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Review

Applications of System Analysis Techniques in Solid Waste Management Assessment

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Abstract

Solid waste management (SWM) is a global issue and has proven to be a key challenge facing many developing countries. SWM constitutes a crucial health and environmental problem. Most cities spend 20-50% of their annual budget on solid waste management, but only 20-80% of the waste is collected. Due to the diversity of different system components that need to be addressed and the inability of a single tool to assess all components, it has necessitated the need for an integrative approach to SWM issues. Recently more integrative techniques and methods are being utilized to address the different issues that arise in solid waste management as a whole. One technique or method is inefficient and cannot encompass all components of a solid waste management system. This paper looks into the different system analysis techniques that have been applied in SWM and shows system engineering tools have a wide and diverse application, require less data, and are quite cost effective when compared to the system assessment tool, which requires a wide and diverse range of data to be applicable and reliable. The system engineering tools when applied do not reflect the actual scenario for assessment and are quite difficult to implement practically. The system engineering tools are very reliable with regard to choosing options and stimulation of a scenario. System assessment tool seem more realistic, practically applicable for the decision makers and analysis/assessment using system assessment tools can easily be understood and simplified. An integration of engineering and system assessment tools seems more appropriate for obtaining a holistic assessment.

Keywords: solid waste, management, assessment, engineering, tools

Introduction

Solid waste management (SWM) is a global issue and has proven a key challenge facing many developing countries. It constitutes one of the most crucial health and environmental problem facing African cities. Most cities spend 20-50% of their annual budget on solid waste management, but only 20-80% of the waste is collected [1]. One of the consequences of population growth and globalization is increased waste generation, with generation varying between cities, cities in Africa with reliable data being difficult to come by [1]. This has become a concern for developing countries and is one of the greatest challenges facing Environmental Protection Agencies in developing countries [2, 3]. A lot of research has applied different methods and techniques to address different issues with regard to waste management. Recently more integrative techniques and methods are being utilized to address the different component issues that arise in solid and waste management as a whole. One technique or method is inefficient and cannot encompass all issues and components of solid waste management.

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Materials and Methods

This study relied on secondary data obtained from past studies, present studies, and existing literature. The data obtained was analyzed using a descriptive method to obtain logical deductions and sequential presentation of facts from the data obtained to give a clear picture of the problem.

Concept of Solid Waste Management

Tchobanoglous et al. [4] defined SWM as the discipline associated with the control of generation, storage, collection, transfer and transport, processing, and disposal of solid waste in a manner that is in accord with the best principles of public health, economics, engineering, conservation, aesthetics, and other environmental considerations. The concept of SWM involves the integration of different disciplines: legal, planning, financial, administrative, institutional, engineering, political, and planning. EPA AU [5] defines solid waste as any waste that is not gaseous and is not a liquid waste. Solid waste means any garbage or refuse, sludge from a wastewater treatment plant, water supply treatment plant, or an air pollution control facility, and other discarded material, including solid, liquid, semi-solid, or contained gaseous material resulting from industrial, commercial, mining, and agricultural operations, and from community activities [6]. Solid waste excludes solid or dissolved materials in domestic sewage, solid or dissolved materials in irrigation return flows, industrial discharges, and special nuclear or by-product material [6]. Not all solid waste is solid; many solid wastes are liquid, while others are semi-solid or gaseous.

Elements of Solid Waste Management

There are six functional elements associated with solid waste management, each interlinked as shown in Fig. 1:
1. Waste generation
2. Waste handling and separation, storage and processing at source
3. Collection
4. Separation, processing and transformation
5. Transfer and transport
6. Disposal

General Overview SWM Studies

Tanskanen [7] developed and applied a computer model to study the Integrated Municipal Solid Waste Management in Helsinki Metropolitan Area (Finland). The model was developed for analyzing on-site collection systems of waste materials separated at the source. The study aimed at finding and analyzing separation strategies and fulfilling the recovery rate targets adopted for MSW in Finland. Chang and Davila [8] offered a unique MSW investigation with regard to both physical and chemical characteristics, illuminating the necessary management policies with greater regional relevancy. Zotos et al. [9] developed a systematic approach for municipal solid waste management at both the household and non-household levels. It aimed at providing a framework in the municipal solid waste management field for municipalities in Greece, as well as other countries facing similar problems.

