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Improved Feasibility Analysis under Volatile Conditions: Case of Waste-to-Energy

Tomáš Ferdan*, Radovan Šomplák, Martin Pavlas

Institute of Process and Environmental Engineering UPEI-VUT, Faculty of Mechanical Engineering, Brno University of Technology Technická 2896/2, Brno, 616 69, Czech Republic
ferdan@upei.fme.vutbr.cz

In these days, the majority of the EU countries, mainly these from Central and Eastern Europe, promised gradual decrease of the municipal solid waste (MSW) landfilled. This has been leading or will lead to landfilling bans or taxation with the aim to establish other methods of MSW treatment. One of these possibilities is waste-to-energy (WTE).
This paper deals with the issue of a new WTE plant conceptual design. The price of MSW treatment at the plant (gate-fee) is the key parameter for the project sustainability. Once the gate-fee is determined from comprehensive cash-flow analysis, it is affected by other incomes and costs and their future unpredictable escalations. This is more and more important in nowadays dynamic world (volatile energy prices etc.). One of the key elements, entering such an analysis, is the heat delivery to third parties (i.e. residential heating via district heating systems or integration with industrial utilities) and related trends in amounts and prices. At the same time, the proposed gate-fee has to guarantee the competitiveness of the project in terms of fulfilling the designed capacity. Every project is very specific and its economy responds to potential scenarios differently, which makes the situation even more unforeseeable.
A new approach towards risk analysis in case of WTE is presented in this paper. It assesses the impact of different scenarios on plant economy. A complex techno-economic model is used to demonstrate the relation between gate-fee and time variable parameters (heat, electricity, gas, chemical, maintenance costs etc.) for specific projects. Fixed return on investment is expected. Afterwards the transportation costs associated with waste delivery are included and results compared to evaluate plant competitiveness. This is performed by in-house developed optimisation tool *NERUDA*.

1. Introduction

An effective waste management is nowadays more and more discussed in EU countries, mainly in Central and Eastern Europe. The study, presented later in this paper, is inspired by current situation in the Czech Republic (CZE), where the waste management should undergo much needed transformation to achieve more effective waste disposal. Today, the major part of municipal waste produced in CZE is landfilled without any possibility of energy or material utilization. Less than 20 % of waste is incinerated in 3 waste-to-energy (WTE) plants with the capacity of 645 kt/y (Pavlas et al., 2012). Until 2020 the Czech Republic has to lower the ratio of landfilled biodegradable waste to 35 % of the amount landfilled in 1996 (listed in European Parliament, 1999). The possibilities, how to fulfil the reduction, are mentioned in European Parliament (2008), where the hierarchy of waste disposal is presented. Waste-to-energy is one of these possibilities. New WTE projects are in preparation at different stages in CZE. One of them is under construction, one has the building permit and others are in stage of conceptual planning when the economic feasibility is evaluated. Generally, planning of investments in new WTE plants is a comprehensive task in the field of infrastructure and energy production. It is also specific by huge capital and operating cost. Capital investment costs for WTE plants are from 700 to 1,000 €/t for 1 y (Šomplák et al., 2013a), the project preparation phase lasts about 2 years at best (Pelloni, 2012) and the plants have a planned life span from 20 to 30 y. The parameters affecting operational costs and profits are changing significantly during the life span. Therefore, it is an advantage to perform complex simulations considering

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uncertain development of key economic parameters. An approach based on an application of Brownian motion phenomena (see below) that involves the uncertainty in development in connection with the appropriate gate fee, is proposed in this paper. Based on our review, such an approach has not been applied in the field of waste management
Various rules are used for capital investments assessment, see Geddes (2002). One of the most used criterions is internal rate of return (IRR). This rule is also used in our case study. IRR indicates the interest rate generated by the project. The formula for IRR evaluation is stated in Eq(1).

$$\sum_{t=1}^{T}\frac{CF_t}{(1+IRR)^t}-IN=0 \tag{1}$$

Where: CF_t cash flow in selected time period,
IN capital investment,
T supposed project life span (case study is considered for 25 y),
t order of a given time period (usually 1 y).

