INTEGRATED ANALYSIS OF THE KRAKOW SOLID WASTE MANAGEMENT SYSTEM

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ABSTRACT
The article presents the application of the integrated municipal solid waste analysis model developed by White. The model is applied for the Krakow area and analyses three planned for the city scenarios of MSW disposal strategies. The current landfilling strategy is compared with the composting option and with the application of the incinerator. The calculated by the model environmental impact is integrated and expressed by the environmental impact index that is a sum of emission charges caused by the whole system of waste disposal.

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

INTRODUCTION

The essence of the integrated approach to the solid waste management is to treat the impacts generated by the waste collection, transportation, processing and final disposal as a whole. That is done by calculating such impacts at all stages of waste management, adding them up, and finally making the decision on waste disposal based on the combined impact. One of the tools to calculate the total environmental and economic impact of the waste system is the White model. (White, 1996). The model has been presented earlier and discussed in detail by Stypka (Stypka, 2003).

The model calculates the list of combined at all stages of disposal emissions of several compounds to air and water. Such emissions are treated as the index of environmental impact of the MSW system. The avoided emissions, due to used recycling is also calculated. The final impact of the White system is a list of emissions where each emission is a difference between the generated and avoided emissions. The economic cost is also calculated

BRIEF DESCRIPTION OF THE MODEL

The components of the integrated waste management system and their interlinks presents Figure 1 White (1997). The scheme shows the general possibilities of the municipal solid waste flow starting from "cradle" – solid waste input, finishing at waste "grave" –landfill. The whole waste stream, or only its fraction, can flow through different stages generating different environmental and economic effects. These stages are "sorting", "biological and thermal treatments" and finally landfilling.

The detailed structure of this system is far more complex. For example, what is presented in the scheme as a "thermal treatment" in detailed scheme is developed to "Refuse-Derived Fuel (RDF) burning" or "mass-burning incinerator of solid waste" or burning as fuel "source-separated paper and plastic". Each of these facilities have different impacts on the environment, society and economy. Additionally choosing one of these options predetermines, to some extent, the selection of the biological treatment as well as the selection system. The whole system is very much interlinked and has to be seen as a unity. The detailed scheme of the system presents Figure 2 (White, 1997).