Turan et al. [10] presented a brief history of the legislative trends in turkey for municipal solid waste management; the study presented the municipal solid waste responsibilities and management structure, together with the present situation of generation, composition, recycling, and treatment. Bovea et al. [11] compared from an environmental point of view different alternatives for the management of municipal solid waste generation in a Spanish town. Tunesi [12] analyzed local waste management strategic and management planning documents. In the paper three different emerging energy recovery strategies where identified, with each energy recovery strategy resulting in different solutions in terms of technology selection.

Ahiamadu [13] carried out a comparative analysis of various waste management options, with emphasis on the health and environmental impacts of MSW and the challenges confronting MSW management in Nigeria. Olanrewaju and Ilemobade [14] researched the Ondo state Integrated Waste Recycling and Treatment Project in

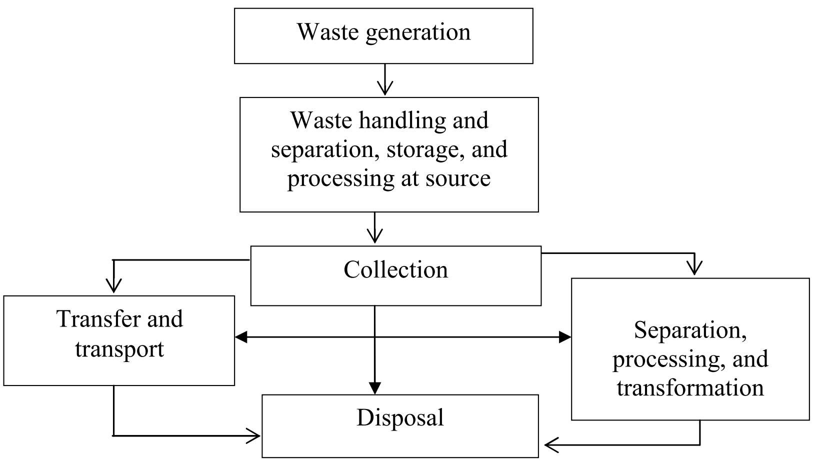

Fig. 1. Interrelationship between SWM functional elements.
Source: [4]

Nigeria, looking into the issue in terms of MSW management before and after the introduction of this system and documenting the success of the project in turning waste to wealth. Babayemi and Dauda [15] evaluated the solid waste generation, categories, and disposal option in developing countries. They used Nigeria as a case study and their study results indicated large generation at high rates without corresponding efficient technology to manage the waste. Onwughara et al. [16] studied the issues of roadside disposal habits of municipal solid waste in Nigeria. The paper emphasized various waste management options and suggested integrated waste management, environmental impacts under health, social effects, and the legislation of extended producer responsibility.

Systems Analysis Techniques

Systems are created to basically solve problems and consist of a collection of components interlinking and functionally interdependent together toward the realization of the objectives that initiated the construction of the system. Fig. 2 is an illustration of the component for every basic system.

System analysis is a process of collecting data, understanding the processes involved, identifying problems, and recommending feasible solutions toward the improvement of the system function. In the analysis of a system one must study the processes, the functional units, gather data, find the gaps, and identify the weaknesses of the system toward recommending possible solutions; improvement of the overall system toward achieving a new efficient system that satisfies the current needs of the users. Assessment of SWM by using systems analysis techniques allows decision makers to learn about total system complexity [17]. System analysis techniques can be further classified into the system engineering models and system assessment models shown in Table 1.

System Engineering Models

Systems engineering models are capable of studying waste production processes and assessing the interactions in numerous types of SWM systems addressing impacts from technical to social, and to economic perspectives. Their contribution is often limited to using a mathematical functional form structured to derive strategic guidelines and orientations in an SWM system [17]. Table 2 shows the contributions of different system engineering models in SWM systems.

