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THE USE OF LIFE CYCLE ASSESSMENT IN THE INTEGRATED SOLID WASTE MANAGEMENT

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Abstract

The continuously increasing solid waste generation worldwide calls for management strategies that integrate concerns for environmental sustainability. Life Cycle Assessment (LCA) applied to sustainable waste management has rapidly expanded over the past few years as a tool that is able to capture and handle complexities and interdependencies typically characterizing modern integrated municipal solid waste management systems. By quantifying environmental impacts of systems, life cycle assessment (LCA) constitutes a useful tool. The objective of this study is to analyze the life cycle of energy output of different municipal solid waste treatment strategies for the city of Thessaloniki that are optimal for the society taking into account environmental and economic effects. The waste management methods include: landfill, recycling of paper and anaerobic digestion of food waste in a biological treatment plant.

Key Words: Integrated Solid Waste Management, Life Cycle Assessment

1. Introduction

During the past decades environmentally sound waste management was recognized by most countries as an issue of major concern. For this reason, a great emphasis was given to sustainability waste management options in EU policy. The hierarchy, which consists of Prevention/ Mitigation, Materials Recovery, Incineration and Landfill, was first introduced in the Waste Framework Directive [1-3] and constitutes a component of all relevant waste directives. At national level, the legal framework includes the Joint Ministerial Decision 50910/2727/2003 concerning the scheduling and permission status of the landfill sites selection [4] and the Joint Ministerial Decision 29407/3508/2002 defining mainly the technical specifications for the landfill construction and operation, as well as the environmental targets to be achieved [5]. In order to implement the aforementioned European requirements is of great importance the existence of a sustainable waste management approach that will propose effective environmental and economic solutions, decide on the combination of collection, processing and disposal systems that will best serve the present and future needs of a particular community.

Life Cycle Assessment in general, is a tool to quantify environmental burdens associated with products or activities throughout their life cycle, in other words "from cradle to grave" [6]. Life Cycle Assessment of integrated solid waste management systems aims at understanding and evaluating the magnitude and significance of the potential environmental impacts of a product system. Thanks to this, LCA is considered as a very useful and effective instrument for optimization and improvement both of products and processes [7-8]. As far as integrated solid waste management systems are concerned they incorporate all the policies, programs and technologies that are necessary to manage the waste streams. The mix and emphasis of approaches that are taken generally varies from region-to-region and depends on local conditions [9]. A number of studies have been published during the past decade, investigating the usefulness of LCA methodology in sustainable waste management [10-13]. The concept of Integrated Solid Waste Management (ISWM) can be defined in various ways, but generally it is considered as an optimized waste management system in which environmentally and economically best solution for each individual case is sought [14-15].

The objective of this study is to use the tool of Life Cycle Assessment, in order to analyze the environmental impacts caused by different waste management methods. Greece's electric energy system is taken into consideration so as to analyze the corresponding air emissions and non renewable recourses that arise from the use of electricity.

2. System Dimensioning

Thessaloniki is the second largest city in Greece located in the northern part of the country. The whole area is served by a sanitary landfill operated by the Association of Local Authorities of Greater Thessaloniki for the last 14 years.

The functional unit used in this treatment of municipal solid waste which is collected during one year in Thesssaloniki.

The fractions of municipal solid waste included in the study are the total amount of food waste, paper and plastic collected during the period of one year. The amounts of these waste fractions are based on 2004 data, whereas their average composition is based on 1998 data, since the change in time is insignificant. These three waste fractions account for 74% of the total waste produced in Thessaloniki and due to their physical and chemical properties, various treatment methods could be utilized to avoid the hazards they create [16].

3. Identification and Description of Municipal Solid Waste Treatment Strategies

The identification of municipal solid waste management treatment strategies is based on the differences of the waste flows (food, paper, plastic) as compared to the different waste management methods (landfill, recycling, anaerobic digestion in a plant). Short descriptions regarding the system under study are listed in Table 1. For each of these systems, a base scenario has been defined.

Waste treatment strategies	***Landfill***	***Recycling***	***Anaerobic digestion in a plant***
System 1	100% for all waste fractions	-	-
System 2	50%for food waste, 100% for plastic and paper	-	50% for food waste
System 3	70%for paper, 100% for plastics and food waste	30% for paper	-
System 4	50%for food waste, 70%for paper, 100% for plastics	30% paper	50% for food waste

Table 1. Overview of the systems studied regarding the flow of the different waste fractions across the different waste treatment methods.