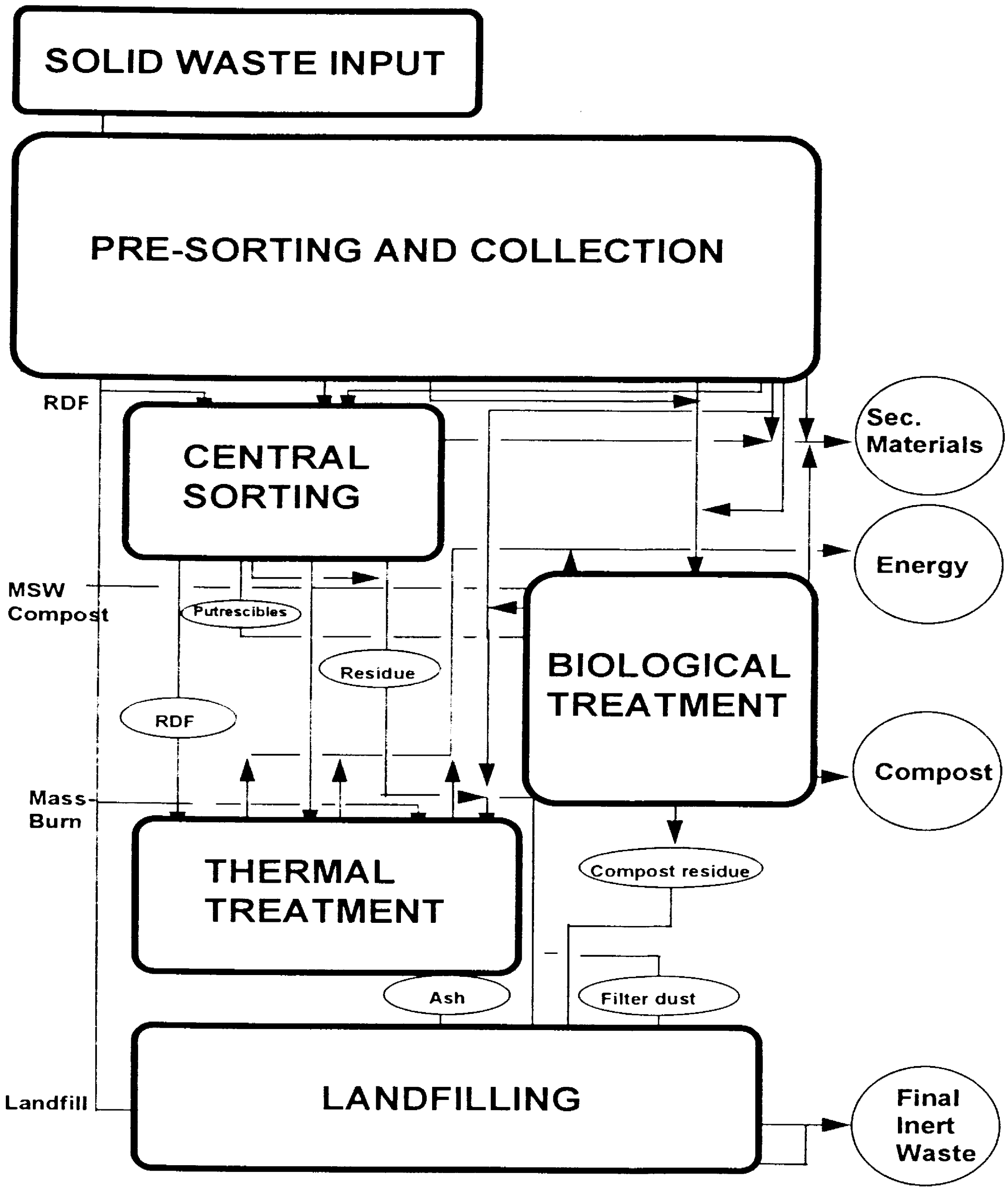

Figure 1. Components of an integrated waste management system (White, 1997).

