

The Logistic Model for Decision Making in Waste Management

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The aim of the paper is to introduce an interesting approach supporting facility planning in the field of waste management. There was only 23 % of municipal solid waste (MSW) thermally treated in EU 27 in 2011. Increased exploitation of its potential for energy recovery would be accompanied by massive investments to highly-efficient and reliable incineration technologies. Therefore, the challenge is to do it efficiently, so in the optimal way. Even feasibility evaluation of every intended plant providing its service for a region represents a complex task. The gate fee (charge for waste processing in the facility) represents one of the most crucial input parameters for the assessment. The gate fee is driven by technology solution, competition, market development, environmental taxation and costs of waste transport to fulfill the plant capacity. Its valid prediction thus represents a demanding task. Firstly, an advanced tool addressing logistic optimization is introduced. The key idea is to focus on the problem of competition modelling among waste-to-energy plants, landfill sites, and mechanical-biological treatment plants producing refuse-derived fuel. Then, the main theoretical concepts are discussed and followed by development of a suitable mathematical model. The goal is to obtain a minimized cost of MSW treatment for the waste producers (municipalities). The application of the developed tool is demonstrated through a case study, where uncertain parameters entering the calculation are handled by repetitive Monte Carlo simulation based on real-world data.

1. Introduction

The paper deals with a recent important issue of municipal solid waste (MSW) management where the proper facilities planning in terms of their processing capacities, as well as, waste logistic plays an important role. Individual EU member countries are committed to reduce the ratio of waste going to landfills. The current state of waste management (WM) in across the EU is shown in (Eurostat, 2012). One of the key economic drivers towards the efficient WM is a landfill tax or total untreated waste landfilling ban (BiPRO, 2012). A general relationship between the price for thermal treatment of waste (WTE), landfilling and recycling, and including analysis of correlations between implementation stage of these strategies is studied in (European Commission, 2012). Further comments on the issue can be found in the paper (Van de Wiel, 2010). A recently developed overcapacity for WTE in some countries accompanied by legislation allowing cross-border transport of waste if energy recovery condition is met, creates a competitive environment by different processing prices. Waste is today understood not only traditionally but also as more valuable commodity - a source of energy and at the same time a source of raw materials (ferrous and non-ferrous metals). These factors lead to situations when it is beneficial to transport the waste even over longer distances. It initiates development of a unified market divided into regions with insufficient processing capacities (sources of waste) and regions where free processing capacities are available (sinks of waste). In such an environment, it is also planned to consent, build and operate new capacities in CEE countries in the near future in order to meet the commitments of individual countries to reduce the landfill of biodegradable waste (European Commission, 2012). These new

capacities will include not only WTE, but also mechanical-biological treatment (MBT) processes producing refuse-derived fuel (RDF) substituting fossil fuels in other combustion plants (power plants, cement plants, etc.). Since these two technological concepts correspond to the overall waste management balance in completely different manner, their different manner, their comparison can be found in Figure 1.

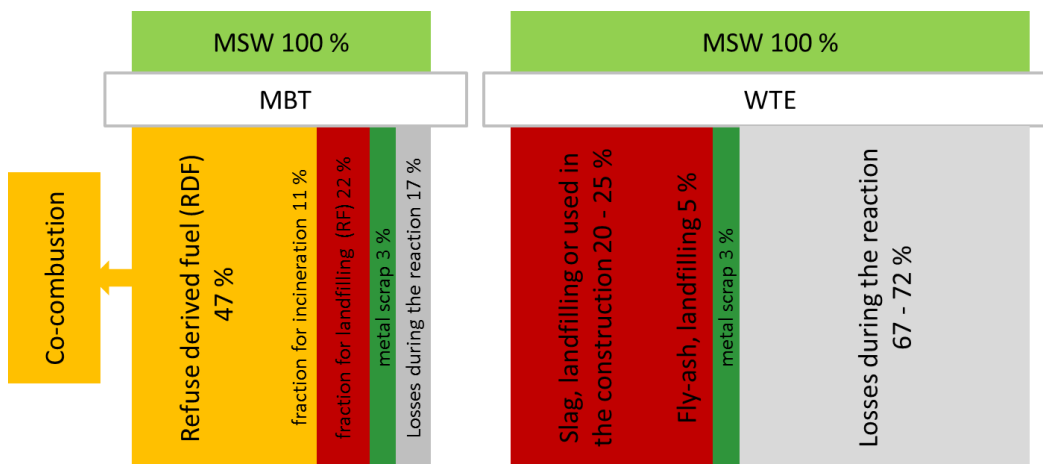


Figure 1: Comparison of overall mass balance for WTE and MBT facilities (Thiel, 2011)

