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Environmental and Economic Evaluation of Municipal Solid Waste Composting Facility in Irbid Greater Municipality, Jordan

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ABSTRACT

Adapting environmentally friendly solid-waste management approaches is essential to reduce the carbon footprints resulting from solid-waste treatments. In this research, the Irbid composting plant for organic municipal solid waste was evaluated considering the environmental and economic aspects. Waste streams to the facility were also evaluated in terms of quantity and quality. The environmental evaluation involved estimating the carbon footprint of the composting facility using upstream-operation-downstream (UOD) procedure and comparing it with the emission levels associated with current management practices. The composting facility led to avoiding an estimated 13.62 Gg CO_2 equivalent each year. Finally, an economic feasibility study was conducted based on estimating the costs (CAPEX & OPEX) and the expected revenues. The results revealed that the composting facility could return the capital cost in about 6.63 years and make a net yearly revenue of 88,250 JOD (124,500 USD), which proves that composting, if performed professionally, offers a low-cost path for solid-waste treatment.

KEYWORDS: MSW management, Recycling, GHG emissions, Economic evaluation, Jordan.

INTRODUCTION

About 3 M tons of annual municipal solid waste (MSW) is produced in Jordan at a rate of (0.9 kg/capita/day) and a growth rate of 3% per year (Alhyasat et al., 2014). Most of it is still managed by traditional systems (end of pipe), where > 60% of the waste is disposed into unsanitary landfills leading to serious risks (leachate & GHG emissions) and ecosystem disturbance (Ferronato et al., 2019). The majority of MSW in Jordan is composed of organic materials (>50%), which reflects the importance of composting as an environment-friendly technique for MSW management (Hemidat etal., 2018). It is considered a highest form of recycling according to the Environmental Protection Agency in the United States (US EPA) and the waste management hierarchy developed. Several methods are used to treat MSW, such as composting, anaerobic digestion, incineration and pyrolysis. However, aerobic composting is easy to handle, suitable for different climates and does not consume power or require high quality or quantity of water.

This research presents environmental and economic evaluation of an aerobic composting plant located in Irbid city to produce compost, fertilizers and soil conditioners using windrow piles' composting system. The facility has a total area of 10,000 m^2 (including administration building, storage and packaging hangers) and is equipped with the needed machines (turner, front loader,… etc.) to treat about 25 tons of source-separated solid waste daily. It is operated by Irbid Greater Municipality with technical and financial support from the German Agency for International Cooperation (GIZ).

The solid waste comprises cow and chicken manure as well as a source-separated organic market waste (fruits and vegetables). For the sake of this study, two experimental heaps were prepared; one consisting of chicken manure + market waste and the other consists of cow manure + market waste. The upstream-operation-

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downstream (UOD) approach was followed to estimate the GHG emissions associated with the composting plant. It is worth noting that the daily amount of solid waste admitted to the composting facility was only about 10% of its design capacity, as this study took place during the initial period of the life of this composting facility.

The legislative framework for municipal solid waste management in Jordan puts the responsibility of waste collection and disposal on municipalities according to Municipalities Law No. 13 of 2011 and its amendments (latest No. 7 of 2012). MSW collection and disposal processes consume the municipalities' budgets (Sweep-net, 2014). The imposed fees on collection and disposal are not sufficient to cover the cost of those processes; for instance, the Greater Irbid Municipality receives a fixed amount of 24 JOD/year on each household (Sweep-net, 2014).

The regulations controlling the treatment and collection of MSW in Jordan should be modified, especially for industrial, commercial and institutional activities.

According to the national strategy for solid waste management, the Jordanian government plans to initiate two composting facilities at an industrial scale. Thus, this study is commensurate with local capabilities and experiences and provides decision makers with an insight into the operation, costs and the potential carbon footprints avoided by the composting facility toward achieving sustainability in Jordan (Ferronato & Torretta, 2019).

LITERATURE REVIEW

Behrooznia et al. (2018) conducted a life cycle assessment (LCA) to evaluate two MSW management scenarios; one with landfilling (100%) and one with composting (48%), landfilling (50.5%) and recycling (1.5%). They concluded that while the first scenario demands less energy, the second has less environmental impacts. Taiwo (2011) compared the options for MSW management in developing countries by considering technical and environmental aspects. He concluded that composting is more advantageous for several reasons. First, it does not require high technical knowledge and is suitable for centralized or decentralized, small- or large-scale infrastructures; thus, it suits developing countries with scarce financial resources. Also, it has fewer negative impacts compared with landfills and incineration, such as GHGs, disturbing nearby ecosystems, surface and groundwater pollution.

Nawaisah et al. (2021) investigated the composting of organic wastes generated at Al-Karak Governorate-Jordan. Three windrow piles containing different proportions of organic wastes were initiated for compost production. The properties of composted matter were examined and the product quality was assessed and checked against German standards. The results of the monitored experimental process showed that all the compost samples are stable and can be rated as a class V product according to German standards.

