

Application of Life Cycle Inventory (LCI) and Life Cycle Management (LCM) methods as useful tools for Municipal Solid Waste (MSW) Management scenario analysis under Uncertainty

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ABSTRACT

The purpose of this paper is to assess the economic feasibility of the waste to energy pyrolysis facility designs for City of Konin, in Poland and to use internal rate of return (IRR) and net present value (NPV) measures to evaluate two new gasification plant projects (two scenarios) based on the American and Australian gasification technologies including a fifteen-year income statement projection, and applied LCI substitution principle. LCI substitution approach is based on the basic concepts of inventory to consider that inventories can also be financial resources.

The paper study uses stochastic modeling to predict the sensitivity of the IRR and NPV values to changes in various analysis parameters. A practical uncertainty analysis method for determining input parameter uncertainties is based on sensitivity analysis, which should indicate how sensitive the results of the study are to data include. In this paper, the MC simulation method was used for the sensitivity analysis. Usually the overall uncertainty of a LCI can include:

- input data required to make an economic evaluation
- probability of success
- capital and operating costs
- waste and gas/electric energy prices

The Monte Carlo sampling was done using an Excel® spreadsheet modified to develop scenarios for inputs given the probability distributions, means values, etc. and Crystal Ball®, a software package offered by Decisionnering, generates random numbers for a probability distribution over the entire range of possible values, based on the assumption variables. The purpose of a large number of Monte Carlo simulations is to provide an understanding of the uncertainty of the LCA/LCI results. Most stochastic investment project models show that projects request more resources than expected. Traditional methods cannot answer the important questions of: how likely are we to overrun? and where is the risk in the project

The new Polish environmental strategy emphasizes the principle of sustainable development and it encourages the government of Konin to develop a waste management plan for their communities based on the use the technology for a gasification with waste to energy system. Two scenarios has been chosen: American Gasification System (design at 200 T/D), and Australian Gasification Process MSW-biomass fuel process (design at 240 T/D, with initial operation at 180 T/D).

Methodology

The importance of LCA methodology as the municipal solid waste decision support tool can be seen by the numerous books and survey articles. Typically, the approaches proposed in the recent literature are based on LCI tools. McDougall [7] describe a number of current LCI models for waste management systems. Hellweg, Hofstetter and Hungerbuhler [6] develop a mathematical model for LCI analysis of waste incineration in Switzerland as well as the fundamental aspects of the different technologies relevant for the LCI are discussed. Notten and Weidema [8] propose an expert system characterized by conventional database search features combination with information on the quality and completeness of the data. It can be applied both to a single and to a network of LCI databases, respectively, thus providing a means for integration of diverse data sources. The use of LCA Tool for the development of Integrated Waste Management Strategies (LCA-IWM) for Cities and Regions with Rapid Growing Economies is a project funded by the European Commission under the Fifth Framework Programme, (Den Boer, Den Boer, and Jager) [2], (Meneses, Rodrigo and Castells) [10] and for planning of sustainable municipal waste management systems (see, for example, Den Boer et al.) [3].

LCA can be a very effective tool for relative comparisons, particularly if a mix of energy-related, material application-related and process-related aspects plays a role [14]. LCI, part of a LCA, is the inventory of materials, energy requirements, and environmental emissions associated with a product or process from the time of the original recovery of raw materials used to build the product (“cradle”) to the time of its ultimate disposal to earth (“grave”) [12], and can be used to compare the performance of different production technologies for manufacturing the same product (e.g. gas production via pyrolysis) as well as should include a goal definition and scoping step for study and an inventory analysis stage.

As a result of request from City of Konin, Poland, two project - scenarios based upon advanced technology of MSW biomass fuel pyrolytic - gasification syngas production was developed. First scenario used the American technology of the pyrolysis-based process, and the other the Australian pyrolysis process equipment. The investment profitability analysis based on the discounted cash-flow analysis (DCF) - net present value (NPV) and internal rate of return (IRR) have been used to study the operational total costs for two new incinerating plant projects.

The LCI boundaries include all aspects of MSW combustion processes once waste is delivered and include useful final products (i.e. incineration of wastes, generation and distributions of energy, inert landfill material or an emission to either air or water).