The cash flow is built on the basis of revenues (inflows) and costs (outflows) evaluation. These inflows and outflows can be variable (operation and energy production dependant) or fixed (e.g. wages, depreciation, payments, etc.). In case of WTE plants, inflows include an income for waste treatment, heat and power sales etc. These inflows are dependent on local conditions, waste quality, plant technology and prices of exported products (either agreed in contract or traded on the energy exchange). Following share in profit is typical for WTE plant: waste treatment about 70 %, energy sale 25 % and 5 % from sale of recovered material (Pelloni, 2012). The structure of incomes might differ from case to case and from year to year depending on actual conditions. Therefore, in case of new WTE financial assessment, they all should be considered uncertain and should be predicted. The main goal of this paper is the analysis of the gate fee providing the required cash flow of new WTE plant under uncertain circumstances. A techno-economic model (T-E model) of the project is made at first. Then the time series of key parameters are generated taking historical data into account (scenarios). There could be a correlation between the key parameters therefore they have to be predicted altogether. The gained scenarios enter the T-E model and are utilized for the project rate of profit and risk analysis (sensitivity testing of IRR).
The described approach is widely used for modelling of financial markets. In this paper, this method is newly used in specific area of WTE for risk analysis of investments in new plant. The results (gate fee) could be used for simulation of a competitive environment in optimisation tool NERUDA, see Šomplák (2013b), or as a support enabling development of win-win strategies projected into contracts between the waste producer and the investor/operator. Trade-off between sustainable service at the lowest cost for waste producer and acceptable risk for operator has to be negotiated, which is even more important in today's dynamic world.

2. Techno-economic model

The return on investment (qualified as IRR) is the key factor in projects planning. The potential investor specifies the IRR based on alternative investment opportunities and potential risk associated with the project. The T-E model is necessary for the estimation of cash flow.
The authors used so-called „Flexi model“ for operational assessment of WTE plant. The technical part is a simplified balance model of key technological parts. The model enables broad range of input parameters settings so that it could be possible to describe any technology pattern of a given WTE plant. The adjustable parameters allows the user to choose e.g. between backpressure and condensing extraction steam turbine with one or two extractions. Another adjustable parameter is the way of heat export. The heat export can be assigned to two turbine extractions: one with higher pressure for heat export as steam and second for export as hot water. There is a possibility to use and integrate the operational data and experience for operation planning in an existing plant.
The technical model is followed up with a complex economic model. This model includes detailed adjustable inputs related to costs (e.g. investments and reinvestments, operation costs, transportation costs, wage costs, taxes, etc.) and revenues (e.g. gate fee, electricity and heat sales, benefits and bonuses for heat and power generation, etc.).
The benefit of the Flexi model is that it allows the simulation of WTE plant for the whole expected life span. The elemental time step for technical part is one month and default configuration is set for 25 year long period. It is possible to provide average monthly data for every input parameter and with this to describe the possible reinvestments/upgrade or change in technology. The economic model is based on average

annual data. The main parameters can change during these time periods (monthly: LHV, waste availability, heat and power production and annually: the price trends of heat, electricity, transportation, etc.).
The key part, for implementation of a new WTE plant, is to ensure enough waste during the life span. This part requires a contract between waste producers and processor. The price of waste treatment (gate fee) is the most important in such a contract. The presented tool provides the information about risk factors for the economy of WTE plant and its impact on gate fee. This information is useful for the investor as well as for the producer with the objective to set the contract for gate fee in a given horizon.
The estimation of future price parameters development is crucial for fulfilling the model main purpose. The historical data and experience from particular areas together with macroeconomic rules can be used for this. The gate fee (waste treatment payment) is the fundamental revenue, but this parameter is affected by competitive environment in the field of waste management. There is an emphasis on potential investment risk, which is directly proportional with the expected revenue, during the planning phase. As was already mentioned, the IRR indicator is used for investment evaluation. The IRR is set to value of 10 % in the case study (section 4.). The authors assume that the energy prices and other costs are given by the competitive environment and by the conditions in particular area and these are outside of investor’s control (they are unpredictable), but the investor has to consider it. Therefore, the only free variable is the gate fee and its choice provides meeting the given IRR for other fixed parameters. The main output of the T-E model is the probabilistic distribution of gate fee for various scenarios of price parameters escalation and operating costs escalation. This information can be used for competitive environment simulation in the computing tool *NERUDA*, see Šomplák (2013b). The competitive environment simulation decides whether the project is competitive or the investor has to lower his IRR requirements.

