# Modeling of waste management processes so as to increase the efficient use of natural resources – outlook and future demands

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**Abstract**

Since the ban on placing untreated waste in landfill sites (Technical Instructions on Municipal Waste) came into force in June 2005, the increasing number of material waste streams in need of coordination has led to increased complexity of the recycling and disposal structures in the waste management and recycling industry, whereby the issues of material and energy efficiency are gaining importance. An approach to analyzing and optimizing these complex processes is offered in a project currently being undertaken at Bremen University of Applied Sciences in collaboration with partners from the industry itself. Here, as the basis for the development of software applications, a material flow model for the waste management and recycling industry is being developed for the purpose of supporting material waste flow management and thus helping to lay the foundations for better resource and cost efficiency in this industry.

**Keywords**

Modeling, waste management processes, resource efficiency, energy efficiency, material efficiency, material flow analysis.

# 1 The need for action

Against the background of complex recycling and disposal structures in the waste management and recycling industry, with its numerous material waste streams in need of coordination, which have developed since June 2005 (when it became illegal to simply landfill untreated waste, Technical Instructions on Municipal Waste), estimating the efficiency of different material streams has increasingly grown in importance. Since this time it has been necessary to treat waste in biomechanical or thermal waste treatment plants. Material, energy and cost efficiency will place big demands on the waste management industry in the coming years. For companies which operate a number of different waste recycling, processing and treatment plants, there is a need for them to be able to manage various material streams within or between the different plants, whereby considerable potential exists in many areas for optimization, especially in the more efficient use of material and energy contained in the available waste streams. However, at the moment, only partial solutions are available for controlling the processing and disposal networks. There are a number of different models available, each of which fails to provide a comprehensive view or, for various processes, does not include the relevant parameters, e.g. EASEWASTE (compare KIKEBY, J. ET AL.). The complexity of a corresponding, closed, comprehensive solution is compounded by a number of factors in the waste management system itself, whereby, economic, legal and specifically local factors are particularly important, as shown in the following Figure1.

