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Review on
Energy Modeling of Urban Municipal Solid Waste Management System to the City of Lake, Bhopal

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ABSTRACT

This paper presents to demonstrate a new tool for designing integrated municipal solid waste to energy systems in the urban environment, in determining how municipal solid waste can be used to generate energy rather than being disposed of in landfills and whether it will be economical to do so. A tool has been developed to design energy system in urban environment looking at the impact of urban form and layout on inhabitants behaviour which determines the demands for various resources, demands through a wide variety of energy conversion technologies sending municipal solid waste to landfill, the results show that the cost of energy provision can be reduced by up to 40% by using either anaerobic digestion or gasification to convert the waste to energy, assuming sufficient waste is available from neighbouring town.

This paper highlights the benefits of using a modelling approach for investigating the feasibility of different urban energy systems. It also quantifies the impact that an integrated municipal solid waste to energy strategy can have on the overall environmental sustainability and economics of a city.

KEY WORDS

Solid waste management system, material recycle, composting, urban energy sanitary landfill and local authorities responsibility.

1. INTRODUCTION

Solid waste consists of the highly heterogeneous mass of discarded materials from the urban community, The principal sources of solid wastes are residences, commercial establishments, institutions, industrial and agricultural activities. Domestic, commercial, and light industrial wastes are considered together as urban wastes. The main constituents of urban solid wastes are similar throughout the world, but the quantity generated, the density and the proportion of constituents vary widely from country to country, and from town to town within a country according to the level of economic development, weather and social conditions. In general, it has been found that as the personal income rises, kitchen wastes decline but the paper, metals and glass wastes increase; the total weight generated increases but the density of the wastes declines (Rao, 1992). Several disposal methods are being used in various parts of the world and the most prominent of these are: open dumping, sanitary landfilling, incineration and composting. Sanitary landfilling is the main method used in industrialized countries and open dumping is very common in developing countries like India. Open dumping of solid wastes is practiced extensively in Bhopal because it is cheap and requires no planning. Generally, the low-lying areas and outskirts of the towns and cities are used for this purpose. Sanitary landfilling is a controlled engineered operation, designed and operated according to acceptable standards. It may be defined as a controlled method of disposing of refuse onto or into land while minimizing nuisances or hazards to public health or safety. The operation is carried out without environmental damage and in areas already spoiled or in need of restoration.

Incineration involves the burning of solid wastes at high temperatures. If incineration is to become an economical method for solid waste disposal, useful materials and energy must be recovered by the process. Heat can be recovered by putting a waste heat boiler or some other recovery device on an existing solid waste incinerator. The heat so recovered can be utilized for generating electricity or for space heating purposes. In general, solid waste has about one-third the heating value of coal, but unlike coal it has a very low sulfur content. All types of incinerators produce air pollution. The contributions to global warming by incineration is much less than those of landfill but comparable to those by composting (Sonesson et al., 1997, 2000).

In contrast to a sanitary landfill, composting of refuse is an aerobic method of decomposing solid waste. Many types of microorganisms already present in the waste biostabilize the organic matter in the waste produce a soil conditioner as a result of the process. Solid wastes contain significant amounts of valuable materials like steel, aluminum, copper and other metals which, if they are recovered and reused, would reduce the volume of the wastes to be collected and at the same time would yield significant salvage and resale income. In addition, better reclamation techniques will help to save valuable natural resources and turn wastes, which could be dangerous, into useful products. Some important solid wastes that have been successfully reclaimed are paper, plastics, glass and metals. In Bhopal, analysis of the composition of the urban solid waste is not generally carried out on a regular basis by the municipalities. The purpose of this study is to develop a system dynamics model of solid waste management systems to predict solid waste generation and electrical energy recovery from the solid waste of the Bhopal city and also to assess different policy options for solid waste management.

MATERIALS AND METHODS

The goal of the Urban Energy Systems project is to explore integrated approaches to urban energy systems with a view to reducing the energy consumption of cities by approximately half, while maintaining the current level of service provision. The modelling platform that has been developed to do this comprises three major components:

- A layout model that optimizes the location of housing, facilities and major transport networks on a greenfield site. Brownfield, or retrofit, studies can be performed by fixing part of the layout and allowing the model to optimize the remaining design choices;
- An agent-based model to simulate the activities and associated resource demands of individual citizens within the city; and
- A resource-technology-network (RTN) model that determines the optimal location and mix of technologies and distribution networks to meet these resource demands.

