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Waste Management Pinch Analysis (WAMPA): Application of Pinch Analysis for greenhouse gas (GHG) emission reduction in municipal solid waste management

Wai Shin Ho [a,*], Haslenda Hashim [a], Jeng Shiun Lim [a], Chew Tin Lee [b], Kah Chiin Sam [b], Sie Ting Tan [a]

[a] *Process System Engineering Centre (PROSPECT), Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor, Malaysia*
[b] *Faculty of Chemical and Energy Engineering, Universiti Teknologi Malaysia, Johor, Malaysia*

HIGHLIGHTS

- A novel method known as Waste Management Pinch Analysis (WAMPA) is presented.
- WAMPA aims to identify waste management strategies based on specific target.
- WAMPA is capable to examine the capacity of waste management strategies through graphical representation.

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ABSTRACT

Improper waste management happened in most of the developing country where inadequate disposal of waste in landfill is commonly practiced. Apart from disposal, MSW can turn into valuable product through recycling, energy recovery, and biological recovery action as suggested in the hierarchy of waste management. This study presents a method known as Waste Management Pinch Analysis (WAMPA) to examine the implication of a dual-objective – landfill and GHG emission reduction target in sustainable waste management. WAMPA is capable to identify the capacity of each waste processing strategy through graphical representation. A general methodology of WAMPA is presented through a demonstration of a SWM case followed by a detailed representation of WAMPA for five waste types. Application of the WAMPA is then applied on a case study for sustainable waste management planning from year 2015 to 2035. Three waste management strategies are incorporated into the case study – landfill, Waste-to-Energy (WtE), and reduce, reuse, and recycle (3R). The results show a 13.5% of total GHG emission reduction and 54.6% of total reduction of landfill are achieved. The major contributor of GHG emission which are from food waste (landfill emission) and plastic (WtE emission) is reduced.

1. Introduction

The generation of municipal solid waste (MSW) has increased in parallel to the rapid population growth, and with changing consumption patterns, economic development and rapid urbanization. Improper waste management happened in most of the developing country where inadequate disposal of waste in landfill is commonly practiced. Improper waste management causes long-term impacts to the environmental, such as pollution of air, soil, surface and ground water, in addition, reduces valuable land space due to landfilling. One of the major consequences of landfill is the generation of methane (CH_4) gas from the decomposition of MSW, where CH_4 contributes to about 21% of global greenhouse gasses (GHG). The negative consequences of landfill are the driving force that pushes governments and municipalities to identify better solutions for waste management planning. Apart from disposal, MSW can turn into valuable product through recycling, energy recovery, and biological recovery action as suggested in the hierarchy of waste management [1].

As the process to identify the optimal strategy for waste management can be rather complex. Regional solid waste management (SWM) strategy are often performed via optimization tool which is often optimized in a “black-box” mathematical optimization approach, emphasizes the design of a system by a specific objective function that gives the best solution to the objective function [2]. Various types of techniques have been implemented as an optimization model for SWM, such as Linear Programing, Mixed

* Corresponding author. Tel.: +60 16 4401186.
E-mail address: hwshin@utm.my (W.S. Ho).

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Nomenclature

3R	reduce, reuse and recycling
CEPA	Carbon Emission Pinch Analysis
CO_2	carbon dioxide
CH_4	methane
EROI	Energy Return on Energy Investment
GHG	greenhouse gasses
MILP	Mixed Integer Linear Programming
MSW	municipal solid waste
NLP	Non-linear Programming
PGCC	Power Grand Composite Curves
PPA	Power Pinch Analysis
SWM	solid waste management
WAMPA	Waste Management Pinch Analysis
WSC	Waste Supply Curve
WtE	Waste-to-Energy

Integer Linear Programming (MILP), Non-linear Programming (NLP), stochastic programming, fuzzy logic and hybrid model. Mathematical optimization approach required the specific mathematical modelling knowledge to develop the models, which might prevent decision and policy makers to understand fully the reason in obtaining the optimal solution.

