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Waste-to-Energy Facility Planning Supported by Stochasting Programming - Part I Introduction

Radovan Šomplák*[a], Martin Pavlas[a], Vladimír Ucekaj[b], Pavel Popela[c]

[a]Institute of Process and Environmental Engineering, Faculty of Mechanical Engineering, Brno University of Technology (UPEI VUT), Technická 2896/2, 616 69 Brno, Czech Republic
[b]EVECO Brrno, s.r.o., Foltýnova 1006/17, 635 00 Brno, Czech Republic
[c]Institute of Mathematics, Faculty of Mechanical Engineering, Brno University of Technology, Technická 2896/2, 616 69 Brno, Czech Republic
somplak@upei.fme.vutbr.cz

This paper focuses on current issue of waste-to-energy (WTE) facility planning supported by modern computational tools. Waste management in many countries of the European Union will have to undergo a significant change in the coming years, which will include the diversion from dominant municipal solid waste (MSW) landfilling to other treatment options (e.g. material and/or energy recovery). For example, the Czech Republic (CZE), which is used in this article as a model region, will have to divert from landfilling more than 3 000 kt/y of MSW by 2020. The only viable alternative is building new WTE facilities to meet this target which entails considerable investment costs and opens the potential for application of optimization procedures. An optimization task aiming at this crucial task is introduced and further discussed in the article. Important background information, which creates a necessary set of inputs for finding realistic solutions, is presented at the same time. Afore mentioned set includes:

- The potential of convenient waste for energy production in the considered region
- Technology development influencing plant performance
- Energy products export possibilities - the existence of district heating (DH) networks for generated heat utilization
- Forecasting of prices development in the future
- Financial sustainability of the project.

The results of several studies from different fields (waste management, DH) are summarized in the article for this purpose. The knowledge gained from this article is further used for the development and practical application of computational tool. The tool supports choice of optimal design parameters of individual WTE facility.

1. Waste-to-Energy in Europe

The waste produced by inhabitants and/or the waste generated by commercial and non-commercial activities and collected by local authorities (so called Municipal solid waste - MSW) represents a worldwide challenge in terms of its effective disposal. The following hierarchy is preferred by EU legislation (European Parliament, 2008): 1. Prevention, 2. Re-use, 3. Recycling/composting, 4. Recovery, 5. Landfilling. The fulfillment of this strategy differs from state to state and it is related to local waste management legislation and other socio-economic factors (see Figure 1).

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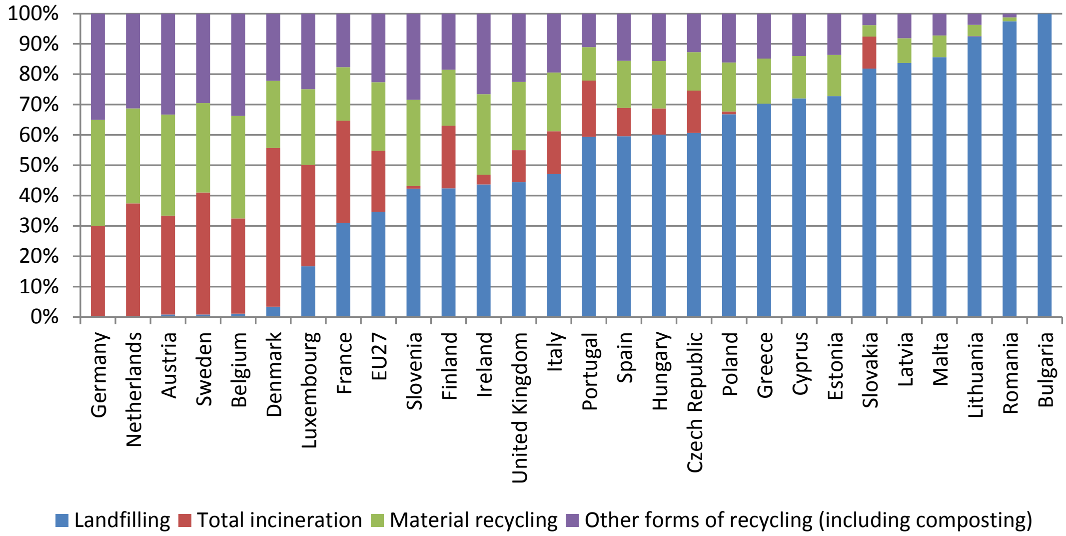


Figure 1: Municipal waste treatment in EU27 in 2009 (Eurostat, 2012).

