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Applying waste treatment scenarios in Toluca region (Mexico).

Nina Tsydenova[1*]

[1]Department of Environmental Economics, Carl von Ossietzky University of Oldenburg, Ammerländer Heerstr. 114-118, 26129 Oldenburg Germany
e-mail: nina.tsydenova@gmx.de

Abstract–*Governments in emerging countries need to analyse waste treatment alternatives, other than landfills, in order to decrease environmental pollution and socio-economic impacts. This study is assessing several alternative scenarios of waste treatment in Toluca municipality (Mexico) such as sanitary landfill, combustion of landfill gas, waste incineration (WtE), mechanical-biological treatment (MBT) and combination of anaerobic digestion (AD) and sanitary landfill under the condition of source waste separation. The objective of the research is the identification of the most feasible waste treatment scenario for developing countries which have the high percentage of organics on waste stream. The assessment is implemented from several perspectives: greenhouse gas (GHG) emissions, economic feasibility and consideration of informal recycling sector. The emissions generated at the baseline scenario are high due to the great percentage of organics in the municipal solid waste (MSW). The WTE and MBT facilities generate the lowest emissions but have a high gate fee. The scenario involving AD and sanitary landfill has the lowest gate fee while its emissions are significantly reduced compared to the baseline. The author believes that widespread adoption of AD systems, together with the source separation scheme, can be the starting point in the implementation of sustainable waste management in transition countries, such as Mexico.*

Keywords *– Assessment methods, waste management, anaerobic digestion, waste-to-energy, mechanical-biological treatment, sanitary landfill, climate change.*

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1. Introduction

The issue of finding alternative, environmentally-sound solutions to the waste problem and appropriate policy instruments has become increasingly salient. However, often decisions made in waste management in emerging and transition countries are influenced by the experts from developed countries a lot. This results in the application of waste solutions which do not comply with the local conditions. Often the local problems as integration of informal recycling sector, public acceptance and different from developed countries waste composition are not taken into account[1].That is why, the most important goal for developing nations is first, to identify the most appropriate and affordable waste treatment option which would consider not only the constrained financial resources but also would be approved of all interest groups involved. This is the problem of many developing countries and this study is trying to find solution to that.

This study is a response on the burgeoning literature that has developed investigating the feasibility of waste incineration technologies Latin American and Caribbean region (LAC) such as Guidebook for application of waste to energy technologies by [2]. There is number of studies which compare different municipal solid waste (MSW) treatment scenarios applicable to the conditions of transition countries, outweigh pros and contras of them, but generally they focus only on one technology or only one aspect[3][4][5]. On the contrary, this study is focused on the evaluation of the combination of indicators, therefore is in compliance with the local situation. This location was chosen based on available data from previous research of [2]and representing the situation in a transition country. The main goal of this study is to assist the decision-making for waste management projects, based on environmental and economic performance of different technologies. On the example of Toluca region it is advised to consider different parameters in order to identify the most affordable and applicable scenario, based on local conditions. The research method applied here unites both economic and environmental approaches: applying the following indicators: the climate change impact, depending on produced greenhouse gas emissions, and economic indicators, commonly used in feasibility studies, such as net present value (NPV) and internal rate of return (IRR). This research focuses on the following scenarios: (1) sanitary landfill, (2) landfill gas (LFG) utilisation, (3) WtE, (4) MBT with composting and (5) combination of AD plant and landfill. There have been a wide range of research papers comparing different waste treatment alternatives, such as [6][7][8][9][10][11]. However, an analysis similar to the one presented in this paper has not yet been made, since other waste treatment technologies were taken into account or other aspects were discussed.

This study has the strong focus on Mexico. However, it is assumed that the results can be also transmitted to other emerging economies. The average waste composition of developing countries in general is characterised by the higher percentage of organic waste which is based on the lifestyle pattern of the population. In high income countries people tend more to pre-cooked food, rather than home cooking, while the opposite is observed in developing countries. Therefore, the organic waste stream in industrialized states does not exceed an average of 30 %, while in emerging countries it can be much higher [12]. Mexico is a typical example of a transition country with the high percentage of food residues in residential waste generation. This tendency is observed for the last decades according to the analysis of [13]and waste composition presented in Figure 1.