Systems Assessment Tools

Systems assessment tools have been applied to evaluate and help in decision making based on environmental issues and have great potential to integrate other aspects, like economics or social impacts [17]. Systems created and implemented eventually require evaluation of their performance and consideration on what and how improvements could be made toward answering the increasing challenges. Models can help decision makers to achieve this; system assessment tools include management information systems (MIS), decision support systems (DSS), expert system (ES), scenario development (SD), MCA, life cycle assessment (LCA), risk assessment (RA), environmental impact assessment (EIA), strategic environmental assessment (SEA), socioeconomic assessment (SoEA), and social assessment (SA) [17]. System assessment tool have been used for SWM systems for decision making and assessments. Table 3 shows the contributions of system assessment tools in SWM systems.

Despite advances in terms of technological development, scheme implementation and economic instruments of MSWM still pose a great problem for many cities [20],

Table 1. System assessment tools categorization.

Assessment Tools Classification	Models	
System Engineering Model	Cost Benefit Analysis	CAB
	Forecasting Models	FM
	Stimulation Models	SM
	Optimization Models	OM
	Integrated Modelling Systems	IMS
System Assessment Model	Management Information Systems	MIS
	Decision Support Systems	DSS
	Expert System	ES
	Scenario Development	SD
	Material Flow Analysis	MFA
	Life Cycle Assessment or Life Cycle Inventory	LCA or LCI
	Risk Assessment	RA
	Environmental Impact Assessment	EIA
	Strategic Environmental Assessment	SEA
	Socioeconomic Assessment	SoEA
	Sustainable Assessment	SA

Linear programming (LP), mixed-integer programming (MIP), non-linear programming (NLP), dynamic programming (DP)
Sources: [11, 17, 18]

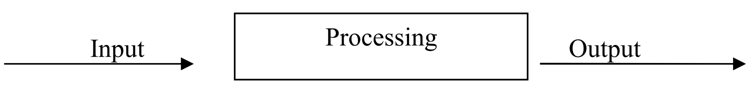

Fig. 2. Basic system components.

Table 2. The contribution of systems engineering models to SWM systems.

Types of Systems Engineering Models	Description	Contribution to SWM System
Cost benefit analysis	To assess positive and negative economic and physical effects independently or support simulation and optimization models for systems analysis	Well-defined cost benefit models may translate environmental aspects into economic terms. However, the intergeneration externalities are difficult to address.
Optimization model	To reach the best solution among numerous alternatives, considering one or several objectives.	Models have solved the following issues:
		-single network planning (Anderson and Nigam, 1967 Anderson, 1968 Fuertes et al., 1974 Helms and Clark, 1974 Kuhner and Harrington, 1975 Jenkins, 1979 Clayton, 1976 Rao, 1975)
		-dynamic, multi-period investment (Marks et al., 1970 Marks and Liebman, 1971).
		-size and site facilities (Chapman and Yakowitz, 1984 Li and Huang, 2006 a,b, 2009 a,b Nie et al., 2007 Li et al., 2007, 2006, 2008 a,b Huang et al., 2001, 2002 Xu et al., 2009).
		-manage infrastructures like landfill (Davila et al., 2005)
Simulation model	To trace the lengthy chains of continuous or discrete events based on cause-and-effect relations describing the operations in complex systems and helping investigate the dynamic behavior of the system (Wang et al., 1996).	Models developed: WRAP (USEPA, 1977).
		Models developed for SWM systems: SWIM (Wang et al., 1996), GIGO (Lawver et al., 1990 Anex et al., 1996), AWAST (Villeneuve et al., 2009), EcoSolver IP-SSK (Krivtsov et al., 2004), TASAR (Tanskanen and Melanen, 1999)
Forecasting model	To characterize waste streams quantitatively and qualitatively and construct a management information system to accumulate information over time. To predict waste generation, time-series regression analysis (Katsamaki et al., 1998Navarro-Ésbri et al., 2002), system dynamics models (Dyson and Chang, 2005), and other regression models have been applied (Grossman et al., 1974).	Models have related variables like:
		population (Grossman et al., 1974), income level (Grossman et al., 1974 Beigl et al., 2005), dwelling unit size (Grossman et al., 1974), total consumer expenditure and gross domestic product (Daskalopoulos et al., 1998), production measures, household size, age structure, health indicators (Beigl et al., 2005), per capita retail and tipping fees for waste disposal (Hockett et al., 1995) to waste generation, total income per service centre, people per household, historical amount generated, income per house and population (Dyson and Chang, 2005).
Integrated modelling systems	To improve synergistic connections among different models, concentrating their total functionalities	IMS have provided:
		- dynamic information of waste generation and waste shipping (Chang et al., 1993)
		- optimal capacity expansion patterns for waste-to-energy and landfill facilities over time (Baetz, 1990)
		-Models developed: ORWARE (Dalemo et al., 1997, Björklund et al., 1999)