Among the optimization techniques present, Pinch Analysis (PA), which has been largely applied through many applications, is significantly important and has the advantage of allowing users to easily grasp and understand the optimization procedure as PA is often presented graphically. PA was first developed based on thermodynamic principles for the synthesis of heat exchanger networks in the 1970s [3]. The fundamental concept of PA is to maximise the process-to-process heat recovery and minimise the external utility loads. Since then, it has been applied to processing problems beyond heat and energy application. For instance, El-Halwagi and Manousiouthakis [4] adopted PA into mass exchange networks of a chemical process. Wan Alwi and Manan [5] proposed a new graphical tool known as STEP to simultaneously target and design heat exchanger network, which later on, the authors [6] extended to consider the placement of utilities with flue gas. Miah et al. [7] proposed a new practical integration framework to solve complex and diverse production line, involving analysis at zonal and factory level. Liew et al. [8] proposed a PA centric framework to perform the heat integration for a total site problem. PA was further adapted in power system planning by Bandyopadhyay [9] to design an off-grid PV/Battery system. Alwi et al. [10] continue to improve the power for hybrid renewable energy sources known as Power Pinch Analysis (PPA). Ho et al. [11] extend the PPA approach by employing new ways of utilising the Demand and Supply Composite Curve methods for the design of an off-grid hybrid energy systems. Giaouris et al. [12] continue to improve the work on PPA by introducing the Power Grand Composite Curves (PGCC) method to adaptively adjust the system operation in short-term power requirements. Other than energy and power, Manan et al. [13] proposed the used of Water Pinch to target the minimum water flow rate. Ng et al. [14] adopted Water Pinch for wastewater recycling issue. Foo et al. [15] developed algebraic and graphical targeting techniques to design the chilled water and cooling water network.

Conventional Pinch Analyses are used to define the target (demand chain) of process system based on the information of stream quantities and quality (supply chain) for a micro-scale industries planning. With contrast to the conventional Pinch approaches, Tan and Foo [16] developed the Carbon Emission Pinch Analysis (CEPA) to address the GHG emission constraints issue of the energy sectors for macro scale regional planning. In CEPA, the carbon reduction target from the energy sector was set based on national or regional development plan, then emissions reduction action is decided to achieve the set target. Tan et al. [17] extends the conventional PA technique from industrial sites to broader macro-scale applications into electricity generation sector to optimize the generation mix based on demand/emissions targeting. Walmsley et al. [18] combined the CEPA and Energy Return on Energy Investment (EROI) to perform macro level energy planning for New Zealand.

This study presents a new application of PA for SWM planning. The proposed Waste Management Pinch Analysis (WAMPA) is analogous to the existing CEPA. Similar to the existing CEPA, users will have to identify the constraint for GHG emission and then adjust a non-carbon emitting option to meet the targeted demand while maintaining the GHG emission at the appropriate level. While CEPA is applied for energy management, WAMPA is for solid waste. In CEPA, the non-carbon emitting option is renewable energy while in WAMPA is reduce, reuse, and recycling (3R) strategy. In addition to that, WAMPA also include an additional target for landfill reduction target as well as provides a more detailed step by step analysis compared to the previous CEPA, to balance the three general strategies in waste management (Waste-to-Energy (WtE), landfilling, and 3R). WAMPA is able to reveal the capacity for landfilling, WtE, and 3R to meet a future scenario where waste generation is increasing and more stringent constraint is set on GHG emission and landfilling. In this paper, WAMPA is also demonstrated for the five major categories of municipal solid waste, food waste, paper, plastic, metal and glass.

In this article, the general methodology of WAMPA will be presented through a demonstration of a SWM case followed by a detailed representation of WAMPA for five waste types. Application of the technique is then applied on a hypothetical case study for sustainable waste management planning. It is noted that the figures presented in the methodology chapter reflects the hypothetical case study. It is then followed by the result and discussion, and finally conclusion.

2. Waste Management Pinch Analysis (WAMPA)

WAMPA is developed base on CEPA approach that identify the optimal strategies based on the defined target for a waste management system. WAMPA introduces a step-by-step algorithm, which involves a more systematic approach for waste management system.

2.1. Assumption of WAMPA

To conduct WAMPA, several assumptions were made:

1. The supply side of waste management is depicted by the capacity of waste processing and disposal technologies, which are such as recycling, WtE, and landfilling.
2. The demand side of waste management is depicted by the amount of waste source.
3. Waste are assumed to be segregated, therefore different types of waste would be processed according to the characteristic.
4. It is assumed that no GHG is release from metal and glass waste.