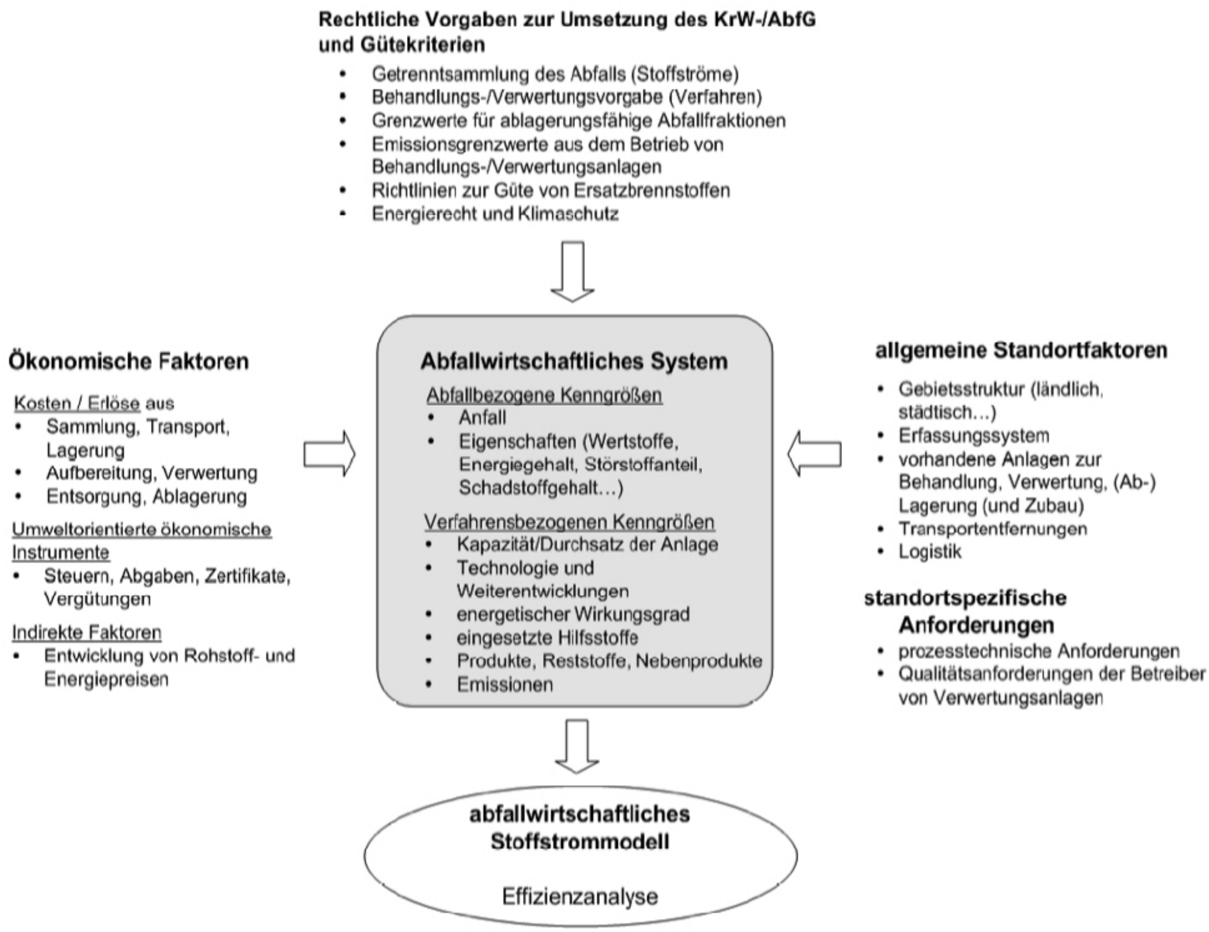


*Figure 1: Basic conditions and factors in the recycling industry*

The reason that comprehensive solution packages are lacking is to be seen in the fact that since implementation of Technical Instructions on Municipal Waste a material stream specific waste management industry has developed. From this, new demands emerge: for example, the course of waste processing is greatly influenced by the type, origin and composition of the waste in question. While in the models currently available, composition of the waste, i.e. the classification of fraction-specific parameters characteristic of a particular waste material stream are inadequately assessed. For companies in the waste management industry, however, it is of interest to be able to include in their assessment any factors, such as contamination limits, quality demands or surcharges related to waste quality, which influence the material flow process.

An additional problem is the large amount of raw data, which can hardly be made use of on a daily basis on account of a lack of analytical tools for modeling such material streams, despite there being a clear need for it if plants are to be successfully optimized, in respect to medium-term planning, as well as in respect to daily operations, so as to maximize both material and energy efficiency, and reduce costs (e.g. disposal services). In cooperation with local partners from the interested (software and waste management) industries, the hope is to improve this situation.

# 2 Project description

## 2.1 Aims

A current project at Bremen University of Applied Sciences is aimed at solving outstanding problems by facilitating contacts between different interest groups, thus increasing efficiency, and, in collaboration with IKrW, Ecologix and other industry sector partners, developing a material flow model for the waste management and recycling industries. The approach focuses on methods of waste treatment and processing, and characterization of the waste in question. The project involves cooperation between well-known industry sector partners (e.g. Nehlsen, swb AG) located in and around the city of Bremen, thus ensuring that the individual parts of the model fit together to form comprehensive solution. This includes features such as methods for calculating regenerative CO2, a material and ecological balance sheet, and technical simulation of planned plants. Of importance for the economics and daily operation of a plant are questions of changing material input parameters and the influence these have on output (increased emissions, waste in need of disposal, etc).

This project, supported by the European Regional Development Fund and the support program, Applied Environmental Research, of Bremen state, attempts to analyze and describe, using suitable parameters, the material streams of the waste management and recycling industry, along with the treatments and processing involved, and present them in a material flow model. In this way it is hoped to discover optimization potential for increasing energy, material and cost efficiency. The result will be the provision of a material flow model for the input of data, representation, evaluation and optimization of material waste flows in the waste management industry.

The particular aims of the project involve the unified characterization and classification of different kinds of waste according to their utility and contamination with pollutants, and data collection on material streams of the waste management and recycling industry, so as to facilitate optimization of treatment selection and plant operation (e.g. biomechanical plants, incineration plants, recycling parks) within particular companies or regions. The discovery and presentation of any potential to optimize the utilization of energy and recyclable materials contained in particular waste streams will also be integrated. In addition, by providing an overview of the distribution of pollutants in a particular waste management system, the model will facilitate assessment of its environmental relevance, thereby helping to assess both the economic (e.g. material and operating costs) and the ecological (e.g. emissions) situation.

The project is aimed at providing a basis for the development of software applications which will support material flow management in the waste management industry and form a solid foundation on which to build a sustainable waste treatment, recycling and energy-producing industry. The results of modeling and developing a material flow management system will also have wide-ranging effects on the whole value creation chain. Besides improvements in material and energy efficiency, technical innovations in respect to automation and efficient transport in the logistics sector (waste management logistics processes) are also expected from this project, thus contributing to the environmentally friendly development of the regions.

