ADOPTING THE INTEGRATED WASTE MANAGEMENT MODEL (IWM-1) INTO THE DECISION PROCESS

T. Stypka

Institute of Heat Engineering and Air Protection, Cracow University of Technology
ul.Warszawska 24, 31-155 Cracow, Poland
(E-mail: stypka@s5.wis.pk.edu.pl)

ABSTRACT
The article presents the analysis of the IWM-1 model potential in the decision process. The model is presented as an application of the Life Cycle Assessment procedure. The differences with the ISO standards are discussed. The possibilities of application of the IWM-1 result table to conduct the Life Cycle Impact Assessment is presented.

KEYWORDS
Integrated solid waste management; LCA, LCIA, solid waste

INTRODUCTION

The ultimate goal of the decision process in the field of environmental management is to make the decisions which will bring the sustainable results. In the field of municipal solid waste (MSW) management such need is particularly urgent, because the decisions are not only costly, but also socially difficult and environmentally harmful.

On the other hand, the decision makers are looking forward for the simple and straight forward answers allowing evaluation of the presented options not knowing that the time of simple answers is already gone.

The Integrated Waste Management model (IWM-1) developed by White (White, 1997) is an attempt to bridge this gap. The Model is an application of the Life Cycle Assessment procedure, but only to the stage of the inventory results. The last two stages of the LCA that is LCA Impact Assessment and LCA Interpretations are still missing and therefore the model can not be simply used and applied by the decision makers.

DESCRIPTION OF THE LIFE CYCLE ASSESSMENT PROCESS

"LCA is a holistic concept and methodology for evaluating the environmental and human health burdens associated with the product, process and activity" (EPA, 1995). This tool of environmental management identifies the inputs and outputs associated with the certain process or product and assess the impact of these inputs and outputs on ecosytems, on human health, natural resources and finally allows comparison between different system options or products.

According to International Standards Organisation (ISO) LCA consists of four interacting phases.

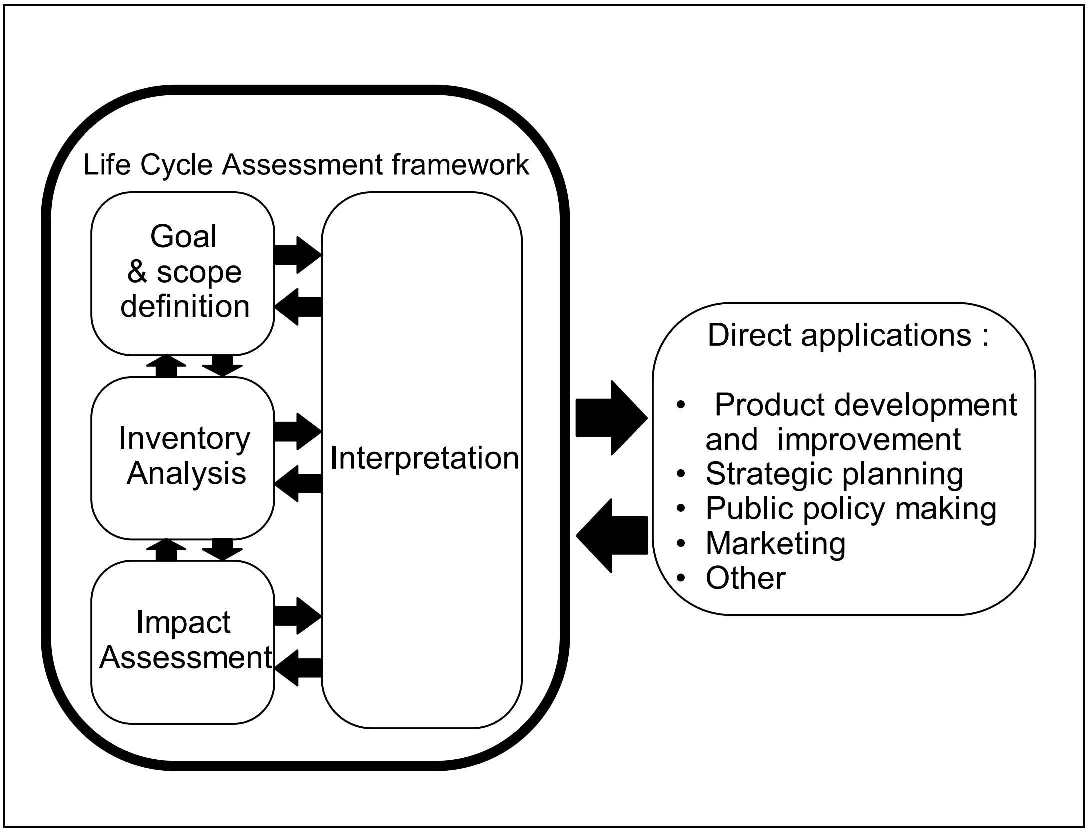

Fig. 1 Phases of an LCA (McDougall, 2001)

The first phase is defining the goal of the study. In ISO 14041 it is defined that "the goal shall unambiguously state the intended application, the reasons for carrying out the study and intended audience". In this phase it is essential to define:

- Options to be compared,
- Intended use of the results,
- The functional unit,
- The system bounders.

