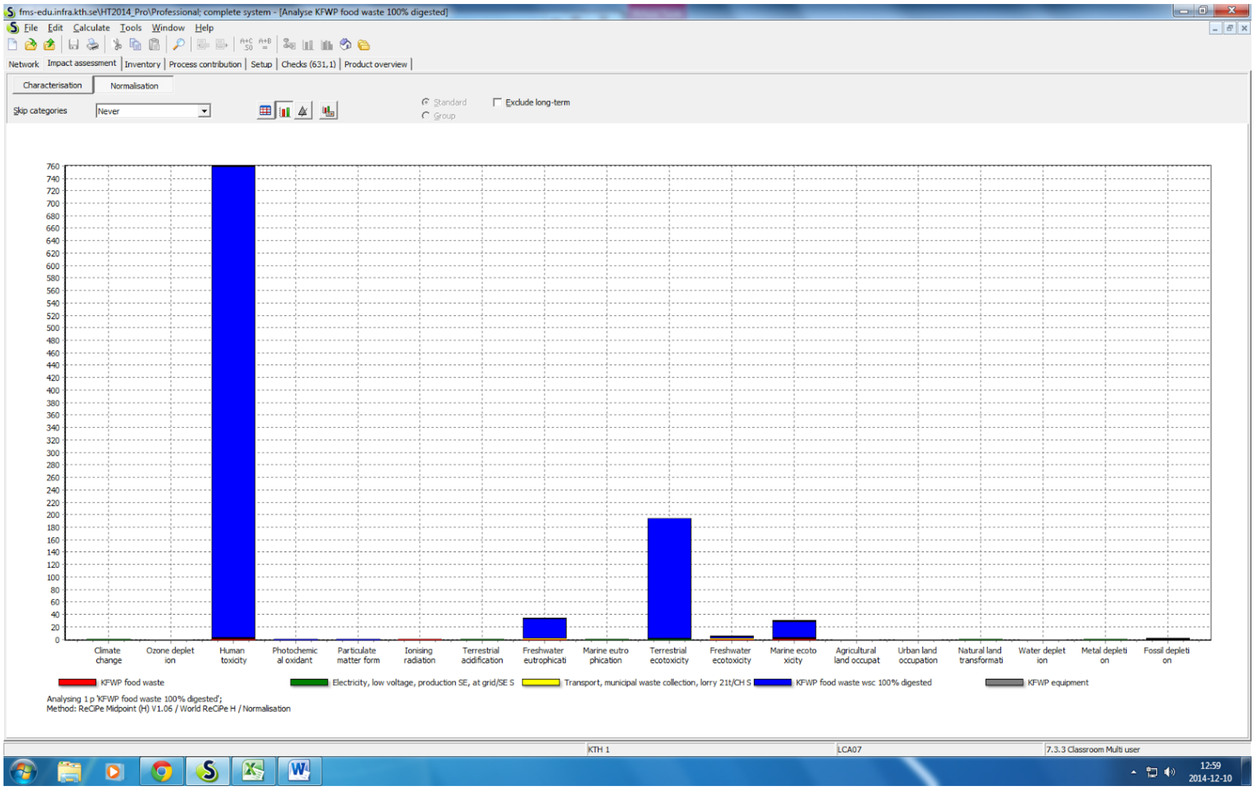
KFWP System 100% digestion Characterisation inventory

