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Modeling of energy consumption and environmental life cycle assessment for incineration and landfill systems of municipal solid waste management - A case study in Tehran Metropolis of Iran

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A B S T R A C T

As the economy has improved in Iran, residents have produced more municipal solid wastes in recent decades. The various scenarios for municipal solid waste management are projected with the main purpose for reduction of environmental impact and energy production. The aim of this study is to evaluate the energy consumption and environmental impacts of incineration and landfill scenarios. The data used in this study are supplied by Waste Management Organization of Tehran Municipality, Iran. Results of the energy analysis show that 406.08 GJ (8500 t MSW)$^{-1}$ of energy is consumed in the process of incineration and landfill with transportation system. Most energy consumption is related to transportation. Life cycle assessment indicates that incineration leads to the reduction of detrimental factors related to toxicity as the results of electricity generation and the production of phosphate fertilizers. Besides, the rates of daily greenhouse gas emissions from incineration and landfill are estimated at 4499.07 and 92,170.30 kg $CO_{2\ eq.}$, respectively. In this study, feed-forward back-propagation models based on Levenberg-Marquardt training algorithm are developed for predicting electricity and environmental factors against energy consumption for municipal solid waste management. An Artificial Neural Network model with 4-5-5-11 structure is selected as the best structure. Results show that, in the selected model, the amount of R^2 varies in the ranges of 0.948–0.999 for training, testing and validation, demonstrating excellent performance in predicting all outputs based on the input factors. Sensitivity analysis for Artificial Neural Network model indicates that transportation has the highest sensitivity in four impact categories including eutrophication, marine aquatic ecotoxicity, human toxicity and terrestrial ecotoxicity.

1. Introduction

The growing waste production as a result of the increase of population, the change in social lifestyle, the development and use of products that are less biodegradable, are causing various challenges for management of Municipal Solid Waste (MSW) in different cities worldwide (Asase et al., 2009). Ruling governments and citizens have become especially conscious and apprehensive about how wastes were managed, during the past few decades (Assamoi and Lawryshyn, 2012). Apart from concerns about health and security, because of significant effects of waste management on the environment, systems of management of MSW having less universal and zonal environmental impacts are favorable (Mendes et al., 2004). A method of management of MSW especially for waste

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that cannot be recycled is incineration. Incineration has been widely used for MSW disposal because it enables large reduction in the mass of waste and the recovery of energy. According to this point, incineration of MSW has been taken into consideration in many countries with limited space of landfill (Yang et al., 2012). Besides, ash resulting from the incineration can be used as soil coverage. The pathogens are all burned to death, and the perishable organics that produce damaging gases are completely oxidized, during the process of incineration (Li et al., 2015). The incineration power plant needs a smaller area compared with landfill sites, and thus the site selection is easier (Liu et al., 2006). On the other hand, the incineration of MSW releases ash to the atmosphere, containing a large amount of toxic heavy metal materials, such as mercury, lead, cadmium, chromium, copper, zinc, and highly toxic substances such as dioxin that pollute water, soil and air, and also leads to acid rain (Shim et al., 2003). As such, despite the evolution in technology, there are still concerns about incineration contaminating the environment and public health.

