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Identifying the full cost to landfill municipal solid waste by incorporating emissions impact and land development lost opportunity: Case study, Sharjah-UAE

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ABSTRACT: *This research was carried out to calculate the total cost of municipal solid waste disposal in the Emirate of Sharjah in the United Arab Emirates. Waste management in Sharjah is centralized and, disposal fee is believed to be very low. To unveil the waste disposal total financial impact, waste transportation, landfill equipment Carbon footprint and Landfill gases was calculated and added to the total operational cost. For the first time, lost opportunity caused by using the land to dispose waste was quantified and included in the total cost as well. The results showed that current disposal fee covers only 34.5% of the total cost. It was also concluded that Sharjah will not be able to finance it's future projects to extract landfill gases and provide other maintenance work, required to ensure safe closure for the coming years. The research concluded that Sharjah may have no choice but to excavate the waste from current location and move it to another one due to the urban development pace around landfill area. By implementing the proposed disposal cost method, waste disposal fee increases by the time considering the increase in the land value until the moment land value becomes equivalent to the expenses to remove all the deposited waste and move it to a newly built landfill. The municipal waste disposal fee in Sharjah for 2021 is recommended to be increased from US $13.61/ton to a minimum of US $39.77/ton.*

KEYWORDS – *Waste, disposal fee, Carbon emissions, landfill, remediation*

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I. INTRODUCTION

The world is in continuous fight to stop waste accumulation in landfills. Individual initiatives taken by organizations, countries and unions made a big change and still have a lot to be done. Europe is perceived as the most advanced in waste avoidance and minimization. It is obvious that European Union (EU) took specific and systemized regulatory actions to achieve high waste avoidance and recycling results, and enthusiastic EU member states voluntarily imposed more strict rules in this regard.

1.1 EU path to reduce waste landfills.

During the last 20 years, the European Union (EU) continued to pursue waste disposal reduction strategy by reorienting waste flow from landfills towards alternative processes to exhaust reuse, reclamation, and recycling potentials, followed by the extensive use of alternative fuel and energy production from the remaining residues prior to disposal (The European parliament and the council, 2006). The new waste management (WM) hierarchy positions the disposal stage to be the last sanctuary after all prevention measures been taken before a substance becomes waste. Another way to enforce waste diversion from landfills is obliging to re-use products or components several times for the same purpose, Preparing products by cleaning, checking, and repairing, recovery operations after which products can be used again, recovering material out of waste for another process to produce final products and recycling by reprocessing secondary raw material (SRM) into products whether for the original or other purposes (The European parliament and the council, 1999). Many European countries went further to ban the disposal of biodegradable waste based on the total organic Carbon content (TOC) in the waste (cewep, 2017). In 2018, new targets for packaging waste were adopted: to achieve a minimum recycling rate by weight of all packaging waste of 65 % by the end of 2025 and a minimum of 70 % by the end of 2030 (European court of auditors, 2020). The European commission decided to introduce new rules that will impose a ban on selected single-use products made of plastic for which alternatives exist on the market and enforce measures to reduce consumption of food containers and beverage cups made of plastic (European Commission, 2019). The understanding of Municipal solid waste as a waste category was altered in some counties, like Germany, to include only that portion of waste which was not practical to separate from the source while packaging waste became a separate category and not allowed to be mixed with others (BMU, 2018). The WM regulations in Germany -for example- echoed those aforementioned regulations by promoting separate collection of paper, metals, plastics, and glass where this is technically possible and economically reasonable, and also set targets to prepare for reuse and recycle 70% of the municipal solid waste (MSW) by January 1st, 2020. The German regulations allow the disposal only of waste that can't be reused or recovered (The Bundestag, 2012). To improve other waste management routes competitiveness from financial perspective against waste disposal, landfill tipping fees and taxes were implemented among all EU member states. The fees start from €3/ton of waste and reach €220/ton while the additional taxes are between €9/ton and €30.6/ton (Table.1) (Horizon, 2014).