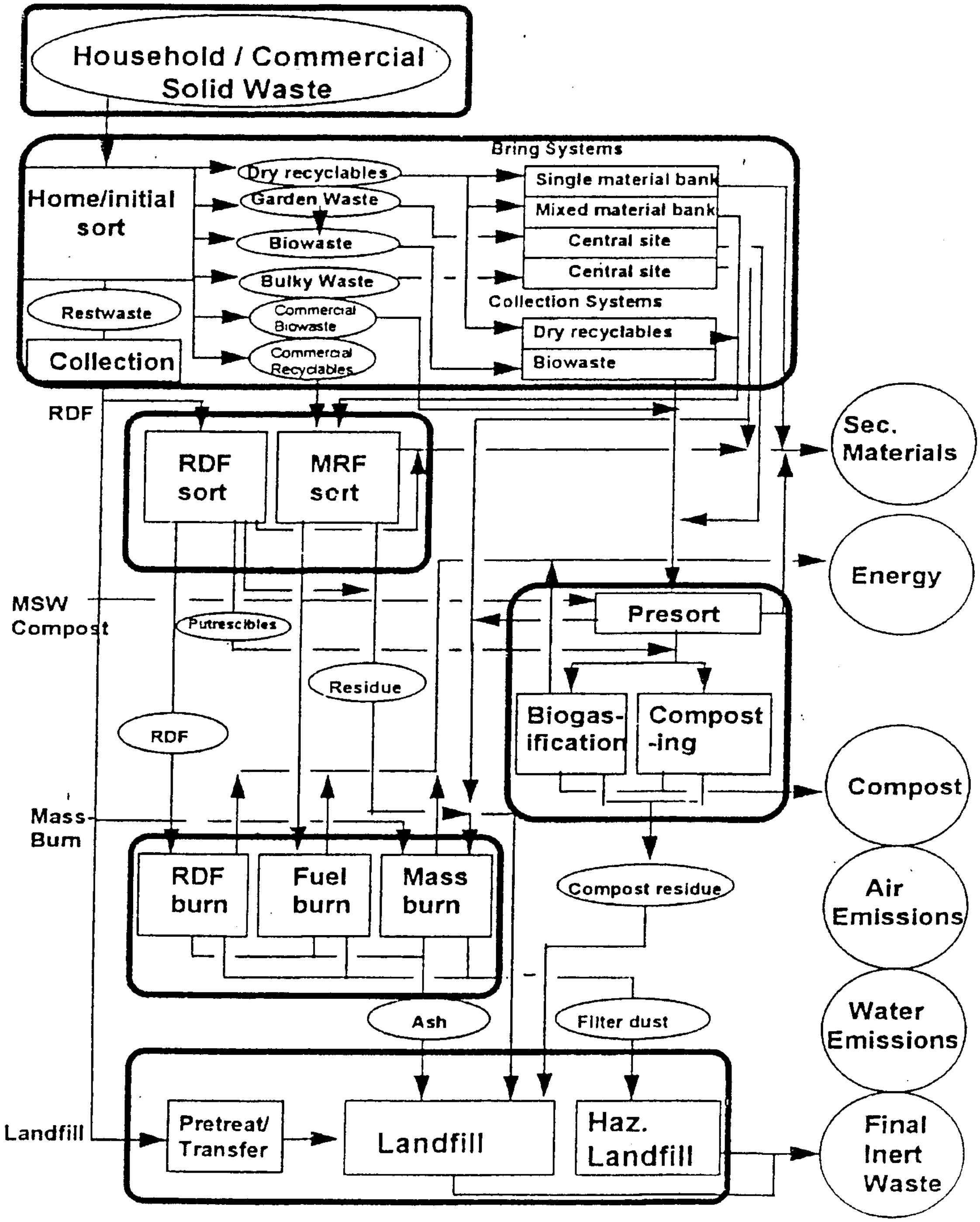

Figure 2 Detailed structure of an integrated waste management system (White et al., 1997).

White et al. (1997) presented not only the conceptual model, but also presented the spreadsheet to calculate the environmental and economic impacts of the different waste strategies. The spreadsheet is based on the average flow data.

The basic input data are the household and commercial waste streams calculated as a product on the unit waste steams and the number of dwellings. The waste stream is analysed in following fractions:

paper, glass, nonferrous and ferrous metals, plastic foil and rigid plastic, textiles, organic fractions and restwaste.

The list of the results presents not only the emission of the compounds, but also the stage of the disposal process at which they are released to the environment such as: collection, sorting, biological or thermal treatment, or landfilling.

Additionally, the results are accompanied with the energy balance of the whole process. The energy consumption and production is measured not only in GJ, but also in energy media such as: petrol, oil, gas and electricity. The cost of the system is also divided by origin. Finally, the unit costs per household are calculated.

INPUT DATA AND THE OPTIONS OF THE KRAKÓW SOLID WASTE MANAGEMENT SYSTEMS

When applying the model it is very important to clearly define the boarders of the system and to make consistent assumptions concerning the waste definitions and to use reliable input data. The model is very demanding on the amount of input data. The required number of data and the needed level of accuracy is very high. In case of the Krakow the reliable estimate of the amount and composition of waste is a difficult. Both, municipal and industrial solid wastes are generated in the city. Both streams are mixed and co-disposed. This creates the basic problem of estimation the amount and morphology of the municipal solid waste stream without its industrial component.

According to the Polish law: municipal solid waste is defined as the waste generated in the households, and the waste with the character and morphology of the household waste if it does not contain hazardous waste. (Dz.U.2001.62.628 20 June 2001)

Polish law presents the list of the municipal solid waste divided into different categories by source. (Dz.U.Nr 112, poz. 1206) The basic categories are:

- MSW segregated and separately collected (code 20 01)
- Waste from gardens and parks (including cemeteries) (code 20 02)
- Other municipal waste (code 20 03)
    - Mixed municipal waste (code 20 03 01)
    - Waste from the open markets (code 20 03 02)
    - Waste from street sweepings (code 20 03 03)

Because there are no reliable data concerning the Krakow waste stream its amount had to be estimated and the estimate verified by comparison with the amount of waste disposed at the landfills, composting facility and separately collected recyclables.

