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Economic and environmental evaluation of climate change mitigation measures in the waste sector of developing countries

Aleksandar Dedinec [a,*], Natasa Markovska [a], Igor Ristovski [b], Gjogi Velevski [c], Verica Taseska Gjorgjievska [a], Teodora Obradovic Grncarovska [b], Pavlina Zdraveva [c]

[a] Research Center for Energy, Informatics and Materials, Macedonian Academy of Sciences and Arts (ICEIM-MANU), Krste Misirkov 2, 1000 Skopje, Macedonia
[b] Ministry of Environmental and Physical Planning, Climate Change Department, Goce Delcev, 1000 Skopje, Macedonia
[c] UNDP Project Office "Third National Communication to UNFCCC", 3rd Makedonska Brigada 10A, 1000 Skopje, Macedonia

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ABSTRACT

According to the IPCC Fourth Assessment Report, the mitigation potential of waste sector in developing countries is three times higher than the one of developed countries, which highlights the role of this sector for mitigation action in the developing world. In this paper, the analytical framework for assessment of climate change mitigation potential of waste sector, which is based on GHG Costing Model (GACMO), is adapted in order to incorporate the specifics of developing countries regarding waste generation, waste disposal and population growth. The methodology is further modified to generate marginal abatement cost curves based on achievable cumulative GHG emissions reduction (over the whole period), thus taking into account the timing of mitigation measure implementation. The adapted analytical framework is applied for the case of Macedonia's waste sector, evaluating the following four mitigation scenarios: Mechanical biological treatment (MBT) with an aerobic treatment (composting), MBT with an anaerobic treatment (anaerobic digesters with energy production), MBT with an anaerobic treatment-anaerobic digesters with energy production and refused derived fuel (RDF) utilization and MBT with an aerobic treatment (composting with RDF utilization). Each mitigation scenario includes also a gas extraction with flaring for the existing non-compliant landfills. The resulting marginal cost curve indicates a total achievable reduction of cumulative emissions for the period 2013–2030 of around 20 Mt, or nearly 80% lower than Business-As-Usual (BAU) waste sector cumulative emissions, at average specific reduction cost in the range 8.9–12.44 US$/t.

1. Introduction

The economic growth and the rise in living standards of the growing populations in many developing countries have been accompanied with an accelerated generation rate of Municipal Solid Waste (MSW). On the other side, often, the whole territory is not covered with waste collection system and separation and controlled selection are not put into practice. Furthermore, the main disposal methods include open dumping and sanitary landfilling without gas recovery, and in many cases, there is a public opposition and shortage of available land for disposal purposes. This has caused widespread illegal dump sand landfills without environmental standards around and in the sites (Menikpura, et al., 2013). The growing volume of waste and the inappropriate waste disposal, have been continuously pressing the environment, health and safety of the population and, at the same time, amplifying the share of developing countries MSW sector in total global anthropogenic Greenhouse Gases (GHG) emissions (third highest anthropogenic methane emission source) (Metz, et al., 2007).

Most of the developing countries are seeking practical solutions, such as rehabilitation of existing municipal solid waste disposal sites, sanitation and closure of illegal landfills, opening of modern regional landfills in accordance with the highest environmental standards, as well as landfill methane recovery, waste incineration with energy recovery, composting of organic waste, and recycling and waste minimization. The conducted literature review has shown that in most cases, the selection of the waste treatment

* Corresponding author.
E-mail addresses: dedinec@manu.edu.mk (A. Dedinec), natasa@manu.edu.mk (N. Markovska), igor.ristovski@gmail.com (I. Ristovski), velevski@gmail.com (G. Velevski), verica@manu.edu.mk (V.T. Gjorgjievska), dori.moeppgovmk@gmail.com (T.O. Grncarovska), pavlina.zdraveva@undp.org (P. Zdraveva).

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technologies is based on their cost effectiveness and contributions for meeting some locally, regionally or nationally imposed targets, while the criterion of climate change mitigation has not been explicitly taken into account and the associated methane emissions reduction is calculated as a co-benefit. For example, in a region of Malaysia, the optimal scenario for municipal solid waste management would be able to achieve the renewable energy target, achieve the recycling target and promote composting as the waste reduction alternative (Tan, et al., 2014). Furthermore, in Chile, landfill gas-to-energy, direct waste-to-energy and gas collecting were evaluated using the criteria of production cost, technical and economic potentials (Bidart, et al., 2013). In a recent study for China (Liu, et al., 2012), a pilot-scale anaerobic co-digestion research is presented to elucidate the feasibility of developing anaerobic digestion as an effective disposal method for municipal biomass waste, focusing on the system performance and biogas production, and then GHG reduction of anaerobic digestion was analyzed compared with landfill. Finally, in a study for Africa, the economic advantages of options for municipal solid waste composting against landfill gas recovery have been shown (Couth and Trois, 2012).

