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Review

Solid waste management in European countries: A review of systems analysis techniques

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ABSTRACT

In the past few decades, solid waste management systems in Europe have involved complex and multi-faceted trade-offs among a plethora of technological alternatives, economic instruments, and regulatory frameworks. These changes resulted in various environmental, economic, social, and regulatory impacts in waste management practices which not only complicate regional policy analysis, but also reshape the paradigm of global sustainable development. Systems analysis, a discipline that harmonizes these integrated solid waste management strategies, has been uniquely providing interdisciplinary support for decision making in this area. Systems engineering models and system assessment tools, both of which enrich the analytical framework of waste management, were designed specifically to handle particular types of problems. Though how to smooth out the barriers toward achieving appropriate systems synthesis and integration of these models and tools to aid in the solid waste management schemes prevalent in European countries still remains somewhat uncertain. This paper conducts a thorough literature review of models and tools illuminating possible overlapped boundaries in waste management practices in European countries and encompassing the pros and cons of waste management practices in each member state of the European Union. Whereas the Southern European Union (EU) countries need to develop further measures to implement more integrated solid waste management and reach EU directives, the Central EU countries need models and tools with which to rationalize their technological choices and management strategies. Nevertheless, considering systems analysis models and tools in a synergistic way would certainly provide opportunities to develop better solid waste management strategies leading to conformity with current standards and foster future perspectives for both the waste management industry and government agencies in European Union.

Abbreviations: ADEME, Agence de l'Environnement et de la Maîtrise de l'Energie; AWAST, aid in the management and European comparison of a municipal solid waste treatment for a global and sustainable approach; BMW, biodegradable municipal waste; CBA, cost–benefit analysis; CERA, comparative environmental risk assessment; DP, dynamic programming; DSD, Duales System Deutschland; DSSs, decision support systems; EASEWASTE, environmental assessment of solid waste systems and technologies; EC, European Community; EDX/EDI, electronic data exchange; EEA, European Environment Agency; EEC, European Economic Community; EIA, environmental impact assessment; EIONET, European environment information and observation network; EPR, extended producer responsibility; ERA, environmental risk assessment; ES, expert system; EU, European Union; EUDIN, European Data Interchange of Waste Notification System; FM, forecasting models; GHG, greenhouse gas; GIGO, garbage in, garbage out; GIP, grey integer programming; GIS, geographic information system; IMS, integrated modeling system; IOA, input–output analysis; ISWM, integrated solid waste management; IWM, integrated waste management; LATS, landfill allowance trading system; LCA, life cycle assessment; LCI, life cycle inventory; LP, linear programming; MCDM, multicriteria decision making; MFA, material flow analysis; MIP, mixed-integer programming; MIMES/WASTE, model for description and optimization of integrated material flows and energy systems; MIS, management information system; MSW, municipal solid waste; NIMBY, not in my backyard; NLP, non-linear programming model; OM, optimization models; ORWARE, ORganic WAste REsearch; PAYT, pay-as-you-throw; PET, polyethylene terephthalate; QAS, quality assurance system; RA, environmental and ecological risk assessment; SA, sustainability assessment; SD, scenario development; SDS, sustainable development strategy; SEA, strategic environmental assessment; SFA, substance flow analysis; SFINX, substance flow inter-nodal exchange; SM, simulation models; SoEA, socioeconomic assessment; STAN, subSTance flow ANalysis; SWIM, solid waste-integrated model; SWM, solid waste management; TASAR, tool for analyzing separation actions and recovery; WASTED, waste analysis software tool for environmental decisions; WHP, waste hierarchy principle; WISARD, waste-integrated systems for assessment of recovery and disposal; WRAP, Waste Resources Allocation Program; WRATE, waste and resources assessment tool for the environment; XML, extensible markup language.

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1. Introduction

In the 21st century, the sustainable management of municipal solid waste (MSW) will become necessary at all phases of impact from planning to design, to operation, and to decommissioning. As a consequence, the spectrum of new and existing waste treatment technologies and managerial strategies has also spanned from maintaining environmental quality at present to meet sustainability goals in the future. Such an orderly evolution allows both waste management industries and government agencies to meet common needs of waste management with greatest green potential, to recycle materials out of waste streams, to enlarge the renewable energy supply, to seek for more socially acceptable options, and to preserve biodiversity and natural ecosystems simultaneously. To achieve such goals, all technical and non-technical aspects of a solid waste management (SWM) system should be analyzed as a whole, since they are inter-related with one another and developments in one area frequently affect practices or activities in another area (UNEP, 2005).

