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Forecasting material flows by using Agent Based Modeling and Simulation
Case Study: Biowaste from Finnish Retail Stores

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Abstract

Final destination of commercial and industrial waste materials, being it reuse or recycling, energy utilization, destruction or landfilling, is partly govern by regulation but very often by waste producers and handlers themselves. Each waste producer and handler wants to deal with the waste in a way which fulfills legal requirements and is most advantageous for himself. Thus waste flows are governed by decisions made by waste producers and handlers along the chain of operators. Each decision maker wants to optimize his own way of being with the waste and the most important criterion is. To forecast the waste material flows in such a system which is partly governed by regulatory requirements but mostly by individual sub-optimal decisions is a demanding task.

This paper describes the use of ABMS (Agent Based Modeling and Simulation) in forecasting the waste material and substance flows from waste producers to sinks. ABMS has its roots in game theory and biological and social sciences and it is suitable for modeling complex adaptive systems. In the model each decision maker is described as an agent. Agents in ABMS are individual entities with their own goals and are capable to adapt and modify their behavior. Every agent has its own decision making rules and goals of operation, it learns from the environment and can adapt to new situations. Simulation results show how the decisions of different stakeholders affect the material flows, environmental effects and economics of the system.

ABMS was applied in a case which studied biowaste material flows from retail sector in Finland. ABMS was used to forecast the effects of the changes to material flows and through them to the substances. The results show varied reactions to the changes in the system.

Keywords: agent based modelling and simulation, decision making, material flow analysis, recycling systems, value chain analysis, retail store waste

1 Introduction

Final destination of commercial and industrial waste materials, being it reuse or recycling, energy utilization, destruction or landfilling, is partly governed by regulation but very often by waste producers and handlers themselves. Each waste producer and handler wants to deal with the waste in a way which fulfils legal requirements and is most advantageous for him. Thus waste flows are governed by decisions made by waste producers and handlers along the chain of operators. Each decision maker wants to optimize his own way of handling the waste and the most important criterion is usually economic, although other criteria are applied, too. To forecast the waste material flows in such a system which is only partly governed by regulatory requirements and mostly left for individual operators sub-optimal decision making is a demanding task.

Efficient recycling systems already exist, but they are not utilized to the extent they could be. One other problem is that we tend to look at the problems on a very detailed level. Often the problems exist, however, on the system level.

If we look at only the problems on a detailed level, it may seem than we are enhancing the processes towards sustainability, but when we look at the whole system level the whole situation may be very different. There is sometimes a very fine line between sustainability and unsustainability. To find out where the environmental burden comes from, we need to understand how the whole system works. Material flow chains and recycling systems include usually many stakeholders. Every stakeholder has their own objectives, which are affected by many factors, such as legislation, taxes, costs and profits.

For instance, LCA (Life Cycle Assessment) is a good tool for estimating environmental effects of products and services based on material flows. Economic situation can be added to the assessment, but the basic problem is, especially in LCA of waste management, that material flows are predetermined in LCA. In a changing regulatory and economic environment the flows are, however, difficult to predict.

1.1 Agent Based Modelling

This paper describes the use of ABMS (Agent Based Modelling and Simulation) in forecasting the waste material flows from waste producers to sinks. ABMS has its roots in game theory and biological and social sciences and it is suitable for modelling complex adaptive systems. For example in the USA (United States of America) ABMS has been used to model deregulated energy markets (Koritarov, et al. 2004).

In ABMS model each decision maker is described as an agent. Agents are individual entities with their own goals and are capable to adapt and modify their behaviour. Every agent has its own decision making rules and goals of operation, it learns from the environment and can adapt to new situations. Simulation results show how the decisions of different stakeholders affect the material flows, environmental effects and economics of the system. For more detailed information about ABMS modelling see for example (Macal and North, 2010).

In waste management ABMS is not a widely used method yet, although some research has been made. This approach with biowaste and especially the delivery of biowaste has been studied in Zurich (Lang et al. 2003). Bi et al. has been studying household's waste management behaviour and effects to costs under different policy situations with agent based simulation in China (Bi et al. 2008). Karadimas et al. has combined Geographic Information Systems (GIS) and multi agent simulation to estimate waste management (Karadimas et al. 2006).