Waste resource allocation programme (WRAP), Solid waste management (SWM), Solid waste integrated model (SWIM), Garbage in garbage out (GIGO), Tools for analyzing separation action and recovery (TASAR), Organic waste research (ORWARE), Aid in the management and European comparison of a municipal solid waste treatment for a global sustainable approach (AWAST),
*Adopted from [19].

and are a major challenge in urban environmental management. The differences in characteristics among cities make it not possible for a single solution to be developed. Over the year the role of stakeholders has transformed from merely recipients of impacts to playing important functions in the design, implementation, and promotion of MSWM systems [20]. In terms of support tools there are diverse types of models that have been developed over the years toward supporting decision making in MSW management.

Applications in Solid Waste Management

Bjorklund et al. [21] evaluated the waste management plan of Uppsala municipality in Sweden using the ORWARE (Organic Waste Research Model) computerized static substance flow model using LCA (life cycle analysis) methodology. The waste management plan being evaluated was newly adopted, and being questioned on the complexity, economic sustainability, and environmental impact. Despite the intention of the new plan toward reduction of

Table 3. The contribution of systems assessment tools to SWM systems.

Systems assessment tools	Description	Contribution to SWM systems
Management information system, decision support system and expert systems	Consists of different methods applied to exchange and manage information, used to help in decision making	MIS/DSS/ES have been applied:
		-to provide information storage and transmission through countries (EIONET, 2009)
		-to yield specific decision support (Chang and Wang, 1996, Barlishen and Baetz, 1996, Haastrup et al., 1998, Bhargava and Tettelbach, 1997, AEA Technology, 1998)
		-to relate waste stream characterization with implications on shipping, processing and disposal of waste streams (MacDonald, 1996)
Scenario development	To create hypothetical sequences of events constructed for the purpose of focusing attention on causal processes and decision points (Kahn and Wiener, 1967)	Has the ability to explore events (events in this case are policies and decisions taken) that might occur associated with SWM on a temporal scale. Such events can be inside or outside the SWM system. Fell and Fletcher (2007) have contributed with scenario developments for future lifestyle trends and forecasting based on lifestyle scenarios for waste composition
Material flow analysis	Consists of a systematic assessment of the flows and stocks of materials within a system defined in space and time (Brunner and Rechberger, 2003)	Software developed in MFA: SFINX (van der Voet, 1995a,b), FLUX (Huijbregts, 2000), STAN (TU Vienna, 2009),DYNFLOW (Elshkaki, 2000),GaBi(PE International, 2006)and Umberto (IFU, 2006)
Life cycle assessment	Consists of a process to evaluate environmental burdens associated with a product, process or activity by identifying and quantifying energy and materials used, wastes and emissions released to the environment, to assess impact of those energy and material uses and releases and to identify and evaluate opportunities that lead to environmental improvements (EEA, 2003)	Models developed for SWM systems: IWM (White et al., 1995, McDougall et al., 2001), WASTED (Diaz and Warith, 2006), WISARD/WRATE (Ecobilan, 2004, Buttol et al., 2007), EASEWASTE (Christensen et al., 2007)
Risk assessment	To relate environmental and human health risk to accidents quantitatively, through a statistical evaluation	Help in the evaluation of transversal SWM systems