In this paper, I focus on the application of the RTN model to the problem of determining the best use of municipal solid waste (MSW) for the provision of electricity and heat in Bhopal. The result of the agent-based model is a set of demands for heating, electricity and transport fuel as a function of time and location within the eco-town. The activities of the agents also produce MSW, which must either be disposed of in landfills or utilised for the provision of resource demands (in which case, a limited additional supply of MSW may be obtained from nearby towns if necessary). The various processes for disposal of MSW or conversion to useful energy are then considered as technologies in the RTN model, which is then able to select the technologies to use, their capacities and locations in order to meet the demands optimally. Various economic and environmental metrics can be used (separately or in combination) as the objective function of the optimisation and in constraints. In this case, I have considered annualised capital and operating costs. The modelling of the environmental impacts was achieved by integrating two additional cost parameters in the production cost.

The RTN model is a mixed integer linear programming formulation based on the State-Task-Network (STN). The STN was developed as a generic way to represent process recipes for batch manufacture of chemicals; it was then used to develop a scheduling model, formulated as a mixed-integer linear program. In the STN, states represented distinct material states and tasks represented any process that transform one or more input states into one or more output states. The RTN model uses a similar representation, where resources (corresponding to states in the STN) can represent any material or energy resource and technologies represent any device that can convert one or more input resources into one or more output resources.

More specifically, resources can be any material or energy service required by the inhabitants of the city or any resource involved in the provision of these. Typical services include heating, cooling, potable water, cooking and electricity, all of which will have associated demands. Heating, cooling and cooking are often aggregated into the demands for natural gas and electricity, but it is preferable to segregate them so that e.g. district heating and solar thermal technologies can be included in the analysis. Other resources include natural gas, solar insolation, wind and biomass, which can be converted to energy services, producing CO2 and other pollutants as byproducts (which are also modelled as resources). The technologies include systems such as power generation (from various resources, e.g. natural gas, biomass, wind), CHP, water treatment, boilers and AC units, heat pumps etc. Technologies may also represent processes that store or transport resources.

To account for the spatial and temporal variations in demands for various services, the RTN model uses a zonal representation of the city with a hierarchical time discretisation: yearly intervals, seasons, days (typically just week day and weekend) and hourly intervals (usually the day is split into a small number of intervals within which the demands do not change significantly). To maintain tractability, there is a trade-off between the spatial and temporal resolution of the model. Problems that require an accurate account of the dynamics are better solved using a lower spatial resolution; problems requiring a fine spatial resolution can be solve using a much simple time discretisation comprising just a peak and average period.

The degrees of freedom are the number and locations of each type of production and storage technology and their rate of operation as a function of time; the location of any transport infrastructural and the rate of operation of any transport technologies using these infrastructures as a function of time. The objective function is to minimize the total annualized cost (capital, operating resources imports etc.) of satisfying the resources demands).

MODELING OF URBAN SOLID WASTE MANAGEMENT SYSTEM

Planning of USWM has to address several interdependent issues such as public health, the environment, the electricity generation potential from the urban solid waste generated, and present and future costs to society. The USWM is a complex, dynamic and multi-faceted system depending not only on available technology but also upon economic and social factors. Experimentation with an actually existing urban solid waste management system containing economic, social, technological, environmental and political elements may be costly and time consuming or totally unrealistic. Simulating an USWM by a computer model one can conduct a series of experiments. Computer models clearly are of great value to understand the dynamics of such complex systems (Bala, 1999). Owing to the intrinsically complex nature of USWM problems, it is advantageous to implement USWM policy options only after careful modeling analyses.

The analysis involves the use of different modeling techniques such as optimization, econometrics, input–output analysis, multi-objective analysis and system dynamics simulation. Forrester's system dynamics methodology provides a foundation for constructing computer models to do what the human mind cannot do (Forrester, 1968), that is rationally analyze the structure, the interactions and mode of behavior of complex socio-economic, technological, and environmental systems. Hence, the system dynamics approach is the most appropriate technique to handle this type of complex problem.