On the other hand, Boldrin et al. (2009) estimated the GHG emissions associated with different composting technologies (enclosed, open and home composting) using upstream-operation-downstream (UOD) procedure and data from the literature for emission factors. The UOD emissions for open and windrow composting involves: diesel and electricity provisions, diesel combustion, direct emission (operation or waste management), methane (CH_4) and nitrous oxide (N_2O) assuming anaerobic pockets during treatment, emissions from the energy production sector, indirect emissions (upstream) and indirect emissions (downstream), which depend on two scenarios: a) using the produced compost to substitute for chemical fertilizers and b) using the produced compost in peat production, which reduces the carbon footprint and could potentially transform the waste management sector from a producer to reducer of GHGs. Though, it is worth mentioning that these estimates relay on many assumptions for such a complex system, which questions the certainty and necessitates a thorough review for each parameter and emission factor before making any conclusion.

Abu Qdais et al. (2019) evaluated the carbon footprint from solid waste in Jordan using four scenarios: 1) Current situation scenario based on current management practice. 2) Sanitary landfilling of all produced MSW with energy recovery. 3) Aerobic composting for 70% of total food waste assuming it is separated at the source and the rest treated according to the 1st scenario (food waste makes up (50-65) % of the generated MSW in Jordan). 4) Anaerobic digestion followed by composting for 70% of the total food waste assuming it is separated at the source and the rest treated according to the 1st scenario. The results showed that scenarios (3 & 4) resulted in less carbon footprint (1.1 million Mg CO_2-eq y^{-1}) compared to scenarios (1 & 2), which resulted in 2.6 and 3.75 million Mg CO_2-eq y^{-1}, respectively.

Al-Ghazawi and Abdulla (2008) proposed scenarios with time horizon from 2005 to 2030 to reduce GHG emissions associated with wastewater treatment and sanitary landfills in Jordan. For wastewater treatment, they proposed continuing to use the stabilization pond or the transformation of treatment technology at As-Samra WWTP plant to activate sludge for the expansion plan in 2005. For solid waste, building two biogas plants to treat 1000 tons of solid waste daily at Al-Akaider and Al-Rusayfah landfills was proposed. For As-Samra WWTP, the results indicated 49 Gg and 146 Gg reductions in GHGs for the first and second mitigation scenarios, respectively. For sanitary landfills, building the biogas plants resulted in 1,406 Gg reduction of methane emissions along 25 years of operation.

The objective of this study was to prove that composting of MSW can be a viable option for MSW management, both economically as well as environmentally. Taking the new Irbid composting facility as a case study, this research aims to analyze the economic and environmental dimensions of the building and operation of MSW treatment facilities in Jordan.

METHODOLOGY

To assess the facility's performance from environmental perspectives (GHG), we assumed that input materials could be modeled as bio-waste and the plant operates at design capacity.

a) Proposed Scenario for Estimating GHG Emissions from the Plant's Current Practice

Landfilling at Al-Akadier landfill was the management scenario followed by Irbid greater municipality to treat the generated SW at the central market for fruits and vegetables. The recently composting facility initiated provides a new SW treatment path with less environmental impact; Figure 1 introduces the former and recent treatment paths.

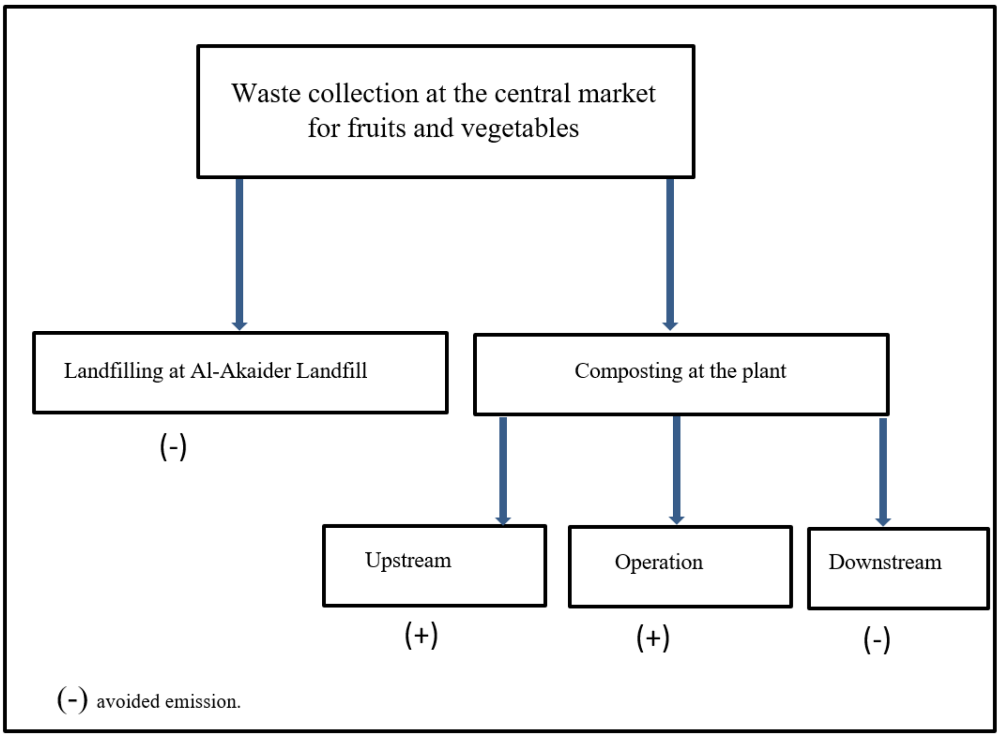

Figure (1): The proposed scenario for estimating GHG emissions from the current practices

Defining the System Boundary

upstream-operation-downstream (UOD) procedure was used to estimate the carbon footprint associated with composting facility operation, which required identifying a clear system boundary. Figure 2 highlights the system boundary and the included emissions.