Environmental impact assessment	A procedure that aims to ensure that the decision-making process concerning activities that may have a significant influence on the environment takes into account the environmental aspects related to the decision (Tukker, 2000)	EIA associated to a specific project attempts to solve controversial issues from the target project such as siting issues originated from the NIMBY effect, technical issues to justifying the choice of technology for emission reduction, and even the rejection of the project (Chang et al., 2009). In Europe, EIA is mandatory for landfills and incineration plants with regard to capacity limits through EU Directive 85/337/EEC (EU, 1985), as amended by EU Directive 97/11/EC (EU, 1997).
Strategic environmental assessment	Consists of the environmental assessment of a strategic action as a policy, a plan or a program (Thérivel and Partidário, 1999)	A good example can be found in Barker and Wood (1999) Its applicability is emphasized by EU Directive 2001/42/EC (EU, 2001), to which it is obligated for the promotion and elaboration of an SEA for SWM plans. More details can be found out in the Dutch Ten-Year Program on Waste management 1992 and 2002 (Verheem, 1999)
Socioeconomic assessment	Consists of computer-based practices that apply integrated market-based and/or policy/regulation requirements for SWM	Has allowed the inclusion of user-charges, landfill disposal fees, recycling credits, product charges, deposit-refund schemes, and producer-responsibility schemes into the decision making in SWM systems, promoting a more sustainable management of waste. For such purposes, several methodologies have been applied: CBA-based LP (Chang et al., 1997, 1996), CBA-based MIP (Chang et al., 2005), CBA-based fuzzy goal programming (Chang and Wang, 1997), fuzzy contingent valuation (Chang et al., 2009), minimax regret optimization (Chang and Davila, 2007), GIP-based game theory (Davila et al., 2005), CBA-based MCDM (Karagiannidis and Moussiopoulos, 1997, Rousis et al., 2008), optimal control of landfill space (Chang and Schuler, 1991) inexact fuzzy-stochastic constraint (Li et al., 2009), IOA (Brahms and Schwitters, 1985, Franklin Associates, 1999, Gay et al., 1993, Hekkert et al., 2000, Joosten et al., 2000, Patel et al., 1998, Nakamura, 1999, Pimenteira et al., 2005)

Table 3. Continued.

Systems assessment tools	Description	Contribution to SWM systems
Sustainable assessment	Refers to the integration of different methodologies in such a way that obtaining an analysis, an evaluation or a planning that approaches several management aspects in which sustainability implications may be emphasized and illuminated	SWM systems assessed to reach sustainable management, focusing on different aspects. Models developed: LCA-IWM (den Boer et al., 2007) and MSW-DST (Thorneloe et al., 2007, Weitz et al., 1999). Several methods have been combined to reach sustainability: Cherubini et al. (2008) have combined LCA with MFA and energy analysis methods, Nakamura and Kondo (2002) used IOA and LCA to construct a waste input output model, Huppes et al. (2006) and Tukker et al. (2009) have combined both methods to obtain IOA with environmental extensions for different sections (including waste management sectors). A Geographical Information System (GIS) combined with LCI, EIA and optimization model has been promoted by Chang et al. (2008, 2009) for landfill siting

European environment information and observation network (EIONET), Management Information system (MIS), Decision support system (DSS), Expert system (ES), Solid waste management (SWM), Cost benefit analysis(CBA), Waste integrated system for assessment and recovery (WISARD), Waste analysis software tool for programme(WASTED), Waste and resource assessment tool for the environment (WRATE), Integrated waste management (IWM), Not in my back yard(NIMBY), Environmental impact assessment (EIA), Geographic Information system (GIS), Life cycle assessment (LCA), Input-output analysis (IOA), Material flow analysis (MFA),Grey intrger programming (GIP), Multicriteria decision making (MCDM), Environmental assessment on solid waste systems and technologies (EASEWASTE), Linear programming (LP), Substance flow iner-nodal exchange (SFINX), Life cycle inventory (LCI) *Adopted from [19].

