INTEGRATED SOLID WASTE MANAGEMENT MODEL AS A TOOL OF SUSTAINABLE DEVELOPMENT

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ABSTRACT
The author applied the first version of the Integrated Municipal Waste (IMW-1) model developed by White P.R., Franke M., and Hindle P., to analyze the present and the planned waste management systems in the two towns: Krakow, Poland and Stockholm, Sweden. To help in the decision process the integration of the model results is proposed. The aggregation is based on the modified Polish emission fees. As a result of this integration the environmental impacts on water and on air are presented in monetary units and are comparable with the economic cost. Such integration allows the simple comparison of the Krakow and Stockholm systems, which is presented.

KEYWORDS
Integrated municipal solid waste analysis; sustainable development; regional planning

INTRODUCTION
The decisions in the area of municipal solid waste management are not only very capital intensive, but also difficult from the environmental and social points of view. There is a need to develop, master and implement a simple, but reliable tool that will help the decision makers in the analysis process. Integrated Municipal Waste (IMW-1) model is a tool which seems to meet all the requirements. (White, 1997) (Bjorklund, 1998) (Eriksson,2002) (McDougall, 2001).
The results of the analysis from the IMW-1 model give vast amount of information, but it is rather fragmented. To help in the decision process the integration of the model results is proposed. The author proposes the aggregation of the emissions based on the modified Polish emission fees. As a result of this integration the environmental impacts on water and on air are presented in monetary units and can easily be compared and combined with the economic cost. Such integration allows the comparison of the Krakow and Stockholm systems, which is presented.
The obtained results do not clearly confirm the environmental superiority of the incineration over the landfilling. May be the value of land and the environmental impact of the landfill gas is underestimated in the model. The increase of the economic cost of the system if the incinerator is introduced, is clearly visible in the results.
In all analysed cases the environmental burden of the MSW system is significantly smaller than the economic one.
The collection stage is the most expensive and the most environmentally demanding stage of the whole process of waste disposal.
The model clearly shows the environmental benefits of recycling.

If the emission integration procedures are improved and verified the model can be a very useful tool for the decision makers.

DESCRIPTION OF THE SOLID WASTE MANAGEMENT SYSTEMS IN KRAKOW AND STOCKHOLM

Krakow, the former capitol of Poland, located at an altitude of 219 meters in Southern Poland occupies 327 km^2 and has approximately 750 000 citizens. Some of them are permanent residents while a significant share are temporary residents such as tourists or students. The central part of the town is medieval and densely populated, but 52% of the town are green areas.

The social structure and the standard of living results in an average of three people per household. The total amount of municipal solid waste MSW generated in the city is 277 815 tons per year. (Kopacz, 2003) It is difficult to estimate such values because the statistics are unreliable. Polish law (DzU.2001.62.628 June 2001) defines what is and what is not a municipal solid waste and a significant amount of waste generated within the city limits does not meet these criteria. Commercial and sometimes industrial waste is mixed with the MSW and disposed together, blurring the statistics. At the same time, a significant portion of MSW is collected by private haulers and disposed of at the remote landfills making the statistics even less certain. The presented data concerning the waste volume and composition is a result of individual research (Kopacz, 2003).

The waste disposal system in Krakow is a traditional one. The city has a recycling program with 150 recycling banks located around the town. They are prepared to collect metal, paper, PET bottles, and glass. Additionally, there are the "bring and earn" recycling centers where one can bring recyclables and collect money. These centres are mainly used by scavengers and by industry located within the city limits. The composting facility (6 000 tons) processes the green waste separately collected in the city. This is the waste from green areas, from the open markets and from the food and tobacco industry located in the city. The last share of waste has to be excluded from the analysis because this waste, according to Polish law, is not a MSW. Textile waste is separately collected by the charity organizations.

In the future, Krakow plans to build an incinerator (200 000 tons) and develop more extensive recycling and recovery programs. The number of recycling banks is planned to reach 450 and also the new material recovery facility (20 000 tons) and a new composting plant are planned for construction (6 000 and 9 000 tons). Also, the separate collection of wet and dry wastes in part of the city is planned for the future.