To estimate the total amount of municipal waste the author estimated and added up the waste from the following sources: household waste, waste from open markets and shops, waste from green areas and street sweepings.

1) Total amount of household waste is a sum of waste generated by permanent residents (709 169 persons) plus waste generated by temporary residents (32 599 people) and by the tourists (3 200 000) (Raport o stanie miasta 2001 rok, 2002).
   The calculations were made assuming that the average citizen of Krakow generates 228 kg of household waste per year (Stępliński, 2000). That means that the permanent residents generate 161 875 tons of waste yearly and temporary residents generate 7 442 tons of waste. If the average tourist spends one day in the city and generates the same amount of waste as the

permanent resident, that is 0.6 kg per day, the total amount of household waste generated in the city can be estimated:

161 875 [Mg/yr] + 7 442 [Mg/yr] + 2000 [Mg/yr]= 171 317]Mg/yr]

2) The amount of municipal solid waste generated in the commercial areas and on the market places was only estimated roughly. The estimate was made based of the amount of waste generated in the supermarkets and at the farmers' markets. It was assumed that the total amount of this type of waste is twice as big.

   By the end of year 2001 there were 36 284 private commerce enterprises in the Krakow area. This is 37.4% of the total number of the companies operating in the Krakow area.

   The shopping centres become new phenomena in the Krakow commerce picture. The amount of municipal solid waste generated in such shopping centre was estimated based on the information from the company serving such a shopping centre. The 11 054 m sq. shopping centre generates yearly about 90 tons of mixed municipal waste. This waste is collected and disposed at the municipal landfill. At the same time the shopping centre collects package waste which is separately collected and disposed. These are mainly cardboard (on average 528 tons/year) plastic film and PET bottles (approx. 132 tons per year). Assuming that these are the average values for the Krakow region, and that the total area of the shopping centres in Krakow is 175 400 sq meters. (Raport o stanie miasta 2001 rok, 2002) The total amount of municipal solid waste generated in the shopping centres can be estimated at 17 334 tons per year.

   There are 32 farmers markets in Krakow with the total area of 262 000 sq. meters. Additionally, there are small vendors scattered around the city. According to OBREM report average market generates 0.99 dm^3 of waste per sq. meter (0.13 [kg/m^2]) (Stępliński, 2000). This give the total amount of waste generated at the markets equal to 12 432 tons per year. Assuming that the total amount of waste is twice as big, one can estimate the total amount of waste in this category at 59 532 tons per year.

   *2*17 334 [Mg/yr] + 2*12 432 [Mg/yr]= 59 532[Mg/yr]*

3) According to the Report on Krakow Affairs (Raporcie o stanie miasta w 2001 roku, 2002) the city has 4 827 hectares (approx. 15 % of the city area) of green areas. 790 hectares of the green areas is a forest (Las Wolski) which does not generate neither waste for composting nor for landfilling. The area of Krakow generating green waste is approximately 3 000 hectares. Assuming 5 tons of green waste per hectare, (Stępliński, 2000) one obtains 15 000 tons of green waste from this source.
4) The amount of waste from street sweeping was estimated based on indexes given in the literature. Wang (Wang, 1998) estimates this type of waste on 13% of the waste stream generated at households and commerce facilities.

Adding the waste stream from all the sources one obtains the estimate of the total municipal waste stream in Krakow.

*(171 317 [Mg/yr] + 59 664]Mg/yr] + 15 000 [Mg/yr])*1.13 = 277 958 [Mg/yr]*

To verify this estimate of the municipal waste stream, the stream of the disposed waste was also calculated. The information from the recycling centres, landfills and the composting facility were collected. Also the information about the collection of the second hand clothing was collected. The obtained results are presented in the Table 1 and 2 and also in Figure 3. (Kopacz, 2003)

Table 1. MSW stream in Kraków in year 2001 and the ways of its disposal.