2. Materials and Methods

2.1 Functional unit

This study is considering the treatment of one mega gram (Mg) of average residual municipal solid waste in Toluca (Mexico). This Mg of MSW is the functional unit of the research, which is treated in different ways.

The Toluca region was selected because it is a medium-sized city, which is representative for Latin America. Toluca is the capital of the State of Mexico, the state with the highest MSW generation in the country. Toluca has a total population of 489,333 inhabitants. The generation per capita of MSW in Toluca is 0.36 tons in 2009. An estimated 186,000 tons of MSW are collected annually. Residues are still not separated at the source, even though the 2007 Biodiversity Code states that citizens in the State of Mexico must separate their residues into organic and inorganic streams. There are no waste transfer stations in Toluca. All collected waste is disposed directly at the sanitary landfill[14].

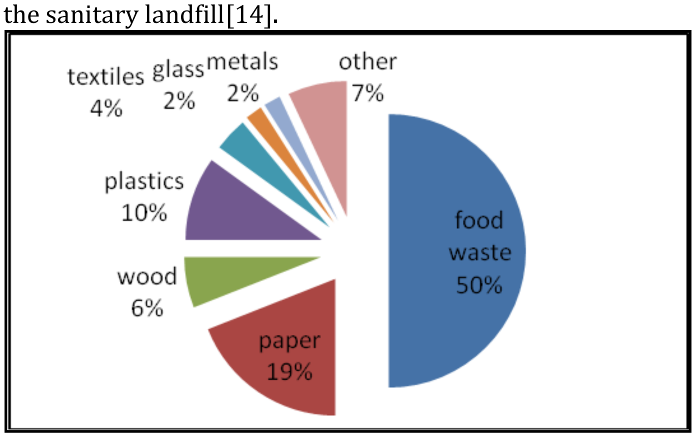

Fig. 1. MSW Composition in Toluca [14]

The main components are food scraps, paper and plastics, which make up 79% of the total weight. The potential energy production depends significantly on the waste composition. The percentage of organics is high (50%), which allows biogas production; however, at the same time, it causes the low heating value available for waste to energy technology.

2.2 Selection of technical alternatives

This research considers the following scenarios: (1) sanitary landfill, (2) landfill gas (LFG) utilisation, (3) WtE, (4) MBT with composting and (5) combination of AD plant and landfill. The first scenario was chosen as a base scenario, which presents business as usual scenario. The LFG scenario was considered to be the next upgrade step for the landfill, where the landfill gas is captured and burnt. The incineration and MBT plants were selected because these options are the most discussed options of sustainable waste management in developing countries[8][15][2]. The last scenario is considered to be the alternative for the others. Due to the high percentage of the food scraps, anaerobic digestion can be very beneficial through energy and fertilizer supply. According to [16], anaerobic digestion is the most favorable treatment option for organic waste through energy and fertilizer supply. However, this option requires the source separation scheme of waste at households. Officially this scheme is already introduced in the Toluca region.

2.3 Assessment of scenarios

2.3.1 Climate change impact

The climate change impact of each technology type is evaluated based on the GHG emission derived through the treatment of one MG of MSW. The calculations are made with the help of "Tool for Calculating GHG Emissions in Solid Waste Management" (SWM-GHG Calculator) developed by IFEU (Institute for energy and environmental research of Heidelberg).

The calculation method used in the SWM-GHG Calculator follows the Life Cycle Assessment (LCA) method. Different waste management strategies can be compared by calculating the GHG emissions of the different recycled and disposed waste fractions over their whole life cycle – from "cradle to grave". The tool sums up the emissions of all residual waste or recycling streams respectively and calculates the total GHG emissions in CO2 equivalents. The emissions calculated also include all future emissions caused by a given quantity of treated waste. This means that when waste is sent to landfill, for example, the calculated GHG emissions, given in Mg CO2eq per Mg of waste, include the cumulated emissions generated during waste degradation. This method corresponds to the "Tier 1" approach described in IPCC, 2006 [17].