There was 22 % of MSW (approx. 70 mil tonnes) thermally treated in EU 27 in 2009. Considerable amount of energy (28 TWh of electricity and 70 TWh of heat) was generated by this activity (CEWEP, 2012). Unfortunately 3 8 % of current production is still landfilled. The overall MSW production rate in most EU countries has increased in last 15 years at least 10 % (Eurostat, 2010) and there are no relevant facts and figures justifying lower increases in future projections. The correlation between MSW production rate (kg per capita and year) and economic indicators (e.g. gross domestic product) is widely discussed (Sokka et al., 2007). The impact of different policies, which can contribute to decoupling the MSW generation rate from landfilled amounts (Mazzanti and Zoboli, 2008) and increasing share of more favorable techniques, is investigated at the same time.
For that purpose, best available technologies (BAT, even BAT plus - emerging techniques (BREF, 2006)) are used ensuring the lowest impact of thermal treatment on the environment. WTE is thus not only disposal method but source of reliable, clean and renewable energy. Since MSW contains about 50 % biodegradable fraction, WTE represents considerable renewable energy source (Fellner et al., 2007). Therefore it can contribute to the future renewable energy production, which is expected to growth to 30 TWh of electricity and 41 TWh of heat in EU 27 by 2020 (CEWEP, 2009).

2. Waste-to-Energy in the Czech Republic - Current state and 2020 Outlook

There was approx. 18 % of generated MSW incinerated in three operating WTE plants (cities of Brno, Liberec, Praha) in 2010. The existing annual capacity 624 kt/y is not still enough to fulfil the country obligation coming out from landfill directive to reduce the amount of landfilled biodegradable waste by 65% of the amount produced in 1995 by 2020. The significant effort will have to be made and financial funds allocated for realization of additional capacities to achieve the target. In this context a comprehensive study for Czech Ministry of Industry and Trade was performed by the authors of this paper in 2011. It was concerned with the following tasks:

- evaluation of potential of WTE in regions,
- location proposal of new WTE plants with respect to amount of waste available and heat supply potential,
- identification of future projects and quantification of total capital costs,
- quantification of optimal subsidies (capital and operation) and evaluation of impact on energy end users,
- proposal for minimum efficiency required to receive subsidies.

Some important figures coming out from afore mentioned study are presented later in this paper. Since approx. 3350 kt/y of waste suitable for thermal treatment by 2020 will be available, waste management system have to be modified. There are two main themes that are frequently discussed:

- Mechanical-biological waste treatment (MBT) with utilization of refuse-derived fuel (RDF) in energy production systems
- Waste treatment in WTE plants.

Both themes were reviewed from economic sustainability point of view using the same scenarios of commodity prices and macro-economic indicators development. In accordance with numerous works, MBT was evaluated as an inappropriate solution in general under the conditions in CZE (Eriksson et al., 2005 and Consonni et al., 2005). RDF can be utilized in cement works which are appropriate for utilization of alternative fuels. However there is a potential to utilize only approx. 80 - 90 kt/y of RDF produced from MSW (200 to 300 kt MSW at the MBT input) as a substitute fuel.

Therefore the concept of location of new WTE plants as well as plants for RDF utilization was proposed for 2020. It would enable satisfaction of the targets of the Czech Republic and it would contribute to effective energy production from waste at the same time. Integration within existing DH networks is emphasized. The concept assumes erection of 11 WTE plants with waste treatment capacity of 100 to 430 kt/y by 2020. The overall waste treatment capacity of WTE plants including existing plants should be then 2800 kt/y. According to EU hierarchy in waste management, legislation in the Czech Republic should provide economic conditions preferring WTE to landfilling. The expected heat and electricity production in case of incentive conditions for combined heat and power production is expected 8 – 14 PJ and 800 – 1000 GWh/y. Expected overall capital costs would be 2.3 billion EUR.