To make the use of LCI tools to support an integrated approach to solid waste management

Uncertainty In LCI

Usually the overall uncertainty of a LCI is dominated by a few major uncertainties. Likewise, the overall uncertainty of a specific process is typically dominated by one source of uncertainty and other sources of uncertainty may be ignored [4]. The uncertainties in the investment projects can include:

- input data required to make an economic evaluation (publications on environmental process data are often incomplete or inaccurate). The data are subject to obsolescence - there are many cases where processing industries have cut emissions by 90% during the last 10 years - the use of obsolescence data can therefore cause distortions [11]
- probability of success
- capital and operating costs
- waste and gas/electric energy prices.

Information about uncertainty in LCI results cannot be fully captured within the LCI database, because a significant share of this uncertainty arises in practice, based on relationship between the data [9]. When the main determining parameters of an uncertainty is known, it can be eliminated or at least reduced to the uncertainty by modeling.

The Financial Assessment of the Project

Pro Forma cash flow statements, the heart of the financial model, for waste to energy gasification plants based on the American and Australian gasification technologies provides adequate financial data, including a fifteen-year income statement projection are shown in Tables 1 and 2 respectively.

The obviously pro-ecological nature of the investment indicates the possibility of obtaining resources from ecological funds dedicated to this purpose. The ecological grant from the National Fund for Protection of the Natural Environment and Water Management for the project will be obtained in the amount of 23,000,000 PLN and based on the contracting agreement American or Australian partners arrange finance for balance of 54,157,200 PLN or 49,700,000 PLN, respectively.

The outside resources (credit) will be borrowed at 10% interest for the duration of the 14 years. The initial capital of the Konin City based on the 7 ha plot of land contribution for the investment was valued at 2,000,000 PLN. Depreciation is not applicable in this financial assessment. Discount rate of 10% to represent the cost of bank credit is selected for calculation NPV. The choice of discount rate is important and should represent at least the cost of capital, i.e. the interest rate charged on money borrowed for investment [1].

First Scenario – Proposed American Gasification System (Design at 200 T/Day) for City of Konin, Poland, and Second Scenario - Proposed Australian Renewable Energy System Utilizing MSW-Biomass Fuel (Design at 240 T/Day, for City of Konin, Poland.

Table : Pro Forma Cash Flow Statement for First Scenario – Proposed American Gasification System

	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	9 Year	10 Year	11 Year	12 Year	13 Year	14 Year	15 Year
Revenues from sales															
Tipping fee	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000
Revenues from energy sales	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000
Other cash from sales	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Total cash from sales	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000
Expenses															
Salaries 25 persons	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Tipping fee	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100
Electricity	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000
Water, etc. legal costs	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000
Maintenance	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000
Fuel	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000
Insurance	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000
Office maintenance	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000
Communications-telephones	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Environmental fee	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000
Taxes, etc.	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200
Administration	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400
Environmental education	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Interest	0	5,415,720	5,028,883	4,642,046	4,255,209	3,868,372	3,481,535	3,094,698	2,707,861	2,321,024	1,934,187	1,547,350	1,160,513	773,676	386,839
Total expenses	4 907 700	10 323 420	9 936 583	9 549 746	9 162 909	8 776 072	8 389 235	8 002 398	7 615 561	7 228 724	6 841 887	6 455 050	6 068 213	5 681 376	5 294 539
Income before taxation	16 070 300	10 654 580	11 041 417	11 428 254	11 815 091	12 201 928	12 588 765	12 975 602	13 362 439	13 749 276	14 136 113	14 522 950	14 909 787	15 296 624	15 683 461
Taxes (19%)	3 053 357	2 024 370	2 097 869	2 171 368	2 244 867	2 318 366	2 391 865	2 465 364	2 538 863	2 612 362	2 685 861	2 759 361	2 832 860	2 906 359	2 979 858
Income after taxation	13 016 943	8 630 210	8 943 548	9 256 886	9 570 224	9 883 562	10 196 900	10 510 238	10 823 576	11 136 914	11 450 252	11 763 590	12 076 927	12 390 265	12 703 603
Initial capital – land contribution	2,000,000														
Ecological grant	23,000,000														
Total cash flows	38 016 943	8 630 210	8 943 548	9 256 886	9 570 224	9 883 562	10 196 900	10 510 238	10 823 576	11 136 914	11 450 252	11 763 590	12 076 927	12 390 265	12 703 603
Total project costs	-50,000,000	-29,157,200													
Credit instalment	0	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,370	-3,868,389
Ending cash balance	-11,983,057	-24,395,360	5,075,178	5,388,516	5,701,854	6,015,192	6,328,530	6,641,868	6,955,206	7,268,544	7,581,882	7,895,220	8,208,557	8,521,895	8,835,213