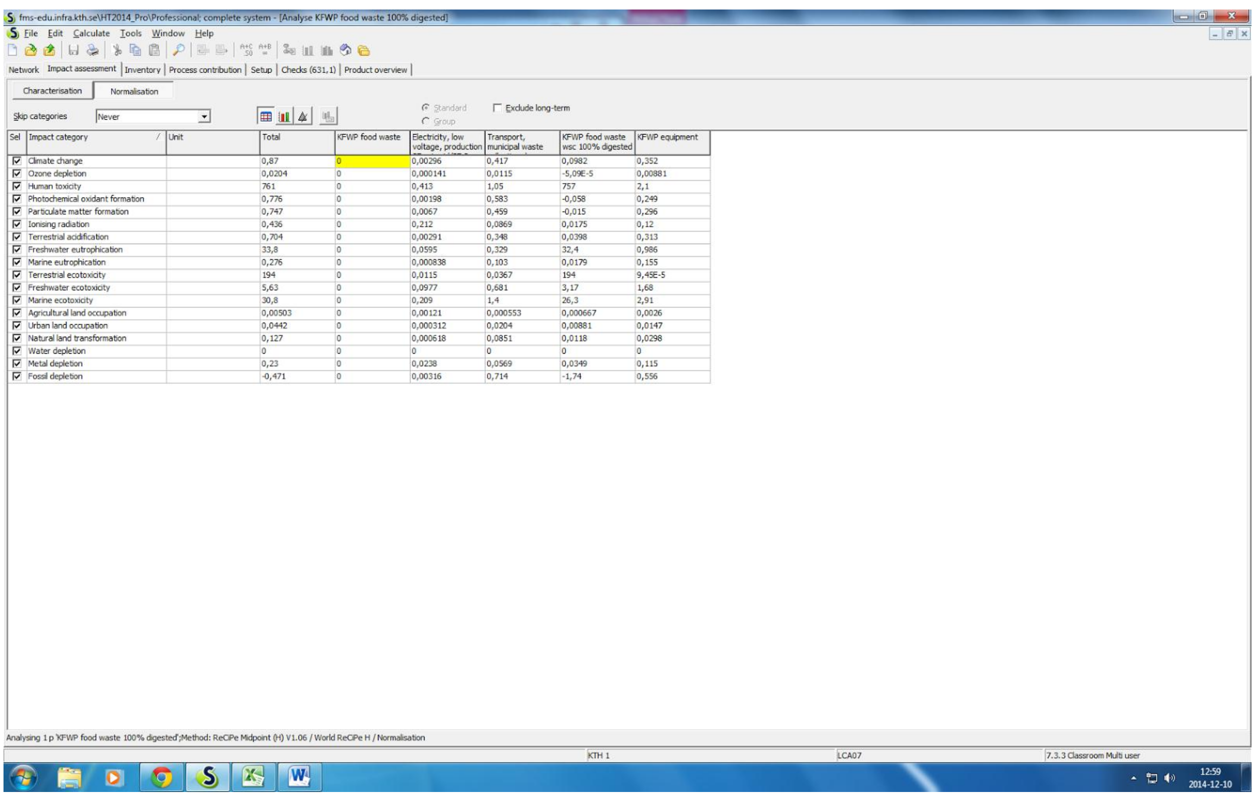


Sel	Impact category	Unit	Show table	KFWP food waste	Electricity, low voltage, production	Transport, municipal waste	KFWP food waste wsc 100% digested	KFWP equipment
☑	Climate change	kg CO2 eq	6E3	0	20,4	2,88E3	677	2,42E3
☑	Ozone depletion	kg CFC-11 eq	0,000767	0	5,31E-6	0,000432	-1,92E-6	0,000332
☑	Human toxicity	kg 1,4-DB eq	8,93E4	0	48,5	123	8,89E4	246
☑	Photochemical oxidant formation	kg NMVOC	38	0	0,097	28,5	-2,84	12,2
☑	Particulate matter formation	kg PM10 eq	10,5	0	0,0942	6,46	-0,21	4,16
☑	Ionising radiation	kg U235 eq	574	0	279	114	23	157
☑	Terrestrial acidification	kg SO2 eq	26,9	0	0,111	13,3	1,52	12
☑	Freshwater eutrophication	kg P eq	9,8	0	0,0173	0,0954	9,4	0,286
☑	Marine eutrophication	kg N eq	2,03	0	0,00615	0,754	0,131	1,14
☑	Terrestrial ecotoxicity	kg 1,4-DB eq	1,26E3	0	0,075	0,238	1,26E3	0,000614
☑	Freshwater ecotoxicity	kg 1,4-DB eq	24,4	0	0,423	2,95	13,8	7,26
☑	Marine ecotoxicity	kg 1,4-DB eq	74,3	0	0,505	3,38	63,4	7,02
☑	Agricultural land occupation	m2a	27,3	0	6,56	3	3,62	14,1
☑	Urban land occupation	m2a	34,3	0	0,242	15,8	6,83	11,4
☑	Natural land transformation	m2	1,53	0	0,00743	1,02	0,141	0,358
☑	Water depletion	m3	25,6	0	1,8	4,34	0,418	19,1
☑	Metal depletion	kg Fe eq	103	0	10,6	25,3	15,5	51,2
☑	Fossil depletion	kg oil eq	-648	0	4,34	981	-2,4E3	764

Analysing 1 p 'KFWP food waste 100% digested';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

