Assessment and System Analysis of Industrial Waste Management

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Abstract

Considerable economic as well as environmental benefits can be achieved when appropriate industrial waste management is implemented. The objective of this study was to find a method of organizing a waste management system and of obtaining an overview of the whole system. The method proposed emphasizes the optimization of waste management with regard to energy, economy and environmental impact in separate evaluations. The case study presented illustrates how the method was applied to the Stora Enso Hylte AB paper-mill in Sweden. The waste management systems studied were: (1) the existing system (used as a reference), (2) an energy-recovery system (in which the waste produced is used for energy production, as far as is possible), and (3) a material-recovery system (in which waste is recovered or re-used, as far as is possible). The second system was found to be preferable with regard to energy, economy and environmental impact, although the lowest carbon dioxide emissions was obtained with the first system. The method presented is also suitable as a basis for the development of more specific methodologies for the analysis of waste handling systems applicable to other branches of industry.

Keywords: Industrial waste; Paper-mill waste; Waste management

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1. Introduction

Waste production in Sweden is increasing, as it is in many other countries. The composition of municipal solid waste (MSW) is fairly well known in Sweden today [1] through studies and measures taken by waste management companies, waste management associations, universities and the Swedish Environmental Protection Agency.

In Sweden manufacturers are legally responsible for the collection and handling of certain categories of waste. Such legislation was introduced for packaging [2, 3] recycled paper [4] and tires [5] on 1 October, 1994. Producer responsibility for cars [6] and batteries [7] was implemented on 1 January, 1998, and similar legislation is planned for electric/electronic products [8], although no date has been set for the introduction of such legislation. Within the rest of the European Union (EU), corresponding legislation for packaging was implemented on 30 June, 1996 and within two to three years legislation governing producer responsibility for cars and tires will probably also be introduced. Legislation covering electric/electronic products will follow. However, in contrast to Sweden, responsibility for waste in mainland Europe, is usually shared between the producer and the municipality in question.

The amount of industrial waste produced in Sweden has, until now, been only roughly estimated [9, 10]. Although the characteristics of bulk non-branch-specific waste are reasonably well-known, [11] no detailed analysis of the amount of industrial waste produced or its composition has been carried out. Of the approximately 66 Mt waste produced annually in Sweden, around 58 Mt consist of industrial waste. Of this, roughly 16 Mt are reused within industry, while 26 Mt (including waste from mining activities) are dumped at industrial dumps. Four and a half Mt (equivalent to 540 kg per person per year) consists of non-branch-specific waste (including construction and demolition waste) and is taken to landfills [12].

During recent years, interest in industrial waste as an important source of energy and material has increased. Many industries are already engaged in extensive environmental audits and are evaluating their own waste management activities. An increasing number of companies are being certified according to the International Organization for Standardization (ISO) 14001 and the Eco-Management Audit Scheme (EMAS). While ISO 14001 is mainly directed towards internal environmentally related organizational routines worldwide, EMAS is aimed more towards a system of external auditors who will evaluate regularly incoming environmental audits from EU companies only.

Today, most manufacturing plants are in need of detailed analysis of their waste management system at all stages of production. Those who have already studied waste streams within the company and who have identified opportunities for recovery and resource saving usually find that there are large economic as well as environmental benefits to be gained when appropriate waste management is implemented [13].

The main objective of this study was to find a method of organizing a waste management system for a particular company, and of gaining an overview of the whole system. All stages of the process were included i.e. waste production, collection, transportation, sorting, container handling, local treatment, recovery of material and energy and final treatment. A methodology is presented which has been developed at the former Division of Waste Management and Recovery, Lund University, Sweden. The application of the method to the Stora Enso Hylte AB paper-mill (hereafter denoted "Stora") in Sweden is presented as a case study [14]. The methodology is currently also being applied to the Swedish pump and mixer manufacturing company ITT Flygt AB.