Systems analysis techniques have been applied to handle MSW streams through a range of integrative methodologies in the last few decades. A total of five system engineering models and nine system assessment tools were formally classified in this field to illuminate the challenges, trends and perspectives (Chang et al., in press). It is worth knowing that the spectrum of these models and assessment tools was classified based on the following two domains although some of them may be intertwined with each other (Chang et al., in press). They are: 1) systems engineering models including cost–benefit analysis (CBA), forecasting models (FM), simulation models (SM), optimization models (OM), and integrated modeling system (IMS), as well as 2) system assessment tools including management information system (MIS)/decision support system (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), and sustainable assessment (SA). Fig. 1 holistically illustrates the interrelationships among these two domains from which fourteen technologies can be connected through such a technology hub in association with these two broad-based domains (Chang et al., in press). In the core part, the five systems engineering models can be seen as the core technologies in which the cost–benefit analysis may be used as a common platform in support of decision making. Integrated modeling systems may flexibly concatenate various optimization models including linear programming (LP), mixed-integer programming (MIP), non-linear programming (NLP), and dynamic programming (DP) models to address the system concerns in which the SM and FM can support the essential background in concert with CBA in the context of systems analysis. With such a core structure, the model-based DSSs can be constructed for separate or collective applications. Yet rule-based, knowledge-based or graphics-based DSSs or ESs can still be formed based on heuristic approaches. All of these core efforts may be enhanced by the rest of system assessment tools described by the eight outer triangles. Communication among the eight triangles canalizes the information flows that in turn improve the credibility of the five systems engineering models being formulated through MIS, DSS, and even ES. Overall, Fig. 1 leads to a sound realization of the structure between systems engineering models and systems assessment tools from which a systems analysis should be well balanced for generating environmentally benign, cost effective, ecologically sound, and socially acceptable solutions (Morrissey and Browne, 2004; Chang and Davila, 2007).

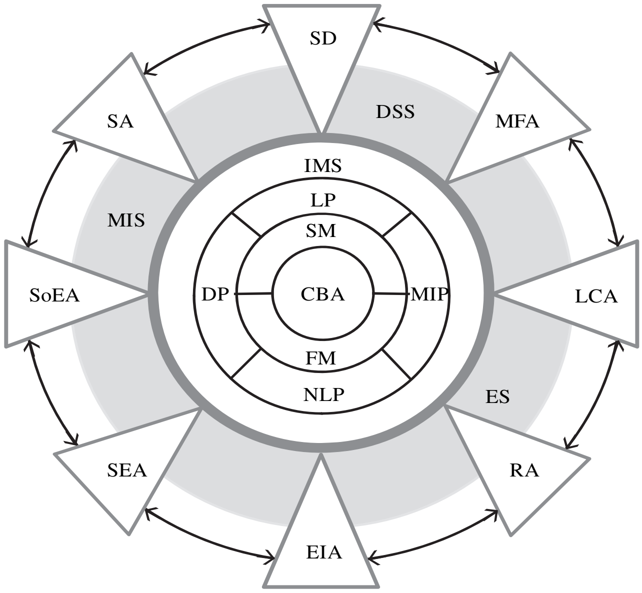

Fig. 1. The technology hub for solid waste management (Chang et al., 2009).

With such a tool, every community can tailor its own unique system to manage various components of the waste streams in a flexible manner (Najm et al., 2002). Yet how to smooth out the barriers toward achieving appropriate systems synthesis and integration of the five systems engineering models and the nine system assessment tools to aid in solid waste management practices in European countries remains somewhat uncertain. It is the aim of this paper to present a thorough literature review and a critical analysis in sequence so as to answer the following key questions: 1) what achievements have been reached so far?, 2) what are the gaps in knowledge of waste management that we need to achieve in the context of sustainable development in the long run? and 3) what are the research needs and future directions in systems analysis for SWM in European countries. At a practical level, discussions of this paper were limited to 15 European Union (EU) member states, facing the same driving forces with similar waste legislation to manage MSW systems. The EU is an economic and political union of 27 member states which are located primarily in Europe, Norway and Switzerland (non-EU members) were also included to understand how other countries within the region with similar waste management legislation applied the techniques of systems analysis to manage their waste management issues. Fig. 2 illustrates the overall study boundaries.

The comparative analysis of this paper provides an all-inclusive view to minimize anomalies of SWM systematically, and should allow possible conflicts associated with different objectives associated with environmental, social, technical, and economic constraints to be confronted more rationally than heretofore. Such a development should enable more solidly based waste management strategies to be pursued, leading to conformity with current standards for both the waste management industry and government agencies in the EU.

2. Current waste management principles in the EU

After the commitments made at the Earth Summit in Rio de Janeiro (1992), the European Council in 2001 adopted the first EU Sustainable Development Strategy (SDS). The overall aim of the renewed EU SDS is to support and promote actions enabling the EU to achieve