When the first two goals of the LCA are quite obvious the functional unit requires special attention not only because the definition is not clear, but because it differs significantly if LCA is conducted for products and for waste.

"Functional unit is a measure of the performance of the functional outputs of the Product System" (ISO 14040). The functional unit is the basis on which the products or services are compared. For example "per kilogram of product made" In case of waste management the functional unit is not on the output from the system, but on the input, that is the amount of waste generated in the certain region in the given time span.

System boundaries need to be defined to clarify what kind of inputs are included into the analysis and which inputs are not included. During the definition process of the boundaries the "cradle" and the "grave" of the product is defined. If LCA is conduced to compare different products the boundaries of the two systems also have to be comparable. Defining the system for the regular products and for the waste management systems is quite different. In case of the product or the package the boundaries are very vertical and start at the raw material extraction and end at the waste management. In case of the solid waste management the LCI boundary have far more horizontal character and include the waste management stage of different products which generate the waste stream. The idea of this difference is presented at the Fig. 2.

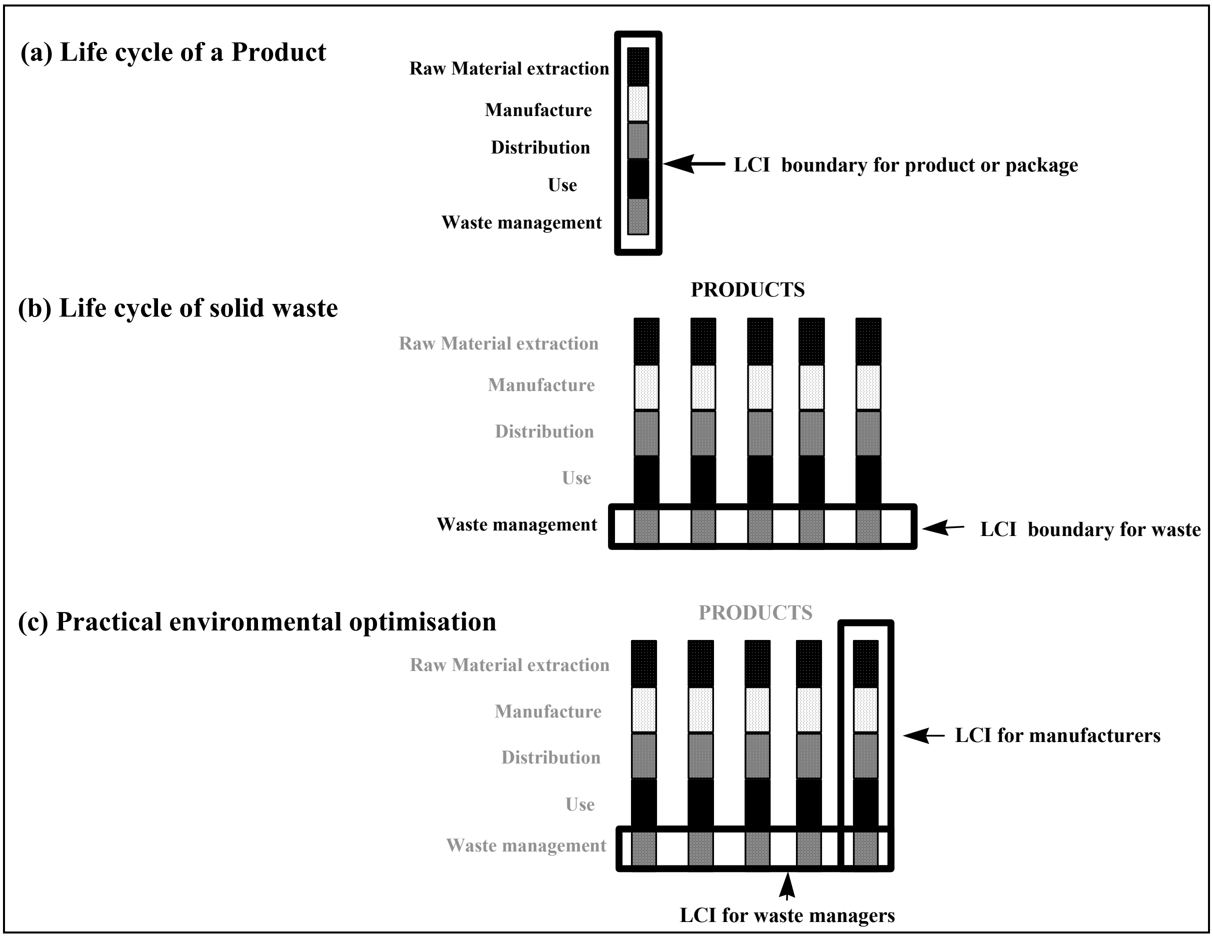

Fig. 2 The Life Cycle of the product. Boundaries for products and for waste management systems (McDougall, 2001)