Economic aspects of waste handling are usually concerned with the cost of the trucks and/or depots used (e.g. [15]), costs connected with municipal facility location and sizing (e.g. [16, 17]), or costs calculated from the simulation of processing systems (e.g. [18]). Studies have been presented on computer models for the optimization of industrial production and costs [19]. Methods have also been suggested for designing waste-minimization programs including balances of material, energy and water [20]. Furthermore, linear programming approaches have been applied to cost reduction with respect to industrial waste reduction and waste management [21]. The optimization model presented in this paper will therefore provide a useful additional tool in the study of economical, energy and environmentally related conditions regarding waste handling systems within a specific company.

2. Method

In order to analyze the complete waste stream at a particular factory or plant, the study can be divided into four steps as described below.

2.1. Basic survey

An inventory and analysis of existing data on the production of waste and its composition forms the basis for the future waste management system at the plant. Specific sampling and analysis are then carried out in order to obtain sufficient information for the analysis of the complete system. This includes the analysis of certain waste categories in order to ascertain whether the waste in question is suitable for incineration or recycling. The system analysis also includes detailed studies of the existing waste handling system. Such an analysis may include detailed analysis of the contents of each waste container with regard to weight, volume and characteristics. In this context, it is important to identify and remove hazardous waste from the waste stream. An inventory of the types of waste produced within the factory is made together with an inventory of possible ways of reusing material and recovering energy from the waste. Incineration tests may be included here since it is important to ensure that waste intended for energy production is suitable for the existing or planned boiler. The combustion process must be efficient, with no environmentally harmful emission to the surroundings. The cost of waste transportation and costs related to final disposal, such as disposal fees, etc., should also be estimated

2.2. Analysis of alternative waste handling systems

Based on the basic survey, other waste management systems can be formulated for the future handling of waste. These may be: (1) the existing system (used as a reference), (2) an energy-optimization alternative (in which the waste produced is used for energy production, as far as is possible), or (3) a material-recovery-optimization alternative (in which the waste is recovered or re-used, as far as is possible). These alternatives are described and compared. The most beneficial alternative from economic, energy and environmental points of view should be chosen. This analysis results in a recommendation regarding future waste handling.

The system analysis approach used in this study is preferable to a Life Cycle Assessment (LCA) approach since the economic aspect of the waste handling system is of the greatest importance, while the main objective of the LCA approach is to describe, compare and evaluate the overall environmental impact of single products or services over their complete life cycle [22].

The economic analysis may include fuel costs, the cost of raw materials, of waste disposal and treatment, of internal waste handling and income from material and energy recovery, etc. The energy analysis should include studies of the use of energy produced internally from waste such as paper, plastic, sludge, etc., compared with that generated externally from fuels such as coal, peat, oil or biofuel. The environmental analysis should include studies of the effect on the environment such as emissions to air, water and ground. Emissions to air occur during the storage and transportation of fuel, raw material, waste etc., and during incineration of fuels and waste. Renewable (bio)fuels can be compared with fossil fuels including their contributions to the greenhouse effect [e.g. carbon dioxide (CO_2)] and the acidification of the environment due to sulfur dioxide (SO_2) and nitrogen oxides (NO_X). If the type and quality of the input fuel vary, this should be considered.

2.3. Proposal for a future waste handling system

The analysis of the various methods of waste handling at the plant in question, provides the basis for the choice of the future system. This includes the design of special sites for the collection of waste and the recovery of material, how and when the containers and bins should be emptied, etc. A thorough waste management assessment is required, including: (1) characterization - physical, chemical, biological and toxicological, of waste characteristics; (2) categorization - type of waste handling required, and (3) evaluation - types of risks and hence the establishment of guidelines to be followed in the handling of the waste [23].

2.4. Implementation of the new waste handling system

If a source separation system is to be implemented, containers of different types and colors (one for each category of waste) can be placed at strategic sites throughout the factory. Different kinds of collection stations can be used.

1. Single containers (where the material is generated, intended for paper, metal or mixed waste)
2. Recovery stations (containers for temporary storage of metals, combustible waste, non-combustible waste or environmentally hazardous waste)
3. A recovery center (special area for the collection of all types of containers, material to be recovered, and waste)

In order for the implementation to be successful, it is very important to build up an interest in, or motivation for, waste management activities among employees. This can be done, for example, through information activities and educational programs. A "kick-off" for material sorting, including, for example, information about the importance of source separation, waste-related competitions, and parties, is recommended.