## 2.2 Development of a waste characteristic

However, for such modeling a important basis is currently lacking: a process-related, easily usable and with data substantiated waste characterization (description). For production-specific wastes, commercial waste and processed fractions of municipal waste no such description is available. All we have is a comprehensive base data set for domestic waste.

Because of the different approaches taken up until now in collecting data, there are limits to the extent that different data sets can be compared with each other or applied to situations other than the one they were collected in. However, against the background of a need to assess material distribution, and for information relating to the concentration or depletion/degradation of certain substances (e.g. pollutants) in the waste in question, such a characterization is of great importance and an essential aim of modeling. To facilitate this, standardization of the approach to data collection is called for, along with a definition of what data are necessary and a method of deducing the required parameters from the data collected. The end result is a characterization for different kinds of waste, according to utilization and pollutant content, which is implemented in the system.

The properties of the waste are essentially determined by its material group composition. These fractions of the heterogeneous waste can be characterized by corresponding parameters. Thus, for example, particle size and bulk density are important parameter for mechanical processes effecting material separation. Also, ferromagnetic and surface properties are used for the separation of metal and plastic fractions. The aim is to separate high calorific waste fractions and through further conditioning produce a fuel from them. The requirements for such substitute fuels depends on the kind of combustion involved, the firing equipment and the kind of regular fuel that might normally be used. Essentially, the decisive parameters are: calorific value, chlorine content, heavy metal content, particle size and the content of interfering substances (compare ECKARDT 2005). The first three named parameters, in particular, are dependent on the composition of the waste input, while the latter parameters can be readily achieved through subsequent diminution and metal separation. Particularly plastics, papers, boards and composite materials, with their high calorific values, should be enriched in the substitute fuel. However, plastics and composites are often sources of chlorine and heavy metals, the content of which fluctuates greatly, depending on the particular plastics or composites involved (compare KOST 2001 AND ROTTER 2002). Thus, in order to determine the composition of various kinds of waste, it is meaningful to be able to recognise and characterize different classes of plastic.

*Table 1: material parameters and their influence on utilization*

| **Material parameter** | **Thermal utilization** | **Bio-mechanical treatment** |
|---|---|---|
| **Particle size** | X | X |
| **Bulk density** | X | X |
| **Surface properties** | | X |
| **Ferromagnetism** | | X |
| **Calorific value** | X | X |
| **Chlorine content** | X | |
| **Heavy metal content** | X | X |
| **Interfering substances** | | X |
| **Ash content** | X | |
| **Water content** | X | X |
| **Organic substance** | X | X |
| **Particle size** | X | |
| **C, H, O, N, S** | X | |

By thermal utilization the relevant parameters can be deduced from the material composition and chemical-physical properties of the waste. Physical properties are ash content, water content, and the content of organic substances. Combustion related properties are determined by calorific value, material composition, bulk density and particle size. Carbon, hydrogen, oxygen, nitrogen, chlorine and sulphur content are relevant to estimating emissions.

It is clear that a multitude of different material properties are necessary in order to adequately describe a waste fraction in view of the technical processes that provide a possible solution.

# 3 Case study: Optimization of a waste-fueled power station

From the perspective of those operating thermal waste treatment plants, their main objective is in achieving a economically and ecologically optimal result. While keeping to the emission limits that are laid down, the most important factors influencing the plant's operating condition are:

- optimal energy coupling out,
- high availability of boilers and
- high through-put rates.

These factors, alongside the available technology and design of the plant, are influenced above all by the properties of the fuel being burned. The decisive material parameters relating to the waste have already been mentioned, but also of decisive importance are economic parameters (e.g. the price paid for taking the waste and disposal costs).

From the above it follows that the choice of waste mixture as fuel for a plant also allows one to control its operation, from which the question arises as to which waste fractions permit optimal use of plant design and technology? Because of the complexity of all the variables, this optimization problem can only be solved using computer software. The following figure shows just a part of the material flow analysis model.