Effective decisions about new projects rely on knowledge of gate fee to provide expected project sustainability (Šomplák et al., 2012a). The cost for waste transport should be included as well since, it becomes more and more important, especially once it occurs over long distances. At the same time, the supply chain composed of all operations following the way of waste from the place of its origin to its final processing place becomes more and more complex (collecting vehicles, waste transfer stations, rail and truck transport, loading/unloading mechanisms, etc.). In such a situation it is useful to have a computational tool at the disposal, which can support decisions related to the following issues: (1) feasible locations screening for WTE and/or MBT sites and their sizing; (2) waste flow simulation between waste sources and waste sinks in rapidly extending EU waste market; (3) support on supply chain planning and infrastructure improvement to remove expected bottlenecks; (4) project feasibility evaluation (risk analysis) focused on an assessment of waste availability and expected processing price (Šomplák et al., 2012a); (5) impact evaluation of regulation and legislation (landfill taxes, ban).

The authors developed a computational tool which can support afore mentioned activities. The description as well as its practical application in a small scale, i.e. for a specific region (the Czech Republic – CZE) is presented in this paper. The basic idea behind our tool is as follows: The producer of waste (municipality in case of MSW) makes its decision about its future MSW treatment strategy. The objective function addresses expenses in terms of cost for waste processing at individual facilities and overall transportation cost to the facilities. Environmental taxation is included as well and reflected in the gate fee. The costs are minimized. This basic idea is graphically presented in Figure 2.

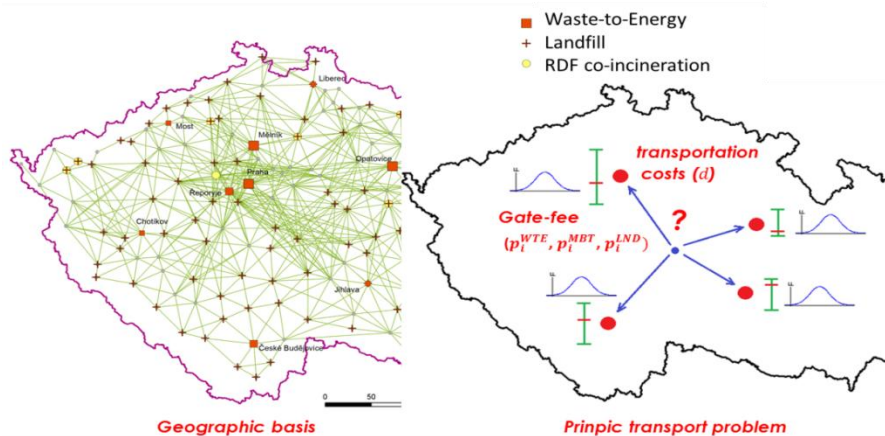


Figure 2: Visualisation of basic ideas of transportation problem behind the developed tool

In general, solving of the aforementioned simple-sound task is quite demanding on processing of real-world data. The sets of inputs can of course differ according to the detail level of investigation. In general, they include information about: (1) existing logistic infrastructure – routes and their quality, taxation, railway corridors and their loading, distances and expected transport times; (2) waste-management statistics – specific waste production, waste lower heating value, availability of separate collections systems for recyclables and their efficiency, demand for secondary raw materials, etc.; (3) facilities – existing landfill sites, incineration plants, new projects under consideration and/or erection; (4) prices – energy prices (heat, electricity, fuels), landfilling taxation, etc.