A scheme is presented below to illustrate the above-described method (Fig. 1).

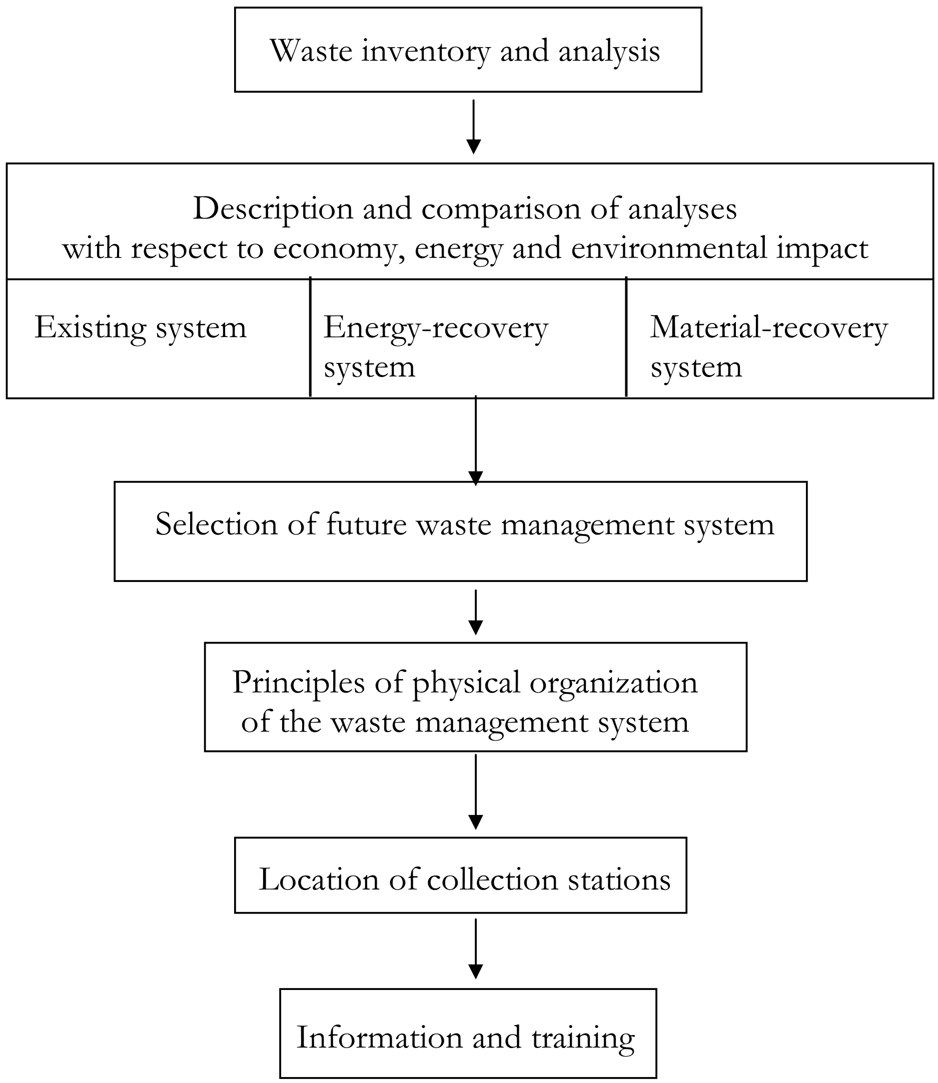

Fig. 1. Schematic illustration of the methodology.

3. Case study

3.1 Background

The aim of the case study was to survey the total waste production and to perform detailed characterization of the waste produced by Stora, one of the largest paper recycling companies in Sweden. The aim was also to analyze the existing waste handling system and to study the possibility of improvements leading to more efficient treatment of the waste regarding economy, energy saving and the environment.

