To dream or not to dream in Havana: multi-criteria decision making for material and energy recovery from municipal solid waste

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INTRODUCTION

Nowadays, landfills are the main final disposal method for municipal solid waste (MSW) in Cuba, harming human health, the environment, and the national economy (Lorenzo & Kalogirou, 2019). In Havana (the nation's capital), where ~27% of the country's total amount of MSW are generated, there is a great potential for material and energy saving from waste. However, selecting the best alternative for resource recovery from waste is a multicriteria decision-making process (MCDM) involving environmental, techno-economic, and social aspects. Aspen Plus is a powerful framework when dealing with process design, environmental and economic analyses. Meanwhile, the Analytical hierarchy process (AHP) (Saaty, 2008) has proven to be a robust decision-making tool for selecting the best waste management technologies. This work is aimed to select the most appropriate technologies for material and energy recovery from MSW in Havana by coupling process simulation and AHP tools.

MATERIALS AND METHODS

Seven scenarios were considered as treatment methods for the MSW generated in Havana. Each scenario comprised an integrated facility (IWTF) with material recovery (MRF) as the first step coupled with an energy recovery facility (ERF) of the refused waste in the second one. The ERFs considered two technologies: (*i*) thermochemical (i.e., combustion (Comb), gasification (Gas), hydrothermal carbonization (HTC)) and (*ii*) biological (i.e., anaerobic digestion (AD)). All the thermochemical ERFs were assessed with and without carbon capture (CC) considering two different solvents, monoethanolamine (MEA) in the post-combustion section (i.e., Comb+CC) and Selexol in the pre-combustion section (i.e., Gas+CC). The hydrothermal carbonization scenarios (i.e., HTC and HTC+CC) comprised the treatment of the organic fraction of MSW (OFMSW) followed by the gasification of the produced hydrochar. Likewise, only the OFMSW was considered as feedstock for the AD scenario. All scenarios were simulated in Aspen Plus® v10.0 and validated with data reported in the literature. A multiparameter comparison (i.e., technical, environmental, and economic) was also carried out. The best scenario selection was based on MCDM, which included those mentioned above and social criteria. The AHP considered quantitative criteria (i.e., simulation results), qualitative criteria (i.e., weighted by experts' criteria), and uncertainty criteria (i.e., risk analysis from Monte Carlo simulation).

RESULTS AND DISCUSSION

The MRF allows recycling 18.2% of the total MSW, from which glass showed the highest recycling rate (i.e., 43.7% of the total recycled materials). Figure 1 shows the results from the multiparameter indicators used to assess the IWTF scenarios. Overall, gasification and combustion outperformed the rest of the scenarios with energy savings of 517 and 511 kWh/t_{MSW}, respectively, leading to energy efficiency of ~26% in both cases (Figure 1a,b). In CC scenarios both, the energy savings and the efficiencies are lower compared to non-carbon capture scenarios. This is explained by an increase in the heat demand for the MEA regeneration (i.e., Comb+CC) and the power intensity of the Selexol process (i.e., Gas+CC, HTC+CC). In this regard, the HTC+CC showed the worst energy performance (only 233 kWh/t_{MSW} energy savings), importing 23.5 kWh/t_{MSW} electricity from the grid, and ~12% net efficiency (Figure 1b). Likewise, in the IWTF including the AD, ~14% energy efficiency was obtained, which is far below the thermochemical scenarios as was expected.

The environmental impact was given by the land requirement and the global warming potential (i.e., GWP in ton CO_{2eq}) measured as the total emissions of the integrated facility and those of the final disposal in landfills. The HTC+CC showed the highest GWP (1562×10^3 ton $CO_{2eq} \equiv 3.1$ ton CO_{2eq}/t_{MSW}) (Figure 1c), from which 94% corresponded to CH_4 emissions from the final disposal in landfills and less than 1% to the IWTF, similarly to AD.

