ENVIRONMENTAL LIFE CYCLE ASSESSMENT AND MUNCIPAL SOLID WASTE MANAGEMENT

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Keywords: Life Cycle Assessment, systems approach, municipal solid waste, environment, planning, greenhouse effect, information technology.

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Summary

Systems approaches such as Life Cycle Assessment play an increasing role in the management of municipal solid waste. LCA represents the state of the art means to estimate the environmental impacts involved with systems of human activities. In addition to contributing to the understanding of environmental issues associated with MSW, LCA is also related to the creation of computer-based simulations of MSW systems that assist in optimizing environmental and economic performance. Such design tools are being developed in the private and public sectors and are increasingly applied in municipal planning.

1. Introduction

The management of municipal solid waste is a significant issue with respect to global and local environments as well as the prosperity of communities. In response to demands for improvements in environmental and economic performance, waste management systems are becoming increasingly complex, both in the technological sophistication of each component and in their organization to form a system. There are many questions that arise with respect to implementing solid waste management systems: What are the real environmental and economic implications of the different available options? What governmental policies are appropriate to minimize environmental impacts? Given the panoply of options, how do communities design an economically feasible and environmentally friendly system appropriate for local conditions? These are complex questions that cut across many issues and disciplines, and thus have no unitary answer. However, Life Cycle Assessment and similar systems approaches of analysis have a substantial role to play in addressing such issues, and that role continues to grow in importance.

2. Environmental and Economic Relevance of MSW Systems

The first step will be to make a case for the environmental and economic relevance of municipal solid waste by overviewing the scope of the issue. In 1994, the total amount of MSW generated in OECD countries was estimated at 484 million metric tons, representing a per capita generation of 510 kg. That the yearly per capita generation of MSW in OECD countries is 7-8 times the mass of a single person is indicative of the huge overhead of materials and energy associated with the current industrial societies. This is compounded by the fact that MSW figures represent only a portion of the total lifestyle overhead, as they generally do not include waste generated by agriculture and industry. The developing world generally has lower generation rates; for example, 180 kg/year/capita is typical of African and Central American countries. These waste figures tend to increase along with industrial development. Assuming a per capita generation of 150 kg/person/year outside of OECD countries, an estimate of the world total MSW is 1.2 billion metric tons per annum.

To get an idea of the economic scale of municipal solid waste activities, note that the costs of managing MSW in the USA range from about US$30 per ton to US$60 per ton, with the lower end being typical for landfills and the higher end representative for waste-to-energy incineration plants. This results in a total expenditure of around US$60 billion per year. To put this figure in perspective with municipal budgets, note that from the New York City yearly 1998 budget of US$35.6 billion, US$754 million was spent on MSW management operation costs, constituting around 2% of yearly expenditures. While this figure is apparently typical, if on the low side, for North American cities, in many developing countries MSW management accounts for a much larger share of municipal budgets. In India, for instance, solid waste services account for around 20% of the total budget, while in Indonesia the figure is 50%. A possible explanation for this large difference in share is that communities in the developing world often have smaller budgets with which to handle an issue of similar economic dimension. Collection is the largest cost element in most MSW management systems, accounting for 60-70% of costs in industrialized countries, and 70-90% of costs in developing and transition countries.

In discussing the environmental implications of a given activity, it is useful to distinguish between *emissions* and *resource-use* aspects. Emissions aspects deal with the effects that an activity has on the environment, such as damage to human health and ecosystems. Progress towards a better environment with respect to emissions aspects represents, for instance, reduced emissions of substances that negatively affect human society and eco-systems. Resource-use aspects deal with how the activity is related to overall "metabolism" of the society it is embedded in, in the context of the long-term sustainability of the system. Environmental progress for resource use represents improved utilization of resources, learning how to deliver similar services using less materials and energy. The sheer magnitude of solid waste indicates that the environmental relevance with respect to resource-use is certainly very significant, and it will become clear from the discussion below that emissions aspects are also important. The environmental implications of MSW systems will be discussed for the main means being implemented to handle wastes, namely landfills, recycling, and incineration.

2.1. Landfills

Worldwide, landfills remain the most implemented option for the management of solid waste. In the OECD, 56% of MSW was estimated to go to landfills, and, as landfill use tends to be even more prevalent in non-OECD countries, the worldwide percentage is no doubt larger. Landfills generally remain the simplest and most inexpensive of waste management options, although, in countries such as Japan, restrictions on land space increase the attractiveness of incineration and recycling.