Table 1: Landfill fees and taxed in different European countries(Horizon, 2020).

Country	Landfill gate fee in €/t	Landfill tax excl. VAT in €/t	total
Austria	70	87	157
Belgium (Wallonia)	40	65	105
Bulgaria		7 to 15	7 to 15
Czech republic	16	20	36
Denmark	44	63	107
Estonia	40	12	52
Finland	59	50	109
France	60	9 to 30	69 to 90
Ireland	70	75	145
Italy	90	7 to 30	97 to 120
Latvia	16	22	38
Netherlands	25	107	132
Poland	70	27	97
Portugal	11	4	15
Slovenia	105	19	124
Spain(Catalonia)	41	12.4	53.4
Sweden	106	47	153
United Kingdom	27	100	127

Studies revealed that incremental landfill fees and taxes increased the number of industrial symbiosis relationships (material exchange) between industries from 1.53% to 41.26% (Fraccascia et al, 2017). More actions were taken to increase packaging waste incineration taxes in some countries like Belgium led to a significant negative influence on the growth of plastic waste generation by firms (Weerdta et al, 2020). Sweden is an example for additional way to increase waste collection and transportation burden on generators by imposing Carbon emission taxes of US $30 per ton back in 1991 then increased to reach US$132 to become the highest carbon tax in the world (Andersson, 2019) despite the views, insisting that a mean value social Carbon cost of $14 per ton in business-as-usual scenario is the optimal option for both, economy, and environment (Hope, 2008). Many countries have tried to implement carbon tax or energy tax schemes that aim at reducing carbon emissions and obtained positive effects (Wei, 2014). Around 90% of the Carbon tax revenues come from the consumption of gasoline and motor diesel (Andersson, 2019) so, preventing waste generation would eliminate the need to transport it and consequently, remove the emissions tax burden from the shoulders of waste generator. Such fees and taxes helped countries like UK to reduce MSW disposal by almost 65% in 10 years (Fletcher et al, 2018). The revenues generated from emission taxes were either invested in "green" spending or returned to taxpayers through other tax cuts and rebates (Carl, and Fedor, 2016).

1.2 Current waste disposal fee calculation methods.

The traditional way to determine waste disposal fee is to ensure that total price paid by the waste generator should cover all the expenses to build, operate and maintain the landfill. A typical landfill cost calculation method would consider land acquisition, landfill construction, operational and other costs (Duffy, 2016). Some methodologies include more details like site access, amenities and service costs, ground and storm water management, and landfill cover and gas management costs in an attempt to grasp all costs associated with waste disposal (Ministry for the Environment- New Zealand, 2002). Other researchers use different costing approach by considering two groups of costs: internal and external costs and benefits- internal costs and benefits are related to the selection of the treatment and disposal system, building, operation, maintenance costs, back-end, transportation costs and revenues while; external costs and benefits "the externalities" can result from the various processes like transportation, recovery and other processes which a product undergoes during its lifecycle (Korucu et al, 2016). Early research in the USA proposed to add the "hosting cost" as an externality, which is the compensation to be paid to the adjacent community to the intended landfill construction area for the environmental damages and their property value decrease (Jenkins et al, 2002). Assessment conducted in Australia concluded that key external costs of landfills are greenhouse emissions, other emissions to air, emissions to water "leachate" and disamenity (BDA, 2009). Capturing the cost of managing temporary processing unit and biogas reactor was added to the total landfill cost in one of the reviewed articles (Farizal and Tammarar, 2019). Recent research started to include the CO_2 to be an expenditure statement as well (Cudecka-Purina and Atstaja, 2017).

