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Carbon Emission Pinch Analysis for Sustainable Landfill

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Renewable energy, energy efficiency and carbon capture and sequestration, are among several initiatives to reduce global carbon emission as an effort to mitigate global warming. Apart from reducing carbon footprint, another alternative to combat global warming is through effective solid waste management for landfill. While landfill is the most common solid waste treatment options in most parts of the worlds, however in densely populated area, as land availability may be scarce, careful planning and targeting is therefore required to reduce the landfilling rate. It is envisaged that an effective solid waste management strategy can reduce the amount of waste channeled to landfill. Since different waste management technologies requires different size of land area and have different carbon emission reduction impact, question that are often asked in correspond to this aspect includes; What is the suitable waste management technology that should be practiced to reduce the carbon footprint? How much land footprint is reduced? What are the carbon emission intensity of a landfill and how much it may contribute to global warming? In order to answer these questions, a new targeting technique based on carbon emission pinch analysis is developed. This technique aims to identify the optimal landfill waste management technologies based on specify carbon emission reduction target. It can also target the footprint of landfill area through graphical representation.

1. Introduction

Rapid growth of the population, changing consumption patterns, economic development, urbanisation and industrialisation have resulted a remarkable increase of the municipal solid waste (MSW) generation. Improper waste management led to aggravate waste disposal problem where over reliance on landfilling is the dominant practice especially in developing nations. The practice had caused exhaustion of landfill capacity earlier than anticipated whilst land available for new landfill is becoming scarce. As landfill has their limited capacity or life span for accepting the waste, hence an effective solid waste management of landfill significantly prolongs the service life and help to reduce for the needs of a new landfill. An optimised landfill capacity through increase the waste density within landfill (Hanson et al., 2010) and minimising waste send to landfill through diversion to other disposal options have to be embraced for the landfill exhaustion problem. However, it is recognised that managing on waste disposal have contributed to the generation of greenhouse gas (GHG) which mainly consists of methane (CH_4) and carbon dioxide (CO_2). As different waste management technologies have different carbon emission reduction impacts, government and waste disposal authorities need a dedicated planning tool to tackle simultaneously aforementioned issues. It is envisaged that proper waste management strategies would reduce GHG emissions. Hence, for further implement the waste management strategies for achieving sustainable landfilling practice, a previous developed technique, i.e. waste management pinch analysis (WAMPA) is extended to identify the optimal waste management technologies based on landfill capacity area limit with the specified carbon emission target. It is also capable to determine the targeted land footprint through visual representation by using pinch analysis.

Pinch analysis was widely used as a tool for optimisation in chemical process and integration. It was developed since 1970s based on thermodynamic principles and its basic concept is to match with available internal heat

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supply and appropriate heat sinks for energy efficiency (Klemes and Kravanja, 2013). It then has been further applied in a number of fields, including mass exchange network (El-Halwagi and Manousiouthakis, 1990), water network synthesis (Foo, 2009) and hydrogen pinch (Fonseca et al., 2008). Another applications with details explanation as such energy pinch, energy-water, oxygen pinch and oxygen-water, were reported in Klemes et al. (2011). All of these applications have the same principle which applies the information based on stream quantities (e.g. flow rate) and quality of a process system (e.g. concentration, temperature) to define the target. As for carbon emission targeting, Linnhoff and Dhole (1993) investigated the total site concept for saving fuel and power in industrial facilities. Perry et al. (2008) continue the work by integrating with renewable sources of energy. In the extended work, Tan and Foo (2007) developed the regional energy planning under carbon emission constraint known as Carbon Emission Pinch Analysis (CEPA). The latter application in carbon-constrained for energy and power generation sector planning have been employed by Lee et al. (2009) and Tan et al. (2009). Related to waste management strategy, a new application method known as WAMPA has been formulated by Ho et al. (2015).The study highlighted an application of pinch analysis in solid waste management based on specified landfill reduction and carbon emission target which then continue the work to consider on the effect of economic assessment of the recycling target (Tan et al., 2015). The feasibility of WAMPA was then further addressed with comprehensive works on the reduction of each waste type (Ho et al., 2016). In general, WAMPA require users to identify the carbon emission constraint with targeted landfill reduction and adjust to three strategies in waste management (Reuse, Reduce & Recycle (3R), Waste to Energy (WtE), and landfilling). However, WAMPA has not considered the landfill area for waste reduction technique to be accommodated in landfill. It has been noted that optimising landfill area is significant to extend the life span for archive sustainable landfilling practice. Therefore in this work WAMPA is extended to target the waste reduction in landfill based on the landfill area limit. The technique involves the diversion and compaction strategies as for carbon mitigation of each waste composition in landfill to meet the targeted demand while maintaining carbon emission at the appropriate level.