Table 2 summarizes the scenarios studied regarding biogas collection- utilization, leachate collection, avoided systems and impact categories.

	Scenario A	***Scenario B***	***Scenario C***	***Scenario "land use"***	***Basic scenario***	***Scenario "natural gas"***	***Scenario "biocells"***
Biogas collection from landfill site:	0%	50%	50%	50%	50%	50%	65%
Biogas from landfill site utilized as electricity:	0%	0%	30% of collected	30% of collected	30% of collected	30% of collected	30% of collected
Leachate collection from landfill site	0%	80%	80%	80%	80%	80%	90%
Heat recovery from landfill biogas replaces:	No heat recovery	No heat recovery	No heat recovery	Heat from oil	Heat from oil	Heat from natural gas	Heat from oil
Land use at landfill site impact category:	No	No	No	Yes	No	No	No
Biogas from anaerobic digestion plant utilized as electricity	30%	30%	30%	30%	30%	30%	30%
Heat recovery from anaerobic digestion plant replaces:	Heat from oil	Heat from oil	No heat recovery	Heat from oil	Heat from oil	Heat from natural gas	Heat from oil
Biogas utilized as heat: (both landfill site and plant)	60%	60%	No heat recovery	60%	60%	60%	60%

Table 2. Overview of the scenarios studied regarding biogas collection - utilization, leachate collection, avoided systems and impact categories included.

4. Environmental Impact Assessment – Results

The Eco-indicator method 99 [17] was used in order to quantify potential impacts from each one of the studied systems and the sensitivity analysis scenarios concerning these. Besides total energy use the following impact categories have been considered: global warming (GW), the combined effect of eutrophication/ acidification (EA) and human toxicology (HT).

The weighed damage factors and the mass balance of the emissions of each system as well as the sensitivity analysis scenario are used, in order to determine the corresponding potential contribution across the different impact categories. The impact assessment calculations were performed using SIMA PRO 5 [18]. The program includes the following data bases: BUWAL 250, [19], IDEMAT database [17] as well as PRE 4 database. All the results are presented per total amount of food, paper and plastic waste, in order to fulfill the functional unit. The comparison of the total energy use for each one of the four systems is shown in Figure 1. The bars stand for the average value of the sensitivity analysis scenarios of each system. System 1 uses the lowest amount of energy. The contribution to global warming for each one of the four systems (Figure 2) indicates that system 4 has the best performance. In addition, based on the findings of Figures 3 through 5, system 4 has the best performance at the following impact categories: combined eutrophication/acidification, contribution to the human toxicology as well as total environmental impacts.

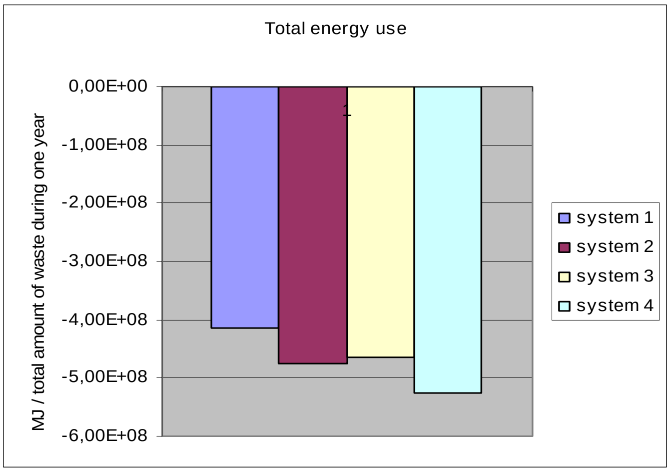

Figure 1: Total energy use for each one of the four systems. The bars represent the average value of the sensitivity analysis scenarios of each system