1.3 Waste Management in the United Arab Emirates (UAE).

The United Arab Emirates (UAE) is a federation of seven emirates comprising Abu Dhabi, Dubai, Sharjah, Ajman, Fujairah, Ras Al Khaimah and Um Al Quwain. The federation was formed in 1971. UAE federal constitution provides for an allocation of powers between the federal government and the government of each emirate (Singh, 2014), and WM is one of those aspects where each emirate practices wide autonomous authorities within the central government vision. UAE stands tall as a role model in providing quality of life and prosperity. The UAE economic growth during the last 40 years was accompanied by a tremendous growth in the MSW generation rates. The MSW generated in the Emirate of Abu Dhabi -for example-, the capital of UAE, in 2019 increased by almost 41% to reach 1.793 million ton compared to 1.272 million ton in 2012. MSW generated per ca pita in Abu Dhabi remains one of the highest globally. MSW generation per ca pita of1.76 Kg/day was reported in Abu Dhabi in 2018 compared to 1.5 Kg/day in 2012 (Center of statistics- Abu Dhabi, 2018). Sharjah is the third largest Emirate and has a fully centralized MSW management body formed by public private partnership in 2007 between Sharjah municipality and private sector, the new company was called "Bee'ah". There are no centralized disposal fees or taxes regulations implemented in the UAE but in general, they vary from US $2.72/truck load and US $13.61/ton. The highest MSW disposal fee in UAE is currently implemented in Sharjah.

1.4 Waste disposal in Sharjah.

One centralized MSW landfill location was authorized by Sharjah Municipality in 2014 and managed by Bee'ah. Since then, several cells were engineered, operated, and capped when became full. The latest cell was built and started to receive material back in 2018. The landfill site is around 35 Km away from the city center and was far away from urban development however, major changes took place since then and the location now is in the center of a rapidly growing industrial and commercial activities' area with multiple industries, accommodations, commercial and office space.

Sharjah emirate is divided into 10 geographic sectors within Sharjah city and 7 other cities in the emirate's east coast and central region (ECCR) from which waste is transported to the centralized landfill. Bee'ah operates 214 trucks to haul MSW from the Sharjah, Maliha and Bathaya cities to either a transfer station located within the city boundaries in the 10th sector or directly to landfill site. If the MSW is delivered to transfer station then, it is reloaded into high-capacity haulage trucks and sent to the landfill site, 18 haulage trucks are deployed for this purpose. Similar 8 haulage trucks are used to transfer MSW from the remaining 5 ECCR cities. Bee'ah owns and operates a large material recovery facility (MRF) located within the landfill site. All the MSW delivered to the landfill gate is directed to the MRF. The rejected material from MRF and the residues remaining after recovery are sent to the MSW landfill cell, four haulage trucks are dedicated for this operation. (Fig. 1).

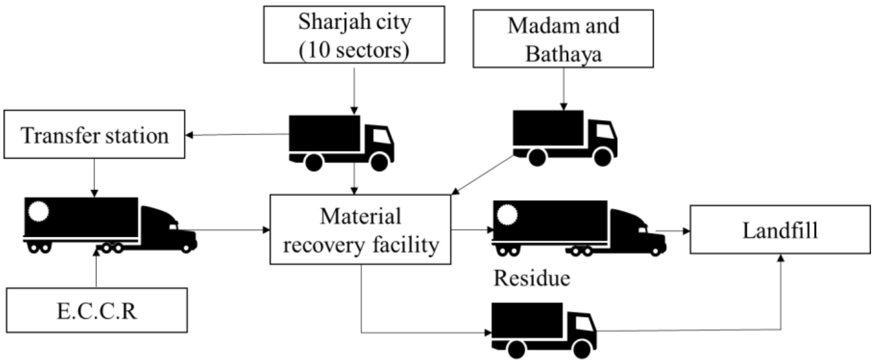

Figure 1: MSW and residue logistics, Sharjah Emirate to the central landfill

In the landfill cell, four specialized mobile equipment are used to ensure proper compaction of 900 Kg/m3 and 1000 Kg/m3, and daily cover activities are timely done to ensure safe disposal. The active MSW landfill cell occupies an area of 126,500 square meters with planned capacity of 2.97 million ton of waste. The landfill cell was duly engineered and built to ensure sufficient waste containment and leak proof with leachate circulation system.

