Improving Solid Waste Management in Gulf Co-operation Council States: Developing Integrated Plans to Achieve Reduction in Greenhouse Gases

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Abstract

Landfills are a significant source of greenhouse gases, which contribute to the process of global warming. In the region covered by the Gulf Co-operation Council (GCC), changes in consumption patterns have led to an excessive dump of municipal solid waste (MSW). Thus, it is clearly an important time to re-evaluate conventional waste management protocols in order to establish methods that not only deal with increased demand but also minimize greenhouse gas emissions and improve efficiency of resource management, in general. Here, I advocate the use of a new hierarchy in integrated municipal solid waste schemes, with the aim of designing more eco-friendly management plans for use in GCC states.

Keywords: Municipal solid waste, Global warming, Greenhouse gases, Gulf Co-operation Council

1. Introduction

Global warming is driven by increase in greenhouse gases (GHGs)—predominantly water vapour, nitrous oxide, carbon dioxide (CO_2), and methane (CH_4)—in the Earth's atmosphere. This has led to major environmental changes worldwide, including (1) rising sea levels that may flood coastal and river delta communities; (2) shrinking mountain glaciers and reduced snow cover that may diminish freshwater resources; (3) the spread of infectious diseases and increased heat-related mortality; (4) possible loss of biological diversity and other impacts on ecosystems; and (5) agricultural shifts that may impact crop yields and productivity (McCarthy, et al., 2001). Current projections suggest that the rate of climate change attributable to GHGs will exceed any natural climate changes that occurred from 1900 to 2010 (Chen, & Lin, 2008; Liamsanguan, & Gheewala, 2007).

One major source of GHGs is landfills, which account for 3.4–3.9% of total annual GHG emissions worldwide (Figure 1) (Chen, & Lin, 2008; Baumert, et al., 2003; Forbes, et al., 2001). This is because large quantities of carbon dioxide and methane are produced by decomposition of the organic fraction of solid wastes in landfills. Methane is particularly problematic, because it has 21 times the global warming potential of carbon dioxide, and according to the Intergovernmental Panel on Climate Change, methane emissions from landfills account for 18% of all methane added to the atmosphere each year, ranging from 9 to 70 Tg (megatonnes) annually. In fact, landfills are the largest source of atmospheric methane in the world (Hansen, et al., 2005b). Thus, in order to reduce GHG emissions, it will be essential to reform solid waste management practices so that solid waste can be used as a resource for generation of new useful products or can be recycled (Forbes, et al., 2001).

In 2010, the Gulf countries generated in excess of 22.2 million tonnes of municipal waste and approximately 4.6 million tonnes of industrial solid waste. Today, many of the Gulf Co-operation Council (GCC) countries (the Kingdom of Bahrain, State of Kuwait, Sultanate of Oman, State of Qatar, Kingdom of Saudi Arabia, and United Arab Emirates) rank higher than developed countries in terms of per capita waste generation. However, GCC countries have also been active in symposia, conferences, and initiatives aimed at combating global warming. These states are in a unique position to enhance their public images by leading the global charge to reduce GHG emissions.

Current models of waste management assume that waste already exists and needs to be managed. In other words, waste management is simply a reaction to the presence of something that needs to be eliminated (Figure 2). However, resource efficiency and sustainable waste management are maximized by preventing the accumulation

of waste. Thus, the current definition of waste may become a barrier to an efficient and sustainable waste management system, as it impacts decisions related to the transport, reuse, and sale of materials.