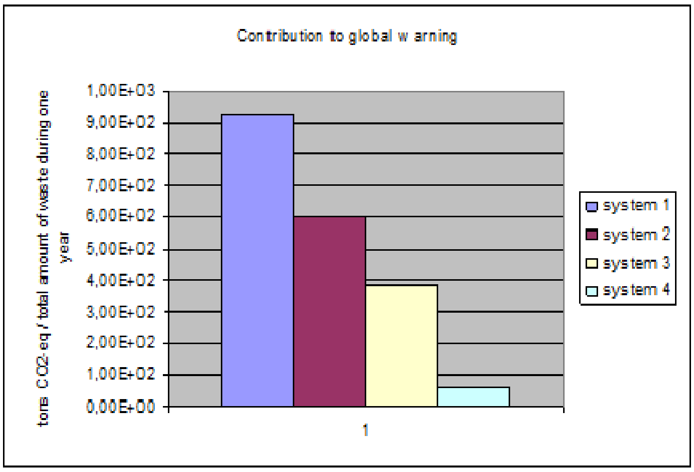

Figure 2: Contribution to global warning for each one of the four systems. The bars represent the average value of the sensitivity analysis scenarios of each system

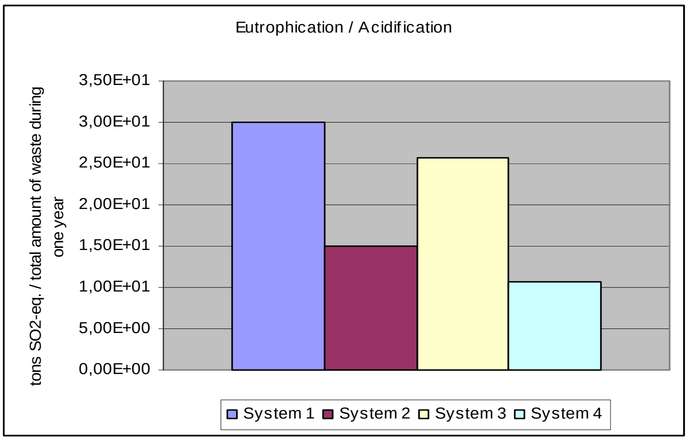

Figure 3: Contribution to the combined eutrophication/acidification impact category for each one of the four systems. The bars represent the average value of the sensitivity analysis scenarios of each system.

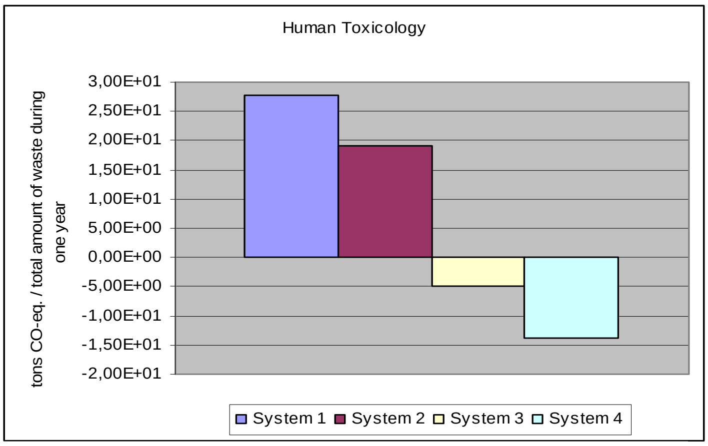

Figure 4: Contribution to the human toxicology impact category for each one of the four systems. The bars represent the average value of the sensitivity analysis scenarios of each system.

Based on the findings of Figure 5, it is obvious the significant decrease of environmental impacts when the solid waste management methods include some kind of recovery from waste. It is well known that paper recycling and anaerobic digestion of food waste is preferable compared to landfilling and this was clearly illustrated on the results of the present study [20].