The handling of waste at Stora today is based on the collection of waste in containers situated in different departments. In total there are 36 containers (each about 16 m^3) available for the collection of different sorts of waste.

The transportation department at Stora has two trucks at its disposal and is responsible for the transportation of waste within the company, as well as to the Borabo landfill, four kilometers (2.5 miles) away. Mixed large waste such as filters, scrap metal and wood from, for example, refurbishing, is taken to the Borabo landfill. During 1995, the cost of disposing of this kind of waste was estimated to be USD 29,000. Recycled paper waste (RPwaste), ash, slag, and other kinds of waste from energy recovery, are also taken to the Borabo landfill. During 1995 the cost of landfilling this kind of waste was estimated to be USD 410,000.

3.2 Data collection

The inventories in this study were mainly made at the site during late 1995 and early 1996. Information was collected concerning the volume and weight of the waste in all 36 containers. Based on this information the total amount of waste generated per year was estimated. The thermal value of the waste was also estimated. It was hence possible to calculate the total amount of potentially extractable energy within Stora. Of the above mentioned 36 containers, 20 were selected for sorting since they contained mainly unsorted and mixed waste. The contents of each of the 20 selected containers were examined before being taken to the landfill. The waste in each container was weighed. The containers were then emptied and the waste sorted by hand. Detailed information about the waste in 9 out of the 16 containers filled with mixed unsorted waste was obtained through interviews and inquiries.

Stora's main product is newspaper which is produced in four large paper machines. These machines are supplied with pulp from the company's own plants. The energy required is covered by purchased electric power, energy generated by steam from four steam boilers, plus energy from a back-pressure turbine. Stora has 1,050 employees. Their annual turnover is estimated to be approx. USD 360 M and 80-85% of their production is exported.

The purpose of this investigation was to obtain a large decision basis for the choice of the most suitable waste handling system for each container. In this way, it was possible to obtain the most beneficial handling solution for every container based on the overall system alternatives presented.

In order to elucidate the environmental consequences of dumping RPwaste at the Borabo landfill, the liquid from compressed RPwaste was analyzed. This was regarded as representing leachate from dumped RPwaste. A comparison between this "leachate" and the mean value from 20 Swedish landfills [24], showed increased values for certain Borabo leachate parameters such as: pH, conductivity, total nitrogen and ammonium. The values for phosphorus and metals were however lower than the mean value.

Incineration tests were also performed using steam boiler number four at Stora. The investigation was mainly aimed at a studying the combustion of RPwaste mixed with other solid waste and fuels. After the removal of visible pieces of metal, the RPwaste was shredded. The material was then weighed and mixed with a known amount of wood chips before being dumped into the feeding device of the steam boiler. Samples were taken of the gas and dust directly after all filters and purification devices. Samples of ash were taken from the electrostatic filter. The energy recovery potential for the RPwaste was calculated through observation of the temperature before and after burning of a weighed sample in an oxygen bomb calorimeter while maintaining constant volume. Fig. 2 below shows the additional need of coal due to a decrease in the thermal value when the steam boiler was fed with RPwaste with a high moisture content.

3.3 Waste management systems

Based upon the information acquired through inventories and analyses, as described above, calculations were performed to identify the most advantageous system for future waste handling at the company, regarding environmental impact, energy balance and economy. Various alternatives were reviewed and throughout the calculations it was assumed that RPwaste was used to recover energy.

Each of the three methods defined above was then described from the point of view of energy requirement, economy and environmental impact. Only the factors that were influenced were studied in the various methods. Concerning energy consumption, only the total impact on external flows was included in the calculations. The general flows of material and energy are shown in Figs. 3 and 4 below for the energy and material recovery management systems.

4. Results and discussion

The results regarding energy, economy and environmental impact for method 2 (energy optimization) which was regarded as the most preferable alternative, are shown in Tables 1-3. It has been assumed that USD 1 = SEK 8.30.

The results of the calculations for all three systems with regard to energy, economy and environmental impact are shown in Tables 4-6. Here, the sums of the calculations are given for the alternatives of optimization of energy and economy and for environmental load, the emissions to air only.