A waste management hierarchy has been developed for use by governments, industry, educators, and environment groups as they make decisions about waste policies and programmes (Table 1). The conventional waste management hierarchy includes 5 stages: (1) reduce (source reduction, using recycled products, and controlling the material to reduce final waste), (2) re-use, (3) recycle, (4) incinerate (energy recovery), and (5) safe transport of remaining waste to landfills (AlAnsari M., 2008; Forbes, et al., 2001). An optimal approach to waste management would be an integrative plan that provides control over processes that generate waste, waste handling, and waste utilization. This more integrated, whole-system approach would enable managers to minimize waste generation from the beginning (Intergovernmental Panel on Climate Change, 2007; Gentil, et al., 2009), a goal that has been pursued by industrial scientists and developers over the past decade. Since good waste management reflects good management in general, the amount of waste minimization can be used as an indicator by financial institutions looking to identify companies that are unlikely to face costs associated with environmental liability (Forbes, et al., 2001; European Commission: Sustainable Development Task Force, 2001; Honkasalo, 1998). Waste policies can significantly influence product characteristics, leading to less waste generation (Figure 3). Thus, some policies have advocated reducing waste and thus reducing pollution and increasing resource efficiency by changing products. However, the changes in products may be defined by contradictory policy objectives. For instance, recycling costs are cheaper when glass packaging is used instead of plastic packaging for beverages; however, this substitution increases packaging weight. To tackle these possible contradictions, waste policies will need to establish an unambiguous hierarchy of different objectives. This includes changes in product design or characteristics leading to at least one of the following three consequences: first, that start with the reduction in the quantity of waste generated by consumption; second, reduction of toxicity of generated waste; and third, facilitation of recycling or re-use (Intergovernmental Panel on Climate Change, 2007; Gentil, et al., 2009; Seadon, 2006).

Although it is preferable to avoid the creation of waste altogether, alternative management tactics include re-use of materials, recycling, thermal treatment with energy recovery, thermal treatment without energy recovery, and landfilling. Unfortunately, the waste management hierarchy has a poor scientific and/or technical basis. For instance, it is always preferable to recycle materials rather than attempt energy recovery, and its utility is greatly improved when a combination of the aforementioned options is used. Thus, it is important to conduct an assessment of the whole system, by considering not only different waste management techniques but also costs (in order to determine the economic affordability of different waste systems) and the wide variety of specific local situations in which the waste management systems must operate effectively.

As applied to manufacturing, the Zero Waste concept involves the design and implementation of industrial processes and products that are beneficial to the environment but are also competitive in the market. To achieve sustainable development, it will be necessary to make fundamental changes in production and consumption patterns and to make these changes in all developed and developing countries. This will have social, economic, and environmental benefits (USEPA, 2005a; Vesilund, 2002; ACT NOWaste, 2005)

2. Brief Overview of Solid Waste Management

Solid waste profiles vary spatially and are dependent on diverse variables, including urbanization, commercial enterprises, manufacturing, and service sector activities. Likewise, attitudes about waste management practices also vary. This is often referred to as the *waste management ethic* and includes feelings towards *recycling* and *littering*. The diversity of practices and opinions has made it difficult to develop a single approach to implement waste management practice worldwide (Gentil, 2009).

Despite these differences, there are some recurring waste management issues in many communities. For instance, one common problem is the increased availability of single-use packaging and disposable items, which add to the quantity of waste produced. The most common method of disposal is licensed landfilling. However, landfills only provide a short-term solution to waste management, as additional plans must be made to manage old, abandoned, and often hazardous dumps. Thus, a variety of innovative strategies are required to deal with the waste we produce today to prevent it from causing problems for future generations (Seadon, 2006).

3. Current Climate of SWM in GCC Countries

Because of fast-paced industrial growth, recent booms in construction, increasing population sizes, rapid urbanisation, and lifestyle improvements, GCC countries have some of the highest per capita waste generation rates worldwide. GCC countries implemented a uniform waste management system and a monitoring mechanism for waste production, collection, sorting, treatment, and disposal in December 1997. Most of the waste

management regulations and strategies adopted are based on the universally accepted scientific approach enumerated in the Integrated Waste Management Hierarchy. Although most of the MSW produced in these countries is largely decomposable and recyclable, most waste is disposed in landfills. This is not likely to be sustainable over the long term, as preliminary estimates put the total volume of solid waste generated in the GCC region at ~120 million tons/year. A huge proportion of this is expected to be waste generated from construction and demolition activities; municipal waste is the second largest source of waste (Grant, et al., 2003).