II. DATA COLLECTION METHOD

In this article, we aim to capture the total cost of MSW disposal including those hidden costs that are not been considered currently. This cost calculation method is meant to spot the real losses encountered by Bee'ah and the municipality due to MSW been deposited in the landfill. The first step to calculate the total landfill cost was to get the operations profit and loss statement for the first quarter of 2021 to figure out the total expenses excluding landfill construction and land costs. Next, the total amount of MSW received during the same period was calculated using the existing records thus, operating cost per ton excluding land cost and construction was obtained. After that, all costs related to the new MSW landfill cell design and consultancy, land excavation and construction were calculated -using existing tendering and project accounting document available in Bee'ah- and depreciated over the total MSW quantity to be disposed of in the cell over its lifetime. By the end of this step, it was possible to identify the operational cost excluding the land value. The next step was to calculate the CO_2 emissions for all groups of vehicles and mobile equipment that were deployed along the MSW supply chain for the same period. Vehicles and equipment fuel consumption and working hours were extracted from the fleet control records, and types of engines, installed in each vehicle was obtained from the technical department, then, by using Euro norm emissions for N3, EDC category (2000 and up), it was possible to calculate the total CO_2 emissions per engine for the first three months of 2021 and thus, per MSW ton. It is worth mentioning that Bee'ah fleet is relatively new where EURO 3 and above engines are mainly used (Table 2).

Table 2: EURO 3 and above engines of Beeah MSW transportation trucks

total waste transportation	244
EURO 3	80
EURO 4	15
EURO 5	71
Total EURO 3 and above	166
% EURO 3 and above	68.03%

In-significant number of the records were missing, their emissions were evaluated based similar engine types and delivered tonnages (marked red in the metadata). It was a great challenge get the information related to diesel consumption and engines models of private sector and municipality owned vehicles and so, average CO_2 emissions per ton of similar to Bee'ah vehicles was used as reference to derive the figures knowing the quantity of MSW delivered by these vehicles to the landfill site in the first quarter.

The next CO_2 emissions sources that was considered in the research were the rejected MSW, the residue and the fines resulted from the sorting process. The three waste streams were analyzed, and the full characterization report was prepared. The aim of the characterization study was to determine the amount biodegradable organic Carbon content (OCi) in this fraction based on the reviewed literature (Zhao, 2019). Simultaneously, moisture content per component (ui) was analyzed to calculate dry base (OCi). Carbon does not fully biodegrade in the fully enclosed waste inside the engineered landfill, in this research, we use the biodegradable fraction per waste component $(fb)i$ in our CO_2 emission calculations (Table 3).

Table 3: Total Carbon and biodegradable Carbon per component

Martial	OCi (KgC/Kg dry)	Fbi ($KgCO_2$/KgC)
Paper	44.0%	0.5
Cardboard	44.0%	0.5
Food waste	48.0%	0.8
Garden waste	48.0%	0.7
Wood	49.0%	0.5
Textiles	55.0%	0.2

The amount of CO_2 emissions resulted from one Kg of Carbon was calculated taking into consideration that12 Kg of Carbon produce 44 Kg of CO_2 upon full decomposition and ideal oxidization (Manfredi, 2009). Thus, it was possible to conclude the total emissions, resulted from landfilling wastes and residues suing the following formula:

$$(OCb)i = OCi \times (fb)i \times (1 - ui).pi$$

(1)

Where:

$(OCb)i$- biodegradable organic Carbon in the component;

pi- wet weight of the component.

And

$$CO_{2eq} = (OCi)b \times \frac{44}{12} \quad (2)$$

Where:

CO_{2eq}- equivalent amount of CO_2 from one Kg of biodegradable Carbon.