KFWP System 100% digestion Normalisation inventory

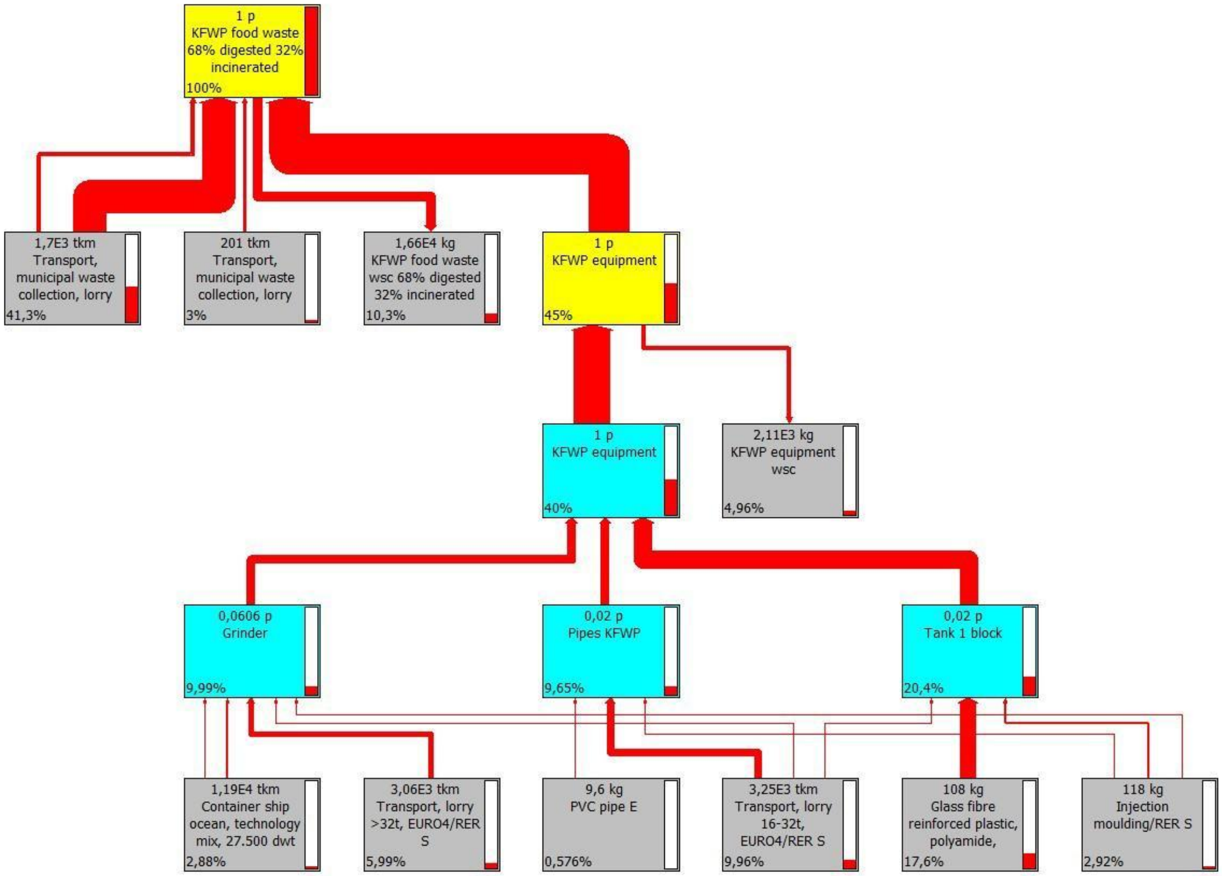




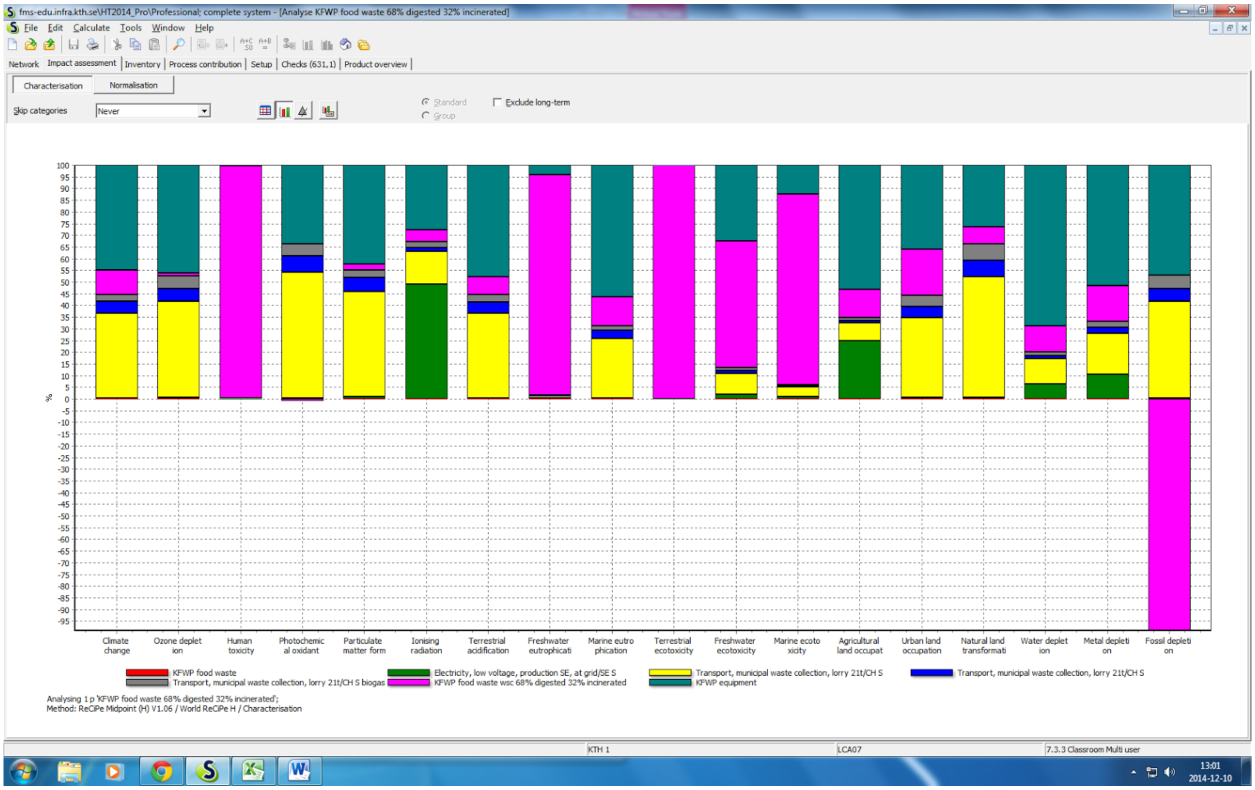
Sel	Impact category	Unit	Total	KFWP food waste	Electricity, low voltage, production	Transport, municipal waste	KFWP food waste wsc 100% digested	KFWP equipment
☑	Climate change		0,87	0	0,00296	0,417	0,0982	0,352
☑	Ozone depletion		0,0204	0	0,000141	0,0115	-5,09E-5	0,00881
☑	Human toxicity		761	0	0,413	1,05	757	2,1
☑	Photochemical oxidant formation		0,776	0	0,00198	0,583	-0,058	0,249
☑	Particulate matter formation		0,747	0	0,0067	0,459	-0,015	0,296
☑	Ionising radiation		0,436	0	0,212	0,0869	0,0175	0,12
☑	Terrestrial acidification		0,704	0	0,00291	0,348	0,0398	0,313
☑	Freshwater eutrophication		33,8	0	0,0595	0,329	32,4	0,986
☑	Marine eutrophication		0,276	0	0,000838	0,103	0,0179	0,155
☑	Terrestrial ecotoxicity		194	0	0,0115	0,0367	194	9,45E-5
☑	Freshwater ecotoxicity		5,63	0	0,0977	0,681	3,17	1,68
☑	Marine ecotoxicity		30,8	0	0,209	1,4	26,3	2,91
☑	Agricultural land occupation		0,00503	0	0,00121	0,000553	0,000667	0,0026
☑	Urban land occupation		0,0442	0	0,000312	0,0204	0,00881	0,0147
☑	Natural land transformation		0,127	0	0,000618	0,0851	0,0118	0,0298
☑	Water depletion		0	0	0	0	0	0
☑	Metal depletion		0,23	0	0,0238	0,0569	0,0349	0,115
☑	Fossil depletion		-0,471	0	0,00316	0,714	-1,74	0,556

