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Evaluation of options for energy recovery from municipal solid waste in India using the hierarchical analytical network process

J.D. Nixon [a], P.K. Dey [b,*], S.K. Ghosh [c], P.A. Davies [a]

[a] Sustainable Environment Research Group, School of Engineering and Applied Science, Aston University, Aston Triangle, Birmingham B4 7ET, UK
[b] Aston Business School, Aston University, Aston Triangle, Birmingham B4 7ET, UK
[c] Mechanical Engineering Department, Centre for Quality Management System, Jadavpur University, Kolkata 700032, India

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A B S T R A C T

In this paper a Hierarchical Analytical Network Process (HANP) model is demonstrated for evaluating alternative technologies for generating electricity from MSW in India. The technological alternatives and evaluation criteria for the HANP study are characterised by reviewing the literature and consulting experts in the field of waste management. Technologies reviewed in the context of India include landfill, anaerobic digestion, incineration, pelletisation and gasification. To investigate the sensitivity of the result, we examine variations in expert opinions and carry out an Analytical Hierarchy Process (AHP) analysis for comparison. We find that anaerobic digestion is the preferred technology for generating electricity from MSW in India. Gasification is indicated as the preferred technology in an AHP model due to the exclusion of criteria dependencies and in an HANP analysis when placing a high priority on net output and retention time. We conclude that HANP successfully provides a structured framework for recommending which technologies to pursue in India, and the adoption of such tools is critical at a time when key investments in infrastructure are being made. Therefore the presented methodology is thought to have a wider potential for investors, policy makers, researchers and plant developers in India and elsewhere.

1. Introduction

Rapid development in India has led to severe problems with managing Municipal Solid Waste (MSW). The management of MSW is complex due to its variable composition, which depends on local demographic and their habits. In developing countries such as India, MSW's complex nature is exacerbated by the fact that additional waste streams from industries, agriculture and hospitals often end up being combined in the solid waste mix. While rapid population growth and urbanisation have resulted in increasing demands for energy services, several areas of rural India still remain un-electrified and even those areas with access to electricity may still suffer from regular blackouts.

In 2006, India produced 90 million tonnes of solid waste and this is expected to increase to 300 million tonnes per annum by 2047 [1]. Despite the introduction in 2000 of the MSW Management and Handling Rules, the collection efficiency of MSW in India is still only about 70% and waste is primarily disposed of through dumping and landfill, around 90% of which is unsatisfactory [2,3]. Some regions even have no collection procedures in place at all due to inhabitants being unwilling or unable to pay. This has given rise to numerous social and environmental issues including pollution from heavy metals, land usage, hazardous and infectious wastes, and leachate and air pollutants as landfill sites usually lack gas monitoring and collection systems [4]. Thus there is an urgent requirement to improve waste prevention and segregation, and to increase MSW energy recovery projects that reduce waste mass and volume, alleviate health hazards from pollution, and provide valuable energy services.

In Europe around 40 million tonnes of MSW is incinerated a year for thermal and electrical generation, 130 million tonnes of MSW is combusted annually worldwide [5]. The estimated potential for energy recovery from MSW in India is 1700 MW; however in 2009 projects totalled a mere 34 MW [6]. India's primary energy consumption mix in 2010 consisted of coal (52.96%), Oil (29.66), natural gas (10.63%), hydro-electric (4.81%), nuclear (0.99%) and renewables (0.95%) [7]. With a poor renewable energy contribution and a heavy reliance on fossil fuel imports, which are rapidly increasing in price, India faces growing concerns over its energy security and sustainability [8]. The MSW composition and

* Corresponding author. Tel.: +44 121 204 4011.
E-mail address: p.k.dey@aston.ac.uk (P.K. Dey).

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generation per capita for a variety of regions of India have been report in the literature [9–12]. The problem for India is that the composition of MSW has a higher moisture and organic fraction than in western countries, making conventional waste-to-energy (incineration) plants unsuitable [13]. There are however many established and emerging energy recovery technologies which are being promoted by municipal authorities. Technologies include incineration, anaerobic digestion (AD), landfill gas, pyrolysis and gasification. Some of these technologies are the subject of considerable R&D spurred also by increasing use of biomass for energy. Downstream there are also many uses for the energy outputs e.g. electricity, combined heat and power, tri-generation and waste-derived fuels. To encourage the development of MSW recovery projects in India a number of subsidies and additional incentives are now in place [14]. The market share for MSW treatment and disposal technologies in India in 1997 was 50% composting, 30% anaerobic digestion, 10% pelletisation and 10% sanitary landfill [15]. However in 2003 it was reported that 315 MW of power generation from the gasification of MSW was under development [16].

As the technological alternatives for generating electricity from MSW grow in number and complexity, so are the strategic decisions required for the effective evaluation and management of these sustainable energy schemes. As a result, Multi-Criteria Decision-Making (MCDM) methods are becoming popular tools to use in sustainable energy planning and environmental decision making, as reviewed in Refs. [17–19]. These tools are already well established in the traditional energy sector [20].

