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RISK ANALYSIS OF THE WASTE TO ENERGY FACILITY PROJECT

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JEL classification: O22

Introduction

The term *thermal treatment* is used to describe a range of technologies that use heat to degrade the constitution of solid matter. These include incineration and its variations, as well as advanced thermal conversion (ATC) technologies such as pyrolysis and gasification.[1]

In order to ensure sustainable development in waste management, faster development and uptake of new technology is necessary. Landfills pollute valuable underground water, incinerations emit dioxin and produce toxic ash. The solution is Integrated Waste Management, which uses all available resources for dealing with the waste problem. Innovative processes utilizing pyrolysis and gasification have attracted publicity as a potential alternative to incineration. The main advantage that gasification has over incineration is its ability to conserve the chemical energy of the waste in the produced syngas rather than convert it to heat energy in hot flue gases. Therefore, gasification has greater flexibility in the recovery of energy and chemical value from waste stream.[2] Gasification is by no means a new process; in the 19th century the so-called: "town-gas" was produced by gasification of coal and used, for example, for illumination purposes.[3] Gasification (and combinations of pyrolysis plus gasification) processes are developed in a number of countries. In Europe, there continues to be a strong desire to avoid incineration and reduce the amount of waste going to landfill in order to meet the EU landfill Directives. In the USA, low disposal costs and plenty of

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[1] M. Everard: *Hot Stuff! – The Role of Thermal Treatment in a Sustainable Society*, "Waste Management World", July–August 2004, pp. 37–45.

[2] A. Klein, K. Whiting, E. Archer, J. Schwager: *Gasification and Pyrolysis: what is the Current Situation for Waste Management?*, "Waste Management World", September-October 2004, pp. 71–75.

[3] T. Astrup, B. Bilitewski: *Pyrolysis and Gasification*, in: *Solid Waste Technology & Management*, Chapter 8.8, Christensen, John Wiley & Sons, Ltd, Chichester 2010, pp. 502–512.

landfill availability in most regions have proved a significant barrier to the construction of any new thermal treatment facilities. Incineration also increases the amount of CO_2 in the carbon cycle because fuel is burnt together with the wastes. The governments of most countries have signed a treaty to limit CO_2 emissions at their 1999 levels. In Canada, a number of waste management projects are planned based on the waste incineration technology. In Japan all leading thermal process companies now offer gasification solutions alongside incineration with financial support from the Japanese Government.

For many people, thermal treatment technologies for waste management represent an image of hell on Earth.[4]

The main potential benefits and advantages of pyrolysis and gasification of waste with respect to incineration are:[5]

– The possibility and flexibility to recover chemical energy in the waste as hydrogen and/or other chemicals feedstocks rather than converting this energy into flue gases.
– Potentially better overall energy efficiency.
– Less trouble with corrosion.
– Potentially better option for CO_2 capture.
– Potentially lower emissions of dioxins.
– Improved quality of solid residues, particular for high-temperature processes.
– Gasification units operating with a low fuel load, potentially facilitating small plants producing less than 1 MW.
– Potentially lower costs.

The main drawbacks of the current pyrolysis and gasification technology are:

– Relatively homogeneous fuels are needed. Either specific material fractions can be fed to the gasifier or mixed waste can be pretreated and homogenized.
– Although theoretically possible, the pyrolysis and gasification processes are complicated to control and problems with slagging, tar production, and contaminants in the produced gas are not uncommon.
– Numerous waste related pyrolysis and gasification technologies exist, many of these only demonstrated in small scale projects and/or applicable to specific fuel types. This requires careful review of the appropriateness of a specific technology for a particular waste mix, local conditions, etc.
– Overall energy conversion efficiencies of existing installations are hardly comparable with modern waste incinerators.

[4] M. Everard: *op.cit.*
[5] *Ibidem.*

Market Interest in Gasification and Pyrolysis

Gasification is a partial oxidation process in which the majority of the carbon is converted into the gaseous form, called syngas, by partial combustion of a portion of fuel in the reactor with air, pure oxygen, oxygen-enriched air or by reaction with steam. Relatively high temperatures are employed: 900–1100°C with air and 1000–1400°C with oxygen. Gasification as a technology underwent major development during the oil price crises of the 1970s and 1980s.