The subject of the comparison is the city of Stockholm, (Stockholm commune) the capitol of Sweden, which has 406 072 households and approximately 755 000 inhabitants. The medieval old town and friendly green areas attract many tourists which generate waste equal to 5 700 permanent residents (Bokota, 2004). A higher standard of living results in 1.8 citizens per household ratio.

The Stockholm waste disposal system is far more technically advanced and developed than in Krakow. The core of the system is the mass burn incinerator at Högdalen. The recyclables can be collected at kerbside plus in 300 collection banks or in the three recycling centers. There are also 22 household hazardous waste collection stations, and small composting and anaerobic digestion plants. These facilities, because of their insignificant sizes and character, have a negligible impact on the waste disposal scheme and therefore were not included in the model. Landfilling is seen as the last resource and used only for 6% of the waste stream.

The two systems are presented graphically in Fig. 1.

The comparison of the main parameters characterising the waste streams in Krakow and Stockholm presents The main difference between the composition of the waste in the two towns (Fig. 2) is higher share of paper in waste stream in Stockholm and higher share of organic fraction of waste in Krakow. This difference is typical for the cities at the different state of development.

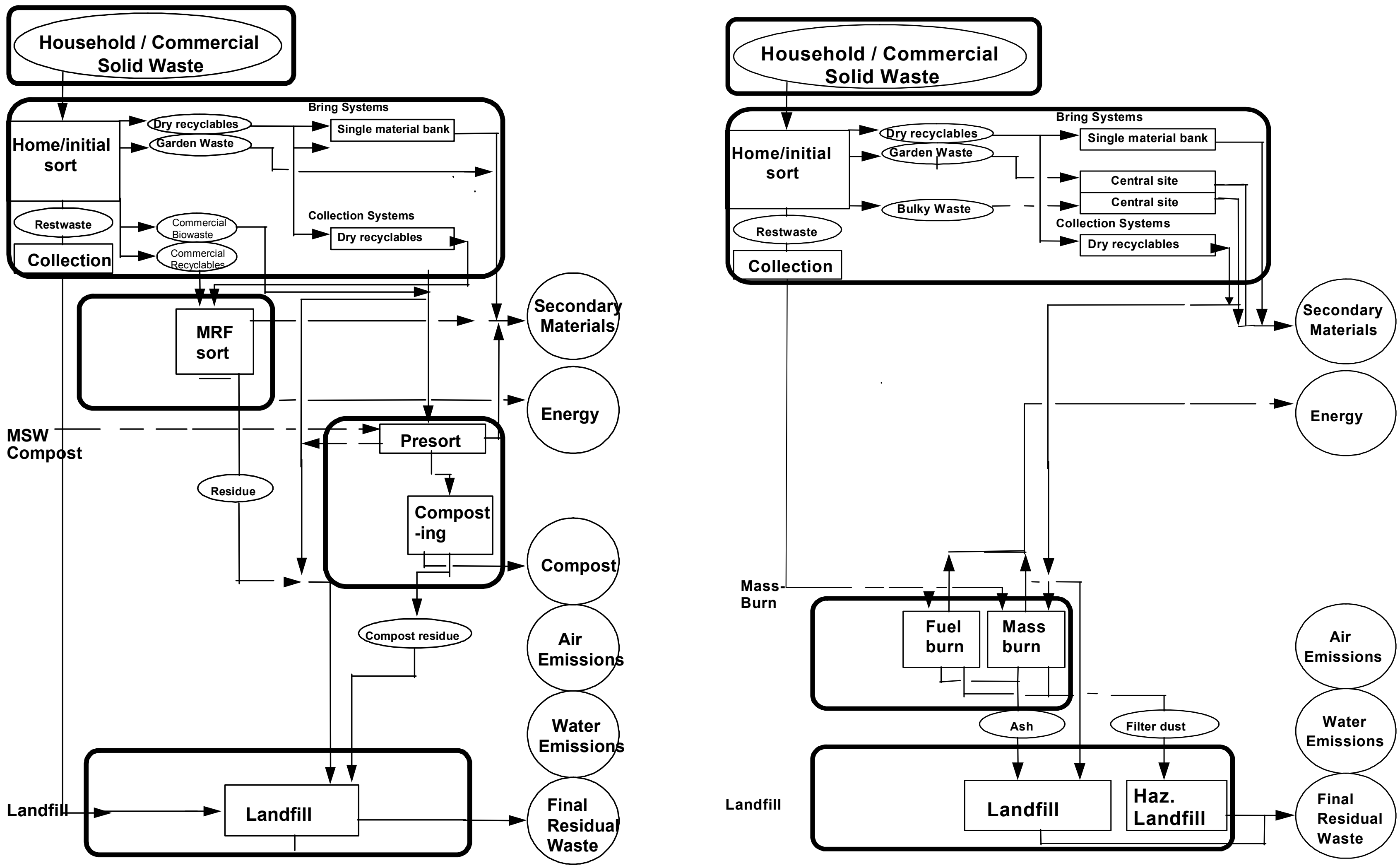

Fig. 1. Detailed structure of the Krakow and Stockholm MSW management models

The significant difference in the waste stream volume is a result of different stage of social development. Higher level of income results in the higher consumption and higher waste generation ratio in Stockholm then in Krakow. Also the extensive application of the recycling program results in the high rate of recycling seen at the graph. Generally, the Stockholm system is very much in compliance with the common trends while the Krakow system is heavily based on the landfilling – technology seen as the out of date method.

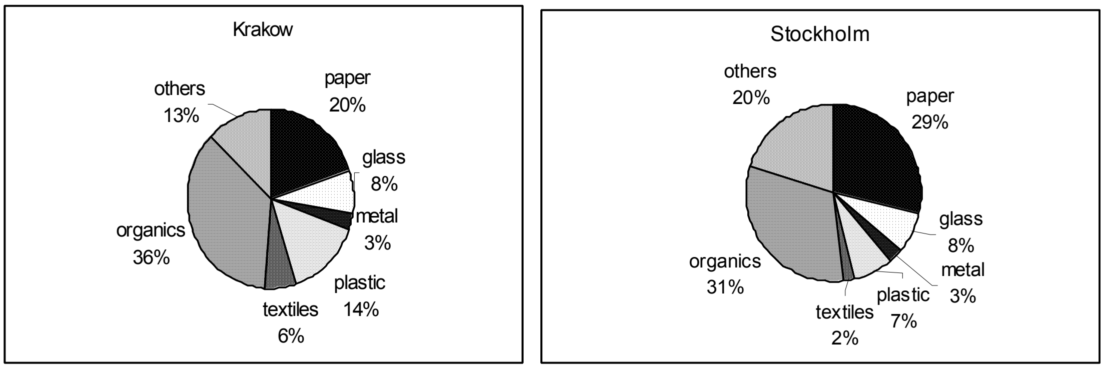

Fig. 2. Composition of the waste streams in Krakow and Stockholm

Different systems of waste disposal result in different waste stream flows. The waste stream flows in the two towns presents Fig 3.

