Estimation of biogas potential in Indian communities using a Geographic Information System combined with Material Flow Analysis

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Keywords: Anaerobic digestion, municipal solid waste management, energy, sustainable development goals

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Abstract

Anaerobic digestion (AD) of municipal solid waste (MSW) for biogas production is interesting for India due to warm climatic conditions in many regions – favouring fast microbial degradation – and a high organic fraction in Indian MSW. Nevertheless, large-scale AD of MSW has not yet been successfully implemented in the country, according to Government sources due to lacking planning capabilities and inaccurate expectations about quality and quantity of substrate supply from MSW. To help overcoming this barrier, we here present an approach to estimate substrate supply and biogas potential in Indian communities using open source Geographic Information System (GIS) and Material Flow Analysis (MFA) tools. Based on publicly available data, field sampling and biochemical methane potential (BMP) tests, promising waste streams are identified and quantified.

Introduction

Rapid urbanisation, population growth and industrial development have led to a number of challenges in India. Thousands of tons of MSW are generated daily with mostly lacking comprehensive MSW management (MSWM), threatening ecosystems and ecosystem services for society, such as clean water. Challenges in energy supply are increasing, requiring sustainable solutions. Incineration and AD of organic waste are available waste-to-energy technologies to harness energy from MSW. AD uses organic substrates such as the biodegradable fraction of municipal solid waste to produce biogas with ca. 50-75% of methane (ca. 38 MJ m^{-3} at 0 °C and 1013 hPa, Wellinger *et al.*, 2013). As a by-product, the solid-liquid slurry can be used as organic fertilizer (Nkoa, 2014). AD could thus contribute to achieve several Sustainable Development Goals (SDGs) including renewable energy supply (SDG7), food safety from organic fertilizer supply (SDG2), and decrease in deforestation, land-use change induced greenhouse gas emissions and gender disparities from firewood collection by young women (SDG15, 13, 5). Simple small to medium scale AD has been successfully applied in India with 4.3 million household scale digesters fed with manure (Government of India, 2016). While some medium scale AD plants are operated in India, no successful large-scale plants for MSW exist (Government of India, 2016). The quantity and composition of organic waste in communities, including MSW and agricultural residues, varies in space and time and it is important to understand the sources, composition and patterns of waste for AD.

Materials and methods

Biogas potential from organic waste was estimated in Pachgaon *Village* with ca. 4'400 inhabitants, Ambernath *Town* with 253'500 inhabitants and Nagpur *City* with 2'405'700 inhabitants in 2011 (population numbers from Government of India, 2011) in the Indian state of Maharashtra using the open source Geographic Information System QGIS (www.qgis.org) in conjunction with the open source Material Flow Analysis tool Stan (http://stan2web.net). First, geographic system boundaries were delimited in QGIS using official municipality documents. Second, land cover was mapped using data of the National Remote Sensing Centre (NRSC, 2016) and area covered by different land cover classes calculated in QGIS. Third, organic waste occurrence and its theoretical biogas potential were estimated based on area covered by different land use classes combined with data on population (Government of India, 2011), MSW generation and composition per capita and year (MMRDA and NEERI, 2011) and agricultural statistics provided by the International Crops Research Institute for the Semi-Arid Tropics (ICRISAT, 2016). Potentially available residues per unit crop yield - excluding proportions used for cattle feeding or left on the fields for soil enhancement - were taken from Hiloidhari *et al.* (2014). Fourth, the methane potential of these organic wastes was calculated using biogas yields from literature (Wellinger *et al.*, 2013) and results from on-going biochemical methane potential assays of local substrates (Breitenmoser *et al., in prep.*). Fifth, the MSWM system was conceptualized in MFA based on available reports (MMRDA and NEERI, 2011) as well as interviews with municipality officials.

Results and discussion

The biogas energy potential expressed per person and year was estimated between 440-1'300 MJ cap^{-1} yr^{-1} in Pachgaon *Village*, 290-970 MJ cap^{-1} yr^{-1} in Ambernath *Town* and 200-800 MJ cap^{-1} yr^{-1} in Nagpur *City* (Figure

1, left panel), which was in the range of 1-5% of the average annual per capita energy requirements in India (World Bank, 2013). The wide range of values was due to uncertainties related to organic waste occurrence and methane potential per unit (e.g. per capita or area) and time. In the city and town, residential waste and commercial waste (mainly food waste from restaurants) combined constituted between 55-80% of the biogas energy potential, whereas this was only 5-10% in the village. As seen in the example MFA in Figure 1 (right panel), residential and commercial organic waste was mixed with a non-biodegradable fraction when collected, requiring a segregated collection or a less favourable segregation of mixed waste. Market waste had generally little impurities and could make up 5-15% of the biogas energy potential. Agricultural residues were particularly important in the village with 85-90% of the biogas energy potential, but were also significant in the town 20-40% and city (5-15%, Figure 1, left panel).

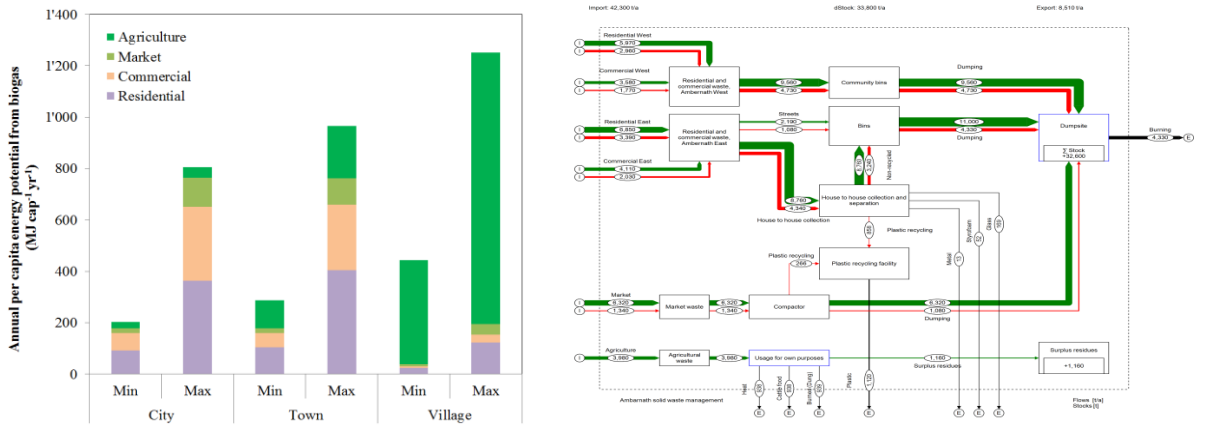

Figure 1. Left panel: annual per capita energy potential from biogas (MJ cap^{-1} yr^{-1}) in the case study city, town and village in Maharashtra; right panel: example MFA for Ambernath *Town* with organic (green) and inorganic flows (red) in tons wet weight per year

Results presented here indicate that AD can play a role in MSWM in Indian communities potentially contributing up to ca. 5% of the average per capita energy consumption. Particularly the direct thermal use of biogas should be considered, e.g. for cooking. Stakeholder events conducted in the case study communities have confirmed the ranges of organic waste occurrence estimated using the approach presented here. Resulting GIS maps and MFAs are currently being used to propose and discuss possible organic waste-to-energy scenarios with local stakeholders. Generalization of the approach for other areas in India is easily possible due to the inclusion of publicly available data.

***Acknowledgements**: The study received funding from the Swiss National Science Foundation and the Indian Department of Science and Technology under the Indo Swiss Joint Research Programme (ISJRP) 2013-2016.*

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