In light with the ongoing discussions on future climate regime and possible quantified commitments for developing counties, and having in view the significant role that waste sector could have in developing countries mitigation action, we argue that an appropriate methodological framework is needed for prioritization of waste management technologies and practices in developing countries, which, at the same time suit best the local socio-economic conditions and maximize achievable GHG reduction. Along this line, in this paper, the GHG Costing Model (GACMO) analytical tool (Callaway, et al., 1999), applicable for optimization of a mitigation strategy taking into account the environmental effectiveness (tCO_2 reduced) and economic effectiveness (US$/t CO_2 reduced) of the proposed mitigation measures, is adapted for application in a waste sector of a developing country. GACMO model usually is used for analyses where base year and target year are defined and only comparison between these two years is made. For example, in (Dedinec et al., 2013) it is used to assessment the climate change mitigation potential of the Macedonian transport sector in the year 2020, while in (Dedinec et al., 2012), the potential of renewable energy sources for greenhouse gases emissions reduction in Macedonia is estimated for the same year. Furthermore, the same methodology is used in (Markovska et al., 2008) in order to determine the economic and environmental effectiveness of wider spectrum of mitigation measures. The interventions in the methodology enable accountability for specifics of developing countries regarding waste generation, waste disposal and population growth. The methodology is further modified to generate marginal abatement cost curves based on achievable cumulative GHG emissions reduction (over the whole period) which, in difference to abetment cost curve generated for a given year, takes also into account the timing of mitigation measure implementation.

The adapted analytical framework is applied for the case of Macedonia's waste sector, evaluating the following four mitigation scenarios: Mechanical biological treatment (MBT) with an aerobic treatment (composting), MBT with an anaerobic treatment (anaerobic digesters with energy production), MBT with an anaerobic treatment-anaerobic digesters with energy production and refused derived fuel (RDF) utilization and MBT with an aerobic treatment (composting with RDF utilization). Each mitigation scenario includes also a gas extraction with flaring for the existing non-compliant landfills. This application has proved that the adapted GACMO methodology is an effective tool for generating a sound analytical base which contributes towards formulation of wise and well-informed waste sector policies, reflecting also the commitment for climate change mitigation.

2. Methodology

For calculation of the methane emissions from waste sector in developing countries two methodologies are used: Mass balance method (Tier 1) and First order decay method (Tier 2). The Tier 1 method calculates the annual methane emissions in certain year originating from the solid waste disposed in that specific year, and is applied for the period 2013–2030. In order to calculate the emissions from the undegraded waste from the past (1981–2012), Tier 2 method is applied, which is accountable also for the emissions originating from the waste disposed previously using half-life of methane decomposition from the years prior to observed year.

Both methods require the following input data:

- methane generation potential for the year $xL_0(x)$, calculated using the Eq. (1)

$$L_0(x) = [\mathrm{MCF}(x)*\mathrm{DOC}(x)*\mathrm{DOC}_F*F*16/12] \quad [\mathrm{Gg\ CH_4/Gg\ Waste}] \tag{1}$$

where:

MCF – Methane correction factor (for managed landfills 1, for unmanaged 0.6),
F – Fraction of methane in landfill gas (default value 50% taken from IPCC),
DOC – Degradable organic carbon, calculated with Eq. (2),
DOC_F – Fraction of degradable organic carbon dissimilated (default value from IPCC: 0.77)

$$\mathrm{DOC} = (0.4*A) + (0.17*B) + (0.15*C) + (0.3*D) \quad [\mathrm{Gg\ C/Gg\ Waste}] \tag{2}$$

where A, B, C and D are fraction of paper and textiles, garden, food and wood in MSW, respectively.

- total municipal solid waste generated in a year x (MSW_T)(Eq. (3)):

$$\mathrm{MSW}_T = P*W \quad [\mathrm{Gg/year}] \tag{3}$$

where P is number of population in certain year and W is annual amount of waste generated per capita [kg].

Using the Tier 1 method the amount of methane generated in certain year is calculated using Eq. (4):

$$\text{Annual CH}_4 \text{ generation} = L_0(x)*\mathrm{MSW}_T*\mathrm{MSW}_F \quad [\mathrm{Gg\ CH_4}] \tag{4}$$

where MSW_F is fraction of MSW disposed at SWDS in year x

For Tier 2 methodology, additionally needed is the methane generation rate constant (k), which depends on the time (t) taken for the DOC in waste to decay to half its initial mass (the “half-life”) as follows:

$$k = \frac{\ln 2}{t^{1/2}} \tag{5}$$