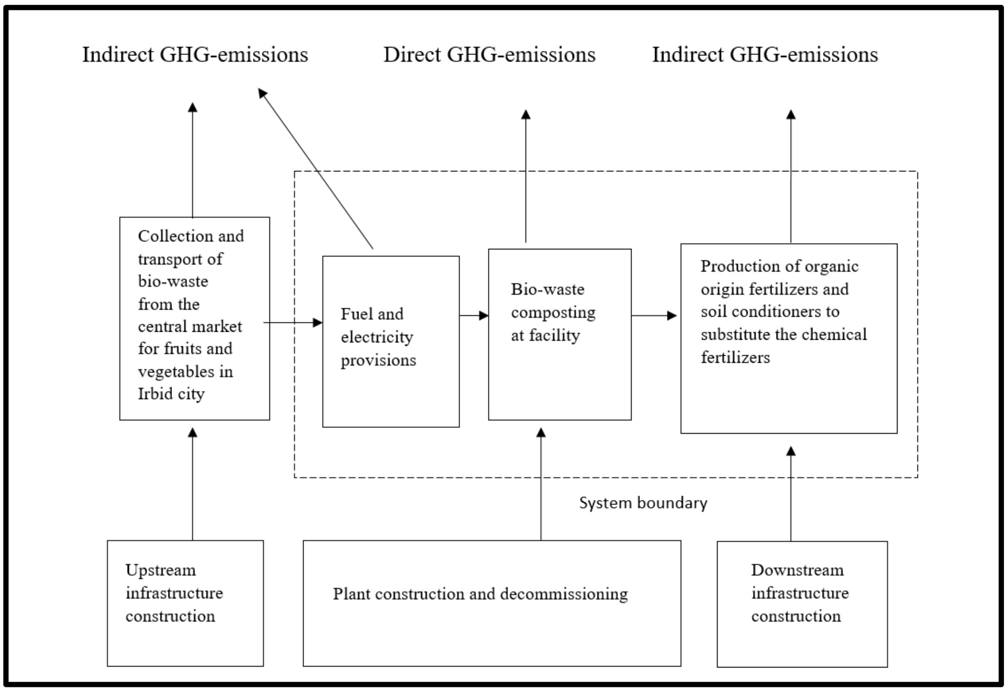

Figure (2): Model conceptual framework showing the system boundaries, upstream and downstream processes (Abu Qdais et al., 2019)

Upstream (Indirect) emissions

The upstream emissions include fuel and electricity provisions. Figure 3 illustrates the expected usage of fuel and electricity per ton of wet waste (W.W.) and the associated emission factors.

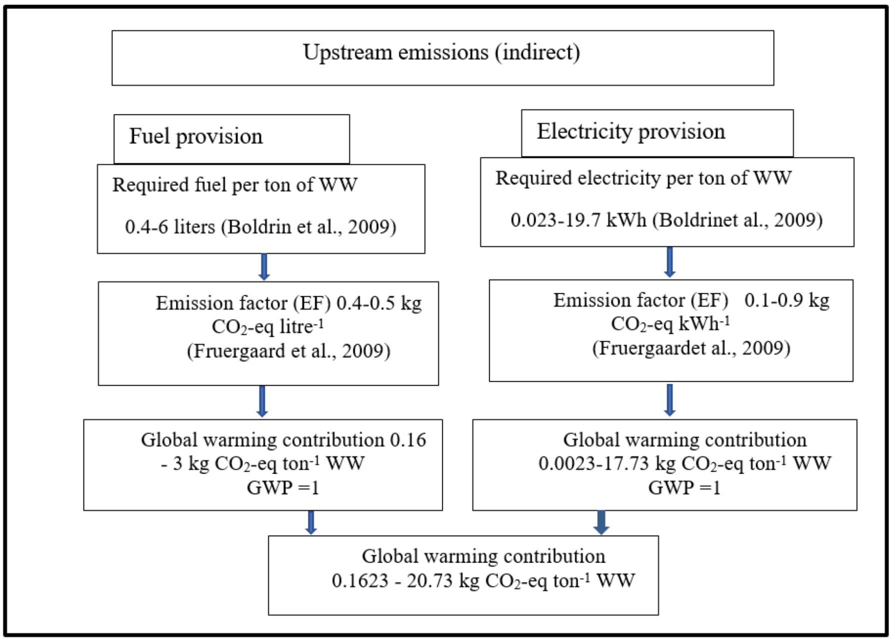

Figure (3): Upstream (indirect) emissions

Operation (Direct) Emissions

The operation emissions from windrow composting include biogenic carbon (which is considered a part of the natural carbon cycle and not counted in the waste sector's contribution to global warming), CH_4, N_2O and CO_2. The source of methane and nitric oxide in the aerobic process is the assumption of anaerobic pockets within the heap structure. Figure 4 highlights the operation emissions and the calculation details.