Increased population density and land scarcity are not as problematic in the GCC states as in other industrialised, developed countries around the world. Thus, the dominant method of waste disposal in GCC countries is landfilling (Table 2), and all landfill sites in the GCC region are governmental premises. Although some of the GCC countries have targeted recycling as the main concern in their solid waste management strategies, the landfill and availability of land, usually old quarries, became an impediment to recycling programs. The only comprehensive form of recycling available within the GCC member states is for paper and cartons. Unlike the European Union, which has planned to meet a recycling goal of 1.7 million tonnes per year, the majority of the GCC states have never set national or regional recycling targets. This is likely to be particularly problematic in countries such as Kuwait and Bahrain, where land is limited. Throughout the region, but particularly in these areas, it is important to encourage not only recycling but also composting and incineration. Moreover, for this region, it is also essential to develop more waste management infrastructure to handle the increased amount of waste generated annually (Gautam, 2009; Grant, et al., 2003).

Table 2 lists waste management land requirements calculated per country, both with and without the presence of a recycling policy. If recycling rates are 19% and land is worth US$ 661 per m^2, recycling efforts could save over US$ 478 million annually. Many researchers suggest that these savings could be used for the research and development studies on recycling.

4. Developing Sustainable Solid Waste Management Plans for GCC Countries

'Waste' includes both products that have reached the end of their shelf life and by products of processes such as manufacturing, commercial use, and construction. These waste products will also be associated with materials that were used to process and transport the product throughout its life cycle. Cumulatively, all these materials are known as the 'ecological rucksack' or 'ecological footprint' (Moisio, et al., 2008; UNESCO, 2008). Additionally, each product 'embodies' other ecological impacts made during its manufacturing, such as land degradation, use of materials and energy, and air and water emissions (Forbes, et al., 2001; Snow, 2003; Hawken, 1999). Typically, MSW materials in GCC states have been produced through many steps, starting with extraction and processing of raw materials; manufacture or processing of products; transportation of materials and products to markets or agents; and finally, use and disposal by consumers (AlAnsari M., 2008).

Even waste management itself has environmental impacts, such as air emissions from garbage and recycling trucks collecting wastes and water used in reprocessing. It also has social and economic impacts. Thus, it is important to consider the 'embodied environmental value' (EEV) when relating sustainability and waste, and to evaluate the broader impacts of each waste management option (including not just actual impacts but also those that might be avoided) when developing a 'waste hierarchy.' It may also be useful to consider the concept of 'biomimicry,' which examines ways in which nothing is wasted in nature, wherein the waste from one process becomes the raw material for another in continuous closed cycles. In human terms, this can be achieved through recycling and composting. Cumulatively, these considerations will promote an organisational and technical shift from a hierarchy dominated by resource recovery to a hierarchy emphasising prevention and avoidance.

The new waste hierarchy should aim to achieve several goals:

1. Avoid or reduce generation of waste; 'do more with less' and/or improve resource use efficiency by using closed cycles that maximise the value of materials (in both environmental and socioeconomic terms).

2. In recovery efforts, attempt to maximise EEV; engage in energy recovery only when materials have no higher end use than to be converted to energy; where possible, eliminate this practice altogether.

3. When selecting recovery options, consider not only the impacts on waste, but also those on socioeconomics, sustainability, and environmental health (e.g., whether the technology generates greenhouse gases, requires water consumption, produces waterborne wastes, etc.) (Gautam, 2009; Grant, et al., 2003; Lewis, et al., 2010).

Cultural and socioeconomic practices are likely to cause challenges for the GCC waste management sector, but this offers unique and exciting opportunities for a variety of private players to use their technical knowledge and experience to make significant contributions for solving waste management problems (UNESCO, 2008; Gautam,

2009). For instance, planning authorities have recently awarded a number of contracts to the private sector for setting up and operating integrated waste management facilities (which will be discussed in more detail below) and waste recycling units (Grant, et al., 2003). However, opportunities in the sector are still largely unexploited. Future efforts should be focused on addressing lack of proper practice and strength of waste collection, transportation, and handling infrastructure.