2. Methodology

The application of the proposed methodology is demonstrated in a hypothetical case study in this section. In Pinch Analysis, the Demand (source) and Supply (sink) is constructed and the point where the Demand and Supply Curve meets is known as Pinch Point. In this paper, the Pinch Point is defined by the users as the carbon emission target and landfill target area. User is required to construct a composite curve based on a landfill waste composition and then set a new target. The carbon emission landfill capacity curve (CLCC) is plotted in the preliminary or conceptual design stage. In CLCC, carbon emission (t CO_2) is plotted against land footprint (m^2). The step by step methodology is as below:

Step 1: Construct the existing CLCC.

The waste supply curve is demonstrated as five major MSW compositions in landfill (plastic, metal, glass, and paper and food waste). The X- axis is the cumulative of waste area in the landfill and Y-axis represent the cumulative of carbon emission arranged from the lowest to the greatest t CO_2/t waste. The study also considers emission of CO_2 and CH_4 as the carbon emission equivalent. Table 1 shows the details of five major waste composition for MSW deposited in landfill which required for the analysis. It is assumed in this case study, waste are segregated and the average waste disposal height in landfill is 20 m with normal compaction factor for the implemented existing landfill. A general formula for estimating land footprint of each waste component (R) can be written as follows:

$$R = (\text{Solid waste generation (t)} / ((\text{waste density (t/m}^3)) * \text{compaction factor/ height (m)}) \quad (1)$$

Table 1: Data for constructing CLCC

	Average solid waste generation in landfill	Landfill emission (t CO_2)[a]	Waste density as discarded (t/m^3)[b]	Compaction factor in landfill (normal compaction)[c]	Compaction factor in landfill (well compacted)[c]
Plastic	40,000	0	0.064	0.15	0.10
Metal	25,000	0	0.320	0.35	0.30
Glass	14,000	0	0.195	0.6	0.40
Paper	20,000	0.37	0.082	0.20	0.15
Food waste	200,000	0.59	0.288	0.35	0.33

[a] Ho et al. (2016)

[b] Christensen (2012)

[c] Tchobanoglous and Keith (2002)

Step 2: Set landfill area limits and carbon emission reduction (Pinch Point).

User needs to set a target demand and construct a supply curve base of existing implemented waste composition in landfill to meet a newly set target. Base on the case study, the area limits permitted for waste disposal in 2026 is 12,000 m^2 with aimed to reduce 80 % carbon emission in landfill.

Step 3: Construct new landfill curve based on proposed implementation of carbon mitigation strategies:

a. Identify the waste diversion curve from the existing CLCC. The length of the waste curve that involve the diversion is depends on the area (m^2) limits of the landfill. In this case, the large portion of biodegradable waste (food waste) will be diverted (Refer to Figure 1).

b. Shift the remaining waste curve to new curve. The length of the curve is residual the portion of the diversion strategies. From the graph on Figure 1 is shown that only a small portion of food waste is shifted to a new curve.

c. Transfer and extend the next waste curve until it touches the x-axis (By referring the graph below, this waste curve represents the paper curve).

d. The remaining target of emission is satisfied by performing waste diversion on paper waste.

e. Maintain the horizontal curve waste which in the case study are the non-biodegradable waste (glass, metal and plastic). The horizontal line depicted as no emission from non-biodegradable waste.