The second phase of the LCA procedure is the Life Cycle Inventory Analysis (LCI). According to ISO 14041 "A Life Cycle Inventory Analysis is concerned with the data collection and calculation procedures necessary to complete the inventory". In this phase the flow diagrams of unit processes are drawn, data are collected for each of the processes as well as the final calculations of the outputs. The main result of the LCI is an inventory table listing the quantified inputs from and outputs to the environment associated with the functional unit. The methodology of this phase is well established, but the need for the large amount of data, the data quality and the aggregation of data is a challenge. The procedures of LCI analysis presents Fig. 3

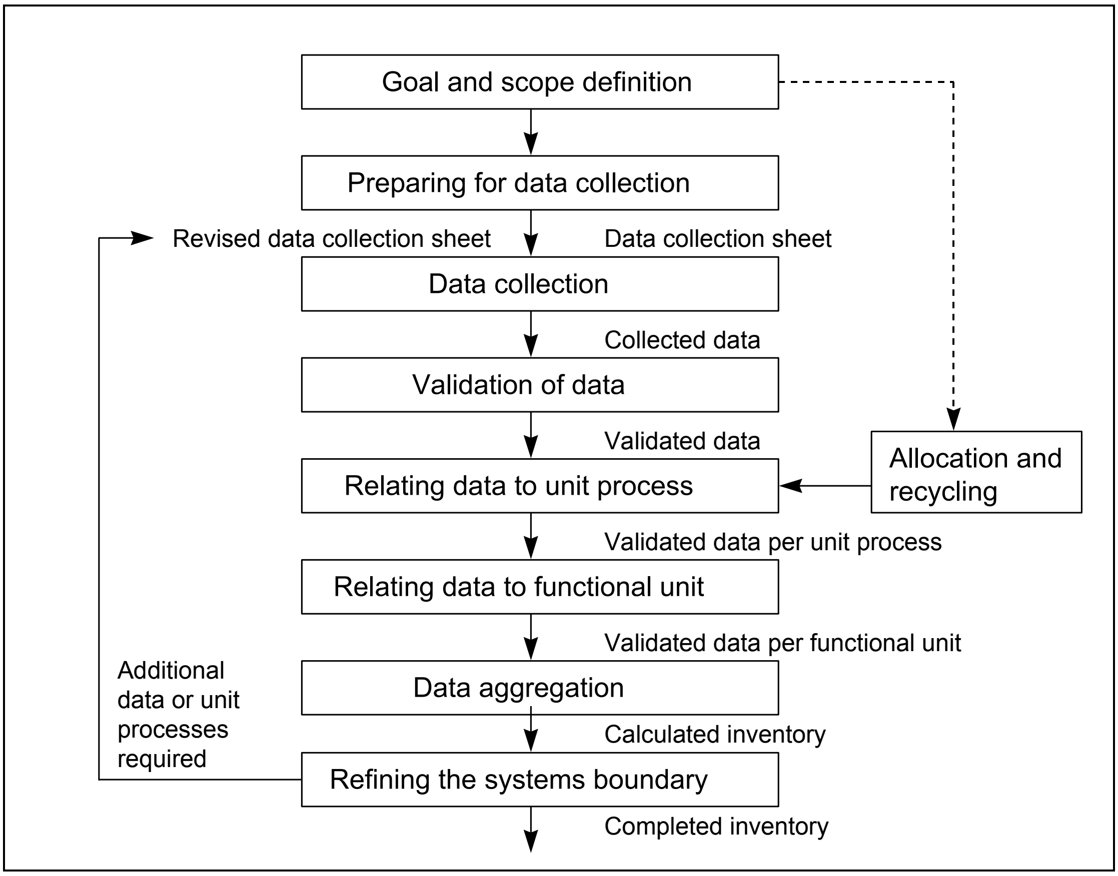

Fig. 3 Procedures for Life Cycle Inventory analysis (ISO 140141)

One of the problems with LCI is the sensitivity and uncertainty analysis of the results. The data used in the analysis should be used with understanding of their quality and limitations. Sensitivity analysis can help understanding how significant is the impact of the missing data on the final results. The missing data are always the case with the LCI because the reality is far more complex then the applied models and some forms of simplifications and omissions have to be made.
The uncertainty analysis, on the other hand, looks on the impact of the made assumptions and measurements on the final results. Often the measured values of flow or pollution vary in time and only one value is taken into calculation. To understand how much the final result can change, depending on the made assumption, is the goal of the uncertainty analysis.