The theoretical work provides a step by step method of obtaining the optimal organization of an industrial waste management system with respect to energy, economy and environmental impact. The results of the case study showed that the second waste management system: combustion for energy recovery was the most advantageous regarding the aspects of energy and economy. As regards the direct environmental impact of the emission of CO_2 the first system was found to be the best. This may be expected since in systems 2 and 3 the waste fuel used contained materials derived from fossil fuels, such as plastic.

Certain problems were also found, associated with relatively high chlorine contents in mainly the ash from the waste fuel. From this point of view, it is thus preferable to use coal instead of RPwaste as fuel. It is, however, possible to deal with chlorine emissions using suitable purification devices.

It should be noted, however, that system 2 is preferable to the reference system with regard to NO_X emissions and only 0.2 per cent worse with regard to SO_2 emissions (see Table 6). In general, system 2 was as good as system 3 with regard to environmental impact. On the whole, if the CO_2 emission aspect is disregarded, the second alternative, involving the incineration of the internally produced waste, was the best alternative. This system requires sorting at the source with division of the waste into combustible waste and non-combustible metal, recycled paper, glass and environmentally hazardous waste.

Sorting at the source at Stora leads to increased environmental awareness of the personnel, and increased faith in the company on the part of its customers, authorities and the public. The amount of waste being landfilled is reduced hence lowering transport costs to the landfill, and a better and safer working environment within the company, and an improvement in the environment as a whole, is obtained.

To implement sorting at the plant, containers of different sizes with different markings corresponding to certain waste fractions are situated at strategic places within the factory. It was suggested that the following three kinds of stations, for the collection of waste and rest products, be introduced at Stora: (1) separate containers at work places, (2) collection stations (with several containers for the collection of certain fractions of waste), and (3) collection centers located at the gate with different containers for the following waste: combustible and non-combustible waste, metal, recycled paper, glass and environmentally hazardous waste.

Finally, a suggestion was made as to how the proposed system could be implemented, tested and evaluated in three phases. Phase 1 covers the specification of system design, a plan of action and the design of a test program. Phase 2 involves an incineration test and the evaluation of chloride emissions. Phase 3 includes tests and evaluation, placing out marked containers, spreading of leaflets describing the new system and finally, information activities, e.g. meetings.

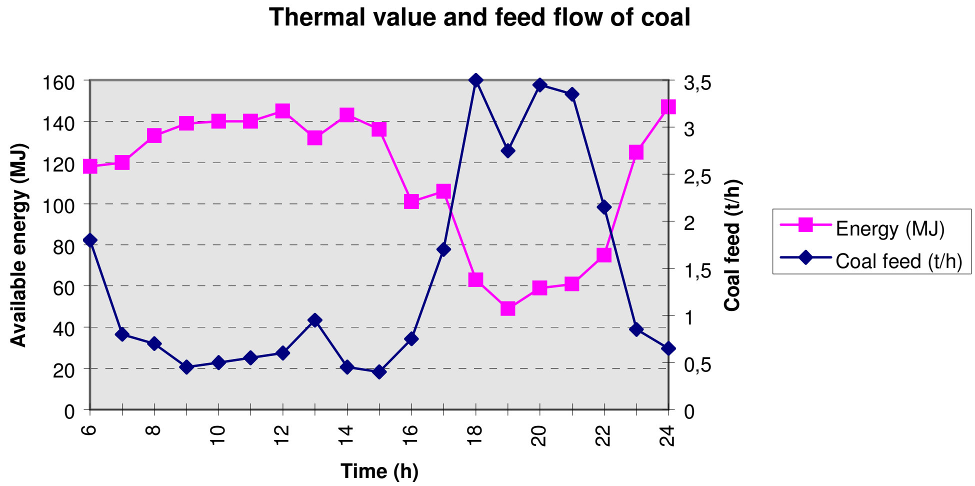

Fig. 2. Variation in the thermal value and the feed flow of coal for the steam boiler during incineration tests [14].