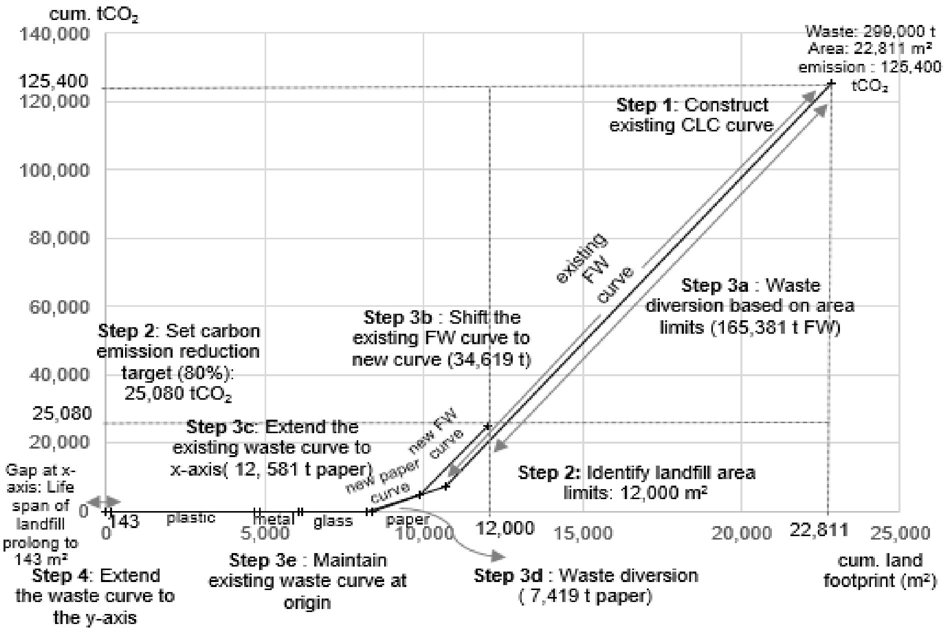

Figure 1: Carbon emission pinch analysis for sustainable landfill

Table 2: Additional data for paper and food waste to construct WAMPA

	Year 2016	Year 2026	Carbon emission reduction target
Food waste			
Total waste generation (t)	200,00	300,000	20%
Wte implementation (t)	30,000		
General emission Wte (t CO_2)	0.28		
Paper waste			
Total waste generation (t)	40,000	65,000	25%
3R implementation	10,000		
WTE implementation (t)	10,000		
General Wte emission (t CO_2)		0.28	
3R emission (tCO_2)		0.00	

Step 4: Extend the existing waste curve to y-axis.
The gap from this line indicates the life span of the landfill can be prolonged.
Step 5: Construct WAMPA (Refer to Ho et al. (2016)) based on the targeted landfill area from new CLCC.
(i.e. the landfill area that can accept food waste is 2,401 m^2 or 34, 619 t). An additional data is given in Table 2 to conduct WAMPA for food waste. Figure 2 shows the result of WAMPA.

