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Effect of a food waste disposer policy on solid waste and wastewater management with economic implications of environmental externalities

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ABSTRACT

In this study, the carbon footprint of introducing a food waste disposer (FWD) policy was examined in the context of its implications on solid waste and wastewater management with economic assessment of environmental externalities emphasizing potential carbon credit and increased sludge generation. For this purpose, a model adopting a life cycle inventory approach was developed to integrate solid waste and wastewater management processes under a single framework and test scenarios for a waste with high organic food content typical of developing economies. For such a waste composition, the results show that a FWD policy can reduce emissions by nearly ~42% depending on market penetration, fraction of food waste ground, as well as solid waste and wastewater management schemes, including potential energy recovery. In comparison to baseline, equivalent economic gains can reach ~28% when environmental externalities including sludge management and emissions variations are considered. The sensitivity analyses on processes with a wide range in costs showed an equivalent economic impact thus emphasizing the viability of a FWD policy although the variation in the cost of sludge management exhibited a significant impact on savings.

1. Introduction

Population growth and development coupled with limited land resources in urban areas have brought about challenges for decision makers to manage continuously increasing quantities of municipal solid waste (MSW). In developing economies in particular, MSW is characterized with a high organic fraction in excess of 60% compared to less than 30% in developed economies (World Bank, 2012; IPCC, 2006). This fraction can be diverted from the waste collection system by introducing a food waste disposer (FWD) at the household level, which direct the food waste stream towards the wastewater collection and management system (Iacovidou et al., 2012a). While effective in reducing the amount of MSW to be managed, FWDs remain controversial because of associated impacts related in particular to the generation of greater and stronger volumes of wastewater and sludge to be managed in addition to increased energy and water consumption, thus requiring scrutiny when proposed to minimize waste sorting or landfilling (Marashlian and El-Fadel 2005). The increase in wastewater biochemical oxygen demand (BOD), suspended solids (SS), and other nutrients due to the use of FWDs contribute to an increase in emissions during wastewater management, coupled with an increase in energy consumption and sludge generation for ultimate treatment and disposal contributing also to an increase in emissions (Iacovidou et al., 2012a).

Past efforts targeted the operational and feasibility of introducing a FWD policy into the MSW management system, with some work reporting on the effect of such a policy on the net carbon footprint (Table 1). The latter consists of the net emissions generated from the diversion of food waste to the wastewater and sludge treatment systems.

On the other hand, while several emissions' accounting models have been developed [such as IWM (EPIC and CSR, 2004); WARM (EPA/ICF, 2016); SIWMS (Hanandeh and El-Zein, 2010); EASTECH (Clavreul et al., 2014); EpE tool (EpE, 2013); IWM-2 (McDougall et al., 2001); CO2ZW tool (Itoiz et al., 2013), and the 2006 and 1996 IPCC models for National Greenhouse Gas Inventories], none was designed to assess the impact on emissions' inventory upon introducing a FWD policy into the MSW and wastewater (WW) management systems.

This study integrates these systems under a single framework model developed to evaluate the carbon footprint of introducing FWDs to reduce waste processing in the context of developing economies where the food waste fraction exceeds 60%. The results were then compared with a developed economy region with a

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Table 1
Selected studies assessing the FWD system.

Reference	Impact coverage	Reported impact of FWD
Battistoni et al. (2007)	Operational and economic	Positive
Bernstad et al. (2013)	Operational	Positive
Bernstad Saraiva et al. (2016)	Carbon footprint and energy	Positive
Bolzonella et al. (2003)	Operational	Negative/Positive
CECED (2003)	Operational	Negative
Constantinou (2007)	Operational and economic	Negative
De Koning and Van der Graaf (1996)	Operational and economic	Positive
Diggelman and Ham (2003)	Environmental and economic	Positive
Evans (2007)	Environmental and economic	Positive
Evans et al. (2010)	Operational and economic	Positive
Evans (2012)	Environmental and economic	Positive
Galil and Yaacov (2001)	Operational and economic	Negative/Positive
Iacovidou et al. (2012 a)	Operational and environmental	Positive
Iacovidou et al. (2012 b)	Operational and environmental	Positive
Jones (1990)	Operational	Positive
Kim et al. (2011)	Economic	Positive
Lundie and Peters (2005)	Environmental	Positive
Marashlian and El-Fadel (2005)	Operational and economic	Positive
Nilsson et al. (1990)	Operational	Negative
Raunkjaer et al. (1995)	Operational	Positive
Yi and Yoo (2014)	Environmental and economic	Positive
Wainberg et al. (2000)	Operational and economic	Positive

lower food waste fraction of 30%. The analysis was conducted while considering the economics of environmental externalities with a focus on sludge management and net emissions for potential carbon trading.