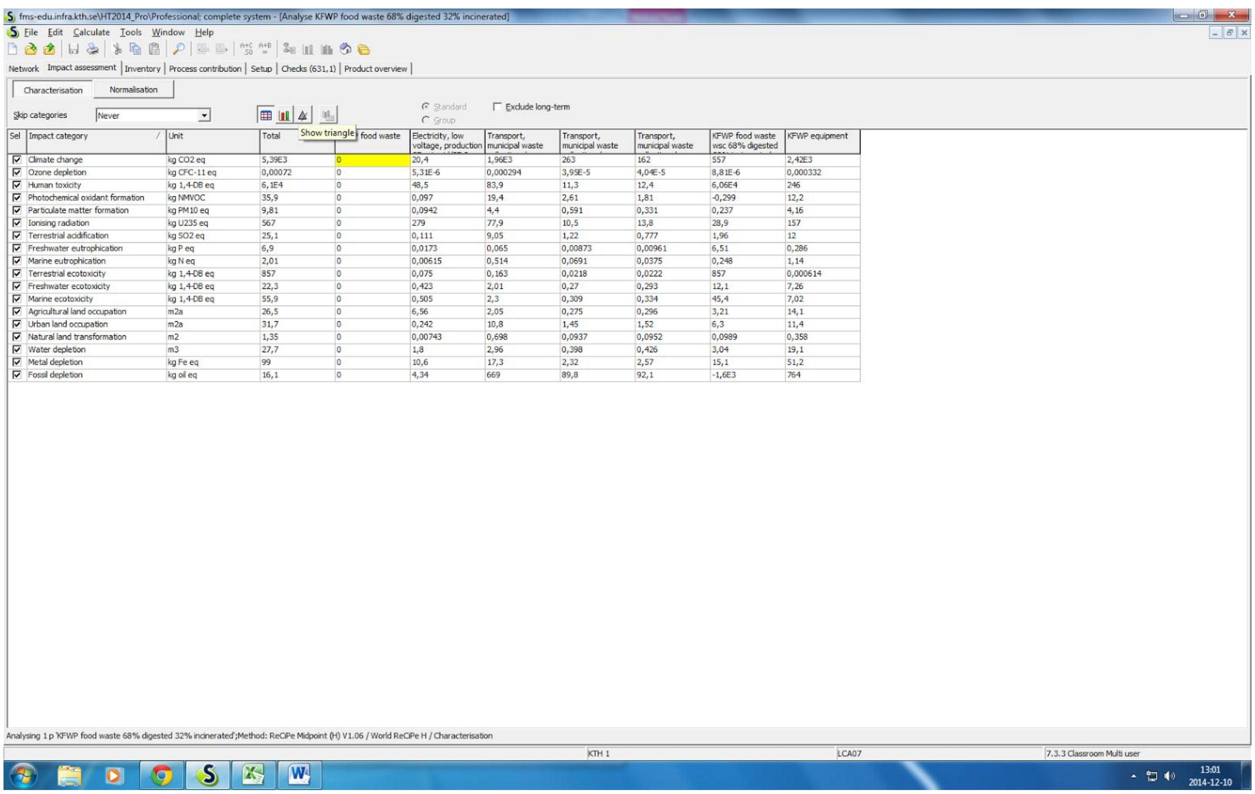
Analysing 1 p 'KFWP food waste 100% digested';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Normalisation