Pyrolysis is the thermal degradation of carbonaceous materials. It occurs at a temperature lower than that of gasification (typically 400–800°C), either in the complete absence of oxygen, or with limited supply of oxygen. Pyrolysis has been promoted for biomass applications and in the treatment of scrap tyres, but rarely as a stand-alone application for MSW.

Energy recovery is a secondary goal of waste incineration: thermal waste treatment and energy recovery are combined within the waste-to-energy plant (Pfeiffer 2004).[6] From an economic point of view, a waste-to-energy plant treating MSW is an enterprise using a special fuel.

Some technologies – including gasification and pyrolysis – offer flexibility in terms of energy production and material recycling, and are an attractive technology option for Integrated Waste Management.

The main advantage that gasification has over incineration is its ability to conserve the chemical energy of waste in the produced syngas rather than convert it to heat energy in hot flue gas. Another reason for interest in gasification is the view of political decision-makers (especially in the UK) that gasification is an alternative to incineration, which would mean that incineration would no longer be necessary.

The United States Department of Energy (DOE) sponsored the 2004 World Gasification Survey in order to accurately describe the world gasification industry as it exists today, to identify planned capacity additions, and to keep the gasification community apprised of current data and trends.[7]

Construction of an additional 38 plants with 66 gasifiers was announced – the plants were to become operational between 2005 and 2010, according to the 2004 survey. The additional capacity from these new plants was 25,282 MW_{th}, an expected increase of 56%. Worldwide capacity by 2010 was projected at 70,283 MW_{th} of syngas output from 155 plants and 451 gasifiers.

– Regional distribution: The Africa/Middle East region would lead the world's regional growth with 43% of planned capacity growth from 2005 to 2010, all from

[6] E. Pfeiffer: *Waste, or Valuable Product?*, "Waste Management World", September-October 2004, pp. 65–69.

[7] National Energy Technology Laboratory (NETL): *Gasification Robust Growth Forecast – World Survey Results*, in: *A Current Perspective on the Gasification Industry – Robust Growth Forecast, Date of access 8 November 2011*, Available from: www.netl.doe.gov/publications/brochures/pdfs/gasification_brochure.pdf, 2005.

a single gas-to-liquids (GTL) project in Qatar that would produce liquid fuels from natural gas. The Asia/Australia region planned projects that comprised 37% of the total planned growth, with China leading in this region. By contrast, plans for new gasification plants slowed down in North America due to such factors as the economy and natural gas prices.
– Feedstock distribution: Coal was the feedstock of choice for new gasification projects, identified for 29 of the 38 new plants (largely on the basis of the 24 chemical plants to be built in China). However, natural gas would be used in the largest single project from 2005 to 2010 at nearly 11,000 MW_{th} gas-to-liquid.

Description of Case Study

Solid waste management is developing into a complex task. New or modified treatment technologies are appearing. During the past two decades, thermal waste management followed heavily disparate trends. In the 1980s, the focus was on new market players, and then in the 1990s on new technologies, especially pyrolysis and melting processes.[8]

New processes utilizing pyrolysis and gasification have attracted publicity as a potential alternative to incineration. Such systems offer some benefits in terms of recycling and public acceptance. However, because they are new, they are less proven in operation than conventional technologies, and may, therefore, be more risky. The main advantage that gasification has over incineration is its ability to conserve the chemical energy of the waste in the produced syngas rather than convert it to heat energy in hot flue gas.[9]

The new Polish environmental strategy emphasizes the principle of sustainable development and it encourages the local government of Konin to develop a waste management plan for its communities based on the use the technology for a gasification with waste to energy system. One scenario has been chosen: American Gasification System (design at 200 T/D). The Capital Budget – Project Costs of the American Scenario are given in Tables 1.

The revenues were based on the Proposal to Design, Develop and Construct a Waste-to-Energy Facility for the City of Konin. The revenues include:
– the tipping fees for landfill,
– the revenues from energy sales,
– other revenues.

Sale prices of marketable material and the tipping fee for each ton of waste delivered to the landfill are fixed in the Waste Program Revenue developed by the city. The general operating parameters of the Konin's Waste-to-Energy Facility are as follows:
– operating weeks/year – 50 weeks,

[8] B. Bieda, R. Tadeusiewicz: *Decision support systems based on the Life Cycle Inventory (LCI) for Municipal Solid Waste (MSW) Management under Uncertainty*, "International Transactions in Operational Research" 2008, Vol. 15, No. 1, pp. 103–119.
[9] A. Klein, K. Whiting, E. Archer, J. Schwager: *op.cit.*

– receiving days/week – 5 days,
– current tons managed – 63,000 Mg/year.