NPV = 7,382,155.86 PLN, IRR=14%

Second Scenario - Proposed Australian Renewable Energy System Utilizing MSW-Biomass Fuel (Design at 240 T/Day, for City of Konin, Poland)

Crystal Ball® Output and Simulation Results

The principal output reports provides by Crystal Ball® are *forecast chart*, *percentiles summary*, and *statistics summary*. When the 10,000 trials are completed, we can analyze results using Crystal Ball® for the forecast chart, an interactive histogram that contains all of the statistics for the 1000 trials [5]. Figures 1 through 2 show the results of 10,000 replications of the spreadsheet using Crystal Ball®) for the two scenarios.

The following important information can be obtained from the charts:

- the mean of the NPV is 7,420,886 PLN with a 92,24% confidence interval (certainty level) around the mean value of 597,151 PLN to 20,590,333 PLN for the First Scenario, and the mean of the NPV is 14,811,196 PLN with a 93,98% confidence interval around the mean value of 2051560 PLN to 20,590,333 PLN for the Second Scenario, respectively. These intervals provide a high degree of confidence that the mean NPV values are positives
- the mean NPV values for the American Gasification System and Australian Gasification System coming above the projected NPV values - 7,382,156 PLN, and 14,753,016 PLN, respectively. In other words, the most likely NPV values are about 7,420,886 PLN and 14,811,196 PLN for the First and Second Scenarios, respectively.

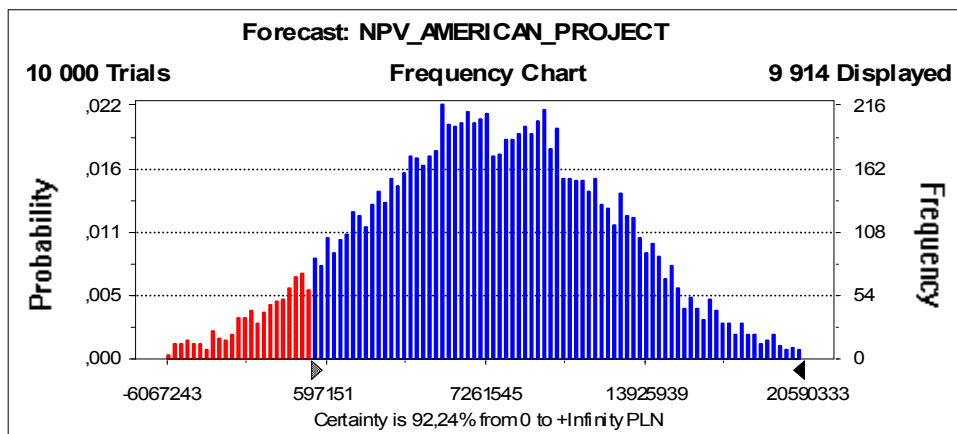


Figure 1: First Scenario - Cristal Ball Forecast Chart for NPV after 10000 replications

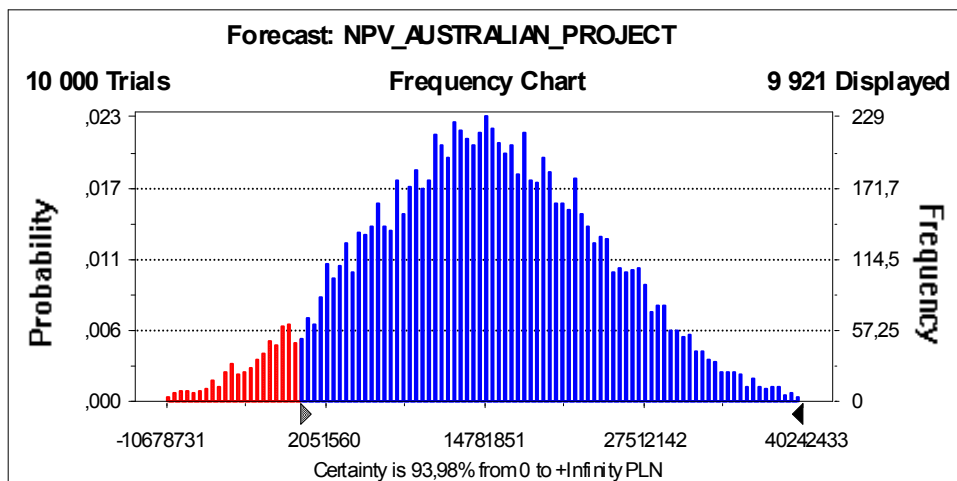


Figure 2: Second Scenario - Cristal Ball Forecast Chart for NPV after 10000 replications