KFWP System 68% digestion 32% incineration



KFWP System 68% digestion 32% incineration Characterisation Inventory

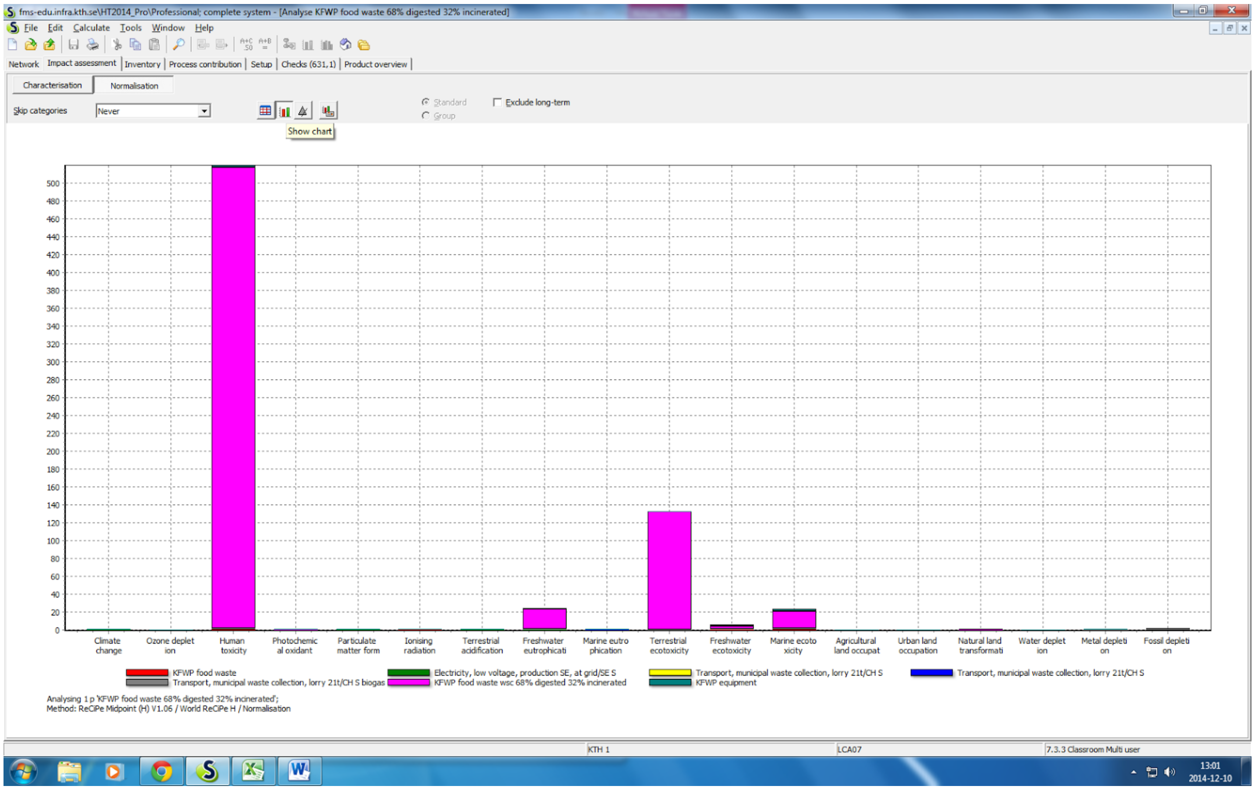


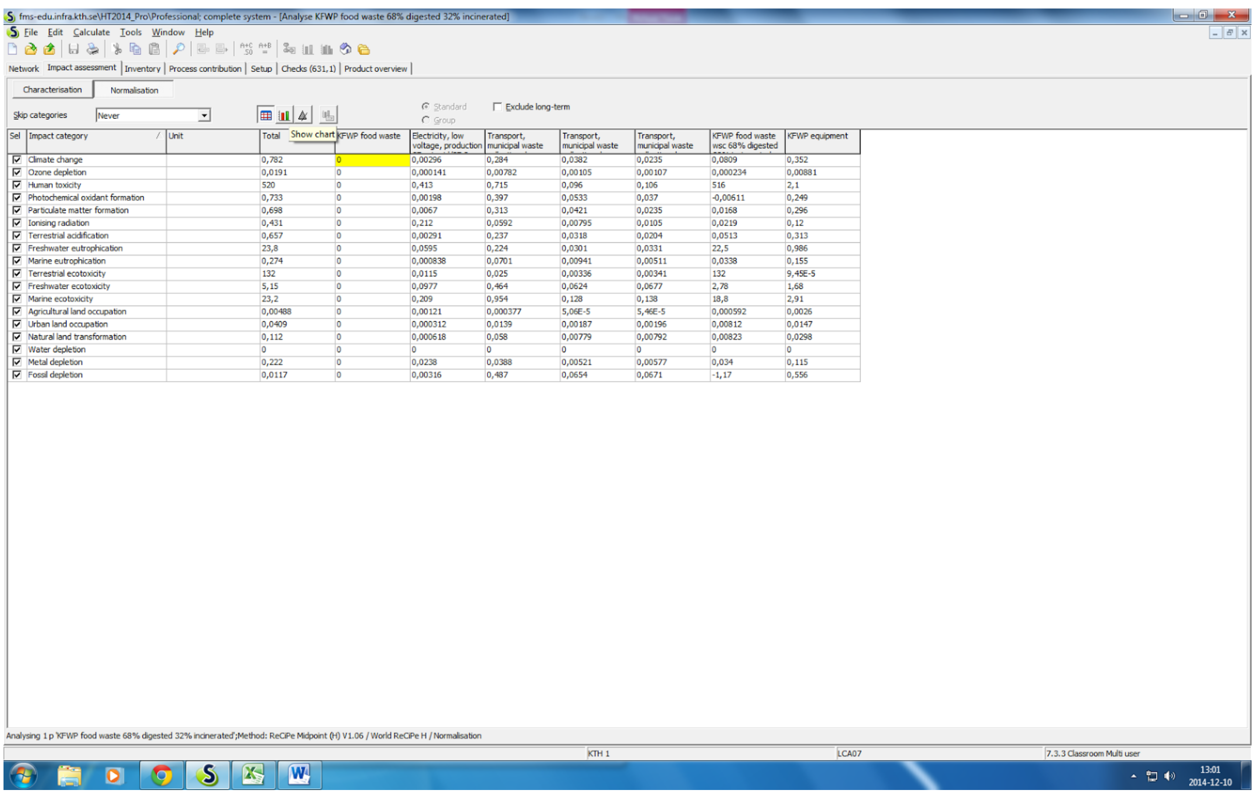


Sel	Impact category	Unit	Total	food waste	Electricity, low voltage, production	Transport, municipal waste	Transport, municipal waste	Transport, municipal waste	KFWP food waste wsc 68% digested	KFWP equipment
☑	Climate change	kg CO2 eq	5,39E3	0	20,4	1,96E3	263	162	557	2,42E3
☑	Ozone depletion	kg CFC-11 eq	0,00072	0	5,31E-6	0,000294	3,95E-5	4,04E-5	8,81E-6	0,000332
☑	Human toxicity	kg 1,4-DB eq	6,1E4	0	48,5	83,9	11,3	12,4	6,06E4	246
☑	Photochemical oxidant formation	kg NMVOC	35,9	0	0,097	19,4	2,61	1,81	-0,299	12,2
☑	Particulate matter formation	kg PM10 eq	9,81	0	0,0942	4,4	0,591	0,331	0,237	4,16
☑	Ionising radiation	kg U235 eq	567	0	279	77,9	10,5	13,8	28,9	157
☑	Terrestrial acidification	kg SO2 eq	25,1	0	0,111	9,05	1,22	0,777	1,96	12