5. Integrated Solid Waste Management in GCC Countries

A vital component of future efforts will be integrated solid waste management (ISWM) schemes, which seek to manage municipal solid waste using all available means (e.g., disposal in a landfill; incineration; recycling; composting; mulching; and, where relevant, hazardous waste disposal). In these schemes, reduction, reuse, and recycling take priority over using landfills, with the ultimate goal of protecting both human health and the environment. ISWM plans incorporate several different approaches for handling the entire MSW stream. Therefore, they are easily adaptable and can be altered over time or to meet specific social, economic, environmental, or geographic requirements. In order for these plans to be holistic, they should include inputs from both the local government and relevant stakeholders (e.g., landfill operators). This will help accomplish the target of reducing MSW generation worldwide by 1% annually, as well as promoting environmental sustainability in general (Finnveden, & Moberg, 2005; Gamble, & Every, 2002; Hawken, 1999).

The following are the major techniques that can be utilized in ISWM plans:

5.1 Recycling

Recycling reduces energy-related CO_2 emissions in the manufacturing process (although not as dramatically as source reduction) and avoids emissions from waste management. Paper recycling increases the sequestration of forest carbon (Forbes, et al., 2001). However, recycling and composting are more than just separation and collection of post consumer materials. The materials must be processed and reused in order to have a beneficial effect on reducing the waste stream (Hansen, et al., 2005b; Smith, 2001). For instance, recovered products can be used in the production of metals and energy.

In the conventional management hierarchy, recovery of materials via recycling and composting means that waste materials are processed industrially and then reformed into new or similar products. This method can be used for preconsumer waste, such as factory cuttings or shavings, as well as post-consumer waste items, including cardboard, newspapers, plastic bottles, and aluminium cans. Although recycling is often viewed as a resource conservation activity, it may facilitate higher energy savings for many products.

5.2 Composting

Composting is a management option for food discards and yard trimmings. Because composting avoids CH_4 emissions, GHG emissions are lower when food discards are composted than when they are landfilled. However, emissions are higher for yard trimmings when they are composted, as landfilling permits only incomplete decomposition and therefore results in carbon storage. Composting and combustion of these materials result in a similar emission of GHG (Liamsanguan, & Gheewala, 2007).

In the conventional hierarchy, composting is used to reduce the quantity of MSW to be incinerated or landfilled by separately treating the organic fraction of MSW. However, there is no definite approach to calculate CO_2 emitted from composted items. Diverting organic materials from landfills also reduces CH_4 emissions (AlAnsari M., 2008; Kolln, & Prakash, 2002). Composting has become an increasingly utilised alternative for MSW treatment in GCC countries, despite the unfortunate failure of a large number of composting plants in the region since 1990's. These have been hindered by low performance, high operation and maintenance costs, and poor management—issues that will need to be addressed to make composting more viable in the future. Of the 3 million tonnes of MSW produced by all GCC states each year, an average of 47% (by weight) are compostable materials and potential feedstock for the GCC's several composting facilities. Approximately 1.4 million tonnes/year of such materials would be potentially available for composting plants (AlAnsari M., 2008; Zeng, et al., 2010; Khan, 1989), suggesting that it may be feasible to establish a regional facility.

5.3 Combustion

Combustion of waste allows energy recovery to displace fossil fuel-generated electricity from utilities, thus reducing GHG emissions from the utility sector and methane emissions from landfills. Relative global warming potential (GWP) is lower for combustion and incineration than for composting and landfilling. Despite this environmental benefit, it is also important to consider feasibility studies and economics when deciding whether to implement this method of waste management (Hassan, 1999). Complete combustion results in emission of CO_2 and N_2O. The emission of non-biogenic CO_2 but not biogenic CO_2 is considered to be beneficial during

GHG emission associated with combustion. Most waste combustors produce electricity that can be substituted for utility-generated electricity. It is important to note that combustion facilities must incorporate some form of heat recovery system in order for energy to be utilized economically; systems should be designed to maximise the efficiency of combustion facilities and incorporate modern air pollution control systems to reduce air pollution.