3. New WTE facility planning - task description

There are many factors influencing the new WTE plant project from its first ideas up to its successful operation: location, amount of waste available, logistic costs, waste treatment capacity, lower heating value of MSW, heat demand, energy prices, legislation, etc. Generally, these parameters undergo development in time. This opens the question how to tackle this phenomenon especially in the process of new facility planning since WTE projects are of complex nature and very often delayed by negative public attitude in countries with low (none) incineration tradition, the project preparation is very time-consuming (5 – 7 y) and therefore it is necessary to consider the development of parameters. Naturally, their future development is uncertain. As an example, the following uncertain parameters important for future WTE plant financial sustainability are mentioned:

- Trend of MSW production in particular regions, which is related to economic conditions – it influences collecting area to satisfy waste treatment capacity.
- Gate fee driven by competition in waste management sector
- Heat demand in DH network and price of heat – decrease of heat demand by implementation of energy savings, decrease in number of customers, brake-up of DH network eventually
- Electricity price and subsides, trend of subsidies, etc.

Uncertainty in these vital parameters and their future trend in combination with the multi-disciplinary character (waste management - energy generation) make the task of new WTE facility planning very complex. Intuition-based design should be replaced by approach involving use of sophisticated computational tools. This possibility is introduced by Šomplák et al. (2012), where the optimization model including stochastic aspects is described and presented through a case study. In this paper some necessary background information and important input parameters are discussed in more details. Capital costs are one of them. It should reflect production factors and also state-of-the-art technology. As far as price forecasting, local conditions related to the CZE are addressed. Forecasting should be made with respect to energy policy, local energy sources and expected development of DH in considered region.

3.1 Capital cost - cost of technology

WTE plant is a capital-demanding technology. During decades, it has developed into complex process securing waste treatment with a minimized impact on the environment and providing renewable and clean energy at the same time. The cost of technology is influenced by its annual throughput, number of lines, heat recovery system and off-gas cleaning system layout, etc. There is often a trade-off between maximum energy-efficiency and the lowest negative impact. Several simple cost models related to WTE were published (Consonni et al., 2005). They commonly reflect the decreasing specific cost with increasing capacity, however they are not addressing all afore mentioned aspects. A comparison between a simple cost model and results of more detailed capital analysis (more lines for higher throughputs considered) is provided in Figure 2.

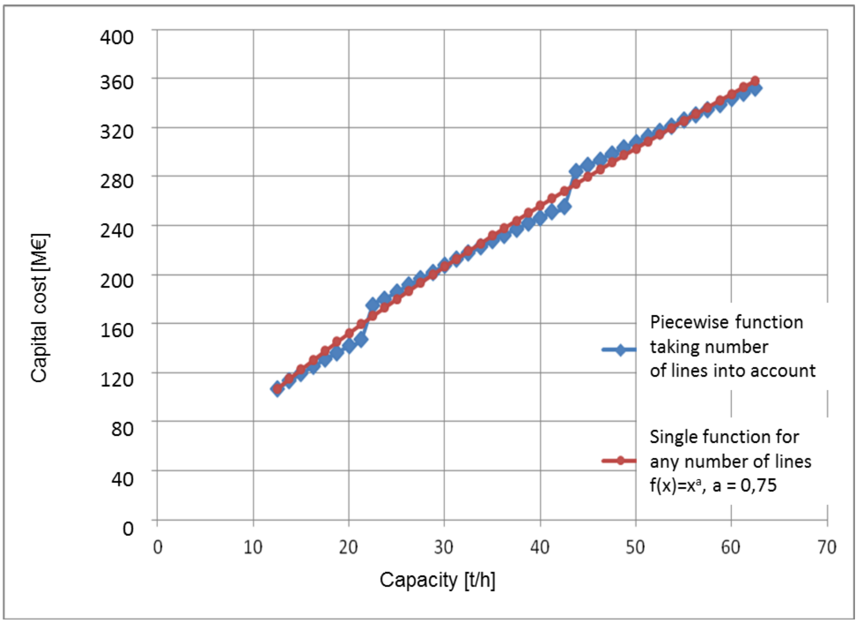


Figure 2: Function for estimation of capital costs

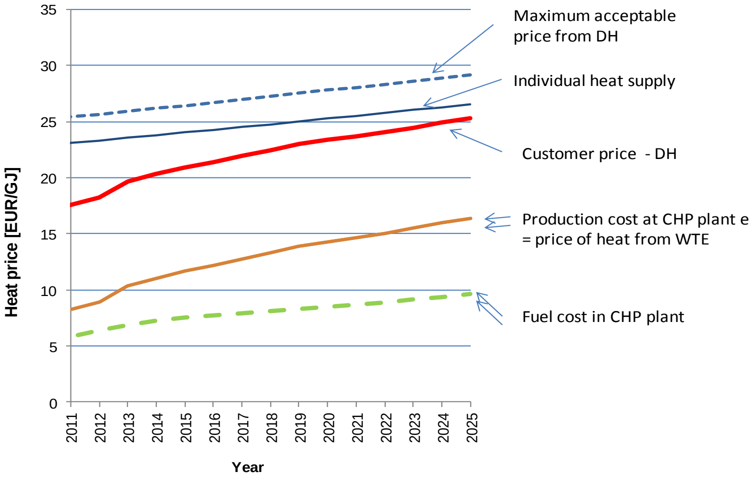


Figure 3: Heat pricing model for selected region with developed DH network.