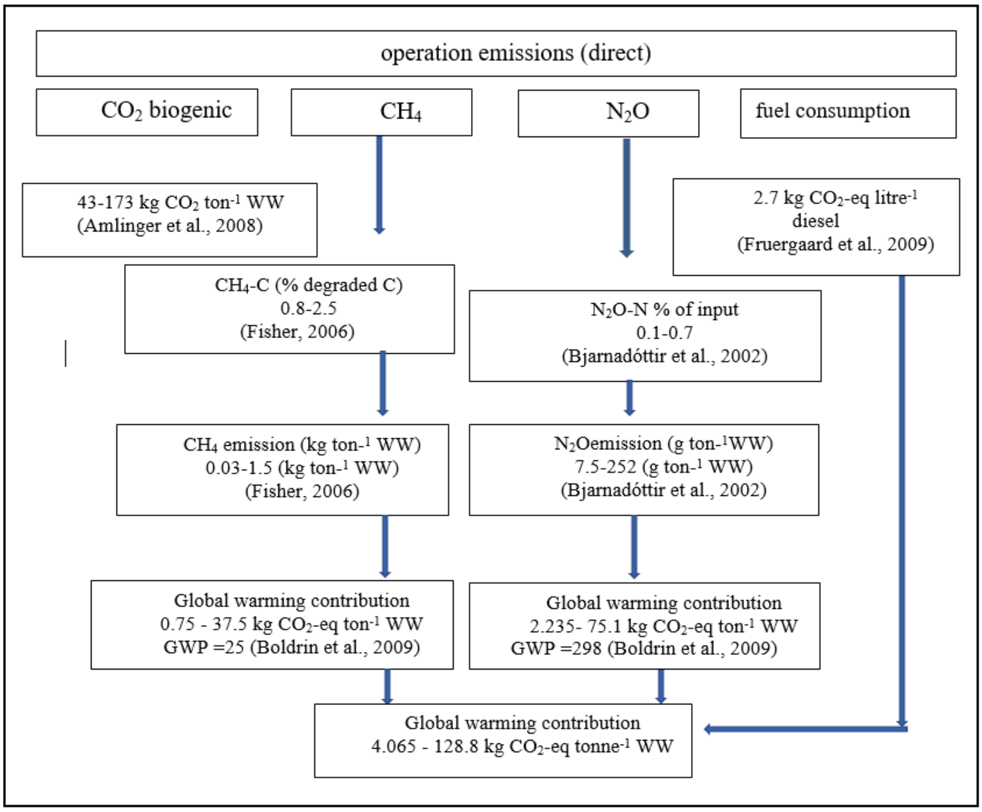

Figure (4): Operation (direct) emissions

Downstream (Indirect) Emissions

Downstream emissions depend on how the produced compost is used. In this study, it is assumed that the produced compost is used to partially substitute for chemical fertilizers. The considered downstream emissions were as follows:

a) CO_2 resulting from binding carbon to the soil after applying the compost is counted as avoided emission and it can be calculated using Equation (1)

$$CO_{2,\,bind} = C_{,\,input} * C_{,\,bind} * \frac{44}{12} \qquad \text{Equation (1)}$$

where C_{input} is the organic carbon contained in the produced compost and C_{bind} is a percentage of the input carbon, assumed based on published literature. C_{input} was assumed based on the organic matter in the wet weight (WW) to be 386 kg, while CO_{2bind} was assumed to be 14% of this figure (Fisher, 2006).

b) Substitution of chemical fertilizers: the produced compost could substitute chemical fertilizers by various percentages depending on its nutrients content. According to (Hansen et al., 2006), substitution percentages for each nutrient are (20-60) % for N, (90-100) % for P and 100 % for K, calculated using Equation (2).

$C_{footprint}$ for each nutrient ($kg_{-CO2-eq}$ tonne-1 WW) =

$$M_N*(1- M_L) *S_R* E_F \qquad \text{Equation (2)}$$

where M_N = mass of nutrient in raw material (kg), M_L = mass loss of raw material during composting expressed as fraction, S_R = substitution percentage for chemical fertilizer, E_F = emission factor from producing the chemical fertilizer ($kg_{-CO2-eq}$ kg^{-1}). Table1 lists the values and references for all factors used.

Table 1. Factors used in the calculation of carbon footprint for each nutrient resulting from using compost instead of chemical fertilizers

Nutrient	Parameter	Value	Source
N	M_N	21.50 kg	(Boldrin et al., 2009)
	M_L	0.60	Assumed
	S_R	0.60	(Hansen et al., 2006)
	E_F	13.00 kg CO2-eq kg^{-1} nutrient	(Hansen et al., 2006)
P	M_N	4.70	(Siebert., 2007)
	M_L	0.60	Assumed
	S_R	1	(Hansen et al., 2006)
	E_F	3.10 kg CO2-eq kg^{-1} nutrient	(Audsley et al., 1997)
K	M_N	13.4	(Schleiss., 2007)
	M_L	0.60	Assumed.
	S_R	1	(Hansen et al., 2006)
	E_F	0.79 kg CO2-eq kg^{-1} nutrient	(Hansen et al., 2006)

c) GHGs of landfilling could be counted as avoided emissions when bio-waste is composted instead of landfilling. According to IPCC tier 1, GHG from landfilling can be calculated using Equation (3).

$$CH4\ (Gg_{-CH4}/year) = (MSWT * MSWF * MCF*DOC * DOCF* F * 16/12 – R)\ (1-OX). \qquad \text{Equation (3)}$$

where MSWT is the total MSW generated (Gg), MSWF is the fraction of MSW disposed (fraction), MCF is CH_4 correction factor, DOC is degradable Organic Carbon (Gg C/Gg MSW), DOCF is fraction of DOC (fraction), F is the fraction of CH_4 (fraction), 16/12 is conversion factor, R is amount of CH_4 recovery (Gg) and OX is oxidation factor.