2.3.2 Economic assessment

The economic assessment of different technologies uses the cash flow model to estimate the gate fee of the project which an operator needs to charge to cover the total treatment of the waste in the plant over the total operating period. Gate fee corresponds to dynamic prime costs which are the discrete total annual costs (capital costs and operating costs) accumulated over the calculated lifetime of the investment, discounted to year 1 of the investment, divided by the cumulated annual discounted total quantity of waste being treated over this period. The cash flow statement shows how much cash is generated and used by a project in a 20-year period. Cash inflows arise from electricity sale and the fee demanded for the waste treatment, while the outflows occur because of expenses and investments.

The costs for the construction and maintenance of the plants are based on the data from the Database of Waste Control, technology providers and[2]. The investment costs include construction work and all the needed equipment. The revenues of the plant are calculated taking into account the electricity sales and the gate fee of the plant. The price of electricity is estimated based on [2] and is €0.05 per kWh. The waste to energy scenario also includes the metal recovery sales. However, the following model has some constraints. The property costs are not considered.

In this case study, the net present value (NPV) approach is applied to estimate the gate fee under which the project is profitable. The IRR of 12% was considered the same as in the paper of [18]. The gate fee of each scenario represents the minimum price of 1 Mg of waste treatment in the facility reaching the break-even point, when the NPV is equal to zero. The debts are not considered in the model due to simplicity.

2.3.3 Informal recycling sector

This study also considers the conditions for informal recycling sector. The quote, "waste is a resource in the wrong place", used to describe the informal recycling sector in Bangladesh, is appropriate for the situation in Mexico as well[19]. Traditionally, small-scale picking, sorting and informal recycling of components in the landfill is tolerated by the municipalities because it leads to a reduction in the amount of waste. Informal recycling is also an important source of income for the urban poor and is tolerated by the local authorities. According to [20]the informal sector in Mexico is not controlled and enjoys considerable advantage in the absence of waste management regulation and induces inter alia the recycling inefficiency. But on the other hand, this huge sector should not be left without consideration. The abrupt change to some waste treatment technologies may affect the people who earn a living from recycling the landfill waste. Therefore, the study also discusses the change of conditions for informal recyclers.

2.4 Description of scenarios

2.4.1Scenario 1: Baseline scenario

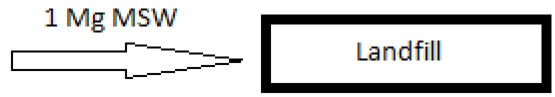

Fig. 2. Scheme of Scenario 1

In the first scenario, all MSW is sent to the sanitary landfill without further treatment. In Mexico, 66% of MSW is disposed of in sanitary landfills. Therefore, this scenario is the base scenario and used as a reference for other scenarios[2]. Sanitary landfill should fulfill the following basic conditions: compaction of waste and daily covering of waste, in order to prevent the influence of the environment and mitigate the negative impact of waste on the environment and public health[21].

According to the SWM-GHG Calculator, the base scenario produces 1,763 Mg CO2eq (Mg MSW)$^{-1}$. The gate fee is not calculated for this scenario, but is based on the value provided within [2]and makes up € 10.44 per Mg of MSW.

2.4.2Scenario 2: Flaring of landfill gas

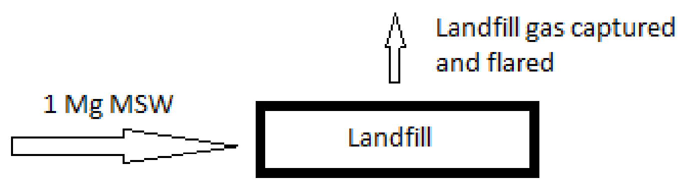

Fig. 3. Scheme of Scenario 2

In the second scenario, the waste is sent to the advanced sanitary landfill, which has the option to collect and burn the produced gas. Landfill design and operation contributes to the decomposition process. Generation starts after the first waste reception and can last up to 30 years after the landfill closes. The average composition of this landfill gas is about 50% methane (CH_4), 45% carbon dioxide (CO_2) and 5% nitrogen (N_2) and other gases [18].