Nowadays, there is a growing interest in the simultaneous utilization of different options for source and waste management with design strategies for management policies of integrated and sustainable resource and waste. The landfill site is for the disposal of MSW by burial and is the oldest form of MSW treatment and stays so in many locations around the world. Regular landfilling is based on anaerobic demolition of waste (consisting of a set of biological processes in which organic matter is converted into biogas and dig estate by micro-organisms in the absence of oxygen (Appels et al., 2011)), uses bottom liner, top soil cover, gas and leachate collection and treatment systems. Though new systems of MSW landfill help to control harmful gases emissions and leachate from the landfill significantly, landfill system of MSW is still a serious threat to the environment due to lack of complete control of systems and the impact of these threats will remain in the environment for many years (Cherubini et al., 2009). To solve the issues caused by the landfill and for better management at the same time, landfilling can be used with other methods of waste management such as recycling, composting and incineration, etc. These methods decrease the amount of waste entering the landfill and prevent adverse effects of the use of landfills (as contaminated soil and water) that can be very profitable in terms of new materials and energy production. The energy efficiency is a major factor in the energy recovery. In order to avoid the increase of the adverse effects of incineration, the efficiency in the recovery of energy should be increased in incineration power plant. In addition to environmental hazards, improper recovery of energy will convert an incineration power plant to an energy-inefficient producer rather than becoming an alternative source for energy supply. Though improvements in combustion technology have created favorable conditions for the construction of many new MSW incineration power plants in various countries, complete analysis of the energy cycle in incineration should be performed to points of recognized high energy consumption and efforts should be made to reduce it. Energy efficiency in landfills should also be taken into consideration, whether in landfills where the gas is produced (similar to those mentioned for incineration) or landfills that are used only for burial of MSW. A general evaluation of the environmental impacts that are derived from the processes of incineration and landfilling is necessary in both qualitative and quantitative terms, while the advantages and disadvantages of incineration should be noted simultaneously. One of the most useful methods for the evaluation of potential environmental impacts is the Life Cycle Assessment (LCA), which is standardized by the international standard ISO (ISO, 2006). The LCA is a powerful tool to assess environmental aspects related to a product, process, or service by recognizing energy and materials used and emissions released to the environment. It is also an opportunity to identify ways to improve the environmental impacts (Consoli et al., 1993). Numerous studies have been published in recent years in which this tool was applied for the environmental evaluation of incineration and landfilling scenarios of MSW in different countries. For example, Tang et al. (2013) evaluated the total life cycle of a MSW incineration power plant by using the method of LCA. Besides, the sensitivity analysis was carried out to recognize the most significant impact source. The study investigated the amount of global warming, acidification, nutrient enrichment, photochemical ozone formation, soot and ashes. Allegrini et al. (2015) reviewed and assessed the environmental impacts of the MSW incineration management system with LCA and identified vital aspects thereof and they provided an improved basis to address environmental assessment of waste-to-energy systems. Borders system with the incineration plant only was included in that study and six impact categories were evaluated. Wassermann et al. (2005) studied the environmental impacts of existing landfills in comparison to landfills for incineration residues (MSWI landfills) and future landfills for residues after mechanical biological treatment (MBP landfills) based on environmental impact categories. Despite the importance of marine aquatic ecotoxicity that was stemming from landfill leachate, the pertinent factors were not examined in that study. Turconi et al. (2011) provided a quantitative evaluation from environmental performance of MSW incinerator in Italy and Denmark, using two LCA modeling tools (SimaPro and EASEWASTE). The system boundaries were extended from the entrance to the incineration plant until the final disposal of all solid residues. Their LCA results were evaluated on the basis of the important differences in the composition of waste, the operation of power plant, the management of residues and the substitution of energy.

For the cycle analysis of energy and environment, it is required to provide a model to estimate the amount of energy output and environmental impacts based on energy inputs. One of the most common modeling methods is the use of Artificial Neural Networks (ANNs). In relation to the forecasted rate of waste production by using ANN, researches were also conducted. For example: Ordóñez-Ponce et al. (2006) applied ANNs to forecast long-term generation rate of MSW and results showed high power of ANNs in the accurate prediction by taking various input variables. Dong et al. (2003) employed an ANN model to forecast the lower heating value (LHV) of MSW. Abbasi and El Hanandeh (2016) forecasted rate of MSW production by ANN for better management of MSW. Besides, Xiao et al. (2009) indicated that the modeling by ANN was suitable to forecast gasification characteristics of MSW.

About 8500 t of waste is produced in Tehran Metropolis daily, which is a serious threat to the environment and people's health. Because incineration can reduce the volume of MSW that is landfilled and thus leading to reduction of the negative impact of the landfill, incineration is a favorable treatment for MSW management in Tehran. Besides, incineration is an ideal opportunity for energy supply according to fossil energy crisis and the daily availability of MSW.

Although so far several studies in relation to LCA of incineration and landfill process have been conducted, yet energy consumption and energy efficiency in these studies were rarely investigated. Moreover, in most studies, emphases were only made on a few environmental factors. Since it is not possible to compare the results and to generalize it to different regions with differences in system boundaries, it is necessary to assess the amount of pollution emission for each area according to the system boundary and area conditions to provide a model to help to make better decisions. The aim of this study is to develop an ANN for forecasting and modeling energy cycle and the life cycle of incineration and landfilling of MSW with consideration of energy consumption in the Metropolis