The parameters used in GHG estimation and the total methane emission from landfilling process are presented in Table 2.

Table 2. Parameters used in GHG estimation from landfilling and total methane emission

Parameter	Value	Source
MSWT	9125.00 Mg per year	Design capacity of the plant
MSWF	1.00	MSWF = MSWT
MCF	0.95	(Abu Qdais et al., 2019)
DOC	0.15	IPCC guidelines and waste composition
DOCF	0.70	(Abu Qdais et al., 2019)
F	0.50	IPCC guidelines
R	0.00	Assume no methane recovery
OX	0.10	(Abu Qdais et al., 2019)
CH_4 emission Mg	546 Mg CH_4 per year	

Economic Evaluation

The economic assessment involved cost-to-benefit analysis depending on total costs (constant & variable) and prices of selling the produced compost. In addition, a break-even analysis based on determining the break-even point (BEP) - the point where total revenues equal the total costs - was provided for multiple scenarios by simulating different conditions. Calculating the BEP helps find the minimum quantity of the produced compost to start making net profits, under given financial and technical constraints.

$$T.C = F.C + V.C * Q \qquad \text{Equation (4)}$$

where T.C is the total cost, F.C is the fixed cost, V.C is the variable costs per ton and Q is quantity produced (ton).

T. R= S.P* Q; where T.R is the total revenue and S.P is the selling price per ton. Equation (5)

N.R = T.R–T.C; where N.R is the net revenue. Equation (6)

By substituting Equations (4 and 5) into Equation (6), we obtain:

N.R= S.P * Q– [F.C + V.C * Q] Equation (7)

By setting the net revenue in Equation (7) to equal zero, we obtain:

S.P * Q – [F.C + V.C * Q] = 0

Therefore: (S.P - V.C) * Q= F.C; $Q = \frac{F.C}{(S.P - V.C)}$ Equation (8)

In any scenario, where certain financial (specific payback period or annual worth) or technical (maximum capacity of the facility) constraints are applied, Equation (8) should be modified. Constant costs (site construction, shredder, screener, truck, front end loader, mechanical turner, labor and insurance), variable costs (product packaging & marketing, electricity, water, internal & external quality control, fuel & lubricants and maintenance), product selling price and data for material recovery from raw materials are needed to perform the analysis.

RESULTS AND DISCUSSION

1) Environmental Evaluation

The results showed that adopting the composting technique for solid-waste management in Jordan is capable of making a huge reduction in GHG emissions of the solid-waste sector. Figure 5 shows the estimation of the avoided GHG emissions, though the number is small compared with the total emissions from the waste sector, as the facility is small. According to Jordan's Third National Communication on Climate Change (MOENV, 2014), the GHG emissions from the waste sector in Jordan reach 3045 Gg CO_2 equivalent per year.

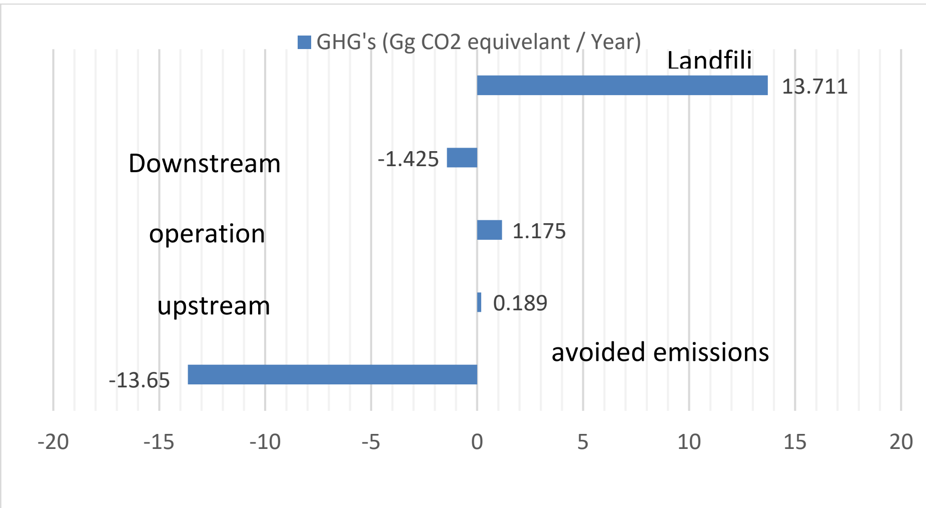

Figure (5): Results for estimation of GHGs resulting from the current practice at the plant

2) Economic Evaluation

Assessing the economic feasibility of the composting facility is very important to convince decision makers and investors both in private & public sectors to invest in such projects. The results proved the economic viability of the facility if operated at its design capacity, as presented in Table 3. The facility was assumed to run at full capacity (25 tons/day), though, it received less materials from the central market than its design capacity. Economic evaluation involves a cost to benefits analysis depending on the total costs and the selling price of produced compost. The compost price mainly depends on its quality; every facility produces multiple quality grades based on input material quality and level of quality control, which justifies the price variation noted in Table 3. The total costs include constant and variable costs in addition to cost-benefits analysis; a break-even analysis was also provided for multiple scenarios simulating different conditions.