The municipality has concluded a contract to supply an average of 200/250 tons of municipal waste per day with options for increased volume as the demand increases.

Monte Carlo Simulation with Simlab®

The first task is to create a deterministic model that represents the most likely scenario. In order to use the SimLab®,[10] we must perform the following steps:[11]

– build model relationships,
– define assumption for probabilistic variables – manufacturing costs,
– define the forecast cell, that is, the output variable – Total and the number of replication,
– run the simulation,
– simulate the model and analyze the outputs,
– report results and make decisions.

Table 1

Capital Budget – Project Costs of the proposed American Gasification System

Capital Budget – Project Costs (USD)		
1.	Stage 1 – Construction Management	600,731.00
2.	Stage 2 – Civil&Site Design/Site Work & Building Permitting, Gasifiers System	21,120,055.27
3.	Stage 3 – Continuous Emission Control, Monitoring Systems	999,599.10
4.	Stage 4 – Automatic Loading Systems	1,687,350.23
5.	Stage 5 – Office Furniture and Computers	4,25000.00
6.	Stage 6 – Contingency Reserve	1,167,264.40
7.	Total Project Costs (USD)	26,000,000.00

In SimLab®, the assumptions or input range for each parameter was defined by choosing a probability distribution that describes the uncertainty of the data. Input distribution may be normal, uniform, triangular, skewed, or any shape that reflects the nature of the measurement being assessed.

[10] SimLab: *Software Package for Uncertainty and Sensitivity Analysis*, Joint Research Centre of the European Commission 2004.
[11] W. Wajs, B. Bieda, R. Tadeusiewicz: *Project Cost Analysis for Niepolomice Municipal Solid Waste using the Monte Carlo Simulation*, International Conference RISK ANALYSIS 2000, Bologna, Italy, Wessex Institute of Technology Publishers, 2000, pp. 225–234.

Results and Discussion

The methodology of risk investments has received a lot attention in the economic literature, and has been discussed by, among others.[12] Projects involve risk by nature.[13] Reduction of the level of risk is extremely important in projects, and indeed results of this study suggest that project managers often use risk management planning practices; this conclusion is consistent with those drawn in previous studies.[14] The Project Management Body of Knowledge (PMBOK) defines risk management as one of nine project knowledge areas, alongside other topics such as scope, schedule, quality, and cost management (PMI Standards Committee.[15] In some project contexts, risk management is perceived as a separate activity:[16]

– In countries with low levels of uncertainty avoidance, project managers place lower importance on risk management and hence do not always follow the required processes.
– In industries with low levels of maturity, project managers do not frequently perform the risk management process.

The principal output reports provided by SimLab® are presented in Figure 1 through Figure 2 (probability distributions assigned to model input parameters), Figure 3 (histograms of the output value-Razem (Total) and Figure 4 – sensitivity analysis based on the *Standardised Regression Coefficients* (SRC).[17] Based on the economic feasibility model presented in,[18] in this study uniform distributions were used.[19] The purpose of sensitivity analysis is to determine the relationships between the uncertainty in the independent variables used in an analysis and the uncertainty in the resultant dependent variables. Sensitivity refers to the amount of uncertainty in a forecast that is caused by the uncertainty of an

[12] T. Odgaard, C. Kelly, J. Laird: *Current Practice in Project Appraisal in Europe*. Developing Harmonised European Approaches for Transport Costing and Project Assessment (HEATCO), Deliverable No. 1, http://heatco.ier.uni-stuttgart.de/hd1final.pdf, 2005; J. Czarnek, M. Jaworek, K. Marcinek, A. Szóstek: *Efektywność projektów inwestycyjnych*, Edited by J. Czarnek, Toruń 2010; O. Gedymin: *Metody ilościowe w zarządzaniu inwestycjami w przedsiębiorstwie. Wybrane zagadnienia*, Wyższa Szkoła Finansów i Zarządzania w Białymstoku, Białystok 2010; E. Ostrowska: *Ryzyko projektów inwestycyjnych*, Polskie Wydawnictwo Ekonomiczne, Warszawa 2002; B. Bieda: *Stochastic Analysis in Production Process and Ecology under Uncertainty*, Springer–Verlag, Berlin–Heidelberg 2012.

