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Optimal Feedstock Blending for Energy Maximization and Emission Compliance at Yangon Waste-to-Energy Plant, Myanmar

Wint Khant* and Aung Myo Lwin

***Abstract* – Rapid urbanization and industrialization in Yangon have led to drastic increases in municipal solid waste (MSW) and industrial waste, requiring a sustainable waste management approach. The YWTEP was developed to convert such waste streams into renewable energy with minimal environmental pollution. This paper develops an LP model that optimizes the mixture of MSW and industrial waste streams for maximum energy recovery within emission standards prescribed by Myanmar. The model is designed considering various waste categories, such as plastics, paper, organic waste, wood, textiles, rubber, and metals, which have different calorific values and emission factors. The optimal waste composition was 28.85% plastic, 35% paper, 26.15% organic waste, and 10% wood, providing 18.95 MJ/kg of energy generation while meeting NOx, SOx, and dust emission limits. Sensitivity analysis showed that such variations in waste composition due to seasonal variations in moisture content could affect energy generation and emissions, thus requiring adaptive operating strategies. In this regard, the results point to the significance of strategic waste blending to improve WTE facility efficiency and sustainability, thus offering practical guidance to policymakers and plant operators. This study, therefore, establishes a fact-based framework for improving the waste-to-energy (WTE) in sustainable waste management and renewable energy supply for Yangon and other cities.**

Keywords—* *Linear Programming Model, Sensitivity Analysis, Renewable Energy, Waste-to-Energy, Calorific Value.

I. Introduction

The rising demand for green energy has placed waste-to-energy (WTE) technologies in the limelight due to their dual benefits of energy generation and waste management. The challenges faced by rapidly urbanizing and industrializing cities such as Yangon are immense. The policy framework should integrate city waste management with energy supply and environmental standards. The quantities of municipal solid waste (MSW) and industrial waste treated at WTE plants depend significantly on the region and technology. Generally, urban areas treat municipal solid waste because of its large volume. Industrial waste is also important but usually treated separately because of its different composition and possible hazardous nature. How these waste streams are integrated into WTE plants differs depending on the nature of the waste, the type of technology available, and the local waste management policies. The Yangon WTE Plant is such a significant project that seeks to convert waste into efficient energy while lowering emission levels. How effective a WTE plant will be, as well as its environmental impacts, heavily depends on what waste it uses. Proper mixing of the waste

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materials generates the maximum energy and minimizes the toxic emissions. Various wastes, like plastics, paper, organics, textiles, rubbers, woods and metals, possess different energy values and generate different emissions. Hence, determining the optimal method to mix these materials can maximize the efficiency and sustainability of the plant. Although waste-to-energy (WTE) technologies are increasingly used worldwide, many studies still lack focus on localized operational optimization. First, although many existing studies use mathematical models for waste blending, they often accept stable waste compositions—and do not account for seasonal variations, such as the higher moisture content in municipal solid waste (MSW) during tropical monsoon seasons. Second, very little research has been done on Myanmar's specific waste management situation. Most leading studies are descriptive and focus on waste generation trends rather than developing the quantitative, implementable frameworks needed to realize the potential WTE infrastructure for this country. Consequently, there is a general lack of local optimization methods that deal with specific operational and regulatory issues regarding the YWTEP.

This study fills this gap by developing an advanced Linear Programming (LP) model that is self-decisive and superior to earlier generalized optimization approaches. Unlike predictable models, the proposed framework integrates local emission limits with the actual thermochemical properties of locally available municipal solid waste (MSW) and industrial waste materials. By considering energy optimization against regional operational constraints, the model thus moves beyond the theoretical approach to a pragmatic, data-driven tool for plant operators and policymakers alike.

II. Literature Review

The generation of waste worldwide is exponentially increasing and has become one of the leading environmental concerns [1]. Traditional technologies for waste disposal, including the landfilling process, are not considered environmentally safe or sustainable in themselves [2]. Waste-to-energy (WTE) technology provides an innovative and sustainable solution for waste management by converting waste into energy [3]. This technique minimizes landfilling and reduces greenhouse gases while generating renewable energy [4]. Integrated Waste-to-energy (WTE) approaches have hence been gaining pace in several countries as part of strategies to tackle waste and energy demands [5].