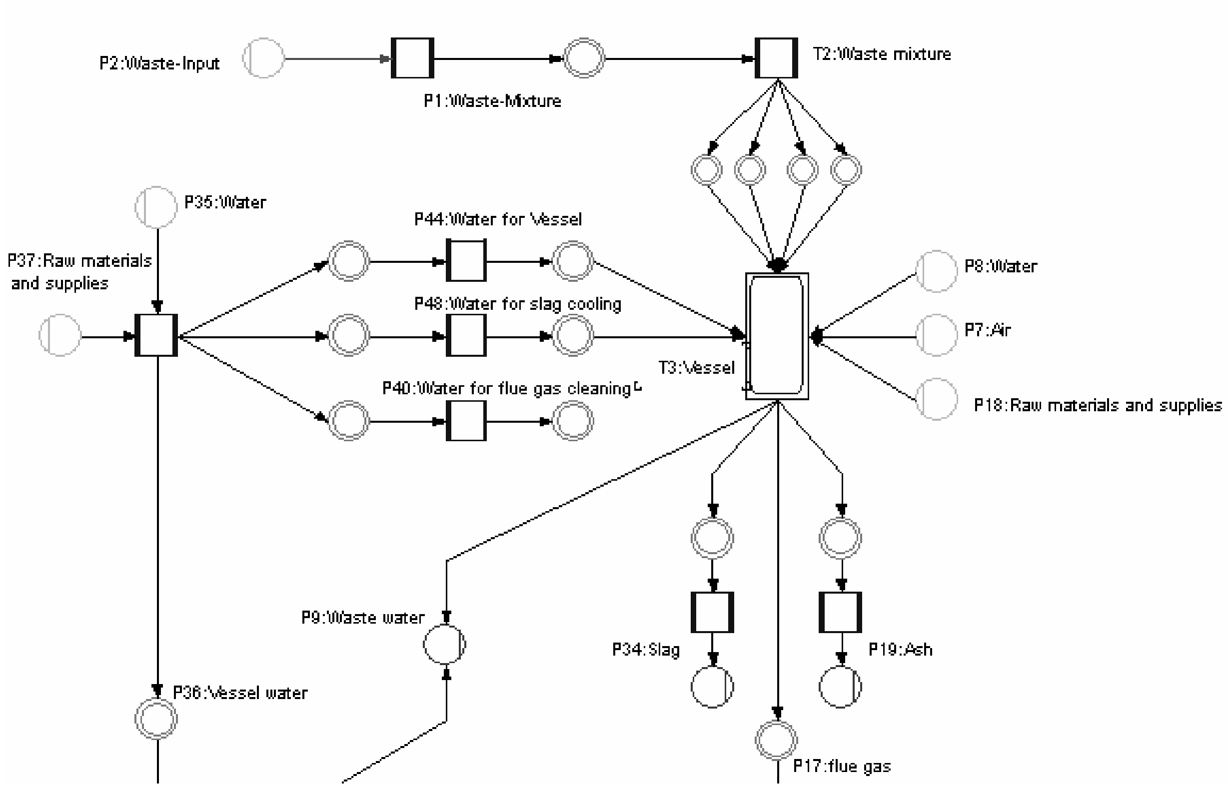


*Fig 2: material flow analysis model for a thermal waste treatment plant*

In modeling a thermal waste treatment plant, emission limits and other constraints have to be taken into account. Through-put on the boiler grate is calculated in relationship to the calorific value of the waste fraction and the thermal output chosen. Via the selected thermal output, a specific amount of steam is produced, which is decisive for the possible yield of thermal and electrical energy.

The result of an initial estimate shows waste fractions with relative low calorific values, ash and heavy metal content, along with a high price for taking the waste, to be the most favored fractions for waste incineration. However, such criteria alone do not suffice when working out optimal plant operation. It is decisive that emission limits and other constraints are taken into account (e.g. max. furnace heat liberation).

Within the framework of a Bremen University of Applied Sciences development project, an attempt was made to support, using models, optimization of a waste-fueled power plant operated by Abfallbehandlung Nord GmbH in Bremen (now the swb AG). To this end, the plants processing units, along with all the relevant material and energy streams and cost factors were diagrammatically represented in a model (see Fig. 2). The waste being fed into the plant was fractioned according to waste type and characterized with actual measurements, supplemented with data from the technical literature (also see SCHMIDT ET AL., 2008).

*Table 2: Results of model calculation for waste-to-energy power plant by variation of waste input*

| | Scenario 1 | Scenario 2 |
|---|---|---|
| **Waste input [Mg]** | 491,000 | 500,000 |
| **Calorific value of waste fraction [MJ/kg]** | 11.8 | 11.6 |
| **Max incineration capacity [Mg]** | 493,000 | 502,000 |
| **Slag [kg/Mg]** | 242 | 257 |
| **Ash [kg/Mg]** | 15.9 | 16.9 |
| **Residue RGR [kg/Mg]** | 29.4 | 31.9 |

In the first scenario, a total of ca. 491,000 Mg was incinerated in the plant, whereby the waste input had a calorific value of ca. 12 MJ/kg. In the second scenario, waste input was varied to the extent that ca. 95,000 Mg of high calorific fraction was replaced with sewage sludge (75% dry substance), shredder light fraction and residue from the sorting of commercial waste. In order to arrive at roughly the same calorific value as before, in this scenario 500,000 Mg of waste were incinerated (compare Table 2).