2. Mathematical model

Firstly, we have to mention related papers to the discussed problem area and solution methods. There are inspiring texts dealing with sustainable supply chains design (Young et al., 2012), energy network solutions for regions (Kettlet et al., 2012), descriptions and simulations by p-graphs (Süle et al., 2011), and multiple criteria reduction in biomass energy supply chains (Varbanov et al., 2012). Among useful sources related to logistic models we have to mention (Ghiani et al., 2004) and for indicator variable integer programming techniques (Williams, 2009). There are also several attempts to tackle the discussed problem by operational research approach, see, e.g. (Lang et al., 2003). To successfully deal with a decision making problem related to the specific WM problem, we have built a specialized transportation optimization model. The key idea is to study disposal of the waste produced in the villages and towns (sources of waste) and to approximately model a competitive environment. We denote sources of waste by nodes and roads are represented by edges, see Figure 2. So, we minimize overall costs as follows

$$\min \sum_j d v_j x_j + \sum_i \sum_j a_{ij} x_j (p_i^{WTE} + p_i^{LND}) + \sum_j e v_j l_j + \sum_i \sum_j a_{ij} l_j p_i^{MBT} \quad (1)$$

subject to (constraints are valid for all nodes i representing sources of waste)

$$\sum_j a_{ij} + o_i + \delta_i^{MBT} \left(\sum_j a_{ij} l_j + \sum_j b_{ij} t_j \right) \leq C_i^{WTE} + C_i^{LND} \quad (2)$$

$$\sum_j a_{ij} l_j \leq C_i^{RDF} \quad (3)$$

$$- \sum_j a_{ij} l_j \leq C_i^{MBT} \quad (4)$$

$$\delta_i^{MBT} \sum_j a_{ij} l_j = \delta_i^{MBT} \sum_j b_{ij} t_j \quad (5)$$

$$\delta_i^{LND} \sum_j a_{ij} x_j + \sum_j b_{ij} t_j \leq C_i^{LND} \quad (6)$$

where x_j is an amount of MSW transported by arc j , l_j is the RDF amount transported by edge j , t_j is the TF amount transported by edge j , a_{ij} is an incidence matrix for MSW and RDF transportation graph, b_{ij} is an incidence matrix for RF transportation graph, d is the MSW unit transformation cost for 1 ton, e is the RDF transportation cost for 1 ton, v_j is the length of edge j (distance between related nodes), p_i^{WTE} is a gate fee for 1 t of MSW in WTE in node i , p_i^{MBT} is a gate fee for 1 ton of MSW in MBT in node i , p_i^{LND} is a gate fee landfill for 1 t of MSW in node i , o_i is an amount of MSW production in node i , C_i^{WTE} is a WTE capacity in node i , C_i^{LND} is a capacity of landfill site in node i , C_i^{MBT} is a capacity of MBT in node i , C_i^{RDF} is a capacity for RDF incineration in node i , δ_i^{LND} is equal to 1, if node i is of landfill type and equals 0 otherwise, δ_i^{MBT} is equal to 1, if node i is a village with MBT and equals 0 otherwise.

Besides prices, the crucial input parameters in the model are the gate fees (constant value or function reflecting the economy of scale). For each facility (intended project to be assessed and/or included in the task) this input is generated by external techno-economic models. The sustainability and financial attractiveness of each new project is determined by many uncertain parameters (an energy price, potential competitive technologies, unexpected out-ages, etc.). All of these parameters have their own positive or negative effect on project profitability (often expressed by internal rate of return - IRR) and influence the projected gate fee offering expected revenues. The sensitivity of IRR under varying scenarios of future trends in uncertain parameters can be tested with the use of complex techno-economic models. The obtained ranges of IRR as an expected result can differ for every single project regardless it is WTE or MBT since it reflects locally-dependent conditions. To make the situation easier in our case study, we

considered the same IRR range 8 – 12 % for each competitive project. The corresponding gate fee intervals were determined in the next step and these intervals entered the optimization task (see Figure 2) as follows. The optimization involving afore mentioned objective function was repeated many (thousand) times for varying combinations of gate fees for individual facilities. The gate fee for each calculation was generated by the Monte Carlo method from the gate fee interval with the use of truncated normal probability distribution function. This stochastic approach that can be considered as wait-and-see approach by terminology of stochastic programming (Birge and Louveaux, 1997) allows subsequent statistical analysis of results (see later).