INTEGRATED WASTE MANAGEMENT (IWM) AS A LIFE CYCLE INVENTORY ANALYSIS (LCI)

The Life Cycle Inventory approach can be applied to the solid waste management. The idea is that such approach allows to look at the environmental impact of the whole waste disposal process and in result, allows some analysis and optimization. The conceptual and computer model (IWM-1), developed by White (White, 1997), looks locally at the all types of generated wastes (recyclable and non-recyclable) and simultaneously their disposal, hoping that this can bring some economical, environmental or social profits. These benefits are also looked for by integrating different sources of wastes (commercial, household, industrial), and the different technical options of waste disposal.
IWM-1 is an application of Life Cycle Inventory and it has all the necessary elements of this phase described in the previous chapter. The model can be used to analyze a certain system or to compare different systems of waste management. It also defines the functional units and the system bounders. The differences between the “regular” LCI and the LCI of waste were described earlier.

The functional unit refers to the input streams not the output streams and the bounders are more "horizontal" covering different products which make the waste stream. The summary of the goal definition of the Life Cycle Inventory of Waste is presented in Table 1

Table 1 A Life Cycle Inventory of waste: goal definition (McDougall, 2001)

1. Options to be compared:	Different systems for managing solid waste
2. Purposes:	To predict environmental performance (emissions and resource consumption) of IWM systems To allow "What if..?" calculations To support achieving environmental sustainability To demonstrate interactions within IWM systems To supply waste management data for use in individual product LCIs
3. Functional unit:	The management of the household and similar commercial waste arisings from a given geographical area in a given time period (e.g. 1 year)
4. System Boundaries:	Cradle (for waste): when material ceases to have value and becomes waste (e.g. the household dustbin) Grave: when waste becomes inert landfill material or is converted to air and/or water emissions or assumes a value (intrinsic if not economic) Breadth: "second level" effects such as building of capital equipment ignored. Indirect effects of energy consumption included

The generic flow diagram for the waste disposal is drawn. It consists of the collection, central sorting, biological and thermal treatment and finally the landfilling. Different technologies are foreseen and it is up to the IWM-1 user to define the exact flow of the waste. The generic flow diagram with the unit processes is presented by Fig. 4

The results of Life Cycle Inventory analysis (LCI) are present in the form of the inventory table. The table in IWM-1 model is very extensive and shows environmental interventions associated with the waste disposal system. It covers both emissions to air, and to water. Thermal energy consumption of the proposed system is also calculated as well as the amount of remaining waste. The emission to air consists of 22 compounds supplemented with the information on the origin of the pollution (collection, sorting, biological treatment, thermal treatment and landfilling). Also the avoided emission of each compound due to material recovery is calculated. The emission to air comes from trucks transporting the waste, as well as from the composting process, anaerobic digesters, incineration and from the landfill site (landfill gas). The air pollution of the MSW system prepared by the IWM-1 is shown in Fig. 5