Waste composition is the most important factor in assessing the LFG generation potential of a site. The maximum potential volume of LFG is dependent on the quantity and type of organic content within the waste mass, since the decomposing organic waste is the source of all LFG produced. Waste produced in LAC typically has higher organic content and moisture content than most North American or European waste and, therefore, would be expected to generate LFG at equivalent or higher rates [22]. Due to the moisture in the waste composition intended for landfill, gas production is high. In the discussed scenario, the collected LFG is not used for power production, but flared in the closed flare.

Therefore, based on the waste composition and collection efficiency of 85 % [23], the emissions of burning of landfill gas are 0.242 Mg CO2eq (Mg MSW)$^{-1}$.

The cost estimation of this scenario is based on the publication of [24], which considers the installation of landfill gas equipment in Astana (Kazakhstan). The costs in the article are applied for a landfill with the disposal rate of 270,000 Mg per year, which is close to the values considered in the scenarios of this article. The estimated gate fee for this scenario is € 16.5 per Mg of MSW.

2.4.3 Scenario 3: Waste to Energy

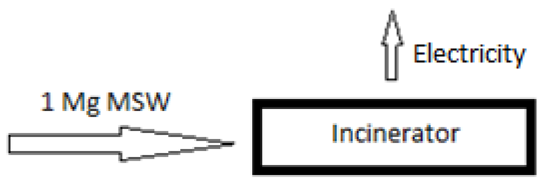

Fig. 4. Scheme of Scenario 3

In the third scenario, the whole fraction of MSW is burned in the incinerator. The incineration of waste with energy recovery is a widespread solution to waste problem. In the 80s and 90s, this way of waste treatment was strongly criticised due to the high emissions of air pollutants. Therefore, the strict emission limits were applied in this sector. The gas treatment technologies of new generation for air pollution control make the incineration made this technology attractive in developed countries [25].

The WtE plant is a controlled mass-burn grate incinerator, which burns at a temperature of 870-1200 ^{0}C, in order to produce high pressure steam for power generation. A grate furnace is chosen for this scenario due to its robustness. This type of incinerator can treat un-separated, heterogeneous waste [26]. The volume of waste is usually reduced by 70-90 % through the treatment. The ashes from the incinerator, about 10 % from the input, are usually dumped at the landfill and cause another environmental hazard[25]. However, in the proposed scenario, the incinerator ash is assumed to be used in road construction and, therefore, not cause any extra emissions. The research of [27], after carrying through the detailed LCA comparing incineration facilities in Italy and Denmark, came to the conclusion that the management of solid residues and recycling of metals generally do not contribute to the overall results. [28] stresses the same. [29]also highlight that bottom ash requires little treatment before landfilling and, thanks to the small organic part, has almost no emissions.

The data for the potential WtE facility is based on the article of[14]. The facility designed for Toluca is a single line of twenty Mg per hour capacity or 160 000 Mg per year. The net electricity production is estimated at 0.6 MWh per Mg MSW (96 GWh per year) and 12 MW of base load electricity to the grid. The heating value of MSW is 10.44 MJ/kg MSW as shown in Table 1. This is near the middle of the range of calorific values of WTE plants operating in Europe and North America (7 MJ to 14 MJ/kg).

Table 1. Calorific value of MSW in Toluca [14].

Waste composition		Calorific value of material (MJ/kg)	Calorific value of MSW (MJ/kg MSW)
food waste	50	4.6	2.3
paper	19	15.6	2.964
wood	6	15.4	0.924
Plastics	10	32.4	3.24
Textiles	4	18.4	0.736
glass	2	0	0
Metals	2	0	0
Other	7	4	0.28
Total	100		10.444

The emissions of the incineration process are estimated to be 0.059 Mg CO2eq (Mg MSW)$^{-1}$. They are so low due to the offset downstream electricity emissions. The average emission factor of electricity production in Mexico is 452 kg of CO2eq (MWh)$^{-1}$, according to the Ecometrica database. Therefore, the offset emissions represent 0.271Mg CO2eq (MG MSW)$^{-1}$ because the electricity production of the facility is 96 GWh per year.

