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Municipal solid waste management and energy production: Consideration of external cost through multi-objective optimization and its effect on waste-to-energy solutions

George Mavrotas[a,*], Nikos Gakis[c], Sotiria Skoulaxinou[b], Vassilis Katsouros[d], Elena Georgopoulou[e]

[a] National Technical University of Athens, Greece
[b] EPEM SA, Greece
[c] FACETS SA, Greece
[d] Athena Research and Innovation Center, Greece
[e] National Observatory of Athens, Greece

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ABSTRACT

Energy production from Municipal Solid Waste (MSW) has become one of the most prominent strategies in MSW management. In this study a multi-objective mathematical programming model is developed in order to provide the candidate (Pareto optimal) solutions for a MSW management system performing structural, design and operational optimization. Besides the economic criterion the Green House Gas (GHG) emissions are taken into account as a second optimization criterion. Therefore, we do not obtain just an optimal solution (i.e. least cost), but a set of Pareto optimal solutions that spread from minimum cost to minimum GHG emissions. Each Pareto optimal solution provides the corresponding technologies and the capacities that are associated with it. An innovative issue is that we incorporate the external costs/benefits associated with (a) atmospheric pollution impacts (b) impacts on soil and groundwater (c) impacts on quality of life (d) electricity use/displacement (e) fertilizer use reduction from compost. Using the external costs/benefits as an additional term in the cost objective significantly affects the results especially regarding the Waste-to-Energy options. This is clearly illustrated in the case study for the MSW management of the Athens region in Greece.

Contents

* Correspondence to: Laboratory of Industrial & Energy Economics/School of Chemical Engineering/National Technical University of Athens, Zografou Campus, Athens 15780, Greece
E-mail address: mavrotas@chemeng.ntua.gr (G. Mavrotas).

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1. Introduction

Municipal Solid Waste (MSW) management is one of the most challenging technical problems of our era given the high level of urbanization. The increased number of technologies and the great variety in the possible paths from collection towards disposal significantly increase the complexity of finding the "optimal" solution. In addition, MSW management has great importance also from the energy perspective. MSW can be used to produce energy through various technologies (see e.g. [1–5]). Therefore, in many countries MSW management and energy system are closely linked by exploiting the economic and environmental benefits from this synergy. Moreover, a great part of the energy production from MSW is considered as a renewable energy source [6].

Various waste technologies are available nowadays in MSW management, with each one of them focusing on a certain task [7]. In addition, various policy goals are imposed for recycling quantitative targets of disposed materials [8]. The adequacy of each technology depends on several issues such as the collection scheme, the mass composition and the imposed policy goals among others. There is not a single dominating technology scheme appropriate for every case so different combinations of technologies should be examined. Due to the complexity of the problem, a systematic approach is required in order to select the "most appropriate" solution.

A proper tool for optimizing complex systems like the MSW management is Mathematical Programming (MP). During the last fifty years MP became one of the most popular tools in Operational Research for solving real problems. MP aims at the optimization of a system and it has been widely used in energy, industry, finance, supply chain, agriculture and water management among others [9]. The MP models describe the system at hand using decision variables (the unknowns of the problem), parameters (the known data) and constraints (the equations that describe the system). The optimization criterion is expressed as the objective function of one or more decision variables. The optimal solution provides the values of the decision variables that optimize the objective function, satisfying at the same time the imposed constraints. MP and especially in the form of Linear Programming (LP) or Mixed Integer LP (MILP) become all the most applicable in real case studies as the size of the model is not a problem anymore, due to the vast improvements in computer speed and in algorithmic effectiveness. Nowadays, MP problems with thousand of variables and constraints can be solved in seconds.

Significant work has been done in applying MP models in MSW management in the last 20 years (see e.g. [10,11]). There are papers that contribute in modeling MSW systems under uncertainty (see e.g. [12–17]) and also studies that deal with application in specific regions, e.g. Munich-Germany [18], Beijing-China [19], Foshan-China [20,21], Regina-Canada [22,23], Thrace-Greece [24], Port Said-Egypt [25], Alleghany County-USA [26].

In this paper we aim at an integrated approach to the MSW management problem giving emphasis to energy recovery issues. We consider, besides cost, the Greenhouse Gas (GHG) emissions as a second objective function to be minimized. The introduction of the second objective function leads to multi-objective optimization. The main difference between single and multi-objective optimization is that in the latter case, there is usually no single optimal solution, but a set of equally good alternatives with different trade-offs, also known as Pareto-optimal (or non-dominated or efficient) solutions. The Pareto optimal solutions are feasible solutions that cannot be improved in one objective function without deteriorating their performance in at least one of the rest. In the absence of any other information, none of these solutions can be said to be better than the other. Usually a decision maker is needed to provide additional preference information and to identify the "most preferred" solution ("optimal" according to his/her subjective preferences). Therefore, multi-objective optimization combines two aspects, namely, optimization and decision support [27]. Actually, multi-objective optimization increases the degrees of freedom in the decision process as more solutions are examined and the final solution is selected by comparing various trade-offs ([28]).

GHG emissions express one of our concerns regarding environmental consequences, namely the global warming issue. However, there are also other environmental issues that should be taken into account (atmospheric, soil pollution etc.). These issues can be incorporated in our analysis through the concept of external cost. External cost quantifies the external effects that have traditionally been ignored when it comes to calculating total costs. Several attempts have been made to attribute monetary values to these external costs, and one of the most comprehensive is the EU's ExternE project [29]. Replacing the objective function of cost with one that incorporates the external cost (total cost = private cost + external cost) significantly alters the results of the multi-objective optimization as we will see in the present paper. External costs in MSW management have been considered in some papers during the last decade (see e.g. [30–33]).

The application that we will deal with in the present paper is the capital of Greece, Athens. We develop the MSW management model for Athens and we generate all the Pareto optimal solutions based on the minimization of two criteria, namely, the cost and the GHG emissions. Subsequently, we modify the first objective function, i.e. the cost, in order to incorporate the corresponding