[13] O. Zwikael, M. Ahn: *The Effectiveness of Risk Management: An Analysis of Project Risk Planning Across Industries and Countries*, "Risk Analysis" 2011, Vol. 31, No. 1, pp. 25–37.

[14] O. Zwikael, M. Ahn: *op.cit.*

[15] PMI Standards Committee: *A Guide to the Project Management Body of Knowledge*, 4th ed., Project Management Institute, Newton Square, PA, 2008.

[16] O. Zwikael, M. Ahn: *op.cit.*

[17] B. Bieda: *Metoda Monte Carlo w ocenie niepewności w stochastycznej analizie procesów wytwórczych i ekologii*, Wydawnictwo Naukowe AGH, Kraków 2011; B. Bieda: *Stochastic Analysis…*, *op.cit.*

[18] E. Liberman: *A Life Cycle Assessment and Economic Analysis of Wind Turbines Using Monte Carlo Simulation*, Master's Thesis Air Force Institute of Technology, Wright-Patterson Air Force Base, Ohio, AFIT/GEE/ENV/03-16, 2003.

[19] W. Pluta, T. Jajuga: *Inwestycje. Budżetowanie kapitałowe*, Fundacja Rozwoju Rachunkowości w Polsce, Warszawa 1995, p. 69.

assumption as well as by the model itself. Sensitivity analysis can be used to find *switch points* – critical parameter values at which estimated net benefits change sign or the low cost alternative switches.[20] Sensitivity plots are not only fundamental to determining the prominent input variables, but can be invaluable indicators of whether a particular project should be pursued.[21] Figure 16 and Figure 17 show the results of the sensitivity analysis. The performance of the SRC is shown to be extremely satisfactory when the model output varies linearly or at least monotonically with each independent variable. MC analysis-simulation is the only acceptable approach for U.S. Environmental Protection Agency (EPA) risk assessments.[22] Because all of the parameters of the economic model are independent, use of the SRC is shown to be extremely satisfactory.[23]

In (Saltelli *et al* 2004)[24] sensitivity analysis has been presented as: "those techniques [which] will answer questions of the type 'which of the uncertain input factors is more important in determining the uncertainty in the output of interest?, or, if we could eliminate the uncertainty in one of the input factors, which factor should we choose to reduce the most variance of the output?." Chapman & Ward[25] have defined "risk efficiency" as the minimum risk level for a given level of expected performance.

SimLab® is didactical software designed for global uncertainty and sensitivity analysis, developed by the Joint Research Centre of the European Commission and downloadable for free at: http://simlab.jrc.ec.europa.eu (Simlab 2004). The sampling techniques available in SimLab® are FAST, Extended FAST, Fixed sampling, Latin Hypercube, replicated Latin Hypercube, Morris, Quasi-random LpTau, Random and Sobol (Saltelli *et al* 2004). There are few packages that can perform risk analysis using the Monte Carlo simulation and performed in Microsoft Excel® (e.g. Risk® and Crystal Ball®, developed by Palisade Corporation and Decisioneering, respectively). In this study the most likely Total Project Cost values are about 2.53563E+007 USD and 2.663226E+007 USD for the analyzed Scenario. Every manager has a different degree of aversion to risk. Positive coefficients indicate that an increase in assumption is associated with an increase in the forecast, negative coefficients

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20 Office of Management and Budget (OMB) – The Executive Office of the President, in: Circular A-4, Regulatory Analysis 2003, Available from www.whitehouse.gov/omb/circulars/a004/a-4.html.

21 G. Koller: *Risk Assessment and Decision Making in Business and Industry – A Practical Guide*, CRC Press LLC, Boca Raton–London–New York–Washington, D.C., USA, 1999.

22 R. Smith: *Use of Monte Carlo Simulation for Human Exposure Assessment at a Superfund Site*, "Risk Analysis" 2006, Vol. 14, Issue 4, pp. 433–439.

23 B. Bieda: *Decision Support Systems Based on the Economic Feasibility Assessment for Municipal Solid Waste (MSW) Management Under Uncertainty Using Simlab® Toolpack*, Proceedings of the Sixth International Conference on Sensitivity Analysis of Model Output, SAMO, Milan, October 2010.