The cost estimates of the WtE plant is based on the publication of[14]. Based on the cash flow for 20 years, the gate fee of €115.50 per Mg of MSW is calculated. It should be mentioned that subsidies from the government, sale of green certificates and heat sales were not considered in the study. The potential energy production of the whole waste in Toluca could reach 180 GWh per year under the current MSW generation conditions of 300 000 Mg. Also, the building of the WtE plant can advance the waste management in Toluca, but high initial expenses and running costs make the implementation of this technology questionable.

2.4.4 Scenario 4: MBT (composting)

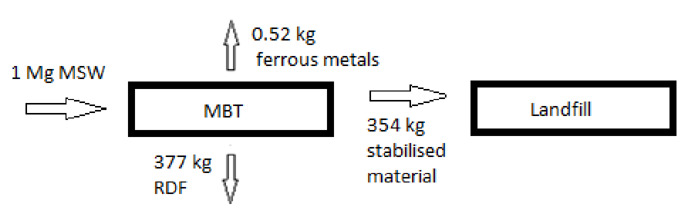

Fig. 5. Scheme of Scenario 4

In the third scenario, the whole fraction of MSW is sent to Mechanical Biological Treatment (MBT). MBT is defined as the combination of mechanical and biological treatment of MSW and aims to stabilize the organic components going to the landfill. Mechanical processes aim at opening bags, sorting the high calorific fractions and creating conditions for the biological step. The biological step considered in this scenario is aerobic stabilisation. The goal is the degradation of degradable components to carbon dioxide and water and the production of stable substances. MBT represents the alternative to landfill, which guarantees fewer emissions[30]. Furthermore, because MBT technology is a combination of different approaches, it is flexible and can be adapted to the circumstances on site[31].

The proposed MBT plant for the Toluca region has a capacity comparable to the WtE plant, at 200 000 Mg per year. The MSW is not pre-treated and is sent directly to the plant. The mechanical steps of the MBT process cause fuel consumption, due to the heavy machinery used for managing the waste which lead to the emissions in this scenario. The main gaseous emission from composting is biogenic CO2. Nevertheless, there is the possibility of CH4 generation in anaerobic pockets of the MBT piles where aeration is insufficient. But due to the recycling activities this scenario has negative emissions of - 0.285 Mg CO2eq (Mg MSW)$^{-1}$, which is significantly lower than that of WtE and landfill scenarios. Table 2 presents default emission factors for recycling used in SWM – GHG Calculator.

Table 2. Emission factors for recycling[17].

kg CO2 eq/ Mg Waste	Paper	Glass	Metals (steel)	Plastics
Emissions	180	20	22	1023
Avoided emissions	1000	500	2047	1437
Net result	-820	-480	-2025	-414

Based on the study of[30], the potential of 80% of the gas production reduction is achieved after 8 weeks of treatment. In this scenario, the option of using compost on land is not considered due to the mechanical step of the proposed MBT. The MBT plant in this scenario uses a screening drum in order to distinguish the organic part from inorganic, so every particle that is smaller than 90mm is considered to be degradable and is sent to composting [32]. This selection system does not guarantee that the hazardous materials are not composted; therefore, the end material of MBT production cannot be sent to the fields. This assumption is confirmed by the study of[29], which reports that the MBT plants in the Campania region of Italy generate two low-quality products: “dry fraction” and “humid fraction”, which cannot be recovered in the region and are, therefore, sent to the landfills and storage sites.

Concerning the economic analysis, there is no specific data available for the cost and revenue of the MBT technology, hence the numbers of the Database of Waste Control, which defines the initial and operational costs. Since the wide range of operational costs was considered in the database the cash flow was made both for the minimal operational costs of € 24 per Mg of MSW and maximum operational costs of € 81. Based on the cash flow for 20 years, the gate fee is € 96.3 and € 210.35 per Mg of MSW respectively.