5.4 Disposal and Land Filling

In the conventional ISWM hierarchy, the last management option is disposal via landfill. Many disposed wastes cannot discharge GHGs, but instead store carbon. Current practices of solid waste landfilling are not sustainable, due to shortcomings in the design, construction, and operation stages of landfill development (Hiettiaratchi, et al., 2007). Gas extraction systems must be installed at landfills in order to control emissions of CH_4 and CO_2, which are produced in nearly equal concentrations due to biodegradation of organic waste. Despite such measures, a significant amount of non-controlled emissions is released into the atmosphere through landfill surfaces (Nolasco, et al., 2009). Some organic matter will not decompose at all and is eventually stored as carbon.

With combustion of CH_4 for energy recovery, credit is given for the electric utility since it avoids GHG emission. Regardless of the fate of CH_4, credit is given for the landfill carbon storage associated with landfilling of some organic materials. It is becoming increasingly easy to recover CH_4 from landfills, reducing GHG emissions by 65–72%. If CH_4 is used for electricity generation, CO_2 emissions can be reduced by 69-72% (Hansen, 2005a; USEPA, 2005a). Bioreactor landfill technology has the potential to further reduce the environmental impact of landfills and maximise CH_4 recovery from these systems, thus providing a positive use for what has historically been a non-valued disposal method.

5.5 Ecodesign

'Ecodesign' describes the concept of minimising a product's environmental impact over the course of its life cycle. Thus, attempts are made to use fewer hazardous chemicals, augment energy efficiency, and reduce ecological footprints. Especially important is the idea of 'resource-use efficiency,' or, in other words, doing more with less. This approach allows economic growth to continue without causing negative environmental impacts. The goal of resource-use efficiency has the potential to be well served by the hierarchy, especially if its emphasis is shifted upwards towards waste prevention and reduction. Unfortunately, solid waste managers in government and industry have little control over production decisions that influence waste generation, particularly in the absence of regulation. Thus, it is important for ecodesign to be advocated by individuals from other sectors.

5.6 Reduction/Avoidance

Waste reduction and/or avoidance, also referred to as "source reduction" or "waste minimisation", is the prevention of solid waste generation. In order to reduce the quantity and toxicity of materials entering the MSW system, waste reduction/avoidance techniques are considered at every stage of a product's life cycle, including design, manufacture, purchase, and use. Thus, this technique, located near the top of the management hierarchy, has the potential to conserve resources, save energy, and reduce pollutants and GHG emissions. It can also reduce solid waste collection system costs and reduce the need for new landfills and incinerators.

Avoidance plans and legislation also typically include the establishment of waste reduction/avoidance targets, economic incentives, and educational efforts, including promotion, technical assistance, planning, and reporting. Because of this broad focus, this method offers the opportunity to reduce GHG emissions in a significant way. For many materials, reduction in energy-related CO_2 emissions from the raw material acquisition and manufacturing process, and the absence of emissions from waste management, combine to reduce GHG emissions more than that using other options (Smith, 2001; Vollenbroek, 2002).

5.7 Resource Recovery

Resource recovery, which includes recycling, composting, and combustion, is the fourth step of the proposed waste management hierarchy because it is a 'waste reuse' technique. The benefits of resource recovery include conservation of natural resources, energy, and landfill space, and provision of useful products and economic benefits.

The need for consistency in quality and quantity, and the benefit of economies of scale, it is suggested that integrated waste management should be organised on a large-scale, regional basis. Further, any scheme or strategy incorporating recycling, composting, or waste-to-energy technologies must be market-oriented. When calculating the overall costs of ISWM plans, waste, energy, and other raw materials should be factored in as inputs, while reclaimed materials, compost, emissions to air and water, and residual landfill materials should be factored in as outputs. A parallel model calculates the overall costs of the ISWM system based on local cost data.