The author chose to consider the cost of one ton of CO_2, released to the atmosphere to be US \$30. Determining the cost of the land used to build the MSW landfill cell was the last to be calculated. Sharjah municipality allocated the land that is operated exclusively by Bee'ah to be the only MSW disposal site in Sharjah city. As urban development approached, this plot became more valuable and nowadays, it is in the heart of an industrial and commercial area (Fig. 2). In this research, land cost was calculated based on lost opportunity by incorporating the current potential land rental cost for commercial and industrial purposes, the reason for choosing annual rental rate is the incremental return losses by the year as rental prices for similar plots raise. The rental prices were identified by approaching three real estate agents to enquire concerning the rental rates of similar plots within the same area. The criteria used to ensure similarity of those plots were the comparable infrastructure, utilities, and plots' sizes.

Figure 2: MSW landfill cell location in Sharjah City

III. RESULTS

The total residues, fines, and rejected MSW sent to landfill cell in the first quarter 2021 was 129,411 ton out of which 21,619 ton were MSW rejected from MRF due to quality and directed to landfill cell as is. The quantity of residue and resulted from the sorting process was 98,474 tons (Fig. 2) and was sent to landfill cell as well.

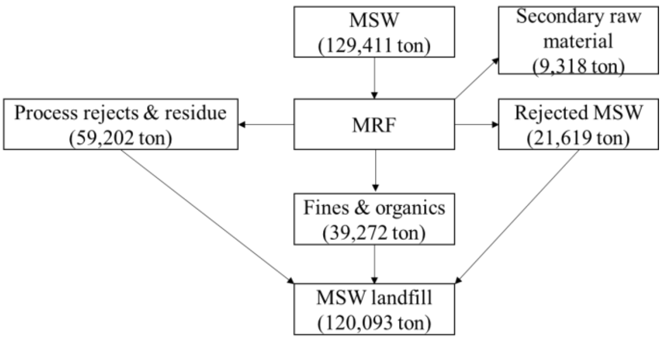

Figure 2: MSW mass flow balance in first quarter 2021

Total operational expenses to safely dispose of one ton of waste and provide all necessary sanitary activities excluding land cost was US \$11/ton (Table 4).

Table 4: Landfill operations cost/ton excluding development cost.

Statement	US \$
Direct Cost - Manufacturing Cost	
Direct Employees Cost	521,516
Direct - Depreciation on PPE	474,240
Material consumed	310,679
General & Admin Expenses	
Office expense	2,876

Legal and professional	2,723
Utilities	10,411
Repairs and maintenance	3,676
Salaries and related benefits	10,704
Depreciation on property, plant, and equipment	2,625
Advertisement and sales promotion	1,497
Others	817
Total	1,341,765
Total/ton	11

The total cost to design, license and build the new MSW cell was US $6,482,949 thus, it was US $2/ton (table 5).

Table. 5: Landfill development cost

Landfill Construction	USD
construction(incl. insulation layers, leachate management and QA	3,496,727
land excavation	2,722,941
Consulting services	263,281
Total	6,482,949
Total/ton	2

From tables 4 and 5 we concluded that total disposal internal cost -excluding land cost- was US $13/ton.

Bee'ah transports the majority of MSW to the landfill site in trucks (Table 6), this fact gives better credit of trust to the derived CO_2 emissions figures and reduces the error margin in the derived figures. The total CO_2 emissions released from MSW trucks that delivered MSW to the landfill was 166.78 ton (Table 7).