The model described here is a theoretical framework for examining urban solid waste generation and its management system in Bhopal city and also to assess electrical energy generation potential to meet the electrical energy consumption requirements of Bhopal city. There is a large gap between the waste generation and management system, which results environmental pollution. Both the uncollected waste and unhygienic disposal of waste create environmental pollution, which gives rise to increase public annoyance and anger and hence public concern develops to reduce waste generation and source separation of recyclable waste. But, waste generation increases with increased population and GDP, as well as per-capita income. Hence, the electrical energy generation potential from the urban solid waste also increases. On the other side, composite index shows the lack of waste collection (uncleared waste). A higher composite index increases management perception, which increases fund allocation for solid waste management.

In Bhopal city, normal practice is that the householders put their solid wastes at different collection points on the street. The Bhopal city corporation's personnel collect the wastes at a particular time and transport them to the disposal site. The disposal method is open dumping in an unhygienic manner. The Bhopal city corporation does not undertake any sanitary landfilling, incineration, composting or recycling. A portion of the recyclable solid waste of Bhopal city is used in recycling industries (plastics, paper, glass, metals, etc.), but this amount is very small and is undertaken informally.

Although the Bhopal city corporation does not have any electricity generation plant fueled by urban solid waste nor any scientific disposal facilities, the electrical energy generation potential from urban solid waste at Bhopal city and the controlled disposal of a portion of collected wastes as landfill, and treatment of waste (incineration, composting, etc.) are included in this model.

RESULTS AND DISCUSSION

Import costs include the cost of importig natural gas and electricity as well as revenue gained by importing MSW. Capital costs are annualised and include the cost of all production and storage technologies and networks. Operating costs include the monetary cost of operating production, transport and storage technologies but not "raw-material" costs as these are accounted for in the resource balance and its impact on how much energy must be imported.

In the landfill case, it is clear that the dominant cost of the system is the import cost, contributing roughly 55% to the overall cost. This can be attributed to the extensive import of natural gas used to cover the demands for electricity and heat.

Introducing an anaerobic digestion (AD) plant of 10 ktpa capacity results in a 6% decrease in the overall cost, due to the decreased import (14%) and operating (44%) costs related to the process, which offset the 58% increase in capital cost. The reduction in import cost is attributed to the substitution of electricity generation from natural-gas powered CCGT with generation from AD, and the subsequent reduction in gas imports, and to the revenues generated by importing waste from neighbouring cities. As the capacity of the AD increases, so does the impact on the import cost, which is diminished by 46% and 100% for the next two AD scenarios. This shows that the cost of importing gas and electricity can be completely offset by the revenue generated by treating the MSW from neighbouring towns if a 50 ktpa plant is installed. The lower import costs more than offset the increasing capital cost, resulting in a decrease in the overall costs by 18% and 38% respectively.

The results are similar in the case of gasification. The overall cost is 41% lower than that of the business-as-usual scenario, marginally lower than the best-performing AD scenario of 50 ktpa. The production cost is higher than the AD cases, but still significantly lower than that of the base case; the capital cost is almost the same as the 10 ktpa AD process; imports are significantly lower, the revenue from waste treatment almost offsetting the cost of gas and electricity imports. The gasification scenario therefore appears to be the most economically viable alternative to the base-case scenario, while at the same time helps diversify the production of electricity and diminish the dependence on fossil-fuel energy.

Due to the small demand for heat and the large capital and operating costs involved in building and sustaining a district-heating network, CHP is not economically viable in any of the studied cases.

CONCLUSION

Solid waste generation, waste collection capacity, and electrical energy generation potential from the solid waste for Bhopal city are increasing with time. Adoption of the policy for electricity from the urban solid waste of Bhopal city should be dictated by the economy of adoption of the technology of electricity generation from the waste and the level of adverse environmental impacts. Uncollected waste, untreated waste, composite index and public concern are increasing with time. Uncleared non-recycling is increasing rapidly but the uncleared recyclable waste and recyclable stock waiting for recycling are increasing gradually with time. With the current trend of fund allocation for USWM of Bhopal city, it is not possible to manage the solid waste. More funds are required to mitigate the shortage of trucks and to meet the cost of collection of all generated waste. If the current budget for USWM is used only for collection, the deficit budget for collection will improve, but a zero balance or surplus fund is not realized. Increasing collection capacity alone does not improve the environmental quality. An increase in the budget allocation for both collection and treating the wastes is essential for improving the environmental

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