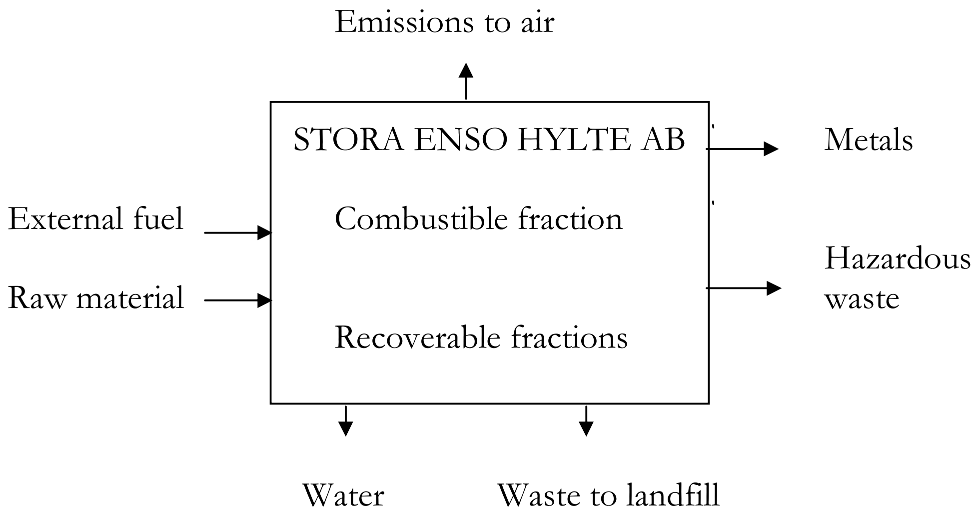

Fig. 3. Total flow of the energy-recovery system (2).

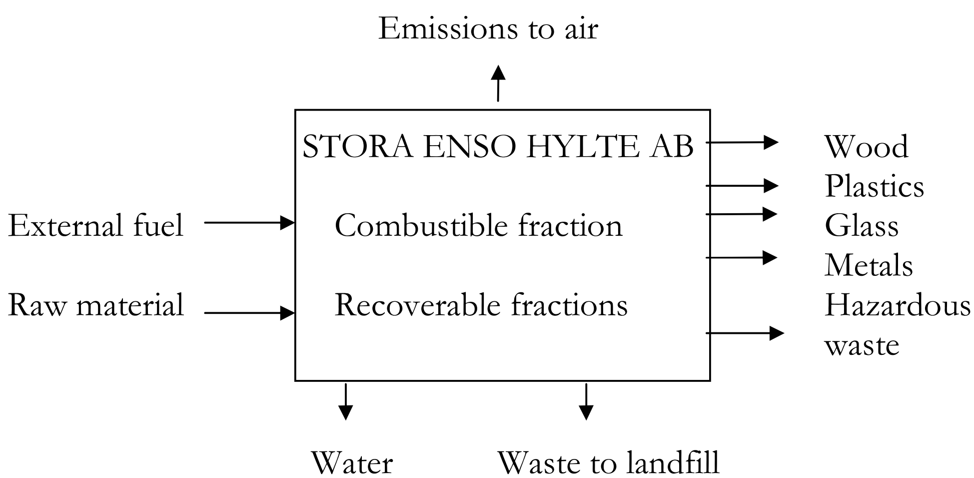

Fig. 4. Flow of material and energy in the material-recovery system (3).

Table 1. Results for the energy parameter in the energy-recovery system (2)

Category	Sub-category	Energy consumption (m^3 o.e.)
External inflow	External fuel (steam boiler 4)	
	Fossil fuel	6,480
	Biofuel	18,146
	Saving of fuel through combustion of RPwaste and wood chips	- 1,541
Total		23,013
Internal flow	Heat energy from:	
	RPwaste	3,255
	Compressed sludge	3,430
	Combustible waste	,272
Total		6,957
External outflow		0

Table 2. Results regarding economy in the energy-recovery system (2)