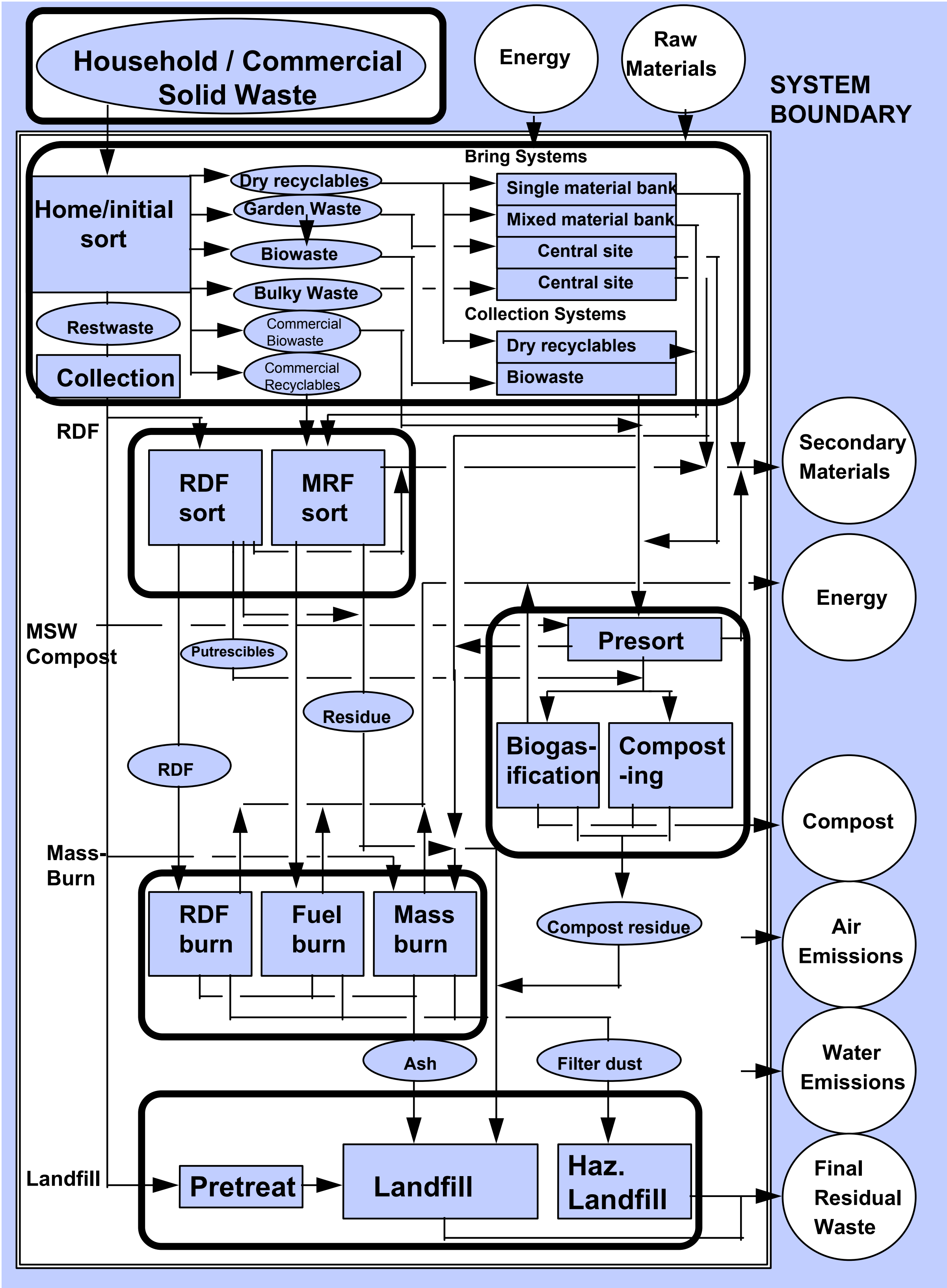

Fig. 4 System boundaries and inputs/outputs for the Life Cycle Inventory of solid waste (McDougall, 2001)

EMISSIONS AIR EMISSIONS(kg)	COLLECTION	SORTING	BIOLOGICAL TREATMENT	THERMAL TREATMENT	LANDFILL	IWM MODEL TOTAL	RECYCLING SAVINGS	OVERALL TOTAL
Particulates	8,12E+03	0,00E+00	5,58E+01	0,00E+00	-3,45E+03	4,73E+03	4,12E+04	-3,65E+04
CO	5,35E+04	0,00E+00	9,89E+01	0,00E+00	3,50E+03	5,71E+04	1,41E+04	4,30E+04
CO2	7,67E+06	0,00E+00	3,16E+06	0,00E+00	3,11E+07	4,20E+07	5,45E+04	4,19E+07
CH4	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,98E+06	6,98E+06	0,00E+00	6,98E+06
NOx	7,97E+04	0,00E+00	3,50E+02	0,00E+00	-2,08E+04	5,93E+04	1,62E+04	4,30E+04
N2O	2,01E+02	0,00E+00	1,98E+01	0,00E+00	-1,24E+03	-1,02E+03	5,13E+02	-1,54E+03
SOx	3,59E+04	0,00E+00	7,09E+02	0,00E+00	-4,42E+04	-7,58E+03	2,89E+04	-3,64E+04
HCl	1,23E+02	0,00E+00	0,00E+00	0,00E+00	1,30E+03	1,42E+03	2,00E+01	1,40E+03
HF	7,59E+01	0,00E+00	2,84E-03	0,00E+00	2,31E+02	3,07E+02	1,08E+00	3,06E+02
H2S	1,17E+01	0,00E+00	0,00E+00	0,00E+00	3,56E+03	3,57E+03	7,03E+01	3,50E+03
HC	3,99E+04	0,00E+00	5,99E+02	0,00E+00	-1,28E+03	3,92E+04	1,89E+04	2,03E+04
Chlor. HC	0,00E+00	0,00E+00	0,00E+00	0,00E+00	7,41E+02	7,41E+02	0,00E+00	7,41E+02
s/Furans (TEQ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,48E-06	9,48E-06	0,00E+00	9,48E-06
Ammonia	9,66E-01	0,00E+00	1,39E-01	0,00E+00	-8,71E+00	-7,60E+00	3,34E+01	-4,10E+01
Arsenic	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Cadmium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,96E-02	9,96E-02	0,00E+00	9,96E-02
Chromium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,17E-02	1,17E-02	0,00E+00	1,17E-02
Copper	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Lead	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,07E-02	9,07E-02	-8,71E+00	8,81E+00
Mercury	4,95E-04	0,00E+00	0,00E+00	0,00E+00	7,29E-04	1,22E-03	1,76E-02	-1,63E-02
Nickel	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00	0,00E+00
Zinc	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,33E+00	1,33E+00	0,00E+00	1,33E+00

