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Development of a decision model for the techno-economic assessment of municipal solid waste utilization pathways

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ABSTRACT

Economic competitiveness is one of the key factors in making decisions towards the development of waste conversion facilities and devising a sustainable waste management strategy. The goal of this study is to develop a framework, as well as to develop and demonstrate a comprehensive techno-economic model to help county and municipal decision makers in establishing waste conversion facilities. The user-friendly data-intensive model, called the **FUN**damental E**N**gineering Princip**lE**s-based Mode**L** for Estimation of **Cost** of Energy and Fuels from **MSW** (FUNNEL-Cost-MSW), compares nine different waste management scenarios, including landfilling and composting, in terms of economic parameters such as gate fees and return on investment. In addition, a geographic information system (GIS) model was developed to determine suitable locations for waste conversion facilities and landfill sites based on integration of environmental, social, and economic factors. Finally, a case study on Parkland County and its surrounding counties in the province of Alberta, Canada, was conducted and a sensitivity analysis was performed to assess the influence of the key technical and economic parameters on the calculated results.

1. Introduction

The management of municipal solid waste (MSW) is a big concern today for city authorities and planners due to increasing population, urbanization, and limited land space. MSW is one of the major concerns to environmental health (Javaheri et al., 2006) and the traditional treatment and dumping of solid waste has some key environmental challenges such as leachate generation and air pollution (Ojha et al., 2007). Such environmental challenges, combined with political, social, and economic issues, as well as the availability of land, are major concerns to be addressed in land evaluation and management (Lein, 1990). On the other hand, increasing population leads to increased fossil fuel consumption and corresponding increase in energy and fuel demands and greenhouse gas (GHG) emissions. Converting solid waste to energy provides an option, not only to produce cleaner energy, but also to contribute to offsetting GHG emissions.

In 2010, 19 out of 32 European countries (EU-27 member states, Croatia, Iceland, Norway, Switzerland, and Turkey) landfilled more than 50% of their municipal solid waste (European Environment Agency, 2013). In 2006, 212 million tonnes of solid waste was generated in China (Zhang et al., 2010), and India generates around 45 million tonnes of waste every year (Shekdar, 2009). These two countries open dump 50% and 90% of their total MSW, respectively (Visvanathan and Trankler, 2003). In 2012 the United States discarded 53.8% of the total generated MSW in landfills (United States Environmental Protection Agency, 2014) and currently many landfills have either reached or nearly reached their capacity (Palmer, 2011). In Canada, most of the waste ends up at landfills as well. About 30% of Canada's landfills either reached or surpassed their capacity at 2010 (PPP Canada, 2014). These landfills produce a sizable portion (about 25%) of Canada's methane emission (Environment Canada, 2014). Obviously, it has become necessary to research and implement more environmentally friendly waste management options to divert wastes from landfills.

There have been many studies conducted on solid waste utilization techniques. A few of these studies focussed on the energy and economic assessment for specific technologies (Bonk et al., 2015; Emery et al., 2007). Others provided current solid waste scenarios and future possibilities for some specific regions only (Boukelia and Mecibah, 2012; Hossain et al., 2014; Kimambo and Subramanian, 2014). Environmental impact and life cycle assessment (LCA) have also been the focus of many research studies, e.g., Fruergaard and Astrup (2011) and Bozorgirad et al. (2013). A number of research studies also used geographic information systems (GIS) to find out a suitable location for solid waste disposal (Sener et al., 2011; Yesilnacara et al., 2012;

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Nomenclature

AD	anaerobic digestion	GHG	greenhouse gas
AHP	analytic hierarchy process	GIS	geographic information system
BDT	bone dry tonne	IRR	internal rate of return
CO_2	carbon dioxide	kW h	kilowatt hour
CO_2-eq	equivalent carbon dioxide	MSW	municipal solid waste
ESA	environmentally sensitive areas	OPEX	operating expenditure
FUNNEL-Cost-MSW	**FUN**damental E**N**gineering Principl**E**s-based Mode**L** for Estimation of **Cost** of Energy and Fuels from **MSW**	WA	waste availability
		WTE	waste-to-energy

Gorsevski et al., 2012). However, the available information for solid waste conversion facility site selection is not comprehensive. Furthermore, although some location-specific and technology-specific waste-to-energy (WTE) techno-economic studies have been conducted (Lemea et al., 2014; Bonk et al., 2015), there is no techno-economic study on solid waste utilization that considers the spatial variation of solid waste, uses real road networks, and compares waste conversion technologies for a wide range of waste availabilities.

