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Electricity generation and GHG emission reduction potentials through different municipal solid waste management technologies: A comparative review

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ABSTRACT

The increasing trend in the consumption of various materials has also led to a huge increase in the final waste streams especially in the form of municipal solid waste (MSW) and the consequent environmental pollutions in particular greenhouse gas (GHG) emissions. These have made MSW management a significant environmental issue for governments and policy-makers. To address these challenges, developed countries have implemented sustainable material management (SMM) strategies which have been comprehensively reviewed herein. Moreover, waste generation statistics reported for most of the developed and developing countries as well as the existing gaps in MSW management among these countries have been fully discussed. The present paper was also aimed at comprehensively assessing electricity generation potentials from MSW using an integrated solid waste management system (including three different technologies of anaerobic digestion (AD), incineration, and pyrolysis-gasification) while the consequent GHG emission reduction potentials as a result of their implementation were also explored. To facilitate the understanding of the potential impacts of these treatment strategies, Iran's data were used as a case study. More specifically, the theoretical and technical potentials of electricity generation were calculated and the GHG emission reduction potentials were estimated using a life cycle assessment (LCA) approach. Overall, it was found that 5005.4–5545.8 GW h of electricity could be generated

Abbreviations: GHG, Greenhouse gas; MSW, Municipal solid wastes; SMM, Sustainable materials management; AD, Anaerobic digestion; LFG, Landfill gas; WTE, Waste to energy; ISWM, Integrated solid waste management; USA, United States of America; EPA, Environmental Protection Agency; MW, Megawatts; RCRA, Resource conservation and recovery act; C & D, Construction and demolition; EU, European Union; GGAS, Greenhouse gas abatement scheme; ACCU, Australian carbon credit units; LAC, Latin America & the Caribbean; GDP, Gross domestic product; LP, Linear Programming; UK, United Kingdom; LCA, Lifecycle assessment; USD, United States dollar; PAHs, Polycyclic aromatic hydrocarbons; PE, Polyethylene; PS, Polystyrene; PVC, Polyvinyl chloride; PET, Polyethylene terephthalate; G-PI, Gasification with Plasma gas cleaning; FP-C, Fast pyrolysis and combustion; G-SC, Gasification with syngas combustion; MW h/day, Megawatt hour per day; GIS, Geographic information system; Ptheoritical, Theoretical potential; Pdegradable, Potential of the degradable fraction; Pdry, Potential of the fraction with high heating value; HHV, high heating value; Pdry-inc, Potential of the dry fraction with high heating value for incineration; Pdry-pg, Potential of the dry fraction with high heating value for pyrolysis–gasification; Pthechnical, Technical potential; CHP, Combined heat and power; Ptechnical-AD, Technical potential of AD technology; GGAS, Greenhouse gas abatement scheme; Ptechnical-pg, Technical potential of pyrolysis–gasification technology; Sc, Scenario; FU, Functional unit; LCI, Life cycle inventory; LCIA, Life cycle impact assessment; Pdry-inc, Global warming potential

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from MSW in Iran annually which could lead to approximately 3561–4844 thousand tons of avoided CO_2eq. Such GHG reductions would be translated into approximately 0.5% of Iran's annual GHG emissions and would be considered a promising achievement given Iran's international GHGs reduction commitment, i.e., 4% reduction of anthropogenic GHGs emissions by 2030 below the business as usual scenario. Such findings could also be modeled for the other developing countries around the world where efficient MSW management is yet to be implemented.

1. Introduction

Growing global population, rapidly-increasing urbanization, as well as vast industrial and economic developments have collectively led to increased consumption of various commodities such as food, minerals, metals, plastics, wood products, etc. This increasing trend in consumption is believed to continue to accelerate, while simultaneously shifting away from renewable resources like agricultural and forestry products toward non-renewable resources such as fossil fuel-derived and metal products [1]. Moreover, various practices involved in the supply chain of these materials, i.e., extraction, harvesting, processing, transportation, and waste disposal have resulted in a variety of environmental pollutions especially greenhouse gas (GHG) emissions [2,3]. This is in fact ascribed to the energy and/or resources required during various life cycle stages of these commodities.

Overall, this increasing trend in consumption of materials has led to a huge increase in final waste streams especially in form of municipal solid waste (MSW) and hence, MSW management is considered a significant environmental issue for governments and policy-makers [4]. For instance, in the year 2012, approximately 1.3 billion metric tons of MSW were generated globally, and this amount is expected to rise to approximately 2.2 billion tons by the year 2025 [5].