24 A. Saltelli, S. Tarantola, F. Campolongo, M. Ratto: *Sensitivity Analysis in Practice. A Guide to Assessing Scientific Models*, John Wiley & Sons, Ltd, 2004.

25 C. Chapman, S. Ward: *Why Risk Efficiency is a Key Aspect of best Practice Projects*, "International Journal of Project Management" 2004, 22(8), pp. 619–631.

imply the reverse (Evans and Olson 1998)[26]. The Sensitivity Charts (Figure 4) indicate that variable Stage 2 is the most influential parameter (98.93%) in the Project Total Costs.

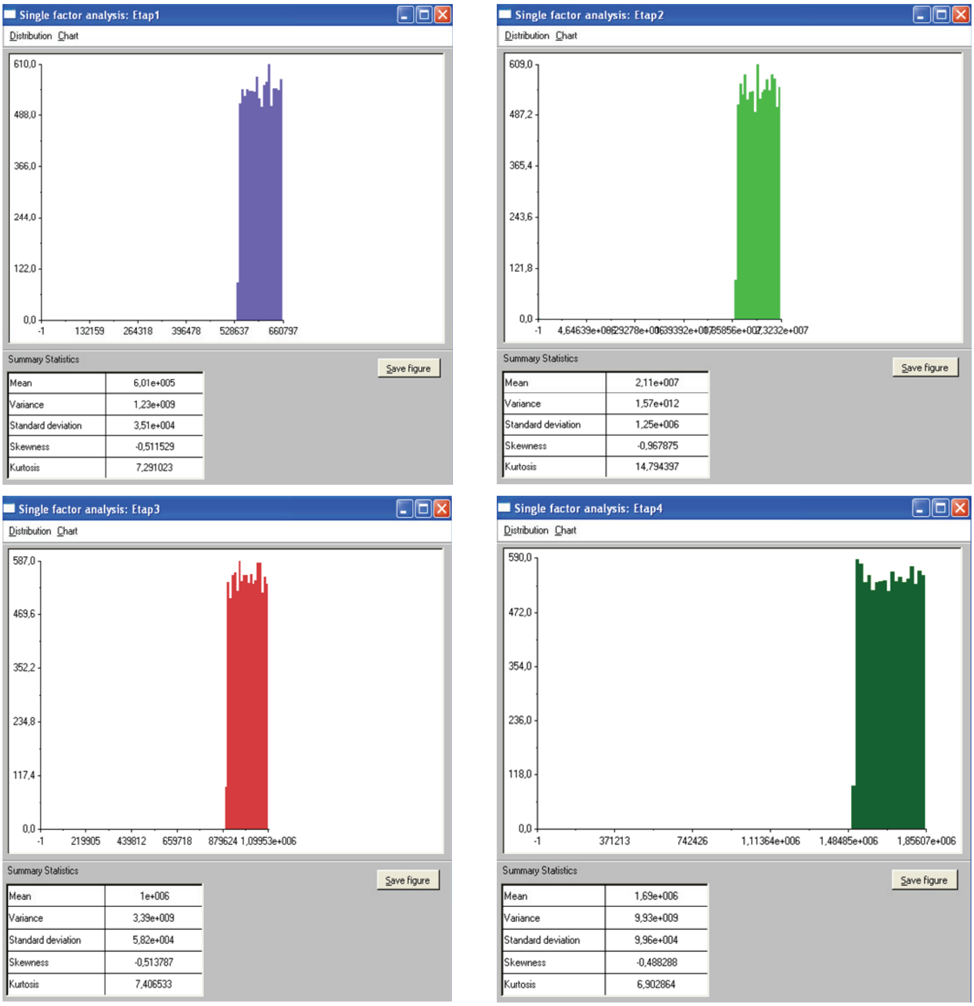

Figure 1. Histogram results for Stage 1 – Stage 4

[26] J.R. Evans, D.L. Olson: *Introduction in Simulation and Risk Analysis*, Prentice Hall, New Jersey 1998.