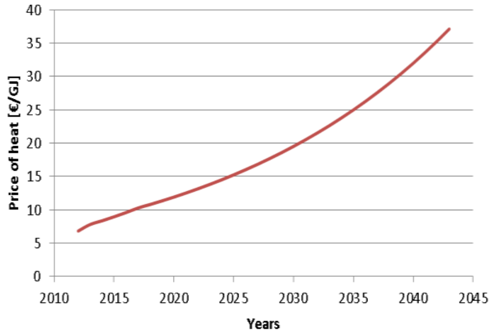
3.2 Forecasting prices development

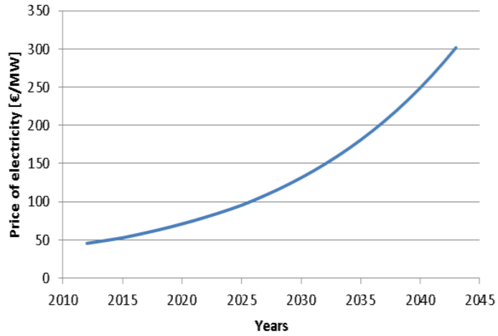
WTE plant economics is tightly bound by actual incomes from provided products (heat, electricity) and services (waste treatment) and operational costs (labor, additives, energy, maintenance, residue handling, water etc.). Both can change during WTE lifetime exceeding 20 years. Two examples of a forecast on price developments related to WTE plant income are presented - price of heat and price of electricity.

Heat generation and its export to the consumers represent a key factor for energy efficient and economically feasible operation. The price of heat purchased from WTE by third person (e.g. DH network operator) is locally dependent and influenced by many factors (DH network, share of heat delivered by WTE, fossil fuel availability). We assume a large DH with total heat demand 4 TJ/y. WTE with capacity of 160 kt/y can supply 20% of the demand. It covers the base load. The rest is produced by central CHP plant and/or other local heating stations (all fired by lignite). The pricing model, where the heat price (from WTE) is equal to production cost at central CHP is presented in Figure 3. Data related to specific region in the CZE are presented.

One can see that the heat price is expected to rise significantly within next few years. This is due to limited coal reserves in the CZE and additional cost associated with emission abatement required to fulfill strict emission limits set for coal-fired plants. The price of heat from WTE rises as well. In 2020 when the WTE plant is in operation (if finished) we expect price approx. 14 EUR/GJ. Increasing price of heat has a positive effect on WTE plant economics only until maximum acceptable price from DH is reached. Once this is exceeded massive customer-driven disconnecting forms serious threat for the whole DH and rises the pressure on decreasing the heat price from WTE. This scenario should be also covered by a risk-analysis.

The forecasted price development during the WTE plant lifetime can be seen in Figure 4a. Similar prediction was made for electricity price (Figure 4b). The price development in next few years was estimated by mapping the current situation in the European energy exchange market. In 2020 it is expected approx. 76 EUR/MWh including penalty due to output deviation. Green electricity and co-generation subsidies were considered as an extra income.





a) b)

Figure 4: Forecast for trend of price a) heat, b) electricity

4. Conclusions

WTE facility planning has very complex and, due to parameters with uncertain future trends, stochastic nature. Moreover such a project is very demanding on capital and therefore, the intuition-based design should be replaced by an approach involving the use of sophisticated computational tools. This paper presents a crucial aspect, which has to be considered in WTE facility project, such as the waste production in the considered location, potential for heat supplies, energy prices, gate fee with respect to competition in energy sector, and their development in time. The paper proposes methods for modelling of initial investments and forecasting of prices in the future. Data related to the current situation in the Czech Republic as an example of country with unexploited potential for WTE are presented. Ideas and results mentioned in the paper are used in Šomplák et al. (2012) where stochastic programming model for waste to energy facility planning is described and presented through a case study.

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