ABMS was applied in a case which studied biowaste material flows from retail sector in Finland. In recent years many new regulations have emerged concerning food waste handling and many new technologies have been developed to produce for instance transport fuels from different types of biowaste and these changes will affect biowaste handling in shops very much. ABMS was used to forecast the effects of the changes to material flows. The amount of agents used in the simulation was significant: retail store agents around 3 500, treatment agents 59 and sink (landfill) agents 41. The results show varied reactions to the changes in the system, as some changes had major effect to the material flows and some very little.

The results of ABMS (material flows in different scenarios) were used to estimate the different routes for substances and their destinations from final sink perspective. The studied substances were; Cadmium (Cd), Chlorine (Cl), Lead (Pb) and Zink (Zn). These substances were chosen because of the information being available.

Feasibility of agent based simulation for modeling the decision making processes in recycling and its effects on material flows and environmental impacts has been studied in (Kangasrääsiö, 2012) and in (Laaksonen et. al, 2012) and the method was considered feasible and promising for this approach.

2 Material and Methods – Case study: Biowaste from Finnish Retail Stores

Computer software specifically designed for this purpose was used in the study (Kangasrääsiö, 2012). The software uses ABMS to estimate the flows, prices and behaviour of the stakeholders in the system. In this case study biowaste values from retail stores in Finland at 2008 were used as a reference material.

The software model estimates the future routes of waste flows. The idea is to see how the different fractions are treated in the future, if the circumstances are changed. For more detailed information of the model see (Kangasrääsiö, 2012) and (Laaksonen et.al. 2012). Three different scenarios were calculated with the model: Reference situation (REF), increasing landfill taxes (TAX), landfill ban (BAN). In the reference situation the values and prices are the same as in 2008. The simulation period was three years in all the scenarios. In the two cases (increasing landfill taxes and landfill ban) all the simulation parameters are kept same, except one. In increasing landfill taxes the price of landfill deposits are getting gradually higher (5 €/ quarter of the year) and in landfill ban, the landfilling is banned unless there is no other reasonable way for the treatment and even then, it's very expensive. However ashes are landfilled in this situation.

2.1 Biowaste from Finnish Retail Stores

Retail stores and biowaste was chosen as a data group as it is compact enough to handle, but also large enough to model the effects of different situations. Retail stores in Lapland (sparse population) and Ahvenanmaa (small island communities) were excluded from the modelling. Department stores were also excluded from the estimation, as grocery sales are only a part of their sales and the waste generation according to the total sales differs from general retail stores.

Retail stores were divided to six different categories according to their size: hypermarkets, large supermarkets, small supermarkets, large markets, small markets and small stores. In the software the supermarkets were also divided according to their locations by regions (17 pcs). Table 2-1. The turnover of the store is dependent on the size and location of the store. The total sales of the region were divided respectively with the store sizes. For simplification an average of total sales was used for one store size in one region. The average sales were counted by the share of sales of different store type from total sales (Veranen 2008).

Table 2-1: Distribution of the retail store agents according to their size and region

Region	Store Size						
	Hypermarket	Large Supermarket	Small Supermarket	Large Market	Small Market	Small Store	Total
Uusimaa	31	122	126	310	113	84	**786**
Varsinais-Suomi	16	63	46	137	52	49	**363**
Satakunta	9	23	32	64	35	17	**180**
Kanta-Häme	8	28	20	51	8	16	**131**
Pirkanmaa	16	62	46	135	51	48	**358**
Päijät-Häme	8	28	20	51	8	16	**131**
Kymenlaakso	6	20	25	40	8	28	**127**
Etelä-Karjala	5	10	15	18	26	18	**92**
Etelä-Savo	10	26	5	41	26	26	**134**
Pohjois-Savo	10	23	23	65	30	33	**184**
Pohjois-Karjala	7	17	17	47	21	23	**132**
Keski-Suomi	10	46	19	51	32	37	**195**
Etelä-Pohjanmaa	13	6	19	70	41	16	**165**
Pohjanmaa	12	6	17	64	38	15	**152**
Keski-Pohjanmaa	5	2	7	25	15	6	**60**
Pohjois-Pohjanmaa	15	26	65	108	50	12	**276**
Kainuu	4	7	17	28	13	3	**72**
Total	**185**	**515**	**519**	**1305**	**567**	**447**	**3538**