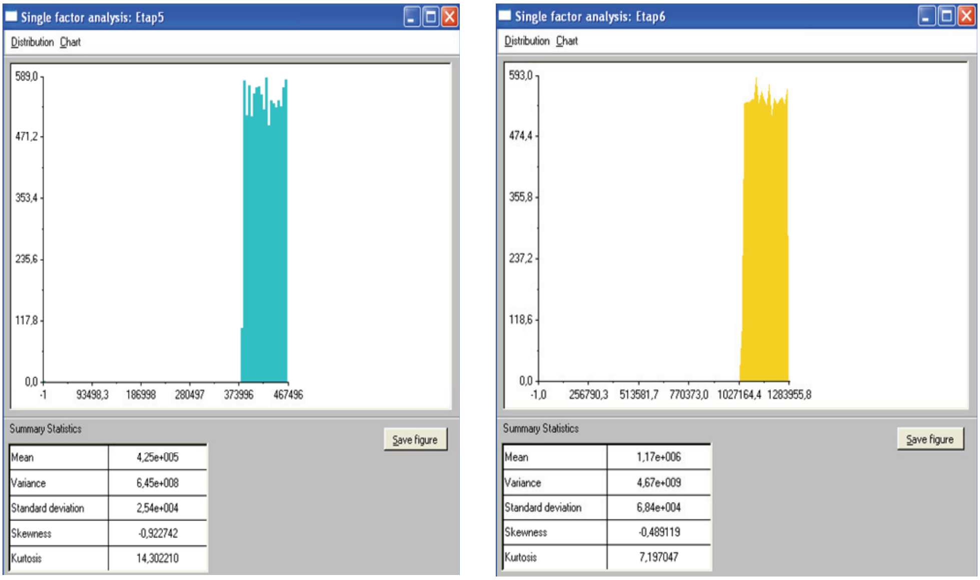

Figure 2. Histogram results for Stage 5 to Stage 6

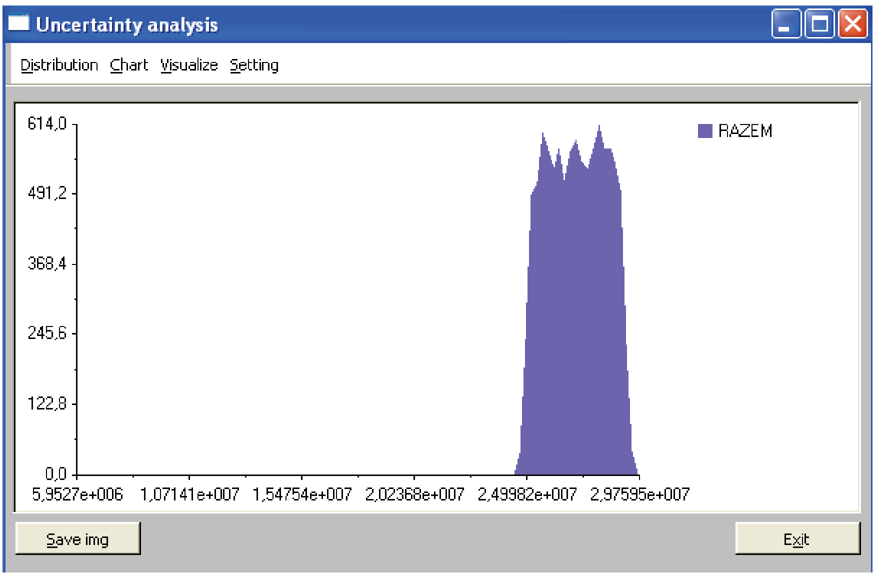

Figure 3. SimLab® uncertainty analysis for RAZEM

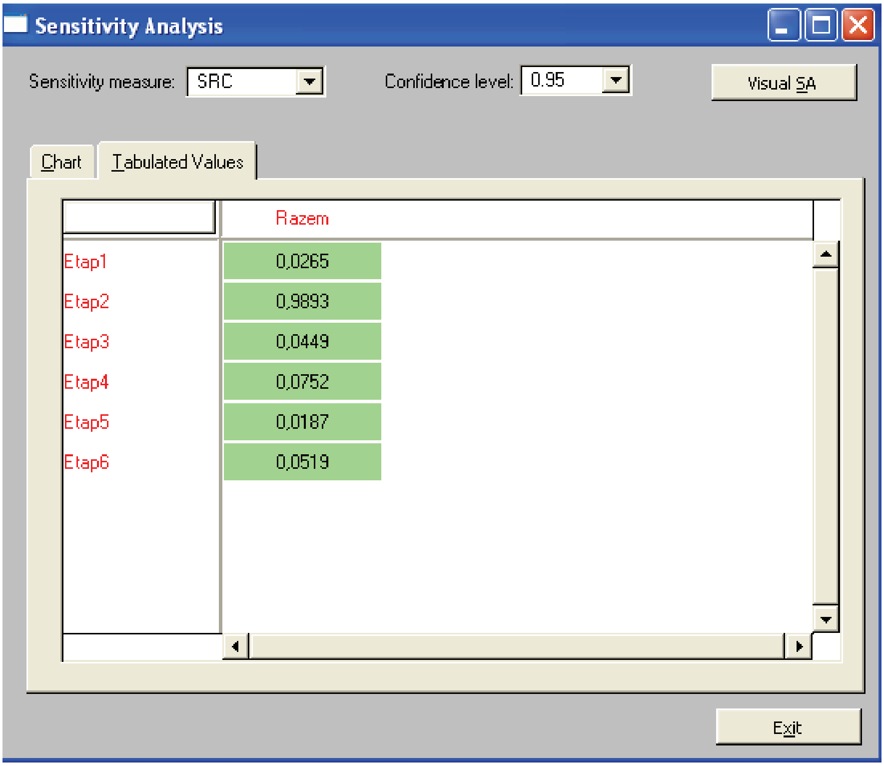

Figure 4. Sensitivity analysis (SRC) for the 95% confidence level

When the 10,000 trials are completed, the histograms provided by SimLab®, given in Figure 1 through Figure 2 form the basis of starting points for the final analysis outputs, presented in Figure 3 (*Forecast Chart*), and Figure 4 (*Sensitivity analysis* for the 95% confidence level).

Conclusions

This study explained the purpose of an uncertainty analysis, which is used to determine the potential directions for waste management decision support systems under uncertainty, because this technique accounts for uncertainties in the assumptions. Because all of the parameters of the economic model are independent, the use of the SRC is shown to be extremely satisfactory.

Cost risk analysis can answer some questions that the traditional estimation method cannot. The questions are:

– *What is the most likely cost?* The traditional method assumes that this is the baseline cost computed by summing cost estimates for the project elements, but this is not so.
– *How likely is the baseline estimate to be overrun?* Traditional methods do not address this problem.
– *What is the cost risk exposure?* This is also the answer to the question: "How much contingency do we need on this project?"
– *Where is the risk in this project?* This is the same as: *Which cost elements cause the most need for the contingency?* Risk analysis principles can be used to answer this question.

Uncertainty reduction in the project is performed during the planning phase of the project using the software package SimLab® for project risk management.