Fig. 5 IWM-1 Inventory Table: Air emissions

The inventory table of water emission includes the list of 23 compounds and indicators. This pollutions come from the landfill leachate and from the biological treatment or waste thermal treatment. The example of the water emissions Inventory table is presented in Fig. 7

The statistics about the recovery rates is also calculated. The calculated costs table is presented in Fig. 6

	COLLECTION	SORTING	BIOLOGICAL TREATMENT	THERMAL TREATMENT	LANDFILL	IWM MODEL TOTAL	RECYCLING SAVINGS	OVERALL TOTAL
(a) COST								
Overall (000 ecu)	13095,22	0,00	427,49	0,00	6977,24	20499,95	-910,41	21410,36
per tonne waste managed(ecu)						90,32		94,33
per household serviced(ecu)	52,96	0,00	1,73	0,00	28,22	82,91	-3,68	86,59

Fig. 6 IWM-1 Inventory table: Cost of MSW disposal

The total cost of waste disposal is divided into stages of waste processing and later compared with the avoided cost from the collection of recyclables. The total cost of the existing system is calculated in the last column.
The inventory table of water pollution is presented Fig. 7

WATER EMISSIONS(kg)	COLLECTION	SORTING	BIOLOGICAL TREATMENT	THERMAL TREATMENT	LANDFILL	IWM MODEL TOTAL	RECYCLING SAVINGS	OVERALL TOTAL
BOD	5,20E+02	0,00E+00	7,68E+02	0,00E+00	1,70E+04	1,83E+04	1,38E+04	4,44E+03
COD	3,80E+03	0,00E+00	1,30E+03	0,00E+00	1,70E+04	2,21E+04	1,23E+05	-1,01E+05
spended Solids	3,34E+02	0,00E+00	4,25E-02	0,00E+00	9,63E+02	1,30E+03	7,25E+00	1,29E+03
rg. Compounds	1,47E+03	0,00E+00	1,33E+00	0,00E+00	-6,44E+01	1,41E+03	3,32E+01	1,38E+03
AOX	3,71E-01	0,00E+00	0,00E+00	0,00E+00	1,92E+01	1,95E+01	1,46E+01	4,89E+00
hlorinated HCs	0,00E+00	0,00E+00	0,00E+00	0,00E+00	9,84E+00	9,84E+00	0,00E+00	9,84E+00
s/Furans (TEQ)	0,00E+00	0,00E+00	0,00E+00	0,00E+00	3,07E-06	3,07E-06	0,00E+00	3,07E-06
Phenol	7,43E+01	0,00E+00	0,00E+00	0,00E+00	3,63E+00	7,79E+01	6,69E-02	7,79E+01
Ammonia	1,13E+01	0,00E+00	1,33E+02	0,00E+00	1,99E+03	2,14E+03	5,00E+00	2,13E+03
Toatal Metals	4,02E+02	0,00E+00	0,00E+00	0,00E+00	9,16E+02	1,32E+03	-5,64E-02	1,32E+03
Arsenic	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,34E-01	1,34E-01	0,00E+00	1,34E-01
Cadmium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,34E-01	1,34E-01	0,00E+00	1,34E-01
Chromium	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,78E-01	5,78E-01	0,00E+00	5,78E-01
Copper	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,20E-01	5,20E-01	0,00E+00	5,20E-01
Iron	3,34E-03	0,00E+00	8,51E-04	0,00E+00	9,05E+02	9,05E+02	0,00E+00	9,05E+02
Lead	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,02E-01	6,02E-01	5,19E-02	5,50E-01
Mercury	0,00E+00	0,00E+00	0,00E+00	0,00E+00	5,72E-03	5,72E-03	0,00E+00	5,72E-03
Nickel	0,00E+00	0,00E+00	0,00E+00	0,00E+00	1,63E+00	1,63E+00	0,00E+00	1,63E+00
Zinc	0,00E+00	0,00E+00	0,00E+00	0,00E+00	6,52E+00	6,52E+00	0,00E+00	6,52E+00
Chloride	8,84E+02	0,00E+00	5,67E-03	0,00E+00	5,63E+03	6,52E+03	1,35E+02	6,38E+03
Fluoride	7,60E+01	0,00E+00	3,78E-01	0,00E+00	-2,00E+01	5,64E+01	1,05E+01	4,59E+01
Nitrate	2,19E+01	0,00E+00	3,74E-01	0,00E+00	-2,35E+01	-1,22E+00	-3,96E-02	-1,18E+00
Sulphide	8,65E-01	0,00E+00	0,00E+00	0,00E+00	0,00E+00	8,65E-01	3,52E+01	-3,44E+01

Fig. 7 IWM-1 Inventory Table: Water emissions

The interesting fact is that sometimes, according to the model, the emissions from the system are negative. This is due to the avoided emission from the energy generation. If there is energy generated at the landfill site, this electricity substitutes the electricity which would have to be generated at the power station. The not emitted emissions from these sources are called the avoided emissions.