The break-even analysis is achieved based on the determination of the break-even point. The break-even point (BEP) is the point where the profit and loss are equal zero. The calculation of (BEP) required to determine the minimum quantity of compost at the facility needs to produce to start making a net profit under given financial and technical constraints.

Economic study under various financial and technical conditions involved the following:

1. Evaluating the Payback Period (PBP) and the Break-Even Point (BEP) when the facility operates at standard design conditions, assuming that there are no significant financial changes (Figure 6).
2. Evaluating the BEP for the lowest possible selling price without making annual worth considering that the facility operates at its full capacity (Figure 7).

Table 3. Cost and benefit breakdown and feasibility calculations in JOD for the composting plant

Item		Note
i. Capital cost (constant)		
Site construction	300,000	
Shredder	60,000	
Screener	40,000	
Truck	30,000	
Front end loader	35,000	
Mechanical turner	120,000	
Total (i) 585,000		
Capital cost normalized for 20 years = 29,250		capital cost / twenty years
ii. Operation and maintenance (yearly) (variable)		
Labor	48,000	4,000 JOD monthly
Maintenance	3,000	mechanical consumables and labor
Fuel and Lubricants	11,400	1500 liter/ month (based on 0.5 JOD/liter) 200 JOD /month for lubricants
Product packaging and Marketing	5,400	1.5 JOD/ton *
Electricity	2,400	200 JOD/month
Water	3,600	1 JOD/ton
Internal and external quality control	2,700	0.75 JOD/ton
Yearly insurance	4,000	
Total (ii) 80,500		
iii. Revenue's breakdown (yearly) (sales)		
Compost grade (I)	140,400	65 JOD/ton, grade (I) forms 60 % from the total production
Compost grade (II)	57,600	40 JOD/ton, grade (II) forms 40 % from the total production
Total (iii) 198,000		
feasibility calculations		
Total yearly cost = 109,750		Operation and maintenance cost plus the capital cost normalized for 20 years
Net yearly revenue = 88,250		Total yearly revenue minus total yearly cost
Minimum time to capital cost return(years) = 6.63		capital cost/ Net yearly revenue
* Based on 300 ton/month production		

3. Evaluating the BEP for the minimum compost quantity required to achieve investment return period of 10 years, assuming no changes in the selling price and variable costs (Figure 8).

4. Evaluating the BEP for obtaining the minimum selling price to achieve a 10-year return period, assuming unchanged variable costs and the facility operates at full capacity (Figure 9).

5. Evaluating the BEP for obtaining the minimum selling price to achieve a 10-year return period, assuming that the facility operates at full and the variable costs increased by 50% (Figure 10).

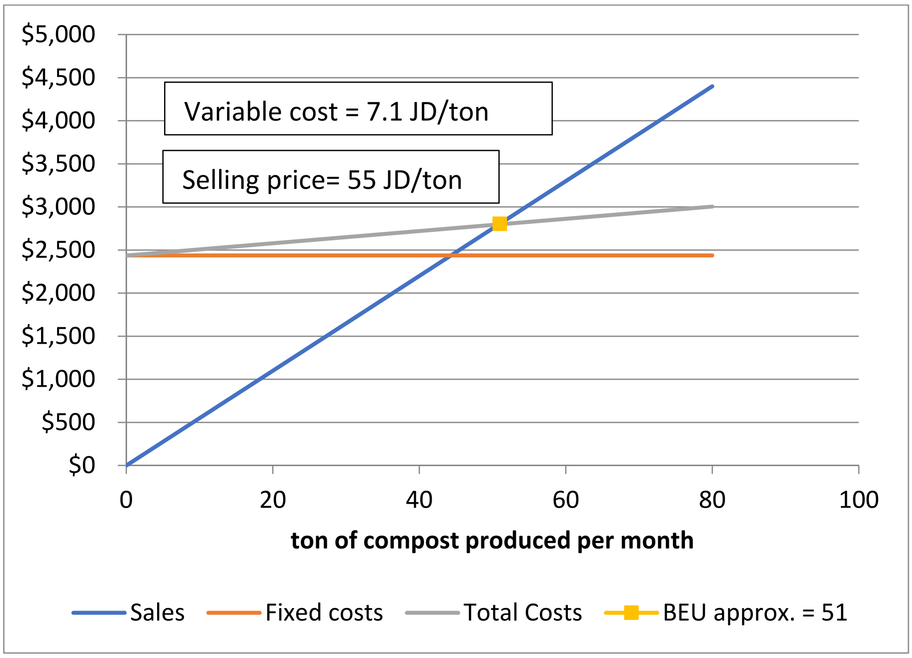

Figure (6): Break-even analysis for the facility at standard operating conditions