3. Scenario creation

In this text “the scenario” is a set of time series describing the future development of particular parameters. One series $S_i(T)$ is generated for every parameter i included in the analysis with respect to correlations. These series give us one scenario of stochastic parameters realisations. The amount of scenarios needed for analysis is given by the time series characteristics (historical data of investigated parameters). In the case study, particular series $S_i(T\ )$are generated using geometrical Brownian motion (chapter 4.). This approach is widely used in financial indicators modelling. It is described in more details in Omar and Jaffar (2011). A generated scenario of each individual parameter is calculated according to the following formula Eq(2):

$$S(T) = S(0)e^{\left(\mu-\frac{1}{2}\sigma^2\right)T+\sigma B(T)} \tag{2}$$

Where: $S(0)$ initial value of observed parameters (e.g. price of heat, electricity and operating costs),
T number of time section (1 section = 1 year),
μ drift (time series trend),
σ volatility,
$B(T)$ a random element from normal probability distribution - *N(0,1)*.

If there is a correlation between two particular parameters it has to be considered in the scenario generation. The correlation is reflected by the component *B(T)* which is obtained by the following way. The first step is the composition of the correlation matrix for considered variables. Next step is to find the Cholesky decomposition of this matrix. The assumption for the decomposition is that the correlation matrix has to be positive definite. A detailed description of Cholesky decomposition and the conditions, which have to be met, are presented in Wang and Liu (2006). Next, the random influences on the considered parameters are generated from normal distribution *N(0,1).* Similar approach is described in Šomplák et al. (2013). The vector of these numbers is multiplied by the Cholesky matrix and together it gives us the final random influence of the time series *B(T)*.

4. Case study

The case study dealing with possible WTE project implementation in particular locality in CZE is presented to demonstrate the applicability of the introduced methodology. The heat demand in this locality is about 2,000 TJ/y (about 98 thousand inhabitants supplied by heat). In current state of project development, the plant capacity is unknown but the goal is to estimate the gate fee interval, which is dependent on the capacity and on the scenarios of economic development.
The two energy products of WTE plant were selected as key parameters for which the future uncertainties were generated. The incomes from energy sales form one of the important economic pillars. Besides the heat price the amount of sold heat is crucial. This amount is capacity-dependent and, in this case study, it is set as a constant value during the project life span. The price, for which the waste will be treated (gate

Table 1: Historical data for the three key parameters

	2007	2008	2009	2010	2011	2012	2013
Heat price [€/GJ]	10	10	10	11	11	13	14
Electricity price [€/MWh]	81	103	66	63	75	62	51
Operating cost [€/y]	1,580,892	1,710,834	1,415,459	1,462,658	2,384,408	2,415,122	2,552,568

fee), is computed considering the required IRR. The method (gate fee assessment) is described in previous sections. There is only one outflow evaluated in this case study and that is the WTE plant operating costs. The operating costs are consisting of costs of chemicals for flue gas cleaning, gas and electricity needed mainly for shutdowns and technology components maintenance. All three considered parameters (heat and electricity price and operating costs) are influenced by fuels prices and therefore it is recommended to take their reciprocal correlations into account. The real historical data of heat prices in this particular locality and electricity prices from the market were used for the correlations assessment. The operating costs were estimated based on the economic data from existing plants. The historical data are presented in Table 1.

The assessment quality of the time series characteristics and the correlation between particular parameters is directly proportional to the data base. However the data for the locality in the case study are available only in a short time horizon. It will be possible to improve the quality of correlation coefficients in the future with updated data. The resulting correlation matrix is presented in Table 2 a). The parameters used for generating of escalatory sequence with the use of geometric Brownian motion are presented in Table 2 b).

Every generated scenario includes 3 time series one for each evaluated parameters. These were implemented into the T-E model, where the gate fee providing expected IRR was calculated. The computation was repeated for 3 new time series for each parameter (1 scenario) established by geometric Brownian motion. A set of gate fees is obtained. The characteristics of probability distribution can be evaluated – the mean value, variance, kurtosis and skewness, see Figure 1. These characteristics describe the searched unknown parameter – gate fee. And they can be used to determine the number of scenarios needed for the unknown parameter estimation to be sufficiently precise.

An approach based on minor change in descriptive characteristics of probability distribution by new scenario involvement is used to find to number of simulations needed. In other words these characteristics converge to a specific value with increasing number of simulations. The goal is that the new simulations won't affect the key parameters estimation. In this moment the estimation is close to real values of probability distribution.