Category	Sub-category		Cost (kUSD per year)
External inflow	External fuel (steam boiler 4)		
		Fossil fuel	,751
		Biofuel	2,075
	Raw material (paper)		23,777
Total			26,603
Internal flow	Saving of fuel		- ,196
	Saving of raw material		
		RPwaste	-,020
		Shredding of combustible waste	,057
Total			-,159
External outflow	Hazardous waste		,008
	Waste to landfill:		
		Ash, slag and rest fraction	,395
		Metal waste	,045
Total			,358

Table 3. Results regarding the environmental impact in the energy-recovery system (2)

Category	*Sub-category*	*Value of environmental impact*		
Inflow	Fuel consumption	23,013 m^3 o.e.		
	Raw material (recycled paper)	350,239 t		
	Emissions to air from	CO_2	NO_X	SO_2
	transportation (t)	8,061	144.8	19.88
Internal processes	Fuel consumption	6,957 m^3 o.e.		
	Raw material	310 t		
	Emissions to air from			
	fuel combustion (t)	CO_2	NO_X	SO_2
	Fossil fuel	23,385	18.01	2.16
	Waste	5,127	4.34	0.52
	Biofuel	0	29.94	3.59
Outflow	Emission to ground			
	Waste to landfill (ash, slag and rest fraction)	31,977 t		
Emissions to air from waste transport (t)		CO_2	NO_X	SO_2
		27.14	0.45	0.05

Table 4. Summation of energy consumption for systems 1, 2 and 3 (m^3 o.e./y)

		System 1	System 2	System 3
External fuel				
	Fossil fuel	6,408	6,408	6,408
	Biofuel	18,146	16,605	16,877
Internal fuel		5,416	6,957	6,685
External outflow		- 1,541	0	- ,272
Total energy		28,429	29,970	29,698

Table 5. Summation of economy for systems 1, 2, and 3 (USD thousands/y)

	System 1	System 2	System 3
Cost of external fuel			
Fossil fuel	751	751	751
Biofuel	2,271	2,075	2,109
Cost of recycled paper	23,777	23,777	23,752
Savings - internal flows			
Material	- 20	20	- 25
Fuel	0	- 196	- 162
Costs			
Internal shredding of waste	0	- 57	- 55
Waste handling	416	359	363
Total cost	27,195	26,689	26,733

Table 6. Summation of emissions to air for systems 1, 2, and 3 (t/y)

System	SO_2 (t/year)	CO_2 (t/year)	NO_X (t/year)
1	26.14	219.61	32,296
2	26.20	197.57	37,347
3	26.12	197.07	37,138

The advantages for Stora as a result of implementing a new waste management program according to system 2, would be as follows: a saving in energy consumption of 1541 m^3 o. e./year; cost saving of USD 196,000/year; reduced emissions to the air: 22.04 t NO_X/year; and reduced emissions to the ground: 7314 t RPwaste/year.

However, the calculations and analyses presented in the case study are based on certain assumptions, for example the saving of externally produced fuels for combustion of internally generated waste is in the form of biofuel, and no tax is levied on the deposition of waste at landfills.

If it is assumed that fossil fuel is saved instead of biofuel, the energy optimization system (2) is still preferable, but the cost would increase by USD 7,200. If it is assumed that a tax is levied on waste deposition of USD 24/t waste, a further saving of USD 192,000 would be achieved in the energy-optimization scenario, resulting in a total saving of about USD 384,000/year, compared with the waste management system of today.

In other branches of industry companies may face different problems in optimizing waste management strategies. For some companies, the optimal waste handling system may include actors outside the company/plant, either through cooperation with other firms or with municipal waste receivers (such as district heating systems). This is taken into consideration in the model by introducing a specific entry, "external resources", into the tables for the energy, economy and environmental parameters for the three optimization systems. The method applied to Stora in this study can thus be used for other industries.

5. Conclusions

The method presented in this paper has proven to be able to cope, in a systematic and logical way, with the problems of organizing integrated waste handling systems within the industry considered in this paper. The method is also suitable as a basis for the development of more specific methodologies for the analysis of waste handling systems applicable to other branches of industry.

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