2. Materials and methods

2.1. Theoretical framework

Fig. 1 illustrates the model's framework linking the MSW and WW management systems upon the introduction of a FWD for grinding food waste and discharging it with the WW stream. The WW management system may consist of aerobic or anaerobic processes with several sludge management (SM) options including anaerobic digestion, composting, landfilling, incineration, or land application. On the other hand, the MSW management system include collection, transport, recycling, composting, anaerobic digestion, incineration/open burning[1], landfilling/open dumping[1]. The assessment targeted emissions, materials recovery (e.g. recyclables), by-products (e.g. compost), economic and environmental externalities, as well as energy produced or consumed across various stages. The model accounts for direct operational emissions arising from systems' operations such as onsite equipment and waste degradation, as well as indirect upstream emissions (inputs of energy and material) and indirect downstream emissions (such as savings related to energy and material substitution as well as carbon storage). Emissions are estimated in Metric Tons of CO_2 equivalent ($MTCO_2E$) with carbon dioxide (CO_2) having a 100-year global warming potential (GWP100)[2] of 1 as a reference, CO_2 biogenic of 0, methane (CH_4) and nitrous oxide (N_2O) of 34 and 298, respectively (IPCC, 2013).

2.2. Scenario definition: policy and economic analysis

The carbon footprint of introducing a FWD policy was examined in the context of developing economies characterized with a high food waste content (Table 2) with the objective to discern viable waste management scenarios with considerations to the economics of the main environmental externalities (i.e. sludge management) while targeting minimal landfilling and emissions' reduction for potential carbon credit trading. The tested scenarios encompassed several variables including (1) FWD market penetration rate of ~75%; (2) amount of food waste grinded at the household level of ~95%; (3) wastewater treatment (aerobic and anaerobic processes) and sludge management alternatives (anaerobic digestion, composting, incineration, or landfilling); and (4) upstream, operating-direct, and downstream (direct and indirect) emissions. A quantity of 4000 Tons/day of commingled MSW collected by a fleet of diesel powered vehicles[3] were considered with the waste composition presented in Table 2. The main scenarios were first tested with a waste composition typical of a developing economy characterized with a high food fraction in excess of 60%, and then compared to a typical developed economy waste with a food content <30%. The analysis also considered variations in waste collected under several scenarios (Table 3) with the food waste diverted from the MSW management to the WW system. Note that many other combinations of scenarios can be tested and only a few were selected for illustrative purposes. The scenarios that were tested are:

Baseline Scenario 1 (SB.1): *Collection/landfilling*. This scenario considers that all MSW is collected and landfilled (100%) with energy recovery from landfill gas (LFG).

Baseline Scenario 2 (SB.2): *Collection/Recycling/Composting/Land filling*. This scenario evaluates the potential to reduce the amount of MSW that is landfilled by recycling and composting instead of a FWD. Materials such as wood, paper, glass, metal, plastic, and textile are recovered for recycling (10%) and food waste fraction is composted aerobically (42%). The remaining waste stream (48%) is collected and landfilled.

Baseline scenario 3 (SB.3): *Collection/recycling/anaerobic digestion/landfilling*. This scenario also evaluates the potential to reduce the amount of MSW that is landfilled by recycling and anaerobic digestion instead of a FWD. Materials such as wood, paper, glass, metal, plastic, and textile are recovered for recycling (10%) and food waste fraction is digested anaerobically (42%) with energy recovery. The remaining waste stream (48%) is collected and landfilled with energy recovery.

Alternative Scenario 1 (SA.1): *Collection/landfilling/aerobic wastewater treatment/anaerobic digestion of sludge*. This scenario is an alternative for the baseline scenario SB.1 that considers the integration of a FWD for grinding food waste (42%) and discharging it with the WW stream for aerobic treatment while the sludge is treated using anaerobic digestion. The remaining waste stream (58%) is collected and landfilled.

[1] Still unfortunately practiced in many developing economies

[2] GWP_{100} are based on the fifth assessment report (AR5) of the IPCC (2013), whereby the values of non-CO_2 gases include climate-carbon feedbacks. Note that without the latter in response to emissions of the non-CO_2 gases, the GWP_{100} of CH_4 and N_2O is 28 and 265, respectively (climate-carbon feedbacks in response to the reference gas CO_2 are always included) (IPCC, 2013).

[3] Using an average of ~6 L/Ton of waste as the overall diesel fuel consumption per Ton of municipal solid waste collected and transported (adapted from Chen and Lin, 2008; Friedrich and Trois, 2013).

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