2.4.5 Scenario 5: Combination of AD and landfill New Graph

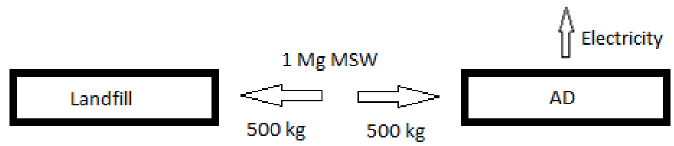

Fig. 6. Scheme of Scenario 5

The following scenario considers the source separated collection of MSW at the households, which is already prescribed in Toluca through the Biodiversity Act, but not fully implemented[2]. This scenario is possible under the condition that MSW is divided into degradable and non-degradable waste. The organic part goes directly into the anaerobic digestion plant, while the other waste is sent to the landfill. Thanks to the lower organic percentage, the emissions of the landfill are significantly reduced. The organic fraction is anaerobically digested, thereby leading to similar weight loss as that of aerobic digestion, but, at the same time, also recovering methane. The degradable part is stabilized without emitting any odour or pathogenic micro-organisms[29].

AD is a waste treatment that generates biogas and stabilised digestate, which can be used as a fertiliser on the fields. Depending on the type of substrate, sanitation can be provided by the AD process itself at thermophile temperature (40 °C) or by a separate pasteurization process, at a temperature of 70 °C. Anaerobic digestion is modeled as a production of 120 Nm3 of biogas of OFMSW with a gas composition of 60 % of CH4 and 40% CO2. The produced biogas is sent to power the engine. The electricity and heat needed for the operation of the plant is supplied by the plant itself.

The emission potential of the plant includes the following fields: biogas combustion, leakage of the AD plant and the avoided emissions due to the electricity substitution. Neither the heat production nor the emissions of the digestate applied on the fields is taken into account in this scenario. Based on the LCA of [7], the use of digestate does not have a significant environmental impact.

The emissions of the whole scenario, including the emissions of the landfilled, inorganic part and the offset emissions due to the electricity production, represent 1.054 Mg CO2eq (Mg MSW)$^{-1}$.

The economic analysis is made based on data from the technology provider. The sales of electricity are estimated based on the assumption that one Mg of organic fraction produces 454 kWh.

Based on the cash flow for 20 years, the gate fee of the whole scenario is calculated to be 23.02€ per Mg of MSW, under the condition that the food scraps go to the AD and the rest is sent to the sanitary landfill. It should be mentioned that no heat production is considered in the study. It is proposed that the disposal of the digestate is not charged, due to the fact that is can be used as a nutrient-rich fertilizer by the farmer responsible for the transfer of the final product. The gate fee of the plant is lower than in the previous scenarios, even though the emissions are not the lowest of all alternatives. However, the AD technology allows the supply of electricity.

This scenario implies the separate collection of food scraps and the rest waste, which increases the collection costs. Waste collection may reach 70% of the total waste management costs; therefore, they need to be considered in this study as well. Due to the lack of data, the collection costs are not calculated explicitly for Toluca, but the default number is given by [34]. 23.75€ costs the collection of 1 Mg MSW in Mexico without separate collection. According to[35], the total waste management costs increase by 75% with the introduction of a basic source separation scheme at the households. Therefore, the collection costs of this scenario are considered to be 41.56€.

3. Results and discussion

The analysis was carried out to compare the different waste treatment alternatives for the Toluca region in Mexico. The sanitary landfill was considered to be the baseline scenario, which is already implemented in Mexico. The other situations being discussed are utilisation of LFG, WtE, MBT and the combination of sanitary landfill and AD plant. The aggregated results of the study are presented in the table 3.

Table 3.Results.

	Sanitary Landfill	**Landfill Gas Flare without energy recovery**	**WtE**	**MBT min operational costs**	**MBT max operational costs**	**AD+SL**	
						AD	**SL**
Net emissions (MG CO_2eq(MG MSW)$^{-1}$)	1.763	0.242	0.059	-0.285	-0.285	1.054	
Gate fee (€)	10.44	16.50	115.5	96.31	210.35	27.58	
Collcection costs	23.75	23.75	23.75	23.75	23.75	42,56	
Total waste management costs	34.19	40.25	139.25	120,06	234.1	70.14	
Work for informal recycling sector	Yes (bad conditions)	No	No	No	No	Yes (improved conditions)	
Electrical output (kWh(MG MSW)$^{-1}$)	-	-	600	-	-	454	-

Based on the results of the study, a strategy of sustainable waste management for Toluca is suggested. The following goals have to be achieved: the impact of waste management on the environment and public health should be reduced and the proposed technology should be feasible. The suggested scenario is chosen based on these criteria.