Once the waste management system has been described, the inputs and outputs of each chosen treatment process must be calculated, using fixed data for each process. The yield should be expressed as useful net energy consumption, air emissions, water emissions, landfill volume, recovered materials, and amount of compost produced.

6. Discussion

Current rates of resource consumption and pollution are unsustainable because they exceed the rates at which resources can be regenerated and wastes can be assimilated by Earth's natural systems. In order to increase sustainability, we will need to develop a more sophisticated understanding of the complex interactions between different environmental impacts, and develop radical new systems that lead to significant, and immediate, changes. In particular, it will be important to improve eco-efficiency, eliminate waste generation, and shift from products to services (Grant, et al., 2003).

New regional philosophies of waste management should be based on the proposed hierarchy shown in Figure 4. In this system, the following methods should be emphasized, in this order: (1) reduction (either at the source or later), (2) reuse, (3) recycling, (4) incineration, and (5) disposal. Successful implementation of this system at a regional level will facilitate successful implementation globally. An emphasis on ecodesign should also help to reduce waste production. Although economics and socioeconomics have not previously been an important consideration during the development of waste management plans, it is essential that they help shape future management schemes. Cumulatively, these techniques have beneficial social and political implications for the GCC region.

One method of maximising sustainability is to include plans for training and awareness as well as pursuing methods of re-engineering and optimisation in order to achieve waste reduction and recovery. Applying material management and economic recovery of residues for feedstock, or for energy production and utilisation, will also increase the success of ISWM.

Unfortunately, ISWM plans do not address performance or competency issues, which may often have negative impacts on waste safety and public opinion. Disposal plans must be reviewed periodically in order to consider changes in local conditions, processes, and technology

7. Conclusion

Waste hierarchies continue to be useful guides when developing waste management plans. However, it is increasingly important to use modified hierarchies that consider broader environmental, social, and economic impacts. For instance, modern hierarchies should emphasise ecodesign and reduction of GHGs. Given our current levels of consumption and production, it will be challenging to shift to more sustainable patterns in order to prevent and reduce waste. However, these are essential goals that should be considered in the future waste management plans of GCC countries, and, indeed, in countries around the world. Implementation of the new ISWM hierarchy worldwide will push both the private and public sector to rework the production process, eventually leading to decrease in CO_2 emissions from the energy used for solid waste transport as well as reduction in CH_4 and other non-CO_2 GHGs from anaerobic landfilling.

Throughout the GCC states, there has been a debate on how to facilitate a shift from waste management to resource efficiency. A significant issue is merging the concept of sustainability and its sub-components (e.g. the hierarchy) into programs that are effective across multiple sectors, disciplines, communities, and professions. In order to accomplish this, strategic thinking and creative action will be needed at all levels; furthermore, plans must be flexible so that they can evolve over time. There are currently many exciting and groundbreaking approaches to, and tools for, achieving resource efficiency, including Zero Waste targets, dematerialisation, life cycle thinking, ecological footprint analysis, sustainable consumption, and design for environment. However, they are generally applied in isolation. In order to develop their full potency, future efforts should attempt to integrate these techniques with each other and in the context of broader ISWM schemes.

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Table 1. Conventional hierarchy of integrated solid waste management

Goal	**Attribute**
Reduce	Preventative
Reuse	Predominantly ameliorative, partly preventative
Recycling and composting	Predominantly ameliorative, partly preventative
Treatment or incineration	Predominantly assimilative, partially ameliorative
Disposal and landfilling	Assimilative

Table 2. Rates of municipal solid waste generation in GCC countries

GCC country	Solid waste (Kg/capita/day)	Population (millions)	Total waste (tonne/year)	Land requirements for disposal (m^2)[a]	
				No recycling	Recycling
Bahrain	1.8	1.04	683,280	145,538.64	109,324.80
Kuwait	1.4	2.23	1,139,530	242,719.89	182,324.80
Oman	0.75	2.3	629,625	134,110.13	100,740
Qatar	1.5	0.46	251,850	53,644.05	40,296
UAE	1.4	2.3	1,175,300	250,338.90	188,048
Saudi Arabia	1.6	23	13,432,000	2,861,016	2,149,120

[a]Calculations are based on a density of 0.5 tonnes for MSW.