Figure 1 shows the results of analysis for one particular WTE plant capacity 150 kt/y. This capacity is in compliance with the amount of possible heat delivery in described locality. The mean value and variance converge relatively quickly. About 20,000 simulations are needed in these cases. The skewness and kurtosis give us more detailed information about the shape of the variable distribution. About 170,000 simulations were needed for these two coefficients to converge with a slight error, see Figure 1. The values of analysed characteristics are shown in Figure 1.

Table 2: a) Correlation matrix, b) Parameters of geometric Brownian motion

a)	Heat price	Electricity price	Operating costs	b)	Si(0) [€]	μ	σ
Heat price	1.000	-0.774	0.842	Heat [€/GJ]	14	0.0085	0.0662
Electricity price	-0.774	1.000	-0.388	Electricity [€/MWh]	51	- 0.0111	0.1826
Operating cost	0.842	-0.388	1.000	Operating cost [€/y]	2,552,568	0.0114	0.1703

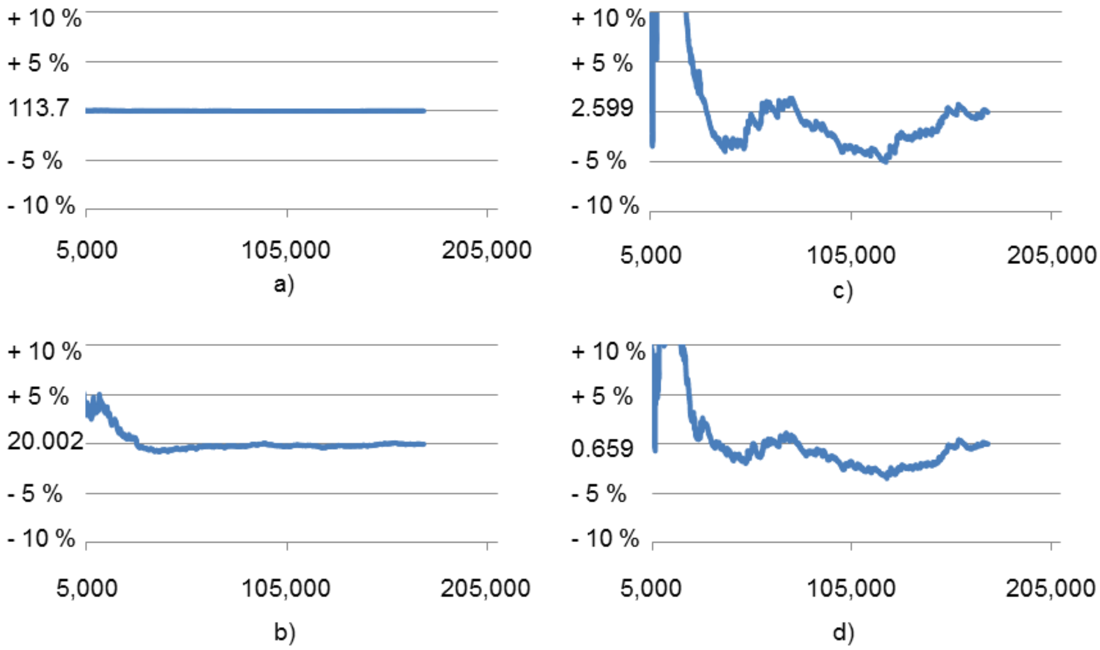

Figure 1: The convergence of characteristic parameters of probability distribution for the gate fee a) mean value, b) variance, c) kurtosis, d) skewnessAbout 170 000 results were obtained for the required gate fee, which guarantees the required profit described by the IRR. These results were obtained by modelling of the potential uncertainty of the key economic parameters. The simulations were carried on for one particular locality and plant with capacity 150 kt/y. The histogram for gate fee, presented in Figure 2, was obtained from the simulations results. The probability distribution shows a moderate skewness (more data are in the left half from the mean), see results in Figure 1 and 2. The majority of result (90 %, percentile from 5 to 95) lies in the interval from 107 to 121 EUR/t.