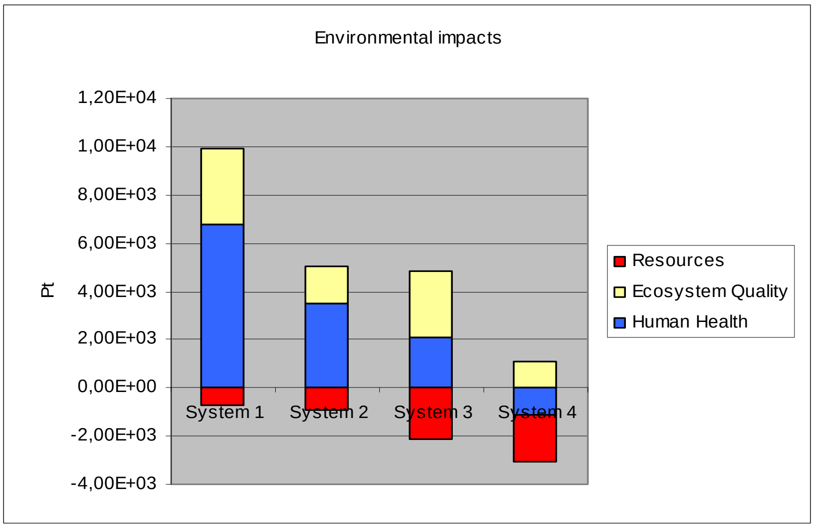

Figure 5: Total Environmental Impacts for each one of the four systems. The bars represent the average value of the sensitivity analysis scenarios of each system. (Method eco-indicator 99, total weighted results, single score)

Despite the fact that landfilling food waste according to the biocells method may be more attractive than anaerobic digestion in a plant, costs are much less and energy recovery is about 45% less. Taken into consideration the above analysis, it is obvious that a new environmental policy is needed so that planning for solid waste management should be performed aiming at achieving the desirable sustainable development. Policies focusing on energy and material recovery from solid waste, as shown on Figures 1 through 5 not only leads to a significant decrease of greenhouse gases, but also has significant environmental benefits (e.g. use of fossil fuels, ecosystem quality). Nevertheless it should be pointed out that the results are sensitive considering the assumptions made about the origin of the energy that is replaced from biogas utilization.

5. Discussion

Detailed applications of LCA to integrated waste management systems are complex and the subsequent analysis necessarily reflects this complexity. Developing waste management strategies is a challenging task which encompasses several aspects**.** LCA can be considered as a useful tool for assessment of the environmental impacts of products, processes or services from raw materials to waste.

According to the main assumptions made in this work, electricity production is based on lignite and this remains constant in all scenarios since lignite is the primary energy carrier in Greece. For this reason, electricity production from biogas (that accounts for the 30% of energy recovery from biogas) is assumed to replace part of the electricity based on lignite. On the other hand, heat production from biogas (60% of the total amount of energy recovery from biogas) in scenarios A, B, “biocells” and “basic”, replaces thermal energy from oil. In the scenario of “natural gas” it replaces thermal energy from natural gas and in scenario C it replaces no thermal energy at all. When heat from natural gas (instead heat from oil) is replaced by heat coming from biogas, a small increase in the impact categories of human health and ecosystem quality is noticed, while the impact category of non renewable resources is positively influenced. In scenario C where no heat from biogas is utilized, it does not seem to effect significantly the results except for systems 2 and 4 where an anaerobic digestion plant is present leading to increased heat energy recovery (even though the difference is too small).

Parameters regarding the landfill site seem to have a significant effect on the overall results. Another very important issue is the fact that the environmental impacts of all systems under study are maximized in the case of uncontrolled waste disposal site (no biogas and leachate control). There is no point (at least though an environmental perspective) in investing money on recycling programs and anaerobic digestion plants while large amounts of waste are disposed at uncontrolled landfill sites. Although parameters regarding biogas and leachate treatment have a considerable effect on the results, the inclusion of land use as an impact category only gave an insignificant increase of 6-16% (depending on the system) on ecosystem quality impact category.

When discussing solid waste management strategies it would be interesting to see how the inclusion of other electricity sources (e.g. from renewable sources instead of lignite based power plants) would affect the results. Additionally, a more detailed study could contain some other relevant waste treatment methods like incineration, composting, recycling of plastic and aluminum and of course the process of waste collection and transfer. That would give a holistic approach to the problem of municipal solid waste management.

It is interesting to note that the presented application of LCA should be taken into consideration along with the objectives of an Integrated Solid Waste Management Plan. As far as Greece is concerned, the objectives of an Integrated Solid Waste Management Plan include actions such as the selective collection at source and recycling of municipal wastes, the creation of modern, sanitary landfills, equipped with sorting and recycling plants, the construction of suitable transfer station networks, the pause in operation of uncontrolled dumps, followed by rehabilitation projects, the development of an integrated public communication strategy, in the context of the common effort for tackling the waste management problem [21].