Critical challenges at various operational levels are operational inefficiencies and perception issues coupled with stringent regulatory requirements [6]. Optimizing the operations of a WTE plant is a challenging task considering many variables and dynamic conditions representative of the operational context. Emission control assumes special significance because of the complex nature of MSW, which brings with it the possibility of creating toxic pollutants through the combustion process. The existing literature makes it clear that WTE technologies have been envisaged to emit signature gases like NOx, SO2 and HCl, apart from PM. Therefore, flue gas treatment units become essential if one wants to comply with environmental laws [16]. Besides this, residue and flue gas from one class of newly discovered pollutants, the per-and polyfluoroalkyl substances (PFASs)-only underscore the derivation of the urgency and the need for effective monitoring and management practices [17]. Henceforth, improvements in operations, advanced filtration systems, and better feedstock control will be needed to reduce environmental impacts and ensure compliance.

Overall, the proportion of industrial and municipal waste processed in WTE plants is a function of local waste composition, economically viable technologies, and financial considerations, with a trend towards increased use of multi-source waste streams to maximize energy yield and environmental benefits [7][8]. One of the most prominent merits of the waste feedstock blending process is the improvement of energy yield and quality; blending different types of waste, e.g., agricultural residues and industrial by-products, can improve the calorific value and burnability of resulting biofuels, thereby enhancing their efficiency in energy recovery [9]. Previous studies highlight the importance of segregation and mixing of waste for enhancing calorific value [14]. Past research emphasizes waste constituents' role in WTE efficiency, namely high-calorific industrial waste materials such as plastics and chemicals, which contribute significantly to energy output, but high-moisture MSW can impede combustion efficacy [21],[22].

The disadvantages, however, are process inefficiencies such as difficulties in feeding blends of mixed materials into burning systems and, as a result, increased maintenance demands and related potential operational instability [10]. In addition, the presence of high ash content in certain blends is bound to impact burning efficiency and increase pollutant output [11]. Besides, some studies have shown that the ideal mixture of MSW-industrial waste can align energy production and counteract operating problems such as residue collection and unnecessary emissions [23]. LP models have also been helpful in optimizing these waste blends for WTE systems in other parts of the world [15].

Due to rapid urbanization and industrialization, waste management has become a significant issue in Myanmar. An increase in municipal solid waste volume poses severe environmental and public health problems. The first WTE plant in Myanmar is being commissioned in Yangon, generating 760 kilowatts of power per day. [24]. However, most of the existing waste-to-energy (WTE) plants operate inefficiently, leading to high operating costs and low energy yield. Hence, this highlights the need for a strategic approach to controlling the composition of wastes to optimize the performance and sustainability of YWTEPs.

III. Methodology

Renewable energy and proper waste management demands have spurred the development of waste-to-energy (WTE) plants. These facilities use municipal solid waste as feedstock to produce electricity or heat, thereby combining waste treatment with energy production. However, the operational optimization of waste-to-energy (WTE) plants becomes complicated due to the multidimensional variables and complex system interactions. Waste management has become a serious problem in Myanmar due to rapid urbanization and industrialization. The increasing volume of municipal solid waste poses serious threats to environmental and public health. WTE plants offer an environmentally sustainable solution by processing waste and generating energy to reduce landfill use and develop a new renewable energy source. The operational efficiency of existing WTE plants, however, is typically low, leading to higher costs and compact energy generation. The WTE plants are truly a promising method to dispose of municipal solid waste and generate renewable energy. In Myanmar, the first WTE plant was established in Yangon, generating 760 kilowatts of power daily [24]. The plant, located in Shwe Pyi Thar Township, Yangon, Myanmar generates about 60 tons of trash per day is shown in Figure 1.