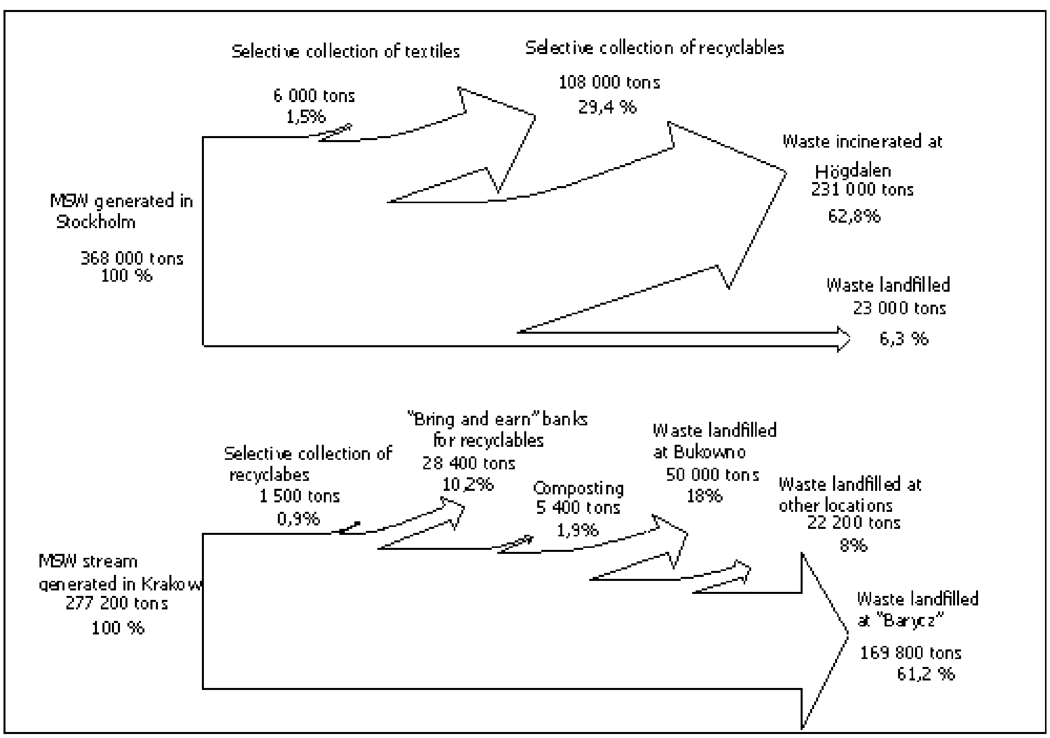

Fig. 3. MSW streams in Krakow and Stockholm.

RESULTS
The IWM-1 model presents the results in table form where number of emissions into air and water are presented. Also the origin of these emissions is indicated in the table. A few integrated indicators of the waste disposal system are also presented. Table 1 presents the results of the comparison for economic cost, energy consumption and landfilled to generated waste ratio.

Table 1. Results of the Krakow and Stockholm MSW systems analysis with the application of IWM-1 model

Stage of the process	Economic unit cost of waste disposal [€/kg waste gen.]		Energy unit consumption [GJ/kg waste gen.]		Ratio of landfilled waste to waste generated [kg/kg of waste gen]	
	Stockholm	Krakow	Stockholm	Krakow	Stockholm	Krakow
Collection	0.068	0.0318	0.00043	0.00056	-	-
Composting	-	0.001	-	0.000006	-	-
Incineration	0.020	-	-0.0084	-	-	-
Landfilling	0.028	0.0277	-0.00006	-0.00075	0.2516	0.8925
Recycyling	0.012	0.003	-0.00183	-0.00110	-0.0096	-0.0077
Total	**0.128**	**0.0635**	**-0.00986**	**-0.00129**	**0.2420**	**0.8848**

The unit cost of waste disposal in Krakow is half the cost in Stockholm. The main component leading to such high cost is the collection stage. A higher standard of living in Sweden accounts for the discrepancies in prices and wages between the two cities. For example, the cost of equipment and labour is higher in Stockholm, directly increasing the cost of the collection stage. Also the unit cost of waste landfilling is high in Stockholm in relation to Krakow. The table fails to indicate the actual unit cost of landfilling, presenting instead the ratio of waste generated, not landfilled waste. In Stockholm, thanks to the incineration process, only a small portion of generated waste is being landfilled (6.3%) while in Krakow, the share of landfilled waste is much higher, at 87.2%.
Energy consumption by the systems in the two cities is negative. Meaning the energy recovered at the landfill site in the form of the landfill gas or in the incinerator plus the energy saved thanks to the recycling program is larger than the energy needed for processing the waste. Because Stockholm has a very advanced recycling system and has an incinerator in which the energy recovery rate is higher than at the landfill site the total energy recovered from each kilogram of waste generated is nine times higher in Stockholm than in Krakow.
One of the main goals of the waste disposal system is to minimize the waste stream which enters the landfill. Landfilling is seen as the last resource of waste disposal. The ratio of landfilled waste to waste generated is an indicator of the efficiency of the waste disposal system. In Stockholm, this indicator is four times higher than in Krakow. This is mainly due to the application of the incineration technology as the main technology of waste disposal. Also the extensive application of recycling has positive, but marginal impact on waste disposal ratio.