environmental impacts, the net effects were contrary, thus the need for evaluation. ORWARE, a computerized model based on substance flow analysis, is applied toward the comparison of various systems for municipal biodegradable waste handling, the model is further developed to include non-hazardous fractions of municipal waste. ORWARE was used for comparative assessment of the environmental impact of municipal waste management systems, but the software is quite complex and requires expertise. ORWARE assessed the impacts of a step-wise realization of Uppsala's waste management plan, enabling comparison between the original and new implemented municipal waste management system. The feasibility of normalization increased understanding and improved evaluation by normalizing emissions from waste management to total emission loadings in the municipality. Apart from the complexity of the software, it involves too many parameters and data. The system boundaries must also be clearly defined with regard to time, space and function due to its influence on the final stimulation results. Also, baseline data is required, which makes application limited.

Ming-Lung et al. [22] reviewed several models developed to support decision making in Municipal solid waste management. The application of models, multi objective programming (MOP), multi-criteria decision making (MCDM), environmental impact assessment models, and life cycle assessment (LCA) were identified as models often used to aid decision making in MSWM. Numerous studies have applied these models and within each model different approaches. A sustainable decision-making model that integrated MCDM and consensus analysis model (CAM) for MSWM was developed. CAM is built up to aid decision making in traditional MCDM methods and to assess the degree of consensus between stakeholders for specific alternatives. The model provided an effective means for assisting decision making for real-world waste management problems. The sustainable decision making model not only accommodates economic, environmental, and social factors but also incorporates public participation into the decision-making process. The model is also applicable to EIA and other environmental problems like water management or air emission control problems.

Zotos et al. [9] addressed the contemporary options weaknesses and opportunities faced by Hellenic local authorities in Greece. The focus of the current municipal solid waste management for Hellenic was still mainly focused on waste collection, with treatment and disposal being a second priority. A systemic approach for MSWM at both household and non-household level was developed. A comprehensive framework was proposed for streamlining the role of local authorities toward adopting waste reduction targets, promoting source separation, and co-operation between the local authorities toward zero waste. A systematic approach was used to look into the possible interactions in urban waste management with priorities regarding the minimization of MSW production, establishing contemporary and integrated programs and plants concerning recycling and sanitary landfilling, promoting source separation programs, and the establishment of a communications strategy for promoting the 4R concept. The local authorities and policy tools are the main strategy of this paper. A critical assessment of the system was carried out and SWOT analysis model was used as a tool for the study. which is not an efficient tool for a critical assessment. Another tool should have been introduced integratively with the SWOT analysis. The research stated they used a systematic approach, but failed to state which tool was used to facilitate it.

In Garfi et al. [23] the different waste management solutions for Saharawi refugee camps in Algeria and to test the feasibility of a decision-making method developed to be

Table 4. Summary assessment tools application in solid waste management.

Year/Author	Assessment Tool	Model	Application
Bjorklund et al. [21]	LCA/SFA	ORWARE	Assessment and comparison of the impacts of two waste management plans
Morrissey and Browne [30]	DSS/LCA/SoEA	CBA/LCA/MCDM	Critic review of current MWM models
Reich [31]	LCA	LCA/LCC	Economic assessment of municipal waste management systems
Ming-Lung et al. [22]	DSS	MCDM/CAM	Develop a sustainable decision-making model for MSWM that also implements public participation in the decision-making process
Ramjeawan and Beerachee [29]	DSS	MCDM/AHP	Site selection of sanitary landfill
Manaf et al. [32]	DSS/ES	MCDM/AHP/UrusSisa	Selection of best solid-waste technology
Khan and Fasial [27]	DSS	MCDM/ANP/Hiernet	Prioritizing selection of appropriate MSW disposal methods
Garfi et al. [23]	DSS	MCDM/AHP	Comparison of different waste management options
Eriksson and Baky [24]	LCA	LCA/LCC	Identification and testing of key parameters using computer stimulation model, Numerical sensitivity analysis for input data used in LCA/LCC
Bovea et al. [11]	LCA	LCA	Proposed alternative systems for MSW
Chung-Chiang [33]	DSS	DEA/AHP	Evaluation of the integrated efficiency of MSWM between urban and rural regions
Giovanni and Sabino [34]	DSS	MCDM/AHP	Verification of stakeholder involvement to rank list of suitable MSW facility sites