Methods of waste disposal	MSW stream in Krakow	
	tons	**%**
Landfill „Barycz”	169 760	61.2
Landfill „Bukowno”	50 000	18.0
Other landfills	13 859	5.0
Recyclabels recovered from landfills	1 740	0.63
Recovery banks	26 670	9.62
Separate waste collection	776	0.28
Second hand clothing	710	0.26
Composting facility	5 360	1.93
llegal landfills	8 310	3.0
Total	**277 185**	**100**
Unit waste stream per citizen [kg/yr.]	**373.7**	

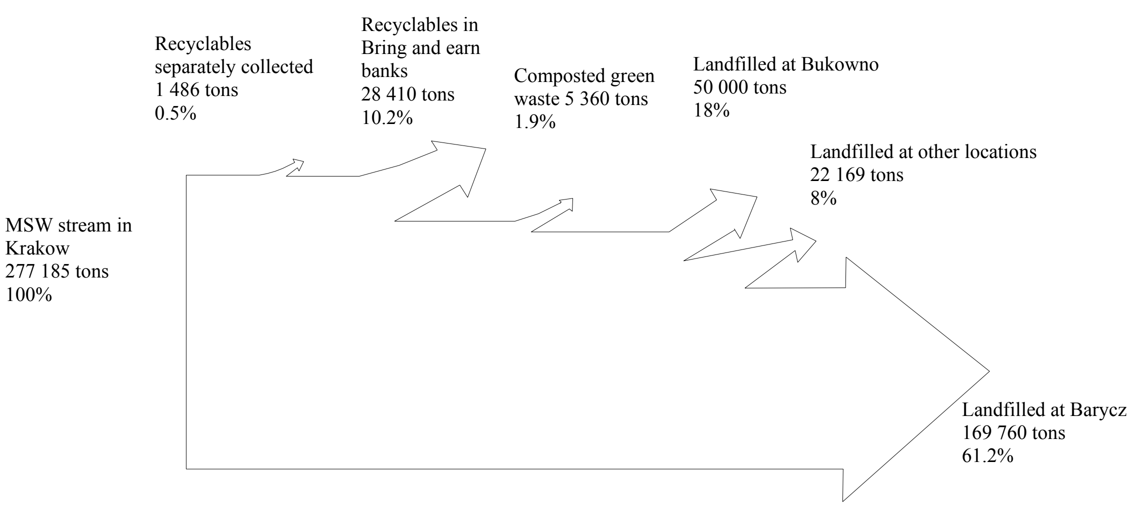

Figure 3. MSW stream in Krakow and ways of its disposal.

The two estimates of the municipal Krakow waste stream are quite similar. The estimate of 277 815 Mg/year based on the waste disposal was taken for further analysis.

Table 2. Disposal methods of MSW in Krakow in year 2001. (Kopacz, 2003).

Disposal methods	2001 yr.	
	[tons/yr.]	[%]
Recovering	29 896	11
Composting	5 360	2
Landfilling	241 929	87
Total	**277 185**	**100**

The morphology of waste is the second crucial set of parameters important for the model. Because the empirical results of analysis conducted in Krakow are not consistent the author decided to use for the further analysis the results obtained by the Institute of Urban Areas Ecology (Sieja, 1997). Figure 4 presents the Krakow waste morphology used in the model.

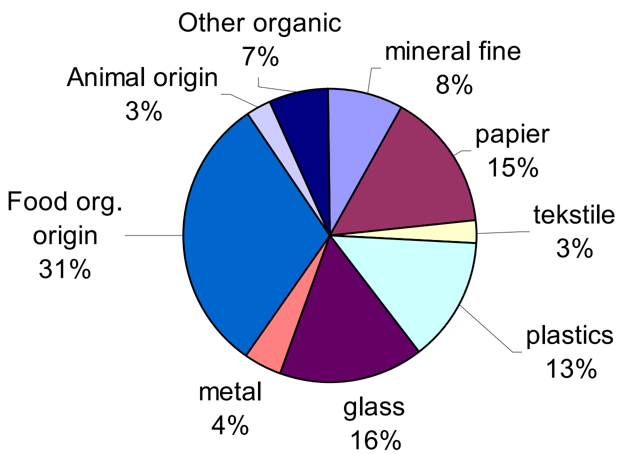

Figure 4. Analysis of MSW at Krakow; forecast for year 2000 [Sieja, 1997].