INTEGRATION OF THE RESULTS OF THE ISW-1 MODELS

The ISW model also delivers information about the environmental emissions generated during the whole stage of waste disposal. Such information is too fragmented to allow any analysis of different disposal systems. There are 12 methods of characterising the impact of man's activity on human health, ecosystems and/or natural resources (US EPA,1995). Not all methods can be used in all cases and some are more appropriate for assessing specific impact categories.

The method of Environmental Standards Relation (ESR) seems to be the best suited for the analysed case. (US EPA,1995) The purpose of ESR is to assess chemical releases to air, land, and water based on their relative potential ecological and human impact. The emission fee was used as a media specific weighting factor. If the emission fee fully covers the external cost of the pollution, by calculating the total fee one obtains the total cost to the environment caused by each option of MSW disposal.

The Polish law implements the emission fees, but it occurs that if treating the maximum allowable concentration of the pollutant in the ambient air as an indicator of the components toxicity, the emission fees for different pollutants are inconsistent with their toxicity. Assuming that the maximum allowable concentration of different pollutants is the good indicator of the toxicity the new, modified emission fees were calculated. For each component, the modified emission fee was defined as: the product of the emission fee for the sulphur dioxide and the ratio of the imission standard of this component to the imission standard of sulphur dioxide. In case of emissions to water, the reference component was not sulphide dioxide, but standards for sulfates discharged with the effluent.

Such method leads to one indicator for the environmental impact of the whole waste disposal system. Additionally, applying such a method both, economic and environmental impacts are in the same, monetary units and that fact allows the direct comparison of the systems. The comparison of the MSW disposal systems in the two cities is presented Table 2. The present and planned MSW systems in Krakow are compared with the existing system in Stockholm. The future system in Krakow was analysed assuming it is processing the present amount of waste.

Table 2. Comparison of the Krakow and Stockholm MSW disposal system

	Krakow – present stage	Krakow – future stage	Stockholm
1. Waste stream [kg]	277 151 634	277 151 634	369 434 219
2. Economic cost of waste disposal according to IWM-1 model [€]	17 575 166	34 898 808	47 261 528
3. Economic unit cost [€/kg] (2 ÷ 1)	0.06	0.1259	0.13
4. Environmental unit cost (per kg of waste) [€/kg]	-0.000051	0.00032	0.00021
5. Total disposal cost per kg of waste [€/kg] (3 + 4)	**0.06**	**0.13**	**0.13**

The present cost of disposal of one kilogram of waste in Krakow is half the cost in Stockholm, but if the system in Krakow is modified, and the incinerator is built, the costs in the two cities will be nearly equal. The present environmental impact of the Krakow system is negative. That means that the avoided emission, thanks to the recycling, is larger than the emission caused by the restwaste collection treatment and disposal. This positive effect will vanish if the new system is introduced; the environmental cost of the restwaste treatment will be larger than the environmental benefits from the recycling. The emissions in Krakow and in Stockholm will be comparable, but the emissions in Krakow will be larger mainly due to lower efficiency of the recycling programs.
Environmental impact, expressed in monetary terms, is insignificant to the economic cost of the waste disposal. Environmental cost is less than 1% of the economic cost. The economic cost alone seams to be the indicator of the waste disposal system.

CONCLUSIONS

Application of the IWM-1 for comparison of the Krakow and Stockholm municipals solid waste system leads to several conclusions. Some of them are of general character and some are site specific.

- The IWM-1 model requires an experienced user to run the model correctly and obtain reliable results,
- The data for comparison studies is very difficult to obtain, because in different systems there are different definitions of the waste and there are different statistical methods employed,
- The economic comparison of the solid waste systems from different countries brings additional uncertainty making the international comparisons more difficult,
- Introduction of the incinerator and advanced recycling schemes doubles the economic cost of the system,
- In the new Krakow system, the positive environmental impacts of the recycling are offset by increased emissions from the incinerator,
- Both, in Krakow and in Stockholm, the environmental impact of the system measured as the cost of the emissions is insignificant in comparison with the economic cost of waste disposal.
- The IWM-1 model does not take into account the social impact of the MSW system, which probably is the driving force in the process of decision-making.
- If developed, the new Krakow MSW disposal system will have a similar economic and environmental performance analogous to the present system in Stockholm.

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