Multi criteria decision making (MCDM), consensus analysis model (CAM), life cycle cost (LCC), analytical hierarchy process (AHP), municipal solid waste (MSW), data envelopment analysis (DEA), cost benefit analysis (CBA), hierarchy network (hiernet)

applied in a specific condition in which environmental and social aspects must be considered. The analytical hierarchy process (AHP) is a multi-criteria analysis (MCA) that uses mathematical technique for multi-criteria decision making, was used. The study area was characterized by aspects typical of a developing country and an emergency situation. AHP enables decision making incorporating planning, setting priorities, selection of the best options among alternatives, and allocating resources. AHP is used for relative critical weighting of indicators and relative critical weighing of evaluators. The best alternatives for waste collection and management for Saharawi refugee camp were obtained. AHP is applicable for criteria weighing and alternative selection, but should also be applied integratively. How the researchers came to the possible alternatives that were being weighed was not stated. Also, the researchers failed to carry out a current assessment for the waste management in the camp and should have reviewed similar situations even if not in Algeria. They failed to justify the current developed plan by not carrying out an assessment and identification of existing gaps from this assessment, which justifies the need or the alternatives being proposed. The study was also stated to be limited to that specific camp which makes the applicability quite narrow, the researchers should have widened their assessment so as to develop a plan that could be applicable to similar scenarios.

LCA and LCC (life cycle cost) are established methods for system analysis, the standard procedures inquire that assessment should include improvement analysis, which is usually performed by sensitivity analysis. An issue in sensitivity analysis is the difficulty in distinguishing input data, which is important to the results. In Eriksson and Baky [24], methods for the identification and testing of potential key parameters were described and the testing of results using computer model stimulations of these parameters. Testing was carried out using sensitivity analysis as stated in the LCA procedure ISO 1997. The methodology employed was numerical sensitivity analysis of input data used in LCA and LCC of municipal solid waste management in Sweden. The method could also be applicably used for similar system analysis, not necessarily only for waste management systems. It is applicable for use as a general approach or framework, an initial phase of a project phase of a project during the LCI to identify potential crucial process data or assumptions. It is also applicable when results from a system analysis at hand toward finding what sensitivity analysis could be of interest to perform. But it is limited related to systems comprising cradle-to-grave for household waste, which limits its applicability. The initial decision analysis normally leads to assess a suite of management options, evaluate managerial and strategic plans, and collect and share information, which are even more influential when managing SWM; decisions and policies are often made with the aid of LCA or LCI in public institutions [17].

Contreras et al. [20] integrated AHP (analytical hierarchy process) and LCA (life cycle assessment) as a decision support tool for MSWM. AHP was developed by Saaty [25] as a multi-criteria method to analyze a decision problem following a hierarchial structure. It is a subjective decision-making process based on multiple attributes [26]. In AHP trade-offs are made based on the advantages and disadvantages of the policy options under circumstances of uncertainty. In the Contreras et al. [20] study, they proposed a set of treatment plans and an array of impacts creating a complex decision for MSW in the city of Boston. AHP was utilized to incorporate the relative importance of the different impact categories and treatment plans into the decision scheme regarding stakeholder group preferences. The results of the AHP application showed that between the impact categories presented, greenhouse gas emissions and landfill capacity are ranked higher rather than cost associated with the operation of the plan and health damage associated with the treatment plan presented among the stakeholder groups. AHP allowed the development of four different scenarios according to the contributions of each stakeholder group to the decision scheme, the use of biogasification was considered the best plan to follow.