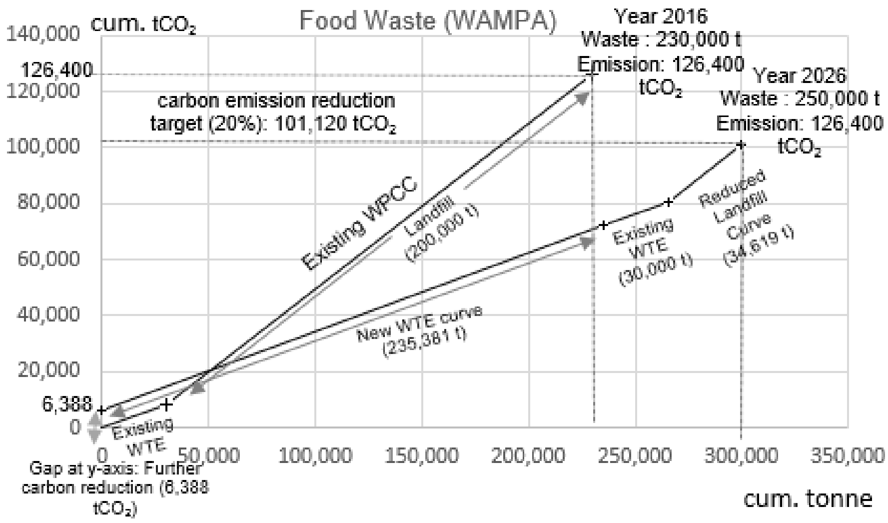

Figure 2: WAMPA for Food waste

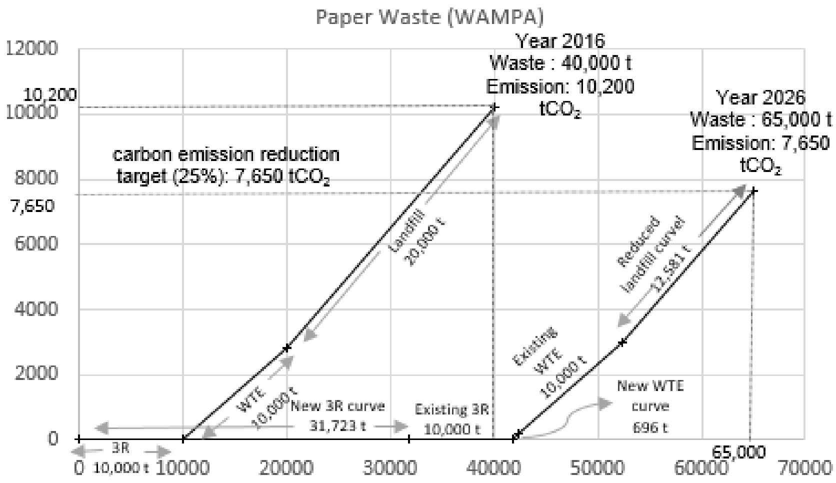

Figure 3: WAMPA for Paper waste

3. Results and Discussion

Table 3 below shows the results of the analysis for carbon emission pinch analysis for sustainable landfill. Based on the case study, it is suggested to satisfy the target of 12,000 m^2 area and 80 % carbon emission reduction in landfill for the year 2026, it requires the diversion of 165, 381 of food waste and 7,419 t of paper waste. On the other hands, the total of waste composition required includes 34,619 t, 16,595 t, 14,000 t, 25,000 t, and 40,000 t of food waste, paper, glass, metal and plastic. As for WAMPA, the reduction until 34, 619 t land footprint of food waste with 20 % carbon emission reduction in total emission of food waste resulted the additional of 235, 381 t in capacity of Waste to energy (WTE) technology. As for paper waste, the reduction until 12, 581 t in landfill resulted the additional of 696 t of WTE and 31,723 t of 3R startegy with the 25 % carbon emission reduction target of total paper waste in year 2026.
To further illustrate the effect of different strategies for future implementation in landfill, Figure 3 depicted the curve of area reduction of normal and well-compacted strategies with 12,000 m^2 targeted land footprint and 80

% emission reduction. It is expected that the land footprint of food waste will be reduced by 82.7 % and 83.7 % in normal and well - compacted strategies. Meanwhile, the area of paper waste will be lessened by 37.1 % and 52.8 % in normal and well – compacted. It can be noted that the land footprint of glass, metal and plastic are predicted to decrease to 33.3 %, 14.3 % and 33.3 % by implementing the well-compacted strategies in order to achieve the set target. No diversion and landfill reduction will be imposed for glass, metal and plastic in normal compaction as more allowance of land are available. Additionally, with reference to Figure 4, the area of the landfill will be prolonged to 3,126 m^2 in a well – compacted and 143 m^2 in normal compaction strategies for the future implementation strategy.

Table 3: Results of carbon emission pinch analysis for sustainable landfill

Waste	Baseline case: Normal compaction (Year 2016)	1st scenario: Normal compaction with waste diversion (Year 2026)	2nd scenario: Well-compacted with waste diversion (Year 2026)
Plastic (t)	40,000	40,000	40,000
Emission (tCO_2)	0	0	0
Area (m^2)	4,688	4,688	3,126
Metal (t)	25,000	25,000	25,000
Emission (tCO_2)	0	0	0
Area (m^2)	1,367	1,367	1,172
Glass (t)	14,000	14,000	14,000
Emission (tCO_2)	0	0	0
Area (m^2)	2,165	2,165	1,443
Paper (t)	20,000	16,595	16,595
Emission (tCO_2)	7,400	4,655	4,655
Area (m^2)	2,439	1,534	1,151
Food waste (t)	200,000	34,619	34,619
Emission (tCO_2)	118,000	20,425	20,425
Area (m^2)	12,153	2,104	1,983
Total emission (tCO_2)	125,400	25,080	25,080
Total remaining area (m^2)		143	3,126

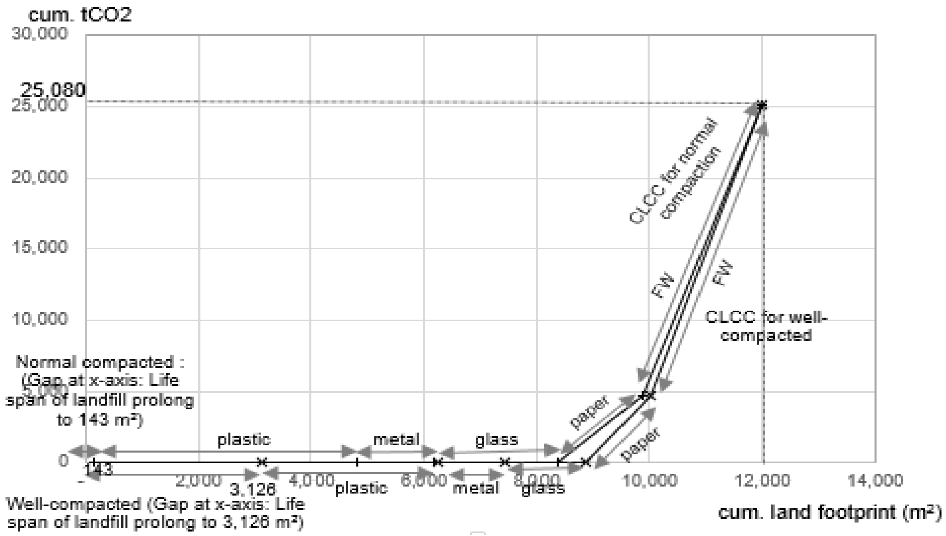

Figure 4: Analysis of carbon emission pinch analysis by normal and well-compacted waste in landfill

4. Conclusion

Based on the overall outcome of this study, carbon emission pinch analysis for sustainable landfill is capable to identify the optimal capacity processing of each waste type in landfill based on specified area limits (m^2) with specified carbon emission constraint. However, it does not measure the cost-effective and the feasibility of the area of other disposal technologies. Carbon emission pinch analysis for sustainable landfill should also consider these factors by using mathematical formulation for the guideline. Further works on this matter need to be addressed.

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