The waste generation of the retail store was estimated from various sources. In calculation for the total annual biowaste production per turnover, the average production from years 2004-2009 13 t/M€/a (HSY 2008) was used, which was multiplied by the total sales to calculate the total waste production per store. The estimated share of biowaste in retail stores is 15% (FGTA 2003). The biowaste generation by turnover was 1.950 t / M€ sold. The total amount of biowaste generated by retail stores was around 27,416.04 t/a, table 2-2. Biowaste fractions were divided into 3 different categories: packed biowaste, pure biowaste and biowaste in mixed waste. The shares how the waste is divided between these categories has been studied in Sweden (Ekvall, 2007). Ekvall, 2007.

Table 2-2: The estimated amount of biowaste generated in one year in the simulation

Region	Store Size and the amount of biowaste [t/a]						
	Hypermarket	Large Supermarket	Small Supermarket	Large Market	Small Market	Small Store	Total
Uusimaa	1 902	2 565	1 004	1 265	283	171	**7 191**
Varsinais-Suomi	583	792	307	387	87	52	**2 208**
Satakunta	268	498	99	160	10	25	**1 061**
Kanta-Häme	217	295	114	144	32	19	**822**
Pirkanmaa	222	260	170	117	14	31	**814**
Päijät-Häme	289	287	217	215	167	24	**1 200**
Kymenlaakso	640	1 012	233	539	227	37	**2 689**
Etelä-Karjala	355	1 111	119	335	32	33	**1 985**
Etelä-Savo	268	65	414	234	48	11	**1 040**
Pohjois-Savo	370	109	120	202	58	12	**872**
Pohjois-Karjala	147	33	45	73	22	5	**325**
Keski-Suomi	338	230	216	287	47	27	**1 146**
Etelä-Pohjanmaa	188	1 441	34	95	23	35	**1 816**
Pohjanmaa	89	482	99	40	22	23	**753**
Keski-Pohjanmaa	127	1 052	117	114	19	31	**1 460**
Pohjois-Pohjanmaa	122	168	63	79	18	10	**461**
Kainuu	412	555	222	282	63	39	**1 573**
Total	**6 540**	**10 956**	**3 594**	**4 568**	**1 172**	**586**	**27 416**

The biggest amounts of biowaste are generated in Uusimaa region, which is the area with the highest population and store rate , with the turnover of the stores being the higher than elsewhere in the country.

The results of the model were studied with Material Flow Analysis -software (MFA) STAN (IWR, 2012), which has been developed in Vienna University of Technology. The results of the analysis are presented in the next chapter. The simulation includes prices and profitabilities of the commodities and agents, but in this study was concentrated only on material flows and especially with the concentration on final sinks of substances.

In this study four substances were observed in more detailed level: cadmium (Cd), chlorine (Cl), lead (Pb) and zink (Zn). Most of the heavy metals for example en up to biowaste with packages table 2-3. The data of substances in retail store biowaste was compiled from different sources and the calculations were done by using averages.

Table 2-3: The concentration of substances.
Data compiled from: Lagerqvist et al, 2011; Pulkkinen et al, 2008; Toukola et al, 2007

	Cd (mg/kg DM)	**Pb (g/kg DM)**	**Zn (g/kg DM)**	**Cl (g/kg DM)**
Packages	248,83	132,79	171,39	1184,49
Clean biowaste	99,87	0,70	32,80	1,27

The distribution of substances in different processes was estimated from various sources from Boldrin et al, 2011; Dalager and Reimann, 2011; Jung et al, 2004; Plahl et al, 2002; Rechberger, 2001 and Schmidt et al. (2001)

3 Results and Discussion

The results of MFA-analysis are presented in figure 3-1 and table 3-1. Figure 3-1 presents the material flows of the reference situation. The same system was used for all the situations. According to the simulation, pre-processing plants are reasonable to use only in landfill ban situation, although they don't provide significant added value for the materials.