6. References

1. European Commission 1975: “Council Directive 75/442/EEC of 15 July 1975 on waste”, Official Journal, L 194 25 July 1975, 39-41

2. European Commission 1989: “Communication to the Council and to the European Parliament of 18 September 1989 on a Community strategy for waste management”. Approved by Council 7 May 1990; Approved by Parliament 19 February 1991. Official Journal, C 122, 18 May 1990

3. European Commission 1991: “Council Directive 91/156/EEC of 18 March 1991 amending Directive 75/442/EEC on waste”. Official Journal, L 078, 26 March 1991, 32-37

4. Joint Ministerial Decision 50910/2727/2003, Measures and terms for the handling of solid waste, national and regional planning (in Greek)

5. Joint Ministerial Decision 29407/3508/2002, Measures and terms on the landfill of waste (in Greek)

6. Kasai, J., 1999, "Life Cycle Assessment, Evaluation method for sustainable development", JSAE Review, 20, 387-393

7. Huybrechts, D., Berloznik, R., Wouters, G., Marion, J.-Y., Valenduc, G. and Vendarim, P., 1996, "The role of ecobalances in environmental decision-making", Journal of Cleaner Production, 4, 111-119

8. Ciambrone, D.F., 1997, "Environmental Life Cycle Analysis", CRC Press

9. UNEP, 2005 "Integrated Waste Management Scoreboard -A tool to measure performance in municipal solid waste management", United Nations Environment Programme.

10. Göran Finnveden , Ann-Christine Albertsson, Jaak Berendson, Erik Eriksson, Lars Olof Höglund, Sigbritt Karlsson, Jan-Olov Sundqvist**, "**Solid waste treatment within the framework of life-cycle assessment", Journal of Cleaner Production, Volume 3, Issue 4, 1995, Pages 189-199

11. Liamsanguan, C., Gheewala, S.H., "The holistic impact of integrated solid waste management on greenhouse gas emissions in Phuket", Journal of Cleaner Production, Volume 20, Issue 1, January 2012, Pages 1-13.

12. Å. Moberg, G. Finnveden, "*Life cycle assessment* of energy from solid waste—*part 2*: *landfilling compared* to *other treatment methods", *Volume 13, Issue 3, February 2005, Pages 231-240.

13. Reich, M.C., " Economic assessment of municipal waste management systems—case studies using a combination of life cycle assessment (LCA) and life cycle costing (LCC)", Journal of Cleaner Production, Volume 13, Issue 3, February 2005, Pages 253-263

14. Sundqvist, J.-O., 1999, "*Life Cycle Assessments and Solid waste. Guidelines for Solid Waste Treatment and Disposal in LCA*", Final Report 279, 1-133, IVL, Swedish Environmental Research Institute, AFR-Report, Stockholm, Sweden.

15. McDougall FR, Hruska JP, 2000, "The Use of Life Cycle Inventory Tools to Support an Integrated Approach to Solid Waste Management", Waste Management & Resources, 18 (6): 590-594

16. Papachristou E., Darakas E., Bellou A., Ioannidou D., Alivanis K., Petridis G., Savvides J., 2002, " Qualitative and Quantitative Analysis of Municipal Solid Waste in Thessaloniki", Division of Hydraulics and Environmental

Engineering, Aristotle University of Thessaloniki, Association of Local Authorities of Greater Thessaloniki

17. Product Ecology Consultants, Mark Goedkoop, Renilde Spsiensma ,2000, "The Eco-indicator 99 – A damage oriented method for Life Cycle Impact Assessment Methodology report"

18. SIMA PRO 5: **www.pre.nl/ simapro**

19. BUWAL Ecopoints –LCA Methods, 1998, Swiss Federal Office of Environment, Forest and Landscape

20. Eriksson, O., Carlsson Reich, M., Frostell, B., Björklund, A., Assefa, G., Sundqvist J-O, Granath J., Baky, A., Thyselius, L., 2005, "Municipal Solid Waste Management from a Systems Perspective", Journal of Cleaner Production, Vol. 13, Issue 3, P. 241-252

21. P. Varelidis, A. Skordilis, 2001, "Integrated Solid Waste Management in Greece" Ministry of Environment, Physical Planning & Public Works