Concerning the environmental impact, the results of the study show that MBT is the option with the lowest emissions, with – 285 Mg Co2eq per Mg MSW. The baseline scenario has the highest environmental impact, due to the large percentage of organic material in the waste composition. This also results in high nitrogen and organic carbon loads of landfill leachates. In the case of incineration, the organic fraction is mineralized; yielding hygienic bottom-ash, which can still, however, leach inorganic materials, salts and metals[29]. The scenario involving flaring of LFG has lower emissions level, but does not allow any electricity production. The AD scenario emits a lot due to the fact that 50% of MSW goes to the landfill. But only in this scenario the organic residue of the treatment suitable for further use as fertilizer on the fields, under the conditions of pasteurization. Therefore, it can be concluded that even though the AD technology does not guarantee the highest emission reduction, it is the only scenario that can assure the closed cycle of organic material.

The WtE and the MBT plants have the highest investment gate fees, being the most environmentally friendly. Emissions of LFG flaring and the level of gate fee are relatively small, but this scenario does not involve power generation of renewable energy sources. Moreover, this scenario is not perfect for the waste composition of developing countries, since the high organic percentage affects the quality of the produced gas. The scenario involving AD and sanitary landfill has the lowest gate fee among all waste management alternatives, allowing electricity production, while its emissions are significantly reduced compared to the baseline. Moreover, the last discussed scenario is considered to be the most feasible economically and extends the lifetime of the landfill. Those factors make the implementation of this scenario the most realistic option for developing countries which want to make first steps towards sustainable waste management and introduce source segregation at households. Nevertheless, AD is still an emerging sector in transition countries, the residual waste is treated by the combination of incineration, composting and landfilling[36]. The reason for this is the requirement of source separation scheme of waste collection at households. However, this scheme is already officially announced in the Toluca region. Unfortunately, the households do not follow these regulations. [37]report, only 11 % of the collected MSW to be separated in Mexico in 2015, as referred by the National System of Environmental and Natural Resources database. Therefore, it is believed that the local authorities should invest more in the proper application of the source separation of MSW. According to the study [38], the operational costs of separate food and waste collection may be offset against landfill costs. According to the assumptions made in the research, the separate collection costs would not influence the overall costs of waste management, since the last scenario still stays the most affordable one.

The scenario involving the AD plant and the landfill is beneficial for the informal recycling sector (scavengers). Due to the source separation, the scavengers have better conditions for work because the waste bags have significantly less wet biodegradable substances. It allows easier picking process. Without source segregation the recyclables are mixed with other refuse and hence damaged, and lose part of its value. Their recycling and sorting is a time and energy consuming activity which does not guarantee the high quality material. At household separated recyclables, clean and of high quality, can enhance the recycling process. Moreover, since the informal recyclers are often the “urban poor”, the better quality of recycables can strengthen their livelihoods and increase the employment opportunities[19]. Other scenarios, unfortunately, withdraw the chance to earn a living for waste pickers since the waste is sent directly to a treatment plant. Only the residues which contain less recyclables end up in the landfill. Therefore, the transition to technical solutions of waste management should be made smoothly, without direct closing of the landfills. The first step to value the work of scavenger is to consider them in policies and waste management planning.

4. Conclusions

The present study shows that replacing landfill by more advanced methods of waste treatment significantly reduces emissions of GHG as in case of scenarios 2, 3 and 4. But on the other hand, these scenarios imply high investment and operational costs, which is not feasible in most developing countries. The main conclusion of this research is to show that the input of advanced treatment technologies may bring environmental benefits, but also changes the whole waste management system, excluding informal sector which exists in developing countries. Therefore, the waste treatment methods should not be just copied from industrial countries but be suitable for the local waste composition, stakeholders involved and budget available.

5. Acknowledgement

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