The problem of sensitivity and uncertainty is also important. The IWM-1 lists only 22 compounds of air emissions while in the literature landfill gas composition consists of 26 compounds.(Kreith, 1994) .Leachate is characterized in the literature by 42 parameters (Bagchi, 1994) while IWM-1 model characterizes only 23 parameters. Additionally leachate composition changes in time what was not addressed in the IWM-1 model and has to be addressed by sensitivity analysis.

The last result table is the waste statistics which is presented in Fig. 8.

(c) STATISTICS	AVERAGE	Paper	Glass	Metal-Fe	Metal non-Fe	Plastic-film	Plastic-rigid	Textiles	Organic
Materials Recovery rate	0.6%	1.7%	0.2%	0.7%	0.2%	0.0%	0.1%	0.0%	
Organic Recovery Rate									0.2%
Overall Recovery Rate	0.4%								
Diversion from Landfill	0.5%								
	Total	Paper	Glass	Metal-Fe	Metal non-Fe	Plastic-film	Plastic-rigid	Textiles	Compost
Sec. materials (Kt/yr):	0.009	0.006	0.001	0.000	0.000	0.000	0.000	0.000	0.002

Fig. 8 IWM-1 Inventory Table: Waste statistics

APPLICATION IWM-1 FOR THE DECISION PROCESS

While using the IWM-1 results in the decision process it is necessary to conduct one or even two next phases of the LCA that is LC Impact Assessment (LCIA) and Interpretation.

In LCIA phase the results of the inventory analysis is further processed and interpreted in terms of environmental impacts and societal preferences. To do so, the list of impact categories is defined, as well as the indicators describing the impact categories. Different models are used to calculate the indicators which are weighted sums of selected items from the inventory table. Finally, the category indicator results can be grouped and weighted to include societal preferences of the various impact categories.

According to the literature (Guinée, 2002) there are three types of the impact categories lists:

- Baseline impact categories, included in almost all LCA studies
- Study-specific impact categories, which may merit inclusion depending on the goal and scope of LCA study,
- Other impact categories, categories not having the baseline characterisation methods and which require further development before are used in the LCA.

To compare different systems of MSW management the following impact categories and indicators can be used:

Unfortunately, not all mentioned in the Table 1 impact categories can be calculated directly from the IWM-1 inventory table. The table gives no information about the land used, extracted minerals and fossil fuels. Also the information about the noise level is not available. These values have to be estimated or these categories have to be dropped from the assessment phase. The results of inventory analysis are transformed after characterisation into the environmental profile. This profile consists of the calculated indicators for the chosen impact categories (Table 2)plus the economic performance and solid waste reduction indicators calculated by IWM-1.

The next step of the LCIA is normalization. ISO 14042 defines normalization as “calculation of the magnitude of indicator results relative to reference information”. The reference information can be the indicator which refers to the whole community, country, continent or even the world. Normalization is not mandatory, but strongly recommended step of any LCA. As a result of this step the environmental profile is transformed into the normalized environmental profile in which the indicators are substituted by the ratios of the indicators to the values referring to the reference areas.

Environmental or normalized environmental profiles are used by the decision makers. Because they still do not give a simple ranking of the analysed options there is a pressure to further aggregate the obtain results. Further aggregation is possible by “grouping” or by “weighting” process. These steps are optional, (but not recommended by ISO 14042) in LCA. There is no specific methodology of weighing or grouping recommended by ISO 14042 and, if weighing is applied for comparative assertions the results can not be disclosed to the public. Significant drop of the objectivity of the results is the main problem. The scale of the potential drop presents **Fig. 9**