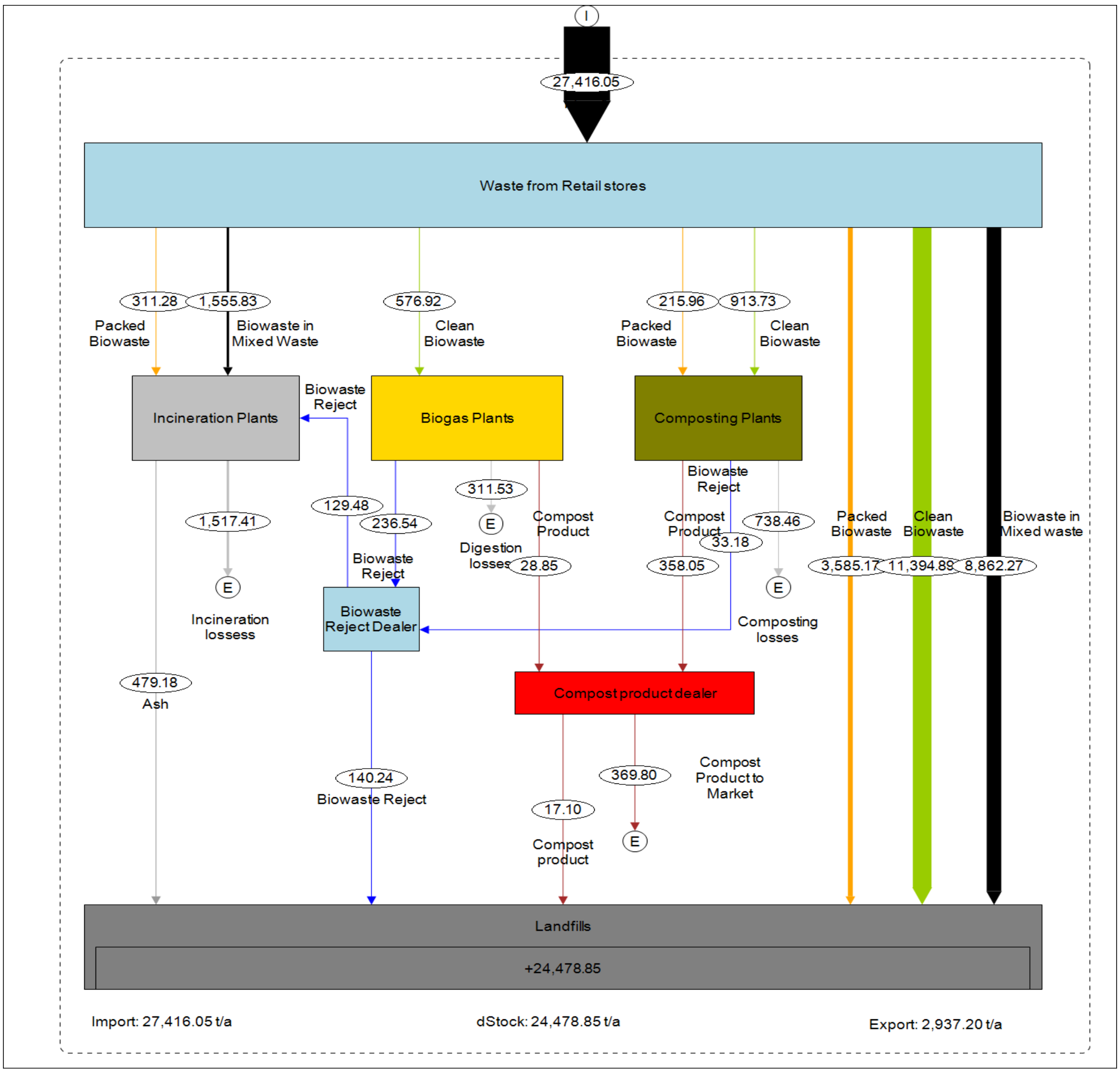

Figure 3-1: Material flow chart of reference situation.

The material flow chart shows that most of the biowaste from retail stores still goes straight to landfilling. The summary of the material flow analyses is shown in table 3-1. The results were analysed from three different points of view: material recycling/reuse, material losses and emissions and landfilling. Biogas and energy production are also presented in the table, but at this stage of the study they are not being evaluated more thoroughly.

3.1 Material balances and substances with different perspectives

Material flows and their balances can be viewed from different perspectives. Current general policy in Europe and Finland, is the waste hierarchy perspective, where the material flows and cycles are the better the less waste is discarded and the more is recycled. (2008, Directive 2008/98/EC).