☑	Freshwater eutrophication	kg P eq	6,9	0	0,0173	0,065	0,00873	0,00961	6,51	0,286
☑	Marine eutrophication	kg N eq	2,01	0	0,00615	0,514	0,0691	0,0375	0,248	1,14
☑	Terrestrial ecotoxicity	kg 1,4-DB eq	857	0	0,075	0,163	0,0218	0,0222	857	0,000614
☑	Freshwater ecotoxicity	kg 1,4-DB eq	22,3	0	0,423	2,01	0,27	0,293	12,1	7,26
☑	Marine ecotoxicity	kg 1,4-DB eq	55,9	0	0,505	2,3	0,309	0,334	45,4	7,02
☑	Agricultural land occupation	m2a	26,5	0	6,56	2,05	0,275	0,296	3,21	14,1
☑	Urban land occupation	m2a	31,7	0	0,242	10,8	1,45	1,52	6,3	11,4
☑	Natural land transformation	m2	1,35	0	0,00743	0,698	0,0937	0,0952	0,0989	0,358
☑	Water depletion	m3	27,7	0	1,8	2,96	0,398	0,426	3,04	19,1
☑	Metal depletion	kg Fe eq	99	0	10,6	17,3	2,32	2,57	15,1	51,2
☑	Fossil depletion	kg oil eq	16,1	0	4,34	669	89,8	92,1	-1,6E3	764

Analysing 1 p 'KFWP food waste 68% digested 32% incinerated';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Characterisation