Structured decision-making methods have been used in the field of waste management by a number of authors. Galante et al. [21] used a fuzzy goal programming and multi-objective approach for the design of an integrated solid waste management system in Palermo, Italy. Goal programming has also been used to optimise the management of computer waste flow streams in India, a growing issue in developing countries [22]. Minciardi et al. [23] developed a non linear multi-objective model to optimise the flow of waste to alternative treatment plants in Genova. Contreras et al. [24] used the Analytical Hierarchy Process (AHP) to select between different waste management plans to implement in Boston, USA. Similarly, Hokkanen et al. used ELECTRE to choose between solid waste management schemes in Finland [25]. Multi-criteria methods such as the AHP have also been integrated with Geographical Information Systems (GIS) for the site selection of landfills and waste management facilities [26,27].

The AHP, developed by Saaty [28], is the most popular MCDM technique and has been widely adopted for technology evaluation and selection in the renewable energy sector [29–31]. Another emerging decision-making method is the Analytical Network Process (ANP), which is an extension of the AHP to consider interdependencies between decision attributes, thus improving the accurate modelling of complex decisions. The ANP was also developed by Saaty and is described in detail in Ref. [32]. Sipahi and Timor [33] give an overview of applications of the AHP and ANP. They predict that ANP will grow in popularity as the benefit of the network approach becomes better understood for dealing with real world situations, especially in developing countries. Wolfslehner et al. [34] compared the AHP and ANP processes for the selection of a sustainable forest management scheme; they also highlighted the advantage of ANP in strategic decision making. Several authors have also adopted a Hierarchical Analytical Network Process (HANP) model [35–37] and introduced advanced fuzzy logic [38]. While these approaches add additional complexity to an analysis, they improve the reliability of subjective information which can otherwise be uncertain or vague.

The ANP has indeed grown in popularity in recent years being used for a variety of applications in the field of sustainability and has been validated in numerous market-share case examples [32]. Meade and Presley [39] used the ANP to select between alternative environmental R&D projects. Erdoğmuş et al. [40] and Köne and Büke [41] used the ANP to select between alternative fuels for domestic heating and electricity generation in Turkey. Atmaca and Basar [42] and Ulutaş [43] applied ANP using the software Super-Decisions for selecting a power source for Turkey. In the field of waste management, ANP has been utilised for evaluating alternative countermeasures for site remediation [44] and for landfill site selection [45]. Khan and Faisal [46] used the ANP to evaluate three alternative integrated waste disposal scenarios for India by considering landfill, composting and incineration.

Nevertheless, there are a number of additional options for disposing of MSW and generating electricity in India, which have not been adequately researched. Therefore the aim of this study is to demonstrate the use of an HANP method for systematically evaluating alternative technologies for generating electricity from MSW, and thus make a contribution to the effective management of waste and provision of energy services in India. Specific objectives of the study are to review the status of the technological alternatives in India, outline suitable evaluation criteria, and carry out and examine an ANP study to identify the preferred technologies for generating electricity from MSW.

The methodology developed to achieve these objectives is outlined in the following section. In Section 3 a short technology review is provided on bio-energy conversion technologies for generating electricity from MSW. Section 4 provides details on an HANP analysis that has been conducted to evaluate and rank these alternative technologies. In Section 5 a sensitivity study is performed to examine the HANP results. Section 6 compares the findings from the HANP with those obtained from an AHP analysis. These results are then discussed and recommendations are made for energy recovery from MSW in India and further works using HANP in the energy sector.

2. Methodology

This study adopts both primary and secondary research methods. A structured literature review is carried out to characterise the technology options for generating electricity from MSW in India. An output of the review is a shortlist of technology alternatives and elevation criteria (grouped into clusters of technical, financial, environmental and risk). To establish subjective priority weightings for the criteria, a questionnaire is developed and delivered to five participating experts working within the Mumbai, Nagpur and West Bengal Municipal Corporations, Jadavpur University and the Government of West Bengal, Municipal Affairs Department. An HANP analysis is then completed using Super-Decisions® (Creative Decision Foundation, USA), a software tool for performing ANP/AHP decision studies. Pair-wise comparisons are performed using a combination of the literature review and questionnaire results. As an output, a ranking order of preference is established for the alternative technologies. To examine the sensitivity of the result, the criteria weighting are varied to determine potential changes in the ranking order. Variations among different MCDM methods are also investigated be conducting an AHP analysis for comparison.

3. Technology review

The purpose of this review is to assess the main technologies applicable to energy recovery from MSW and to research factual information relating to their use in India (units are presented in US dollars, converted from Indian Rupees (INR) at a rate of 0.018). Technologies for generating energy from biomass fall into two