ANALYSED OPTIONS OF WASTE DISPOSAL

The present and officially planned ways of waste disposal in Krakow were subject of the analysis. The planned strategies were adopted from the official documents of the City – „Program of Municipal Solid Waste Disposal in Krakow County" Three options of waste disposal were analysed and compared. Option I – present state; Option II – implementation of the first stage of the program and Option III implementation of the second stage of the program.

<u>Option I</u> – the present state of the MSW disposal can be described as follows:

- Separate collection of recyclables (paper, glass, plastic and metal) applying „bring" system, centres located in 150 places around the city.
- "Bring and earn" collection banks (paper, metal, glass).
- Curb site collection of mixed household waste picked up from each household.
- Composting of green waste (glass clippings and branches) and waste from open markets (fruit and vegetables)

- Disposal at „Barycz" and other landfills in the Krakow neighbourhood.

Option II is the first stage of the municipal waste disposal upgrade program. This option can be described as follows:

- Expansion of the "Barycz" landfill,
- Construction of the container type composting facility located at the "Barycz" landfill, with the throughput of 6 000 tons per year,
- Construction of the central sorting facility at the "Barycz" landfill with the throughput of 20 000 tons per year,
- Expansion of the existing system of paper, glass, metal and plastic recycling banks to 450 units.

Generally, this option looks very much like the option I system with the more elaborate composting unit, which this time, also delivers the restwaste to the landfill.

Option III

Option III is made with the following assumptions:

- There is a mass burn incinerator,
- The city has the central sorting facility with capacity 10 000 tons/year,
- There is a program of construction and demolition waste disposal,
- There is a program of bulky waste disposal,
- The household hazardous waste disposal program is implemented.

Option III was analysed with the following detailed assumptions:

- There is a mass burn incinerator; capacity 100 000 tons per year in option IIIA and 200 000 tons per year option IIIB,
- There are two composting facilities (2 x 6 000 tons/year and 9 000 tons/year) and 40% of the green waste delivered to the actually operating facility comes from industrial sources,
- There is a sorting facility with the capacity of 20 000 tons per year located at the Barycz landfill,
- Thanks to the increased environmental awareness the amount of recycled waste is increased by 25% in comparison to option II,
- The separate collection of dry and wet waste is introduced in selected parts of town,
- The pay recycyling system operates unchanged including the recycling organizations,
- Organic waste is collected from green areas, open markets, community gardens, and individual homes districts,
- The collection system is based on bring principle.

RESULTS AND DISCUSSION

The White model presents the results of the analysis in the form of a table. The amount of information is very big, but does not give the clear answer about the ranking of the options. The economic cost of the analysed options presents Figure 5. The costs of different options are presented both as the total costs and also with the division on different stages of the disposal process. It is clear that making the system more complex increases the cost. The present system is significantly cheaper than the three others. The first stage of disposal – the collection is the most expensive. The cost of this stage is about 50% of the total cost.