Table 2: Pro Forma Cash Flow Statement for Second Scenario – Proposed Australian Gasification System

	1 Year	2 Year	3 Year	4 Year	5 Year	6 Year	7 Year	8 Year	9 Year	10 Year	11 Year	12 Year	13 Year	14 Year	15 Year
Revenues from sales															
Tipping fee	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000	10,050,000
Revenue from energy sales	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000	8,928,000
Other cash from sales	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000	2,000,000
Total cash from sales	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000	20,978,000
Expenses															
Salaries 25 persons	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000	600,000
Tipping fee	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100	422,100
Electricity	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000	1,260,000
Water, etc. legal costs	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000	81,000
Maintenance	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000	400,000
Fuel	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000	754,000
Insurance	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000	270,000
Office maintenance	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000	96,000
Communications-telephones	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000	12,000
Environmental fee	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000	565,000
Taxes, etc.	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200	338,200
Administration	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400	74,400
Environmental education	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000	35,000
Interest	0	4,970,000	4,615,000	4,260,000	3,905,000	3,550,000	3,195,000	2,840,000	2,485,000	2,130,000	1,775,000	1,420,000	1,065,000	710,000	355,000
Total expenses	4 907 700	9 877 700	9 522 700	9 167 700	8 812 700	8 457 700	8 102 700	7 747 700	7 392 700	7 037 700	6 682 700	6 327 700	5 972 700	5 617 700	5 262 700
Income before taxation	16 070 300	11 100 300	11 455 300	11 810 300	12 165 300	12 520 300	12 875 300	13 230 300	13 585 300	13 940 300	14 295 300	14 650 300	15 005 300	15 360 300	15 715 300
Taxes (19%)	1,553,649	3 053 357	2 109 057	2 176 507	2 243 957	2 311 407	2 378 857	2 446 307	2 513 757	2 581 207	2 648 657	2 716 107	2 783 557	2 851 007	2 918 457
Income after taxation	13 016 943	8 991 243	9 278 793	9 566 343	9 853 893	10 141 443	10 428 993	10 716 543	11 004 093	11 291 643	11 579 193	11 866 743	12 154 293	12 441 843	12 729 393
Initial capital – land	2,000,000														
Ecological grant	23,000,000														
Total cash flows	38 016 943	8 991 243	9 278 793	9 566 343	9 853 893	10 141 443	10 428 993	10 716 543	11 004 093	11 291 643	11 579 193	11 866 743	12 154 293	12 441 843	12 729 393
Total project costs	-50,000,000	-24,700,000													
Credit instalment	0	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000	-3,550,000
Ending cash balance	-11,983,057	-19,258,757	5,728,793	6,016,343	6,303,893	6,591,443	6,878,993	7,166,543	7,454,093	7,741,643	8,029,193	8,316,743	8,604,293	8,891,843	9,179,393

NPV = 14,753,015.98 PLN IRR=18%

Conclusion

1/ Life Cycle Inventory (LCI) decision support systems using Monte Carlo simulation with the Cristal Ball® analysis tool, spreadsheet add-in software, is a practical methodology for Municipal Solid Waste (MSW) management under uncertainty. An important benefit of the approach is that it permit use of the stochastic models to predict the sensitivity of the NPV of the new waste to energy gasification plants based on the American and Australian gasification technologies including a fifteen-year income statement projection.

2/ Several LCI models for waste management are in advanced stages of development. LCI models do not make the decisions. Present study using LCI substitution approach based on the basic concepts of inventory to consider that inventories can also be financial resources, can provide an approach to waste management Decision Support Systems.

3/ The research described in this paper can also serve as the basis for future work. The potential directions for future research is to continue using risk assessment for analysis in LCI models for waste management decision support systems under uncertainty, because this technique accounts for uncertainties in the assumptions, and to introduce the sensitivity analysis in LCI data collection to aid in the optimization of design aspects in the waste management systems.

4/ The benefits of Monte Carlo simulation are saving in time and resources. Crystal Ball® eliminates the need to run, test, and present multiple spreadsheets [13]. With Crystal Ball® analysis we can show the benefit of investing more on a monthly basis. Cristal Ball® can handle dozen assumptions simultaneously, and can establish correlation coefficients among variables.

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