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Multi-criteria analysis as a tool for sustainability assessment of a waste management model

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ABSTRACT

To assess the sustainability of waste management scenario with energy recovery, it is necessary to carry out an adequate analysis of all influential criteria. The main problem in the analysis is to determine the indicators that clearly and fully sublimate the most important influential factors. The model for the assessment of the sustainability of waste treatment scenarios based on multi-criteria analysis AHP (analytic hierarchy process) method is developed. The model predicts an increase in the number of indicators, if it found that a selected number of indicators are not sufficient to distinguish between scenarios and new criterion for the selection of indicators: the relevance of the indicator for certain waste treatment. The model is verified in the case study the city of Niš. Four scenarios were selected and examined: business as usual scenario (landfilling of waste) and the other are created as scenarios with energy recovery and recourses preserving: composting organic waste with recycling inorganic waste, incineration of waste and anaerobic digestion of waste. The assessment of the sustainability of waste treatment scenarios was made in several steps. It is found that the best sustainable scenario is composting of organic and recycling of inorganic waste.

1. Introduction

The problem of waste management is not new, but has become current with population growth, economic development and recognition of the negative effects of waste on the environment. To solve the problem of waste management, the possibility of using waste for energy recovery has been recognized. The amount of waste generated in 2010 was 258 million tonnes in the EU, 230 million tonnes in the USA and 154 million tonnes in China [1]. Under the European conditions, municipal solid waste is a fuel with the heating capacity from 7.2 to 14.9 GJ/t [2], which shows that there is a great potential for energy recovery from waste.

There are various technologies for recovering energy from waste. The most used of these are thermal (incineration, fast and slow pyrolysis, gasification, production of refuse derived fuel), biochemical (composting, anaerobic digestion) and chemical conversions (esterification and other processes to convert waste to biodiesel) [3]. Each of these technologies varies according to the amount of recovered energy, waste volume reduction, greenhouse gases emission, investment and operational costs etc. Murphy and McKeogh [4] investigated several technologies which produce energy from municipal solid waste: incineration, gasification, anaerobic digestion and utilization in a combined heat and power plant. They concluded that incineration has the highest gate fee and the greatest investment cost, anaerobic digestion has a significantly lower investment cost than either incineration or gasification, but gasification provided by far the best energy recovery in terms of electrical product (1083 kWh/t), and anaerobic digestion provided a relatively poor energy recovery (151 kWh/t). On the other hand, the anaerobic digestion offers a greatly increased reduction in net greenhouse gas production compared with other technologies [4]. Other research suggests that comparing incinerator facilities with energy recovery and landfill dispatching, the incinerator allows a green house gasses reduction of 360 $kgCO_2eq/t$ waste and in the case of a traditional landfill with no provision for landfill gas capture, the difference with respect to incinerators increases to 650 $kgCO_2eq/t$ waste [5].

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Since energy has become a crucial element for sustainable development and the well being of any country in the modern era, the amount of energy recovered from waste is one of the aspects of sustainability of a certain waste treatment. When making the decision on the selection of waste management scenarios one should take into consideration all of the aspects of the sustainability of a certain waste treatment (environmental, economic, social). For decision-makers it is particularly important to visualize the advantages and disadvantages of specific waste technologies, to know the importance of an integrated waste management, the economic benefits in the long term, the impact of waste treatments on the environment, social benefits, etc.

Different research has been done in order to determine a sustainable decision making model for waste management scenarios. Several decision-making models have been developed in solid waste management: models based on cost benefit analysis, models based on LCA (life cycle analysis), and models based on the use of multi-criteria analysis [6]. Each of them has different approaches, benefits and limitations: for models based on the cost benefit analysis all criteria for assessing scenarios translate into a monetary measurement, for models based on life cycle analysis the assessment of scenario is carried out based on the analysis of environmental impact of all phases of a product that lead to the creation of waste, and for models based on the multi-criteria analysis the assessment and selection of scenarios is carried out based on environmental, economic and social criteria. The research that has been done in practice in several European cities has shown that there is no one correct way to manage waste, but an integrated approach to waste management with economic, social and environmental concerns must be added to the system [7].