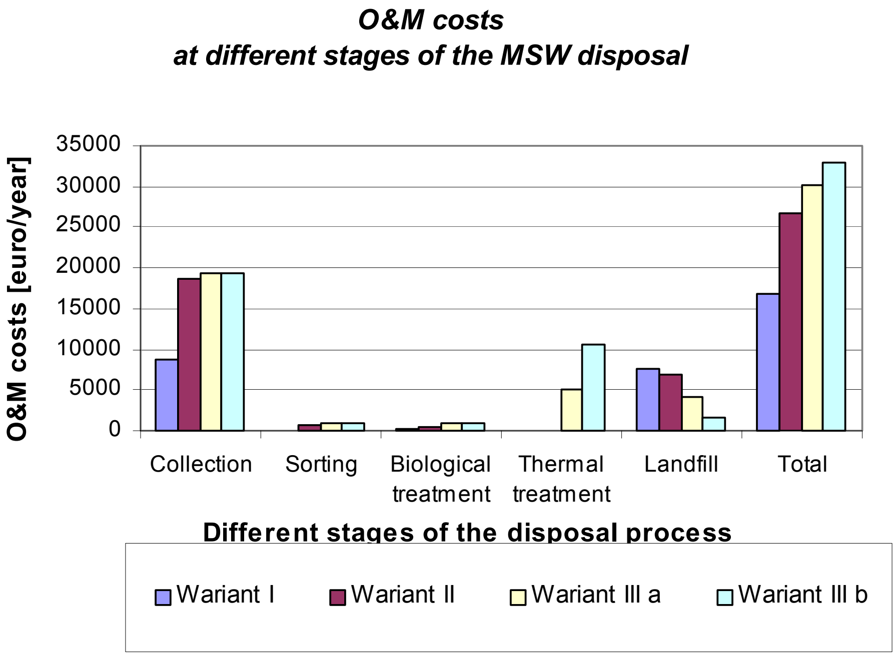

Figure 5. Economic costs of different options of the municipal solid waste disposal in Krakow.

Another factor of waste disposal is the waste stream. The goal is to reduce the stream the stream of finally landfilled waste. Introduction of the incinerator into the waste disposal system reduces the volume of landfilled waste. In option I the disposed waste steam was more than 223 000 tons in option IIIb (with the incinerator) the mass of waste is reduced to 48 000 tons. The introduction of the waste incineration results, on the one hand, in reduction of the waste stream, and on the other hand, with the increase of the hazardous waste stream. The increase of the hazardous waste stream is the consequence of the fact that fly ash from the incinerator has to be treated as such.

The emission of SO_x for different options of waste disposal has a typical distribution pattern for many particles. The landfilling of waste allows the recovery of landfill gas. The landfill gas can be used for generation of electricity and heat and can substitute the production of electricity from conventional sources. The model calculates this avoided emission and that is the reason why SO_x emission at the stage of landfilling is negative. Generally in this case, the introduction of the more complex system results with the higher emissions. Figure 6 presents the SO_x emission for different options of waste disposal.

Also in this case the waste collection is the most environmentally intensive stage of waste disposal.

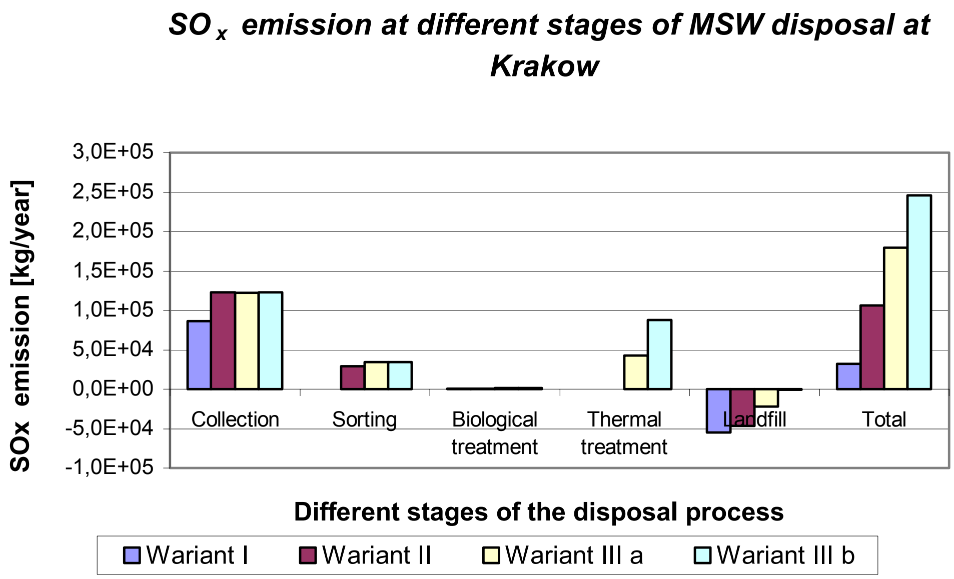

Figure 6. Emission of SOx for different options of waste disposal in Krakow [Kopacz, 2003].

Because the White model gives so much information there is a problem of its integration which will lead to simple optimisation procedure. According to the literature (EPA, 1995) there are 12 methods of characterising impact of man's activity on human health, ecosystems and/or natural resources. Not all methods can be used in all cases and some methods 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. 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 waste disposal.

The present Polish emission fees and calculations of the environmental impacts on air for three options of MSW disposal presents Figure 7. Total cost of emissions to air and water combined with the economic cost of disposal give more complex picture of the quality of the solutions and allows better analysis. The comparison of the three options which include the environmental and economic cost of disposal presents Figure 8.