Table 6: Actual and derived MSW transportation CO_2 emissions , first quarter 2021

		Actual CO_2 emissions/ton delivered (g)	Derived CO_2 emissions/ton delivered (g)
Total MSW delivered in truck (ton)	71,656.68		
Bee'ah Share	77.34%	108,167,379	
Private share	22.54%	No data	31,524,373.27
Municipality share	0.12%	No data	173,092.23

Table 7: Total CO2 emission across the MSW supply chain, first quarter 2021

Operation type	CO_2 emission in quarter 1, 2021(g)		
	Bee'ah	Municipality	Private companies
City to transfer station	52,976,533		
Transfer station to MRF	11,289,422		
City to MRF	55,190,847	173,092	31,524,373
E.C.C.R to MRF	5,585,036		
MRF to Landfill	5,972,809		
Disposal	4,068,110		
Total	135,082,757	173,092	31,524,373
Grand total			166,780,222

The total financial impact, caused by releasing CO_2 to the atmosphere during the control period was found to be US $5,003 and equivalent to around 3.9 cent/ton.

The results of morphology analysis, conducted on organics fraction, residues and rejected MSW, together with moisture content, $(OCb)i$ and $(fb)i$ per component (Table 8) show that 10,730 tons of biodegradable Carbon was generated by all types of waste sent for disposal during the first quarter of 2021. The data reveal that 91.7% of the total Carbon was generated by food waste (9,836 ton). Despite being substantial contributors to CO_2 emissions, wood and garden waste adverse effect was in-significant in this research due to their low content in the waste. Fines fraction was the major contributor to the CO_2 emissions (55.8%) followed by the residue (25.7%) and finally, rejected MSW (16.6%).

Table 8: Total biodegradable Carbon per component in each waste stream sent to landfill.

	Fines			Residue			Rejects from input			Total fbi (ton)
Material	ton	ui (%)	fbi (ton)	ton	ui (%)	fbi (ton)	ton	ui (%)	fbi (ton)	
Paper	579	46.7	59	2,298	27.0	136	550	27.0	33	229
Cardboard	333	46.7	34	1,091	27.0	65	506	27.0	30	129
Food waste	32,841	46.7	5,889	13,993	46.7	2,509	8,014	46.7	1,437	9,836
Garden waste	0	46.7	0	0	45.0	0	1,346	45.0	204	204
Wood	42	46.7	5	3,973	12.0	117	1,066	12.0	31	153
Textiles	64	46.7	3	4,539	25.0	125	1,875	25.0	52	180
Total	33,859		5,991	25,894		2,952	13,356		1,786	10,730
Share			55.8%			27%			16.6%	

The total CO_2 emissions cost/ton, resulted from all types of waste sent to landfill was calculated as follows:

$$10{,}730 \times \frac{44}{12} = 39{,}343\ ton \quad ; \quad (3)$$

$$39{,}343\ ton \times US\ \$30 = US\ \$1{,}180{,}290; \quad (4)$$

$$\frac{US\ \$1{,}180{,}290}{129{,}411\ ton} = US\ \$9.12/ton \quad (5)$$

It is worth mentioning that US $9.83/ton is the average CO_2 emissions cost, US $26.95/ton would have been the disposal fee if the waste were pure food.

The asked rental rates for three similar plots to the existing landfill cell were US $6.26, US $6.81, and US $8.17 per square foot (SQF) per year. MSW cell area was converted to SQF and average rental value of US $6.18/SQF was chosen to calculate the total opportunity cost of the existing landfill cell as follows:

$$1{,}361{,}635\ \times 6.81 = US\ \$9{,}272{,}734 \quad (6)$$

The cost per ton of waste sent to landfill, assuming that mass balance is stable over the year (4 quarters) was calculated as follows:

$$\frac{9{,}272{,}734}{129{,}411 \times 4} = US\ \$17.9/ton \quad (7)$$

Based on the full cost analysis provided, it was found that the total cost to dispose one ton of MSW is US $39.76 (Table 9). The results showed that current MSW disposal fee, implemented in Sharjah of US $13.61 covers only 34.5% of the total cost. The highest cost is the one incurred from the lost opportunity to utilize the land for more profitable purpose, followed by total operational cost. CO_2 emissions come third with 22.9% of the total disposal cost. However, transportation and mobile equipment emissions were never considered earlier, they form in-significant portions of the cost (0.01%).