It should be noted that at the first glance, waste management might seem a bit irrelevant to materials consumption, however, formerly called MSW management reports and strategies are now emerging as sustainable materials management (SMM) reports and strategies which also includes consumption features [6]. More specifically, SMM refers to how material resources should be managed as they flow through the economy, from extraction or harvesting of materials (e.g., mining, forestry, and agriculture), to production and transport of goods, and finally to the use and reuse of materials, and, if necessary, disposal. In line with that, waste management through sustainable management strategies such as source reduction and reuse, recycling, and energy recovery could play an important role in the SMM.

“Source reduction and reuse” aims at achieving waste minimization and thus, reducing the amount of waste entering the waste stream [7]. This option is an essential prerequisite for any waste management strategies as well. “Source reduction and reuse” also includes preventing/enforcing acts to ensure optimized utilization of energy and resources throughout the upstream activities of materials production. An example for this option is the “lightweighting” of beverage cans which could result in less aluminum usage while maintaining the same function; or reusing half-printed papers in printing which could ultimately cause additional carbon sequestration in the forests through reduced tree harvesting [3,8]. Overall, “source reduction and reuse” could offer several advantages such as saving natural resources, conserving energy, reducing pollution of upstream activities, reducing the toxicity of waste, and finally saving both consumers and producers their hard-earned dollars [8].

Through “recycling” of a specific amount of a given material, environmental emissions associated with its re-fabrication from virgin inputs could be avoided. However, there is a necessity to use efficient recycling systems in order to maximize the environmental and economic benefits of recycling [8]. By considering this, recycling could offer numerous advantages including preventing the emission of a great deal of GHGs and water pollutants, energy savings, further develop-

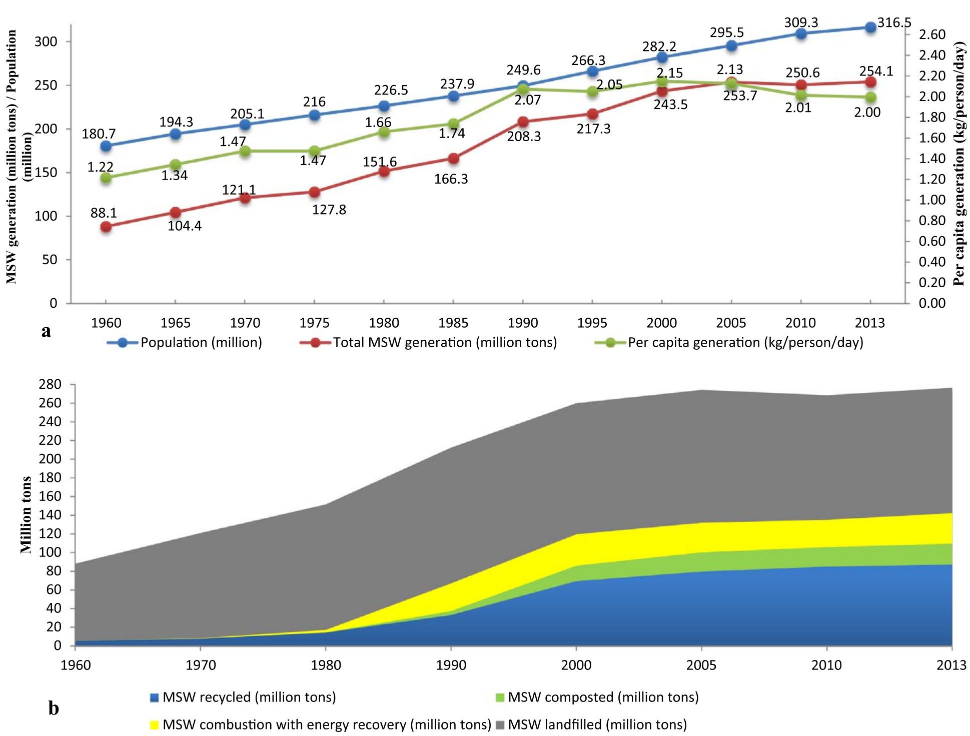

Fig. 1. a) Population (in million), total MSWs generation (in million tons) and MSWs generation per capita (kg person^{-1} day^{-1}) in the USA (1960–2013). b) Changes in the contribution of different MSWs treatment options in the USA (1960–2013).