Regarding the emissions aspects of the environmental impacts of landfills, the two central concerns are the leakage of harmful leachates and emissions of greenhouse gases. Leachate is mostly rainwater that, while filtering through the landfill, picks up contaminants along the way, and often has high concentrations of toxic substances. If this liquid escapes the landfill and enters local groundwater sources, contamination is possible. For example, 1990 monitoring of water quality in New York's Jamaica Bay revealed lead and nickel levels of 100 times the state standard, believed to be due to leakage of leachate from two nearby landfills. These environmental risks of contamination are sufficiently high that its avoidance is a central design issue for modern landfills. With respect to global warming, emission of methane and other gases from landfills represents a significant anthropogenic contribution to greenhouse gas emissions. Methane is formed in a landfill due to the action of anaerobic bacteria digesting organic components of waste, with 286 MTCE of methane typically generated per wet ton of mixed MSW. This represents around 9% of global anthropogenic emissions of methane. For countries such as the United States, who rely heavily on landfills for waste management and with a high waste/capita generation, the landfill emission of methane is particularly relevant. For the period 1990 to 1996, landfills represented 37% of US methane emissions, or roughly 3.6% of total US GHG emissions.

To address these emissions issues, modern sanitary landfills have evolved considerably from the original "open dump", as used by civilizations for centuries. Well-planned landfills are carefully sited in locations well above local water table. The bottom of the landfill is lined with plastics and absorbing material to prevent leakage, and leachate extraction and treatment equipment is installed. The methane emissions can be mitigated through collection of the gas at the landfill, which can be combusted on site or collected to be used as fuel.

In terms of resource-use environmental impacts, landfilling involves the least investment of resources to implement compared to other means, but offers almost no return on this investment, with insignificant material or energy recovery.

2.2. Recycling

Recycling involves the conversion and reuse of waste materials, and post-consumer systems for recycling many metals, paper, and many plastics have been implemented worldwide. Recycling rates vary considerably depending on the material and location; paper recycling rates typically range from 10 to 50%, with a world average of 30%. In 1988, 30% of aluminum was recycled worldwide.

The environmental implications of recycling depend very much on the substance being recycled and for what purpose. For a meaningful interpretation of the environmental impacts, a given recycling technology needs to be compared with those which yield a similar product made from virgin materials. It is often but by no means universally the case that making a product from recycled materials involves fewer environmental emissions than production from virgin resources. A very clear-cut example of a case where recycling is good for the environment is that of aluminum, where the energy and process requirements are so much lower than for virgin metal that the economic as well as the environmental argument in favor of recycling is strong. It is evident that recycling for many materials becomes a large-scale enterprise, and, as such, has considerable environmental impacts that need to be minimized, as with any industrial activity.

With respect to resource-utilization aspects, recycling represents substantial opportunities for increasing the utilization of materials and thus reducing the need for virgin inputs. However, in framing the relevant questions for recycling, it is important to go beyond asking, “Is this material being recycled?” to progress to the more complex one, “Is this material being recycled for the maximum return on investment?” Investment here is meant not only in the economic sense, but also in terms of the materials and energy used to carry out the recycling process.

2.3. Incineration

Incineration is the combustion of waste materials, either with or without co-generation of energy. Incineration is never complete, resulting in some non-combustible slag and/or ash, but weight is reduced by up to 75% and volume by up to 90%. The leftover ash is then transported to landfills, often especially designed to handle incinerator waste. The reduction in volume and weight is a major impetus driving the implementation of incineration, as far less landfill space is required. In 1992, roughly 23% of MSW was incinerated in OECD countries.

The main environmental concerns regarding incineration are regarding emissions of harmful substances into the air and the fate of toxic substances remaining in the ash. The emission of dioxins formed in the incineration process is one of the major concerns regarding air emissions from incinerators. Ash landfills, as with usual landfills, have the potential to contaminate groundwater through the leakage of leachate. To deal with air emission problems, modern incinerators are designed to burn waste at a sufficiently high temperature (above 900 ^{o}C) to prevent the formation of dioxins and other toxics. They are also installed with end-of-pipe pollution control devices. Though some argue that such modern incinerators do not emit significant amounts of harmful substances, the public debate continues and incinerators remain politically contentious, with local communities often vehemently opposing construction of incinerators.

Regarding resource use, it is possible to extract energy from municipal waste through utilizing released heat to generate electricity. Such practice can replace a certain amount of energy generated via conventional fossil fuel plants. To the extent that the waste stream is composed of natural organics, this represents generation of energy from renewable materials. A ton of typical MSW yields around 525 kWh of electricity (plus or minus 75 kWh), enough to supply about 10 homes for one month. However, the apparatus and running costs for incinerators is expensive, representing a significant investment with respect to the energy recovered. As with landfills, there is no significant recovery of materials.

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Biographical Sketch

Eric Williams is Project Coordinator at the Institute of Advanced Studies, United Nations University in Tokyo. He completed a Ph.D. in theoretical physics at the State University of New York at Stony Brook in 1993 and subsequently did postdoctoral research at the University of Minnesota and the University of Tokyo. From 1997, he began working in the environmental field at United Nations University in Tokyo, focusing on life cycle assessment and industrial ecology. His main research interest in recent years has been environmental assessment and management of the Information Technology revolution.