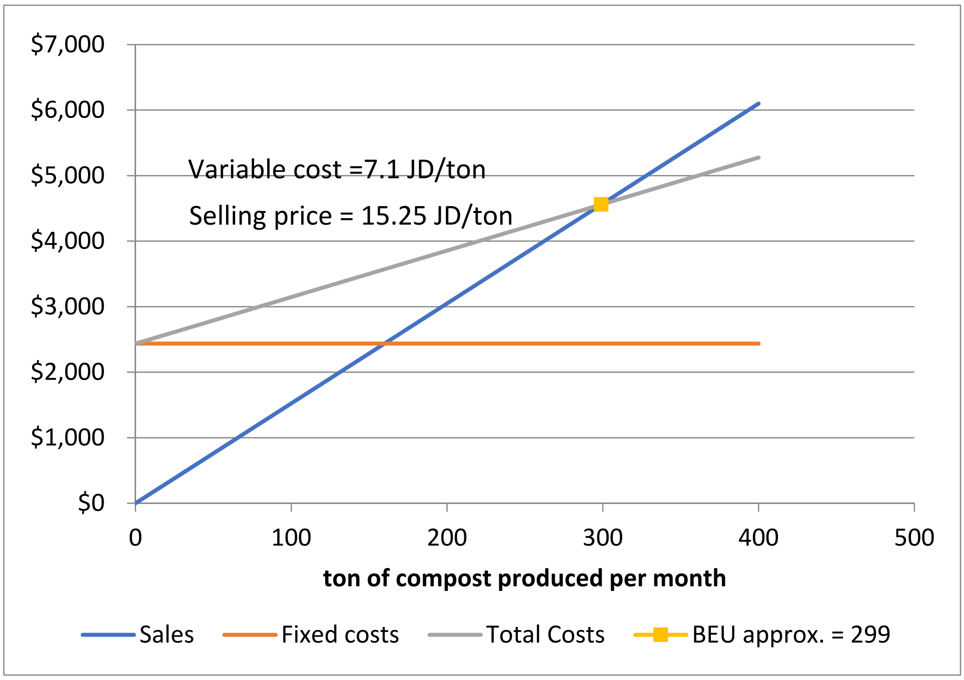

Figure (7): Break-even analysis for the facility operating at full capacity, assuming lowest possible selling price without annual worth

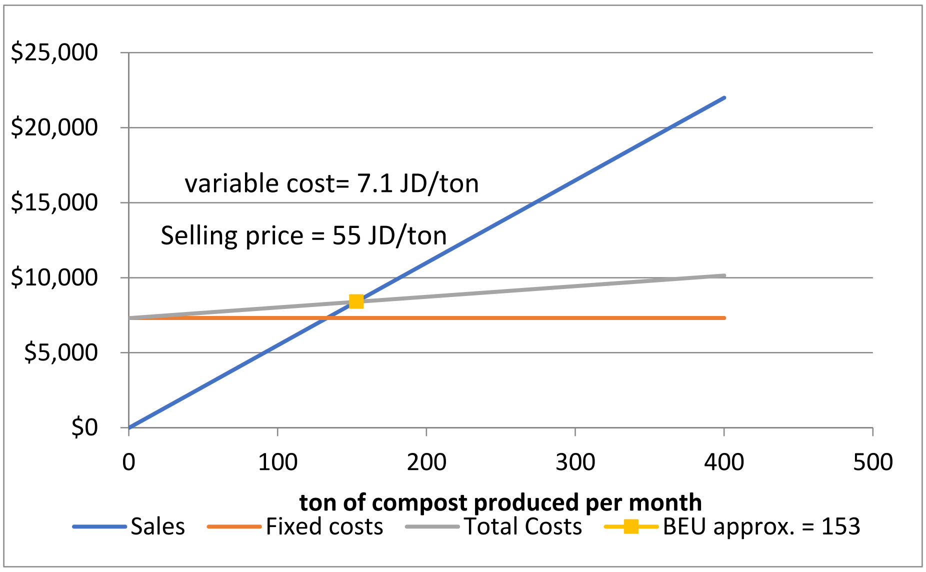

Figure (8): Break-even analysis for the minimum required quantity of compost to be produced to make a return period of 10 years assuming that selling price and variable costs do not change