Table 2 Potential impact categories for comparing different MSW disposal systems

Impact category	Characterisation factor	Unit of indicator results	LCI results
Baseline impact categories			
Depletion of abiotic resources	Abiotic depletion potential (ADP)	kg (antimony equivalent)	Extraction of minerals and fossil fuels (in kg)
Impact of land use	1 for land use	m^2yr	Land use
Climate change	Global Warming Potential (GWP 100)	kg(carbon dioxide eq)	Emissions of greenhouse gases to the air
Stratospheric ozone depletion	Ozone deplition potential (ODP steady state)	kg (CFC-11 eq)	Emissions of ozone-depleting gases to the air
Human toxicity	Human toxicity potential (HTP)	kg (1,4-dichlorobenzene eq)	Emissions of toxic substances to air water and soil
Ecotoxicity: freshwater aquatic	Freshwater aquatic ecotoxicity potential (FAETP)	kg (1,4-dichlorobenzene eq)	Emissions of toxic substances to air water and soil
Ecotoxicity: marine aquatic	Marine aquatic ecotoxicity potential (MAETP)	kg (1,4-dichlorobenzene eq)	Emissions of toxic substances to air water and soil
Ecotoxicity: terrestrial	Terrestrial ecotoxicity potential (TETP)	kg (1,4-dichlorobenzene eq)	Emissions of toxic substances to air water and soil
Photo-oxidant formation	Photochemical ozone creation potential (POCP)	kg (ethylene eq)	Emission of substances (VOC, CO) to air
Acidification	Acidification potential (AP)	kg (SO_2 eq)	Emission of acidifying substances to the air
Eutrophication	Eutrophication potential (EP)	kg (PO_4 eq)	Emission of nutrients to air, water and soil
Study-specific impact categories			
Odour malodorous air	Reciprocal of odour threshold value	m^3 (air)	Emissions of odorous substances to air
Noise	1	Pa^2s	Emissions of sound

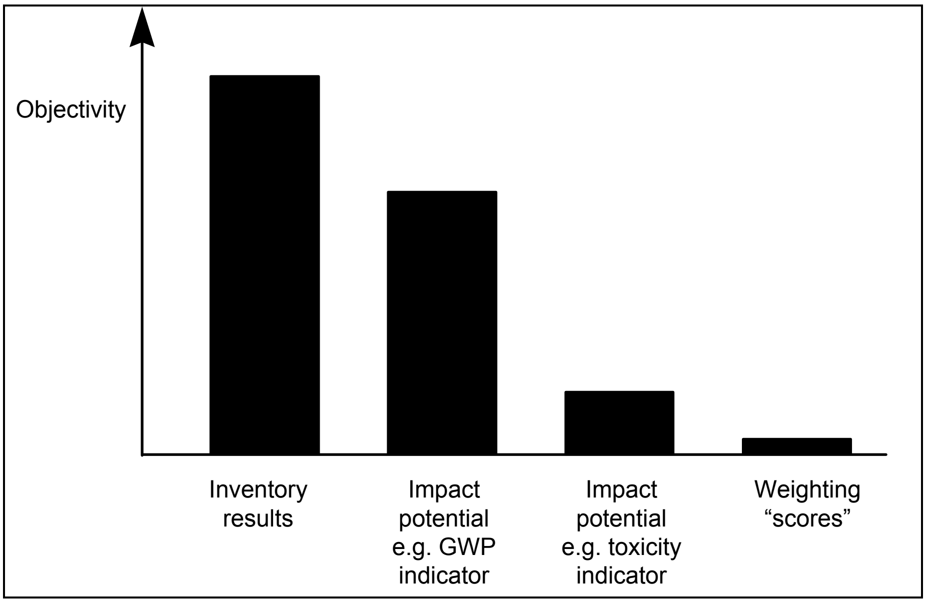

Fig. 9 Decreasing objectivity and reliability across an LCA (McDougall, 2001)

The different LCIA indicators are of different level of objectivity, but the weighted scores are significantly below that level.

CONCLUSIONS

The IWM-1 model is a computer tool to help the decision makers in the evaluation of the MSW systems. The model is based on the LCA way of looking at the environment and conducts two first phases of the LCA: goal and scope definition and inventory analysis. The model's result table is the LCA inventory table. The IWM-1 result table, presenting the environmental interventions, is too detailed to allow any decision making. To adopt the results for the decision process one has to conduct the life cycle impact assessment (LCIA).

The IWM-1 results allow calculation of the many indicators from the baseline and study specific impact categories numerated in literature (Guinée, 2002). If normalized environmental profiles obtained after LCIA are still not helping in the decision process, the grouping or weighting are possible, but significant drop of the obtained results objectivity can be expected.

REFERENCES

EPA, 1995, "Life-Cycle Impact Assessment: A Conceptual Framework, Key Issues, and Summary of Existing Methods"

McDougal, F., White P., Franke M., Hindle P., (2001) Integrated Solid Waste Management: a Life Cycle Inventory. Blackwell Publishing 2001

White P.R., Franke M., Hindle P. (1997). Integrated Solid Waste Management - a Lifecycle Inventory Blackie Academic & Professional.

Kreith Frank, (1994) *Handbook of Solid Waste Management* McGraw Hill

Guinée, J. B.,(2002) Handbook on Life Cycle Assessment Operational Guide to the ISO Standards Kluwer Academic Publishers