KFWP System 68% digestion 32% incineration Normalisation Inventory

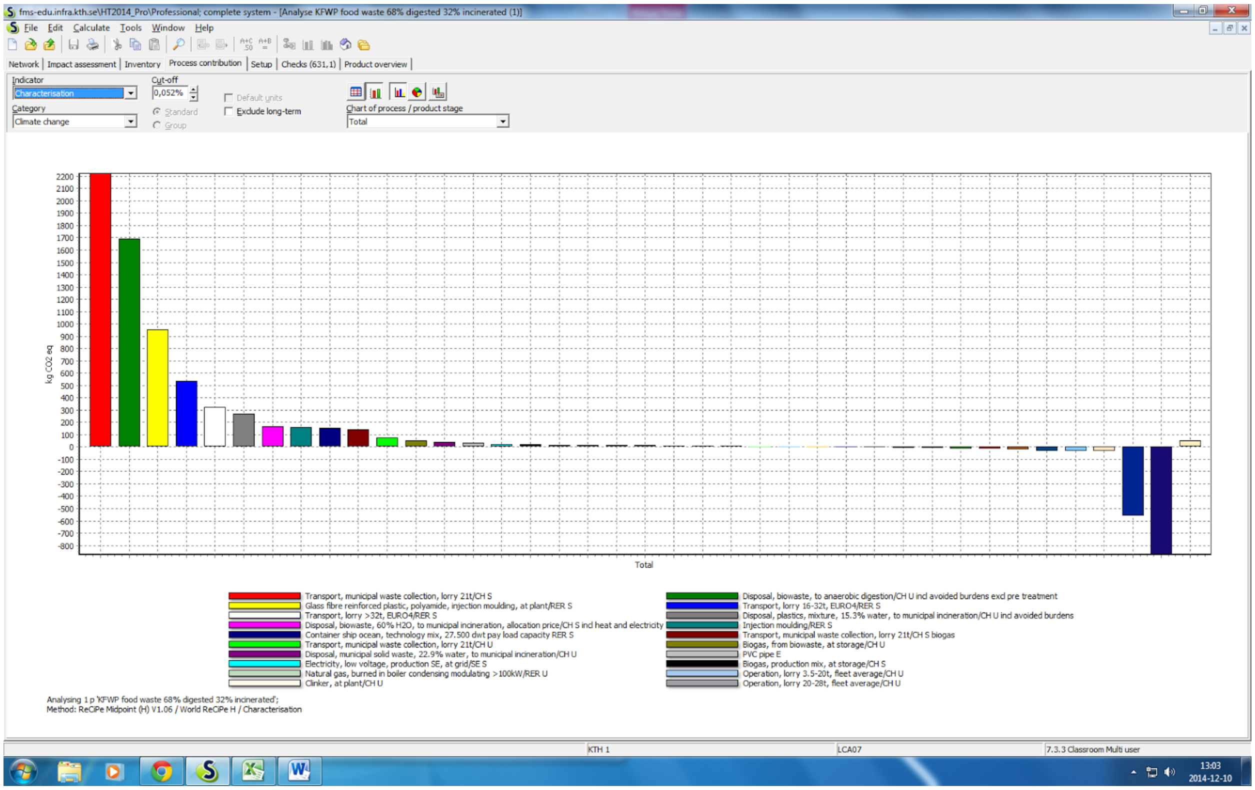




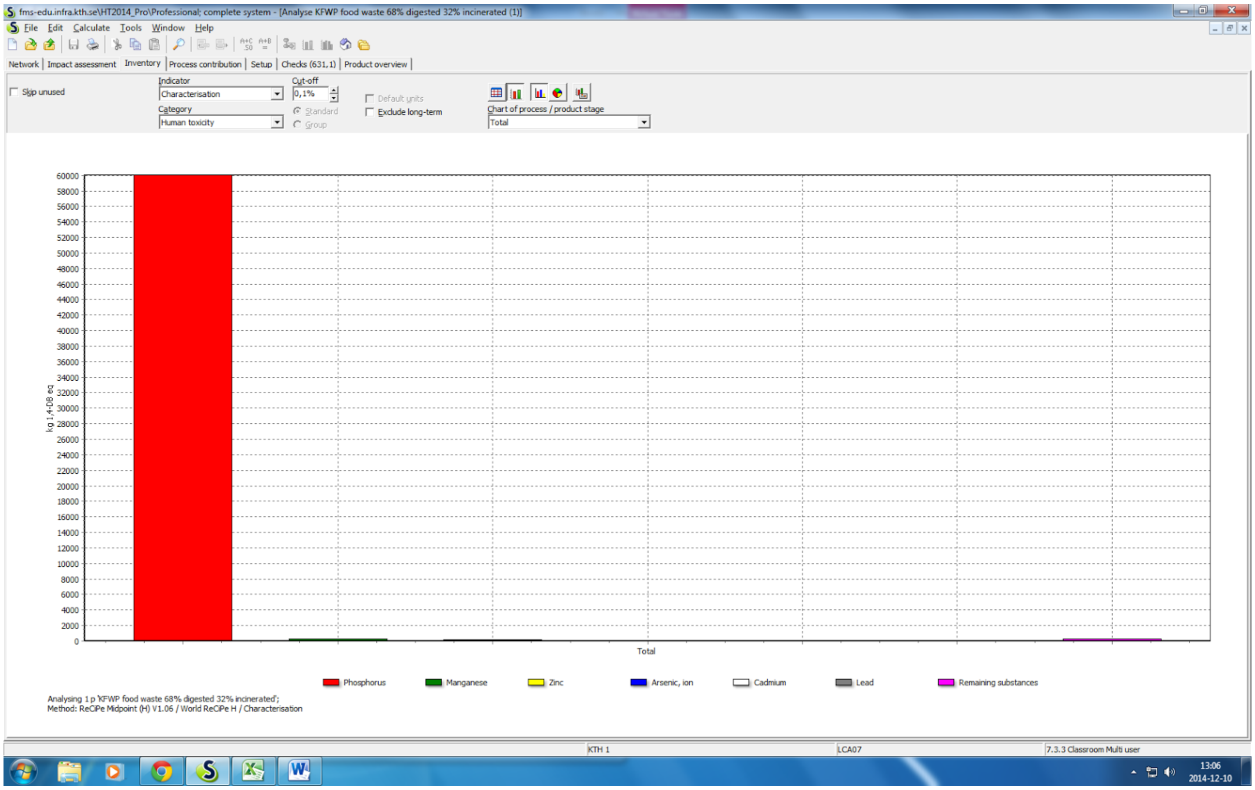
Sel	Impact category	Unit	Total	KFWP food waste	Electricity, low voltage, production	Transport, municipal waste	Transport, municipal waste	Transport, municipal waste	KFWP food waste wsc 68% digested	KFWP equipment
☑	Climate change		0,782	0	0,00296	0,284	0,0382	0,0235	0,0809	0,352
☑	Ozone depletion		0,0191	0	0,000141	0,00782	0,00105	0,00107	0,000234	0,00881
☑	Human toxicity		520	0	0,413	0,715	0,096	0,106	516	2,1
☑	Photochemical oxidant formation		0,733	0	0,00198	0,397	0,0533	0,037	-0,00611	0,249
☑	Particulate matter formation		0,698	0	0,0067	0,313	0,0421	0,0235	0,0168	0,296
☑	Ionising radiation		0,431	0	0,212	0,0592	0,00795	0,0105	0,0219	0,12
☑	Terrestrial acidification		0,657	0	0,00291	0,237	0,0318	0,0204	0,0513	0,313
☑	Freshwater eutrophication		23,8	0	0,0595	0,224	0,0301	0,0331	22,5	0,986
☑	Marine eutrophication		0,274	0	0,000838	0,0701	0,00941	0,00511	0,0338	0,155
☑	Terrestrial ecotoxicity		132	0	0,0115	0,025	0,00336	0,00341	132	9,45E-5
☑	Freshwater ecotoxicity		5,15	0	0,0977	0,464	0,0624	0,0677	2,78	1,68
☑	Marine ecotoxicity		23,2	0	0,209	0,954	0,128	0,138	18,8	2,91
☑	Agricultural land occupation		0,00488	0	0,00121	0,000377	5,06E-5	5,46E-5	0,000592	0,0026
☑	Urban land occupation		0,0409	0	0,000312	0,0139	0,00187	0,00196	0,00812	0,0147
☑	Natural land transformation		0,112	0	0,000618	0,058	0,00779	0,00792	0,00823	0,0298
☑	Water depletion		0	0	0	0	0	0	0	0
☑	Metal depletion		0,222	0	0,0238	0,0388	0,00521	0,00577	0,034	0,115
☑	Fossil depletion		0,0117	0	0,00316	0,487	0,0654	0,0671	-1,17	0,556