Table 9: Total MSW disposal cost per ton across the supply chain

Cost	US $/ton	%
Operational cost	11	27.6
Design & construction	2	5
Opportunity cost	17.9	45
Transportation emissions	0.039	0.01
Landfill emissions	9.12	22.9
Total	39.77	

IV. DISCUSSION

The current MSW and residual waste disposal fee in Sharjah matches the lowest fees corridor implemented in some European countries like England and Spain but, much lower the fee in any EU member regarding organics and bio-degradable waste (Horizon, 2014). Making a conclusion that residual waste disposal fee, however, is fair for Sharjah is not fully correct. Waste management system in EU is built to be fully integrated across the supply chain to eliminate all major hidden costs: 1-disposal fees consider all costs including gas, leachate management, and aftercare costs; 2- biodegradable waste without being dried and stabilized, to eliminate CO_2 emissions, can be landfilled only in strictly limited quantities (The European parliament and the council, 1999); 3- Cardboard and paper should be collected separately, 85% of this material is to be recycled by 2030 (The European parliament and the council, 2018). Reducing the amounts of waste disposal through intensive recovery and recycling, and banning, or strictly limiting, biodegradable material, added to comprehensive producers' responsibility and awareness programs form the crux of the fight against waste disposal. Thus, high disposal fees act as the last action taken to discourage those, who still insist on holding to old consumption and waste generation habits. Considering that bio-degradable organics, cardboard board, and paper are the major contributors to CO_2 emissions in landfills (Lee, 2017), not implementing obligatory source segregation regulations for MSW in UAE, led to low recovery and recycling rates and increased amount of organic waste been disposed of thus, high CO_2 emissions concluded to be released from landfill in this research seems to be logical.

Average landfill CO_2 emissions cost is obviously not the best way to evaluate the adverse effect, caused by the disposal of untreated food waste, wood, green waste, paper and cardboard, any change in the waste composition changed the emissions cost drastically. It is thought that separate CO_2 emissions cost calculations are provided per component is conducted to draw a complete picture.

In fast growing economies like UAE and Sharjah city in specific, simple land cost method seems not to be able reflect the real adverse effect, caused by missing the opportunity to utilize it for other profitable purposes and doesn't measure the impact on the valuation of the adjacent lands for generations to come as well, this long-term effect on the adjacent territory is worth being analyzed in future research and included as additional hidden external cost.

Using updated transportation equipment, with over 68% of the truck engines, rated EURO 3 and above showed effectiveness in MSW transportation emissions reduction but, can be reduced further by gradual shifting of all fleet engines to EURO 5.

V. CONCLUSION

Current MSW disposal fees in Sharjah need to be revised otherwise, upcoming investments mentioned below will face big challenges to be economically justified:

1. Biodegradable waste recycling to produce energy and compost, or biological stabilization to reduce moisture and Oxygen demand which eliminates landfill gas emissions.
2. Landfill gases extraction and consequent cleaning, and flaring or converting into electrical power
3. Land remediation anticipated being the main topic in 3-5 years from now. Such project will involve waste relocation, new landfill construction, and soil cleaning in the existing landfill location.
4. Switching to more sustainable waste transportation technology. The options include using vehicles with Euro 5, electrical or recycled bio-fuel engines.

The landfill cost, as per this method, increases continuously even after MSW was deposited and years after the landfill been closed. By the moment the value of the land, used for waste disposal becomes equivalent to the total cost of new landfill construction, waste relocation and old landfill soil remediation, it is recommended relocate all deposited waste, to be able to do so, disposal fee needs to be revised periodically as land cost changes.

It is concluded that US $40/ton is the minimum waste disposal fee that could be economically acceptable in Sharjah as of 2021.

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