Since the environmental, economic and social criteria are partially or completely conflicting and by nature very diverse and expressed in different units, the probability or subjective evaluations, the multi-criteria decision analysis (MCDA) is the appropriate method for assessing sustainability of a waste management model. The benefit of multi-criteria analysis in assessing the sustainable scenario is that it allows the use of both qualitative and quantitative criteria (sustainable development indicators). It also allows participation of different groups of decision-makers even with opposing goals in defining indicators and decision-making. The conducted literature review has shown that multi-criteria decision analysis is quite often used as a decision making model in waste management. In recent literature multi-criteria decision analysis was used for evaluating alternative technologies for energy recovery from municipal solid waste [8]. Also, MCDA was used for ranking municipal solid waste treatment alternatives based on the ecological footprint [9]. To improve the waste reduction policy multi-criteria decision-making was applied [10]. The integration of the geographical information systems and multi-criteria decision analysis was used for landfill suitability analysis [11] and for siting a municipal solid waste incineration plant [12]. A novel approach in the form of risk-based multi-criteria assessment (RBMCA) was introduced, which can be used by decision makers, in order to select the optimum alternative of a waste management project [13].

Other authors developed sustainable decision-making models that include not only economic, environmental and social factors simultaneously, but also incorporates public participation into the decision-making process [14]. Some studies developed a decision support system designed to help decision makers of a municipality in the development of waste integrated programs. In those studies the objective function takes into account all possible economic costs, whereas constraints arise from technical, normative, and environmental issues [15].

The aim of this paper is to present a model for assessing the sustainability of waste management which assists decision makers in the selection of waste management scenarios with energy and resource recovery. This model can be applied for the comparison of various waste treatment scenarios in terms of sustainability. A model based on multi-criteria analysis – the AHP (analytic hierarchy process), is developed. The model is tested in the case study of waste management in the city of Niš. Four scenarios were selected and examined for waste management in terms of sustainable development indicators: environmental, economic and social. Based on the obtained results improvement of model is done. The assessment of the sustainability of waste treatment scenarios was made in several steps by increasing the number of indicators. The influence of the increase in the number of indicators of the sensitivity of the system is examined. Finally, sensitivity analysis was performed to determine the impact of certain sustainable development indicators on the sustainability of scenarios.

2. The AHP (analytic hierarchy process)

The AHP (analytic hierarchy process) is a multi-criteria decision making technique, quite often used to solve complex decision making problems in a variety of disciplines: manufacturing industry, environmental management, waste management, power and energy industry, transportation industry, construction industry, etc. [16]. In the energy sector, the AHP method is used for evaluation of power plant types according to the technological, economic and sustainability aspects [17], for evaluation of bio energy developments regarding regional sustainability [18] or for selection of renewable energy sources for sustainable development of electricity generation systems [19]. In waste management, the AHP method is used to evaluate options for energy recovery from municipal solid waste [8], to evaluate solid waste treatment technology [20] or to rank suitable municipal solid waste facility sites [21]. Contreras et al. [22] used the AHP to select between different waste management plans to implement in Boston, USA. A wide range of applications of the AHP method shows that AHP is a powerful decision tool for assisting decision makers in the selection of a sustainable waste management scenario.

The AHP hierarchical structure allows decision makers to easily comprehend problems in terms of relevant criteria and sub-criteria. Additional criteria can be superimposed on the hierarchical structure. Furthermore, if necessary, it is possible to compare and prioritize criteria and sub-criteria in the AHP practice, and one can effectively compare optimal solutions based on this information.

The decision procedure using the analytic hierarchy process (AHP) is made up of four steps:

1) "define the problem and determine the kind of knowledge sought.
2) structure the decision hierarchy according to the goal of the decision – in the following order: the objectives from a broad perspective, through the intermediate levels (criteria on which subsequent elements depend) up to the lowest level (which usually is a set of the alternatives).
3) construct a set of pair-wise comparison matrices. Each element of the matrix in the upper level is used to compare elements in the level immediately below.
4) use the priorities obtained from the comparisons to weigh the priorities in the neighbouring level. Do this for every element. For each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained." [23].

The most important step of these decision-making processes is a correct pair-wise comparison, whose quantification is the most