Mannapperuma and Basnayake [28] assessed the institutional and regulatory framework for waste management in the western province of Sri Lanka using SWOT analysis. It was identified that the western province contributed to more than 60% of the total national quantity of solid waste generation, leading to the inability of the local bodies responsible for solid waste management to manage this waste properly, which has consequently led to open dumping and open burning by the local authority. SWOT analysis was used to assess the current scenario and to identify a comprehensive waste management strategy to address most of the identified problems. In their study, simple questioners were used to gather all relevant quantitative and qualitative information, and they were administered to representatives of administrations, environmental, technical, and health sectors of all the local authorities of the province. But the study failed to present details of the identified problems and sufficient supporting quantitative data to validate the strategy options or recommendations. The researchers also identified that the province had the highest waste quantity nationally but also failed to find a strategy specifically toward waste minimization or waste diversion to addresses this stated problem in terms of institutional or legal strategy.

Ramjeawon and Beerachee [29] studied the application of multi-criteria analysis; analytical hierarchy process for the location of a sanitary landfill on the small island of Mauritius. The economic growth has caused the volume and nature of waste materials generated by the different economic sectors to change considerably. The identification of site location for the construction of sanitary landfill has possessed a major challenge for waste management authorities worldwide, especially on developing small island states. Several alternative methods of evaluation including financial assessment, social cost benefit analysis, and non-monetary evaluation techniques were highlighted as options. In their study Ramjeawon and Beerachee [28] used multi-criteria evaluation as a tool for evaluating quantifiable and non-quantifiable criteria to assess and rank four candidate sites after the evaluation of the technical, environmental, and socio-economic factors. Under the MCDA methods, multi-attribute utility/value theory (MAUT/MAVT), analytical hierarchy process (AHP) and outranking were highlighted as types of MCDA methods that differed, but also were applicable for this study. The researchers highlighted MCDA methods offering many advantages, but choosing among MCDA methods proved a complex task. The strengths and weaknesses of each method differed; from a better grounded mathematical theory, considerations of data availability and ease of implementation on each applicable method. AHP was selected and adopted for the study dues to its easy application; users do not have to understand the intricacy of the complex mathematics behind the technique before they can use it. It allows consideration of both objective and subjective factors in selecting alternatives. Even though AHP requires more time and effort in comparison to the other MCDA methods, AHP results show lower variance in the assessments produced by different decision makers. Table 4 shows a summary of some applications of assessment tools in SWM.

The most common practices for waste management in European countries are those using various systems assessment tools, rather than system engineering models. In many European countries with lacking sustainable development concepts in waste management have no prevalent application of systems analysis techniques [17].

Discussion

System engineering tools have a wide and diverse application and are quite cost effective, compared to the system assessment tools, which require a wide and diverse range of data to be applicable. The system engineering tools, when applied, do not reflect actual scenarios for assessment and are quite difficult to implement practically. The system engineering tools are very reliable with regard to choosing options and stimulating scenarios.

Conclusion

Several studies over the years have been carried out toward addressing these issues, different methods have been applied toward resolving different aspects of solid waste and waste management issues as a whole. Currently there is an increasing popularity of the system analysis techniques in the assessment and management of solid waste, specifically the system assessment models. This requires less time, effort, raw data, and variety of application. It is flexible and can be used integratively with other decision tools.

When selecting assessment tools/methods, selection should be based on the tools/methods that will provide the most useful and relevant information. Many outcomes will be difficult to assess using only one measure, so an integration of two or more methods is recommended [35]. System assessment tools seem more realistic and practically applicable for the decision makers, and analysis/assessment using system assessment tools can easily be understood and simplified. An integration of engineering and system assessment tools seem more appropriated toward obtaining a holistic assessment.

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