The results based on this model showed the following:

- Increase in revenue from the waste thanks to a higher through-put of 10,000 Mg compared with Scenario 2.
- Increased operational costs due to need for more additives in scrubbing flue-gases, because of higher levels of pollutants, mainly contained in the sewage sludge and shredder light fraction, in the waste mixture burned in Scenario 2.
- Increased disposal costs due to greater content of ash and slag in Scenario 2.

This example illustrates the complex interrelationships involved in waste incineration. It was possible to show that the models which have been developed reflect these interrelationships well and can be helpful in optimizing the operation of a waste-fueled power plant.

In order to make a final determination of optimal operating conditions for a waste-fueled power plant, one also needs additional methods of optimization from business studies/commercial informatics. A software tool developed at University of Pforzheim within the framework of a project dedicated to the “combination of optimization methods and material stream analysis for the improvement of material utilization”, named KOMSA, was thus applied in this project, to see if it was capable of providing a solution to its optimization problems. The goal was to produce a mixture of waste from a selection of waste fractions with different waste parameters, taking into account required emission limits and other constraints, for optimal operation. With the help of optimization algorithms contained in the optimization prototypes, different waste mixtures were automatically produced until the optimum composition for the waste-fueled power plant was found. For this case study, the numbers were anonymized, so that they didn't correspond to any real situation. In Figure 3, possible economic operation results are shown - and with them the optimization potential – in relationship to the composition of the waste. The graphic also shows the optimization methods used and the necessary calculations.

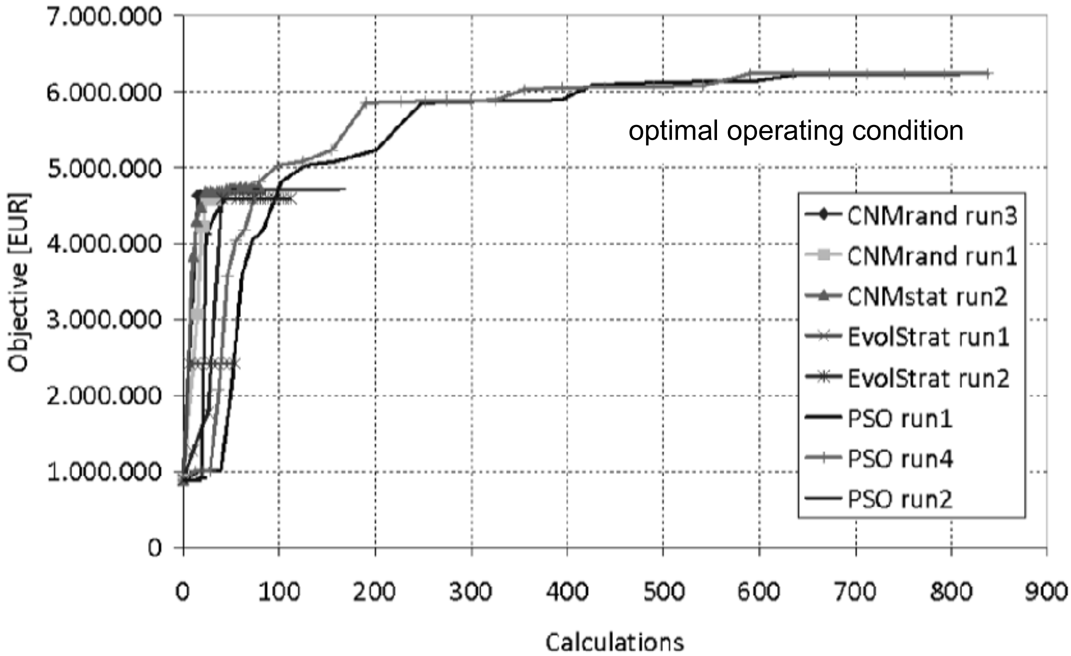


*Fig. 3: Anonymized representation of the results from six optimization alogrithms.*

With this combination of optimization methods and material analysis, the waste and corresponding material, energy and cost streams can in future be used as a basis for prompt assessment and optimization of efficiency in waste management systems and strategies.

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