There is a need to develop a decision-making model to help small counties/towns/municipalities decide whether to dispose of waste at out-of-county or town landfills, use waste in a waste conversion facility, or make their own landfills and dispose of their waste there. Each option has a set of economic and technical parameters and needs to be evaluated. The overall objective of this work is to develop a comprehensive decision-making model to help municipalities make informed decisions on the disposal and use of their waste. The specific objectives are to:

- Develop a framework and conduct a site selection by spatial analysis of waste availability and considering environmental parameters.
- Develop a decision-making model based on economic, environmental, and other parameters to select optimal waste disposal.
- Calculate transportation cost using a real road networks incorporating GIS and other attributes (road speed limits, direction of traffic, etc.).
- Determine the optimum size and location of an MSW processing facility for a particular municipality.
- Compare nine different waste conversion technologies over a wide range of waste availabilities to provide a clear idea about the cheapest technology for a certain amount of waste availability.
- Conduct a specific case study on Alberta's Parkland County to find out the optimal waste disposal option for the county.

2. Methodology

The geographic information system (GIS) software ArcGIS 10 (ESRI, 2015) and its geodatabase were used to find suitable locations for a waste conversion facility based on environmental, social, and economic factors. Then, a user-friendly data-intensive model called the **FUN**damental E**N**gineering Principl**E**s-based Mode**L** for Estimation of **Cost** of Energy and Fuels from **MSW** (FUNNEL-Cost-MSW) was developed. This model can compare various waste conversion technologies and landfilling approaches. The current version of FUNNEL-Cost-MSW calculates the gate fees (the payment that the waste conversion facilities take per tonne of waste received) and internal rate of return (IRR – the interest disbursed or earned on the unrecovered balance such that the net present value of the initial payment is zero) for nine waste management scenarios and helps the user to understand and compare the economic feasibility of every scenario. There are some other considerations that affect waste management decision making, such as the remaining landfill life, available spaces for future landfills, and current rules and regulations. Nevertheless, comparison of different waste management scenarios in terms of economic assessment is considerably valuable in waste management decision making.

2.1. Site selection

The suitable and optimal location of a waste conversion facility depends on some environmental, social, and economic factors as well as waste availability. In this study, site selection was performed in two stages through an exclusion analysis and preference analysis (Sultana and Kumar, 2012). The exclusion analysis screens

Table 1
Identified constraints and corresponding buffer zones.

Criteria	Specifications	Source/Reference
Rivers, lakes, and other water bodies	More than 300 m from water bodies	Government of Alberta (2010a, 2010b)
Rural and urban areas	More than 1 km from residential and urban areas	Eskandari et al. (2012) and Ma et al. (2005)
Airports and heliports	More than 8 km from international airports and 3 km from local airports	Southern Alberta Energy-From-Waste Alliance (2012) and Ma et al. (2005)
Industrial and mining zones	More than 1 km from industrial and mining zones	Sultana and Kumar (2012)
Environmentally sensitive areas (ESA) (flood plains, conservation areas, habitat sites)	More than 1 km from ESAs	Eskandari et al. (2012)
Natural gas pipelines	More than 100 m from natural gas pipelines	Sultana and Kumar (2012) and Ma et al. (2005)
Park and recreational areas	More than 500 m from these sites	Sultana and Kumar (2012)
Wetlands	More than 200 m	Sultana and Kumar (2012)
Roads	More than 30 m	Sultana and Kumar (2012)
Power plants and substations	More than 100 m	Sultana and Kumar (2012)
Transmission lines	More than 100 m	Sultana and Kumar (2012)
Land surface gradient	Areas with slopes larger than 15% are screened out	Sultana and Kumar (2012)