3. Practical application

In this section we introduce the benefits of our tool through its practical application. We follow the discussion about future WTE potential capacities in the selected region of CZE as mentioned by Šomplák et al. (2012b) and (Pavlas et al., 2011), where up to 11 new WTE projects with overall capacity of 2200 kt/y and few MBT plants are considered in the new WM strategy. In this paper we are going one step further in the analysis and with the help of our tool we simulated performance of this newly developed market from economic point of view. The concept as whole is only viable while all projects included are attractive, viable and reveal expected sustainability. The conditions under which this will happen are studied as well. Since the limited space, only few examples of obtained results are presented. The first result is related to risk analysis, where two WTE projects to be sited in different locations (denoted as X and Y) are compared. Figure 3 shows that they perform in completely different manner. The risk is expressed by the probability distribution of the optimal objective function value that is obtained by 1 thousand times repeated optimization task (see Figure 3). In each run one capacity for project of our focus was proposed reflecting the current gate fees of all competitors. The survival function (complementary cumulative distribution function or reliability function) then expresses the percentage of experiments resulting in capacity higher than this capacity. Moreover, two different scenarios related to legislative development (Sc1 – supporting only to WTE, Sc2 – supporting both WTE and MBT) were included. Under the assumption that the same capacity 150 kt/y for both projects was proposed by the preliminary concept we conclude that the project Y is less sensitive to future competitors whereas the project X is very risky and probably feasible only under specific circumstances resulting in a lower gate fee. One can speculate about the effect of even higher landfill tax than the expected one in Sc1. This situation is depicted in Figure 4 where the relationship between the risk and landfill tax is shown. The project in locality X, remains highly-risky even under conditions of the high landfill tax. Other ways how to enhance its competitiveness have to be investigated (e.g. establish it as a municipal project with lower return on investment expectations).

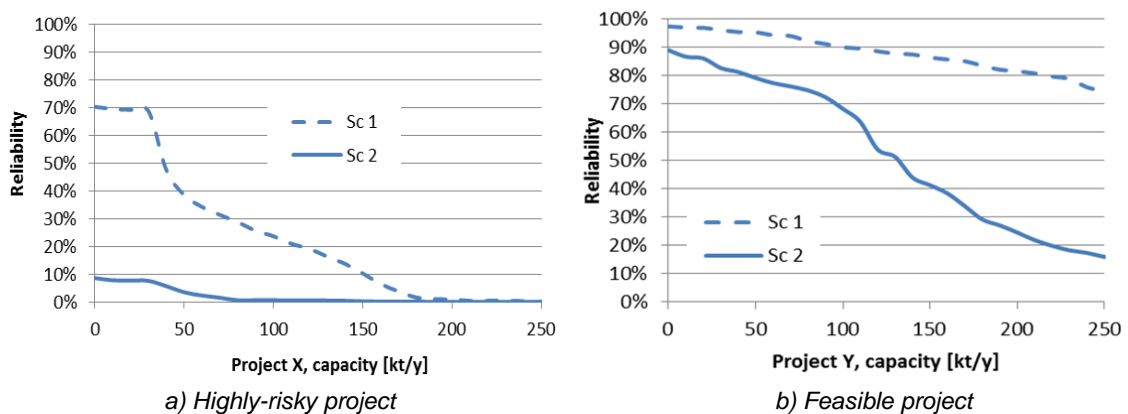


Figure 3: Risk-analysis related to reliability of capacity fulfilment performed on two projects in different localities for two different scenarios of future legislation development

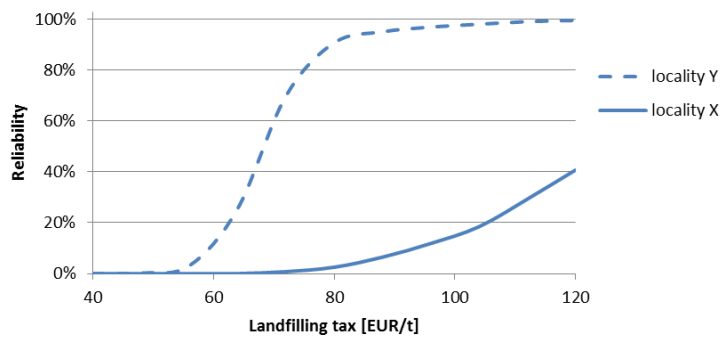


Figure 4: Risk-analysis related to reliability of capacity fulfillment performed on two projects under different landfill taxation rates