Analysing 1 p 'KFWP food waste 68% digested 32% incinerated';Method: ReCiPe Midpoint (H) V1.06 / World ReCiPe H / Normalisation

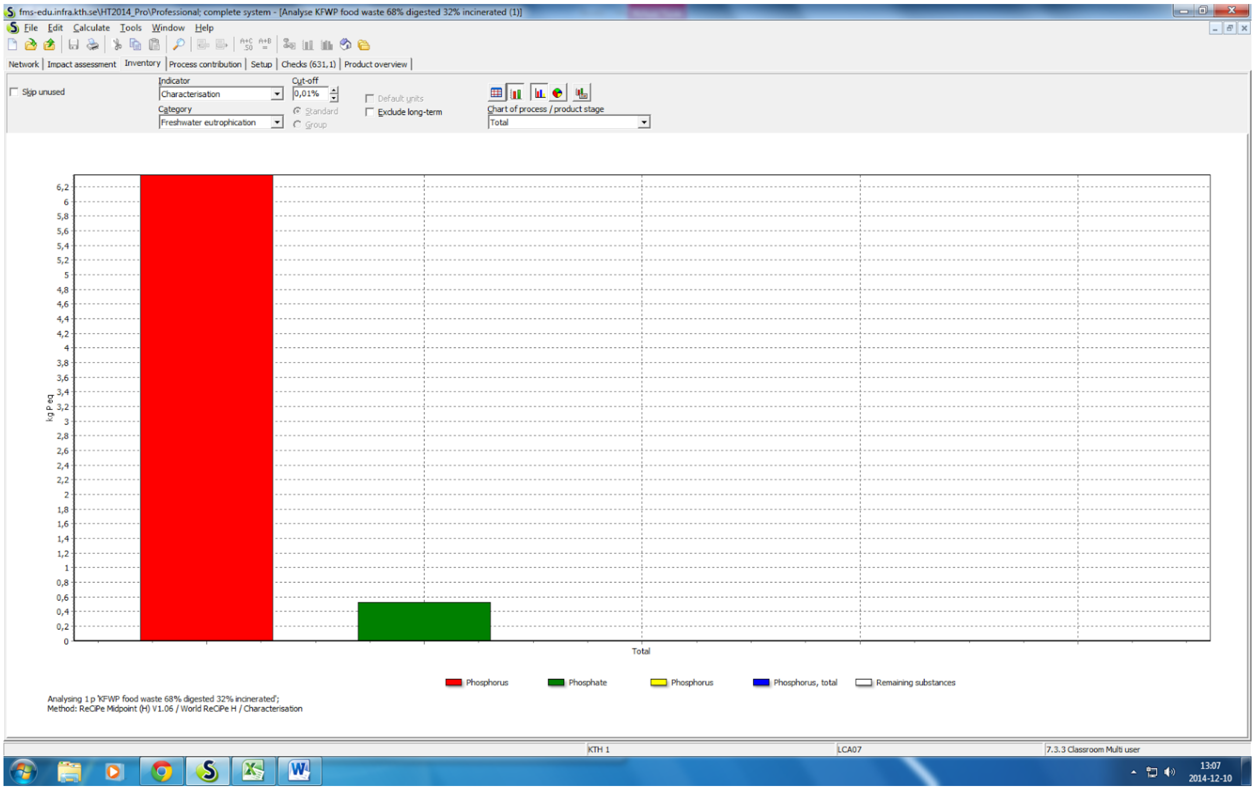
KFWP System 68% digestion 32% incineration Characterisation process contribution to Climate Change



KFWP System 68% digestion 32% incineration Characterisation process contribution to Human Tox



KFWP System 68% digestion 32% incineration Characterisation process contribution to Freshwater eutroph



KFWP System 68% digestion 32% incineration Characterisation process contribution to Terrestrial acidif