[b]Calculated based on an assumption of US$ 661/m^2 as research over statistical land prices in GCC survey done by researcher over lands in the GCC(2011)

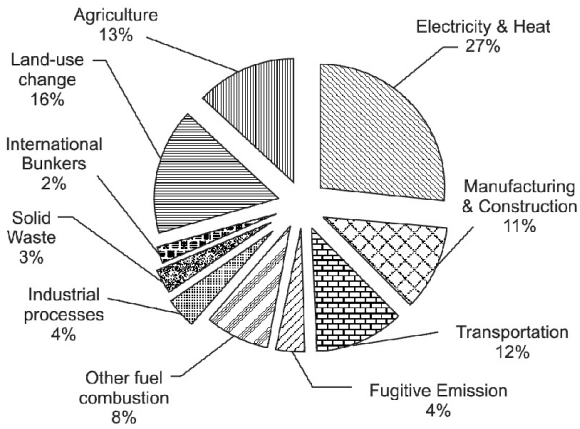

Figure 1. Comparison of the sources of GHG emissions

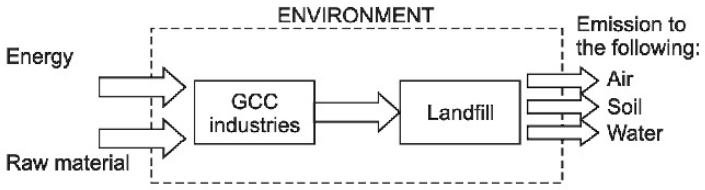

Figure 2. The relationship between energy, raw materials, environment, and emissions

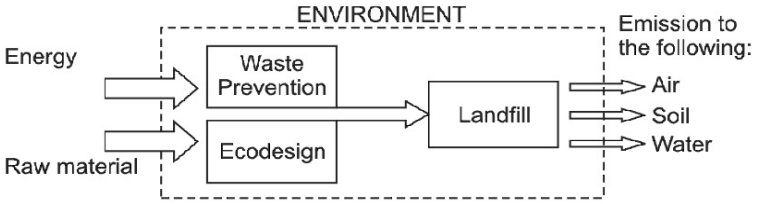

Figure 3. Philosophy of waste prevention and minimisation.

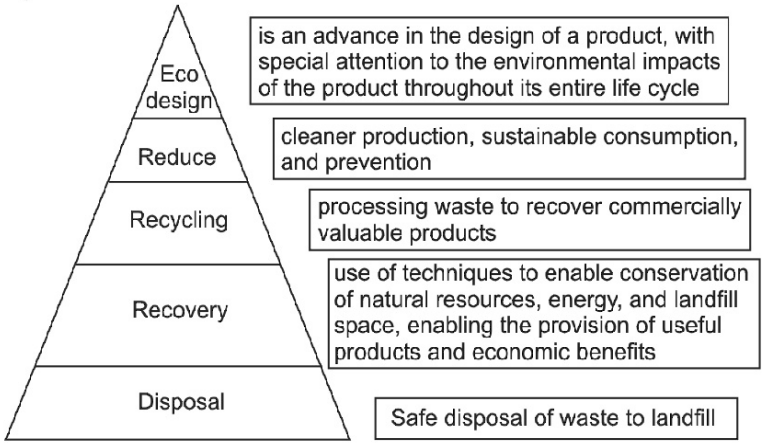

Figure 4. Proposed hierarchy of integrated solid waste management. Figure reproduced courtesy of Zeng et al. (2010)