The calculation also proposes collection areas for each facility, and therefore, maps expected future flow of waste in the region. This information is crucial for survey of the traffic load and missing infrastructure planning. A graphical illustration of such a result is depicted in Figure 5. The layout fully corresponds to the proposed concept of WM, where all WTE facilities are in operation. Majority of waste is incinerated directly; only small portion goes through MBT process and/or is landfilled. These streams are excluded to keep Figure 5 clear.

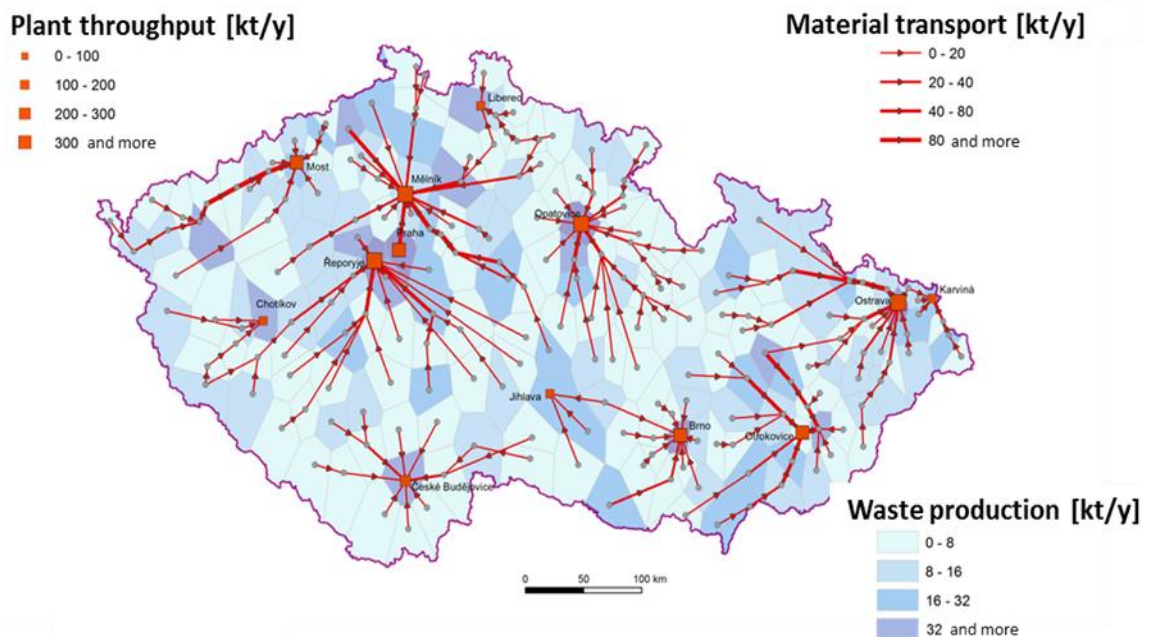


Figure 5: Visualization of results of the transportation model for one particular scenario

4. Conclusions and further research

In the paper, the tool for conceptual planning of new waste-to-energy capacities is introduced. By using the results of calculations, waste management policies can be realized through legislative amendments. In addition, it is also possible to determine the attractiveness of potential sites for the construction of new facilities. Therefore, the presented optimization model represents an important contribution towards managing waste effectively.

The model represents a transportation problem implemented for this field. Its practical application is demonstrated through a case study related to specific region (the Czech Republic). A risk analysis of two WTE projects located in different areas is performed. The stochastic approach that can be considered as

wait-and-see approach includes repeated calculation and subsequent generation of reliability functions. Obtained functions than indicate risky and/or attractive projects.

We further plan to focus on generalization and modification of our model to involve uncertain parameters in more complex way, see, e.g. (Huang et al., 2001) and (Birge and Louveaux, 1997). Another challenging task is an application of our tool for simulation and/or optimization of spreading EU waste market. This means its introduction for larger area exceeding the border of one country with all its consequences in increased demand on input data.

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