In summary, integrating risk analysis into waste to energy pyrolysis facility project management processes may be useful for the project managers. In this study the most likely Total Project Cost values are about 2.53563E+007 USD and 2.663226E+007 USD for the analyzed Scenario. Every manager has a different degree of aversion to risk.

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Summary

Investment risk analysis has received a lot of attention in the economic literature. This paper describes stochastic evaluation of the waste to energy facility project using the Monte Carlo simulation with Simlab® software package. Sensitivity analysis of the stochastic cost model of the investment project, built in simulations, provides information about the element of the project cost model which has the largest impact on the end value of the project. In conclusion the author encourages a wider use of Monte Carlo simulation in economic analyses of investment projects.

ANALIZA RYZYKA PROJEKTU INWESTYCYJNEGO BUDOWY ZAKŁADU ODZYSKIWANIA ENERGII Z ODPADÓW

Streszczenie

Analiza ryzyka inwestycyjnego znajduje obszerne miejsce w literaturze ekonomicznej. Prezentowana praca opisuje stochastyczne podejście w analizie projektu inwestycyjnego budowy zakładu odzyskiwania energii z odpadów z użyciem symulacji Monte Carlo wraz z pakietem komputerowym Simlab®. Analiza wrażliwości stochastycznego modelu kosztowego inwestycji, utworzona w wyniku symulacji, dostarcza informacji, który element modelu kosztowego inwestycji ma największy wpływ na wartość końcową wartości inwestycji. W konkluzji, prezentowana praca zachęca do szerszego użycia symulacji Monte Carlo w analizach ekonomicznych inwestycji.