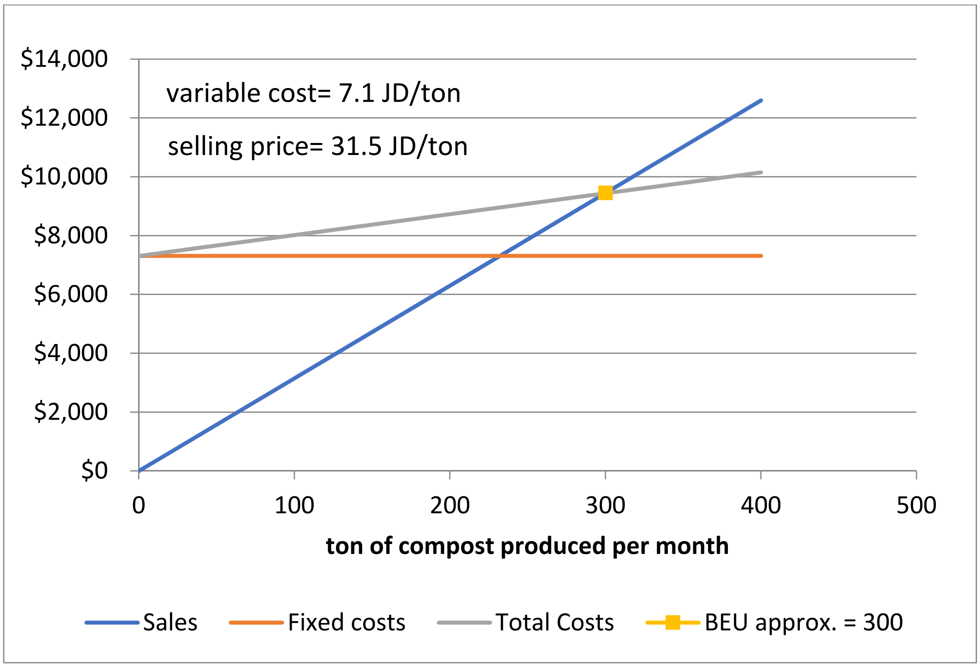

Figure (9): Break-even analysis for the minimum selling price to make a return period of 10 years assuming that the facility operates at full capacity

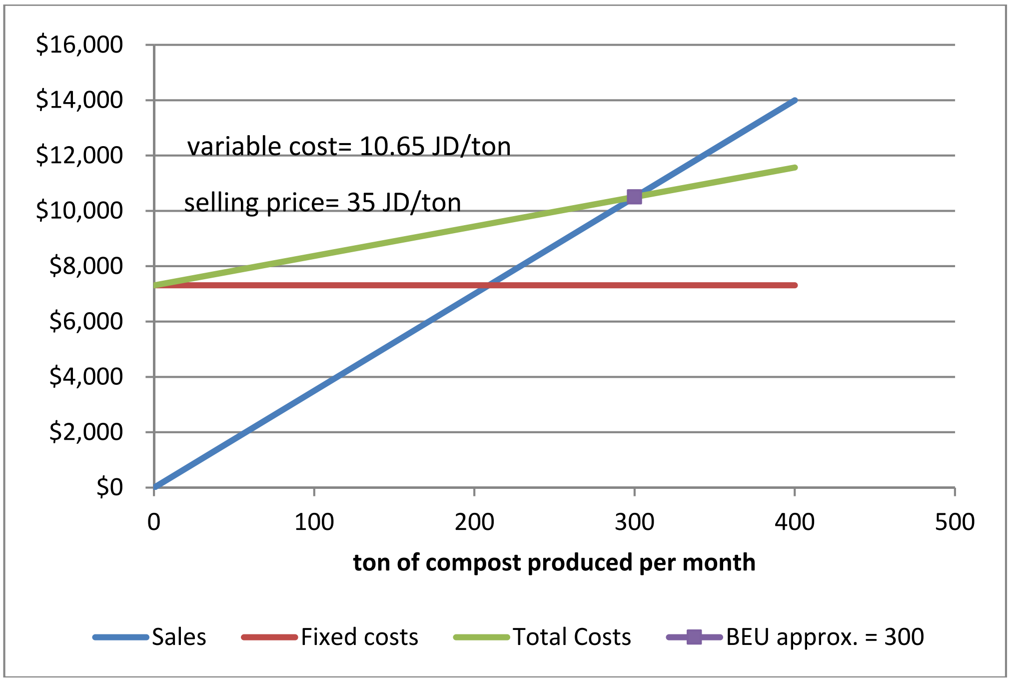

Figure (10): Break-even analysis to obtain the minimum selling price to make a return period of 10 years, assuming that the facility operates at full capacity and the variable costs increased by 50%

CONCLUSION AND RECOMMENDATIONS

This research offered evaluation of the performance of a new and the only municipal solid waste (MSW) composting facility in Irbid city, considering the environmental and economic perspectives.

Regarding the environmental assessment, the use of upstream- operation-downstream (UOD) procedure was adopted to estimate carbon footprint resulting from the MSW management. The results showed that an estimated 13.62 Gg CO_2 equivalent of GHG emissions was avoided per year compared to other current management practices. The results of the techno-economic investigation showed that the payback period of the project is 6.63 years and that the facility could make a net yearly revenue of 88,250 JOD, which confirms the economic viability of aerobic composting as a strategic choice for municipal solid waste management. Finally, the following recommendations were suggested for future development:

1) Input materials and mixing ratios should be characterized before composting, in terms of quality and quantity, to avoid long treatment time and odor nuisance issues.
2) More advanced models based on country-specific data should be used, instead of default data from IPCC-tier ones, for evaluating the plant performance like assessing the solid-waste landfilling emissions.
3) Appropriate legislative frameworks are needed to govern & promote MSW composting at large scale and set clear guidance for MSW separation at the source.
4) As the national strategy for MSW management evolves toward large-scale composting facilities, gathering and storing the data of composting facilities is crucial to optimize their operation as well as economic and environmental aspects.

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