Final sink perspective is rather different from waste hierarchy (policy) perspective. When looked at the substances from final sink perspective the ideal situation is when the substances end up to safe sinks. Brunner and Tjell (2012) define safe sinks as "A proper sink for waste materials may be defined as a facility or process that ensures that an input is stored or sequestered safely and that any outputs to the environment are released at a slow enough rate that they do not harm any facet of the receiving environment such as a lake, the sea, groundwater, soils and sediments, or the atmosphere." Kral et al (2012) have proposed following definitions for sinks and final sinks: a "sink" is defined as a process that receives anthropogenic material flows that have no positive value for present societies. A "final sink" is a sink that either destroys a substance completely, or that holds a substance for a very long time period."

Table 3-1: The results of different situations and comparison of the results with "final sink" perspective. P significates the best option according to current policy recommendations.

	Reference Situation	Landfill ban	Increasing Landfill Taxes	The best option from final sink perspective
Material losses from processing (Emissions)	P 2,567 t/a	17,796 t/a	11,329 t/a	Landfill ban situation is good, because processing plants and their emissions are strictly controlled.
Material Reuse	370 t/a	P 4,777 t/a	3,448 t/a	Reference situation is the best, because the use of materials can't be always controlled.
Energy Production (incineration: heat and electricity)	1,960 MWh/a	P 9,486 MWh/a	4,976 MWh/a	Power plants and their emissions are well controlled.
Biogas Production	43,300 m3	P 90,000 m3	38,100 m3	Power plants and their emissions are well controlled
Landfilling	24,479 t/a	P 4,846 t/a	12,639 t/a	In the short run the reference situation is good if the landfill is well operated, but in the long run the landfill ban situtation is the best, because it is never sure what will happen in the future.

If the results are studied from material reuse (waste hierarchy) perspective, the landfill ban scenario is the best, due to the highest material reuse rates. The difference between landfill ban and increasing landfill taxes scenario is not remarkable, but if the landfilling rates are studied the landfill ban is remarkably smaller between the two scenarios, but if the material losses in the three different scenarios is reference scenario the smallest.

When the results are compared from "final sink" perspective, the situation changes. Material losses in processing phase can be considered as a safe final sink, because the processes are under strict control and the emissions are controlled and the material losses and emissions are treated or should be treated in a proper way. This applies in most of the western countries; of course the situation would be different, if the emissions from the processing weren't supervised. If the results are observed with this point of view, the situation with high material losses would be the preferred one, in this case the landfill ban scenario.

Material reuse is not seen as good option with final sink perspective. The reusable materials end up to markets and after that the buyer is responsible of the material. The places where the material is used or set is not that controlled anymore (uncontrolled sinks). In this case it is usually a garden or a field and the substances in the compost product end up to the ground and water. This way of thinking turns the usual approach (waste hierarchy) to other way around.

Landfilling can also be a good option from the final sink perspective especially in short term scale. In the long term scale it's not consider as a safe final sink, if the landfill is not operated properly. In the worst case the harmful substances may end up to ground water and other places. But in short term, if the landfill is well observed, it may be considered very safe final sink to different substances (controlled temporary sinks).

Material can contain different substances, some more harmful than the others. Biowaste in general don't contain much harmful substances if compared to waste electronic and electrical equipment (WEEE) for instance. However some heavy metals for instance may end up to biowaste flows through packages. In this research was estimated the routes of cadmium, chlorine, lead and zinc. The distribution of substances in the three different scenarios with final sink perspective is presented in the figure 3 – 2.