	Option 1 present stage PLN	Option 2 sorting plant PLN	Option 3 incinerator PLN
economic cost	73 819 967 zł	119 036 549 zł	134 388 842 zł
cost of air emission	13 818 zł	- 31 660 zł	144 026 zł
cost of water emission	- 593 179 zł	- 1 146 153 zł	- 1 401 081 zł
Total cost of emission	- 579 361 zł	- 1 177 813 zł	- 1 257 055 zł
Total cost of MSW system	73 240 606 zł	117 858 737 zł	133 131 787 zł

Figure 7. Economic and environmental costs for different options of MSW disposal in Krakow

		Air emission by White model			cost of emission		
Name of compounds	fee [PLN/kg] (Dz.U.03.55.477)	Option 1 present stage kg	Option 2 sorting plant kg	Option 3 incinerator kg	Option 1 present stage PLN	Option 2 sorting plant PLN	Option 3 incinerator PLN
1	2	3	4	5	6	7	8
Particulates	0,43	-1,44E+05	-2,44E+05	-2,79E+05	-61 977	-104 776	-119 808
CO	0,105	1,57E+05	1,71E+05	1,79E+05	16 526	17 987	18 786
CO2	0,00021	6,92E+07	7,72E+07	1,40E+08	14 531	16 210	29 418
CH4	0,00021	9,51E+06	8,12E+06	3,98E+06	1 996	1 706	836
NOx	0,4	1,79E+05	2,11E+05	1,94E+05	71 413	84 405	77 407
N2O	0,4	-3,62E+03	-3,71E+03	-6,16E+03	-1 448	-1 483	-2 466
SOx	0,4	-8,81E+04	-1,02E+05	-6,28E+04	-35 225	-40 777	-25 123
HCl	0,94	2,31E+03	2,10E+03	2,53E+04	2 174	1 977	23 805
HF	0,94	5,08E+02	5,33E+02	1,00E+04	477	501	9 408
H2S	0,94	4,60E+03	3,71E+03	1,52E+03	4 329	3 487	1 428
HC	0,59	-7,56E+02	-2,24E+04	-1,28E+05	-442	-13 091	-75 024
Chlor. HC	0,94	1,01E+03	8,61E+02	1,00E+04	948	810	9 435
Dioxins/Furans (TEQ)	279,95	1,29E-05	1,10E-05	5,35E-05	0	0	0
Ammonia	0,32	-1,86E+02	-2,32E+02	-2,68E+02	-59	-74	-86
Arsenic	279,95	0,00E+00	0,00E+00	2,40E+02	0	0	67 294
Cadmium	139,97	1,36E-01	1,16E-01	4,81E+01	19	16	6 737
Chromium	39,99	1,60E-02	1,37E-02	6,06E+02	1	1	24 224
Copper		0,00E+00	0,00E+00	6,06E+02	0	0	0
Lead	32	1,75E+01	4,54E+01	6,63E+02	559	1 452	21 202
Mercury	139,97	-6,13E-02	-1,12E-01	4,79E+01	-9	-16	6 711
Nickel	279,95	0,00E+00	0,00E+00	2,40E+02	0	0	67 294
Zinc	4,2	1,82E+00	1,55E+00	6,07E+02	8	7	2 547
				Total cost Emission to air	13 818 zł	- 31 660 zł	144 026 zł

Figure 8. Calculation of the environmental impact of MSW at Krakow on air.

Generally, the environmental costs are negative. That means that benefits of avoided emissions obtained thanks to recycling and recovery is much higher than the cost of emission generated during the waste disposal (mainly collection). The cost of environmental impacts is insignificant in comparison with the economic cost. In other words, from the environmental point of view the present recycling level is far below its optimal value.

More advanced recycling and disposal systems (option III) can double the environmental benefits, but in total the advanced solution (option III) is twice as expensive as the present one. The model does not calculate the environmental impact on soil which can be very different depending on the used method of waste disposal. This impact is to some extend covered by the cost of landfilling, because the cost of leakage and landfill gas treatment is included in impacts on water and air.

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