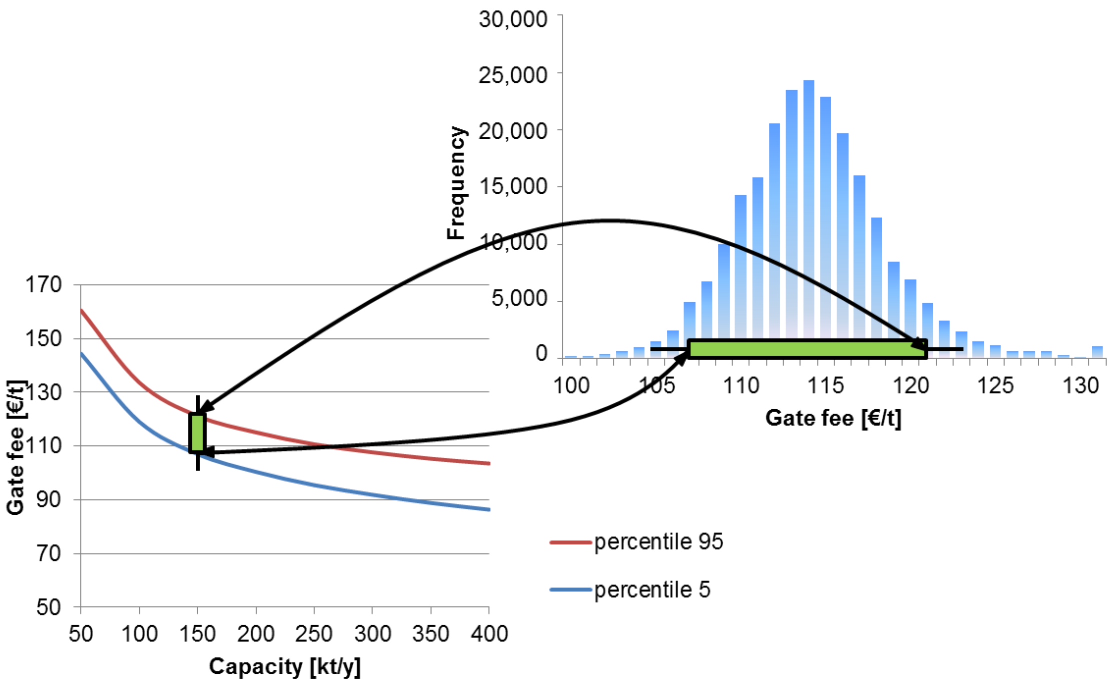

Figure 2: The dependence between gate fee and capacity and the gate fee histogram for 170,000 simulations – capacity 150 kt/y

Finally, 8 different capacity solutions in the interval from 50 to 400 kt/y (1 step = 50 kt/y) were analysed. The results can be applied in the modelling tool NERUDA despite the large degree of uncertainty in input parameters.

The gate fee is affected by the capacity of a particular project. The specific investment costs are decreasing together with increasing plant capacity. On the other hand there is a limited amount of possible heat delivery for plants with higher capacity, particularly in summer days. This effect is more significant in localities with smaller district heating network. The resulting dependence between gate fee and capacity is shown in Figure 2. The interval for gate fee from 170,000 simulations for 8 capacities is displayed in the graph.

5. Conclusion

This paper analyses an impact of an unknown future development of the key parameters on economic sustainability of a new WTE plant. Scenarios based on geometrical Brownian motion have been generated for selected parameters (price of heat, electricity and operating costs). The existing correlation between particular parameters is taken into account by the scenarios creation. The result of the simulation is the assessment of the gate fee which guarantees the requested rate of profit from the investment. It was necessary to perform about 170,000 simulations for one fixed capacity due to dynamic progression of variation in price parameters. This number provided the right estimation of main characteristics of the probability distribution for the required variable - the gate fee. The procedure has been made for 8 different capacities within the range from 50 to 400 kt/y. In this article a detailed analysis is described for capacity of 150 kt/y.

The result of calculation is the estimation of probability distribution of gate fee in particular locality with fixed capacity. The gate fee dependence on capacity was generated from these calculations. Using this approach, it is possible to get the results for more locations suitable for potential construction of new WTE plants. The price dependences can be implemented into the existing tool NERUDA (developed by the authors) and afterwards the competitive environment in the field of waste management can be simulated (waste control – to ensure enough waste for processing capacity). One of the applications is the attractiveness evaluation of particular location for new WTE plants together with the impacts on waste producers.

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