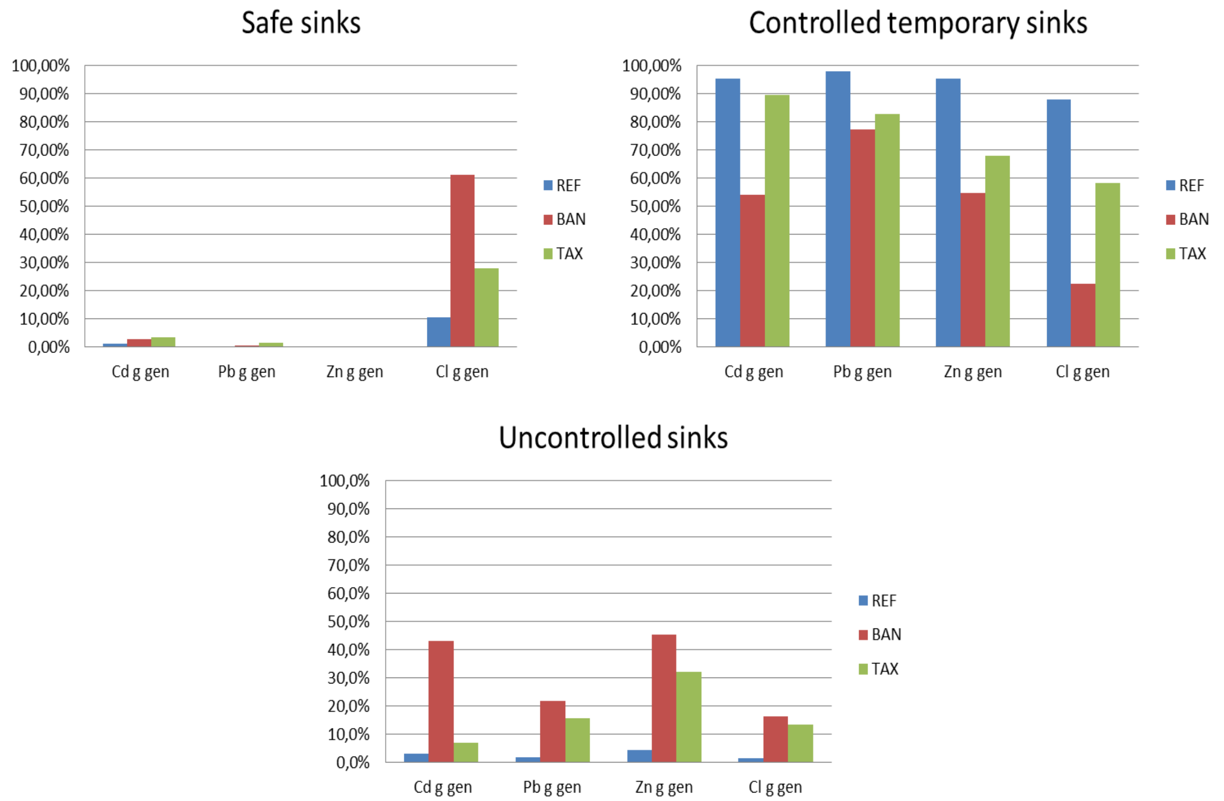

Figure 3-2: Distribution of substances to different sinks in three different scenarios.

The results show that within the current political mind-set, the substances don't end up in to safe sinks. Only in one scenario (BAN) one substance (chlorine) ends up to safe sinks. In the other cases most of the substances end up to controlled temporary sinks. Landfill ban scenario can be considered as the worst scenario from final sink perspective, in the case of cadmium, lead and zinc. Different materials have different routes and different effects so it is difficult to estimate which has the most significant environmental effects. A detailed impact assessment would be needed. An LCA analysis would be the next step of estimating the environmental consequences of the different situations.

The results in table 3- 1 and in figure 3 - 2 differ from each other. To fully evaluate the situation, results in the table 3 – 1 and figure 3 – 2 has to be evaluated together.

Even though the estimation is done rather a rough way it already shows the direction of current situation and the potential of this kind of approach. It also shows that waste management needs new and better indicators to estimate the whole system and performance of recycling society.

4 Conclusions

The approach and model was tested with the biowaste from retail stores in Finland, using the year 2008 as reference year. The model is a promising tool for estimating different policy and economical changes. With the ABMS model can be seen the effects of the changes in waste flows, which can be used for estimating the environmental effects of the changes. The model is an easy way to test and see the possible effects when planning new legislation for example.

The model is flexible and it can be adjusted in many ways. It is also applicable to other waste streams. When using the model and interpreting the results, it has to be remembered that there are multiple factors which can affect the material flows and the results should be observed keeping that in mind. The used simulation period was rather short and simulation for a longer period is recommended, although the longer the simulation period, the more the accuracy of the results is affected. However, already significant changes can be observed even with a shorter simulation, as can be seen with the example case.

In the future the model will be validated with more detailed data and also other ways to handle the biowaste will be considered. Other waste materials and substances should be observed too. The model is promising tool for estimating the material flows and is a useful tool to be used together with MFA and LCA.

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