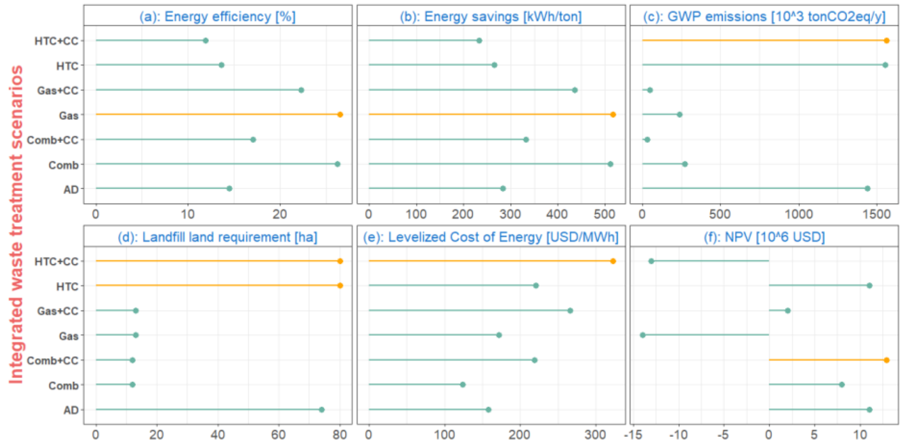

Figure 1. Multiparameter indicators of IWTF with energy recovery in Havana

An opposite trend was obtained for combustion and gasification where main emissions were given by the operation of the integrated facility, however, total emissions are much lower as significantly more waste is diverted from landfills. The latter also led to lower land requirements for final disposal in all combustion and gasification scenarios (i.e., 12 – 13 ha) compared to HTC and AD. This is because only a small fraction of the total OFMSW can be treated by these technologies, meaning that a considerable amount of waste must be sent to landfill with the corresponding land requirement.

The financial results showed that the most competitive scenario in terms of the Levelized Cost of Energy (LCOE) was Comb (i.e., 124 USD/MWh). Likewise, the high CAPEX and OPEX of HTC+CC scenario led to a non-competitive scenario for electricity generation. Overall, the Comb+CC showed the best economic performance (i.e., highest NPV= ~13 MMUSD), while HTC+CC and Gas resulted in non-profitable scenarios (i.e., NPV < 0) (Figure 1f). However, when CC is considered in gasification (Gas+CC) the small margin of profits by the concept of the CC led to a profitable scenario (NPV > 0) (Figure 1). The combination of lower CAPEX of the ERFs and the MRF section's income rates in the HTC and AD led to higher NPV compared to the Comb facility even when much less electricity is sold in the formers. Monte Carlo simulation for uncertainty quantification over the electricity price, the gate fee, and the CAPEX of the ERFs showed that the lowest risk among all the scenarios corresponded to the ERF with AD followed by the Comb scenario (data are non shown).

The AHP shows that environmental criteria had the highest priority (~63% and ~73% higher than society and techno-economic, respectively). Multiparameter indicators in figure 1 along with additional qualitative criteria were used to synthesize the hierarchy model for the MCDM as shown in Table 1. From Table 1, the best scenario for Havana would be an IWTF with AD, while Comb+CC and Gas+CC were ~98% and ~93% as good as the AD, reflecting the environmental concerns during the selection process over the rest of the parameters.

Table 1. Synthesized priorities for the selection of the best scenario

	Scenarios						
Priorities	**AD**	**Comb**	**Comb+CC**	**Gas**	**Gas+CC**	**HTC**	**HTC+CC**
Normal	0.1925	0.1156	0.1893	0.1178	0.1798	0.0920	0.1129
Ideal	1.0000	0.6000	0.9833	0.6120	0.9340	0.4779	0.5863

CONCLUSIONS

This study assessed different scenarios for material and energy recovery from waste in the city of Havana. The most energy-efficient scenario was gasification, but it was the most expensive and is therefore not economically feasible. The scenarios with the highest emissions and landfill land requirements were HTC and AD because a limited amount of OFMSW can be treated (i.e., 17 and 25%, respectively). The scenario of Comb+CC yielded the highest NPV, while the AD was the most appropriate alternative according to the MCDM and the APH model, reflecting the environmental and social concerns around the rest of the scenarios. The results obtained are valuable for decision-makers interested in investing in technologies that ensure proper waste management in Havana.

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