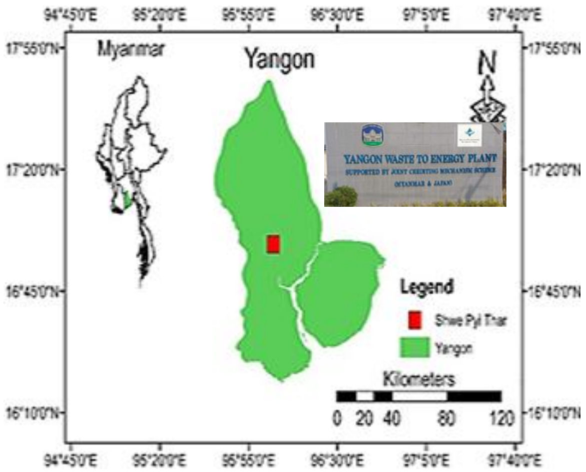

FIGURE 1. Location of the Waste-to-Energy plant in Yangon, Myanmar

The goal of WTE technologies is to convert municipal solid waste (MSW) into energy that may be used for electricity. The most common WTE technology is incineration, which involves burning waste at high temperatures to produce heat. After that, this heat is converted to steam, which powers turbines to create electricity. Incineration is widely used due to its ability to significantly reduce the volume of waste by up to 90%, and its capability to handle a variety of waste types, including non-recyclable plastics and organic waste [25].

A. *Waste Receiving System (or) Preliminary Storage*

The waste is transported into the waste yard once the truck scale has determined its weight. The waste yard has a sufficient capacity so that waste can be pre-checked to segregate the prohibited waste and mixed before transferring it to the waste conveyor system. The floor of the waste yard is sloped so that leachate from the waste and wastewater used for the cleaning of the floor are discharged to the leachate storage tank smoothly. A waste loader is used to process moist waste from the city of Yangon to drain and stir it in the pit. The facility will be designed so that the waste pit can store the received waste for more than 5-7 days to sufficiently drain it considering that the moisture level of the drain will reach up to 60% in the rainy season.

Waste will be unloaded in a dumping area situated 2 meters above the ramp. The waste loader will have to transfer the waste from the dumping zone to the preliminary storage zone, according to the capacity of the waste receiving zone. In the waste yard, the storage area is divided into 6 sections (household wastes and industrial wastes). Four sections include household wastes or municipal wastes, and another two sections are industrial wastes. Each section must store 7 days in the rainy season and 5 days in the summer (or) winder season due to reducing moisture content in wastes.

B. *Quality of Waste and Waste Calorific Value*

It is necessary to evaluate the waste quality prior to designing an incinerator facility. Although Yangon City Development Committee (YCDC) is now examining waste quality, not enough information has been gathered. Thus, we concur with YCDC that the quality of municipal garbage for this study should be as indicated in Table I. Waste quality according to the achievement of WTE plants and (Japan, Fe (for iron), and Engineering) JFE's experience in Southeast Asian countries. It is assumed that the proportion of water in waste of the city of Yangon increases at certain time of the year mainly due to the rainy season. We therefore assumed that the proportion of 4-10 water in low quality waste to be 60% according to the local interview and the historical performance of WTE plants.

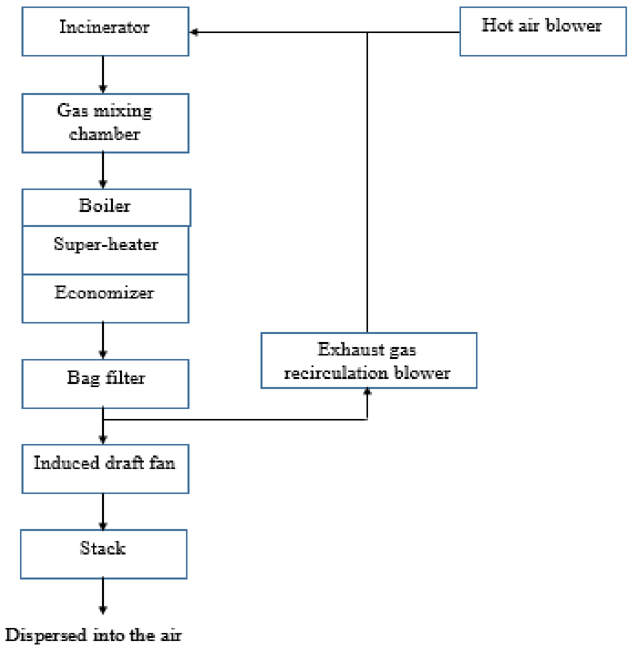

FIGURE 2. Yangon Waste-to-Energy Plant Technologies

TABLE 1. Waste quality

Item		Unit	Waste Quality Low	Standard	High
Low Calorific Value (LCV)		Kcal/kg	1,300	1,800	2,200
		KJ/kg	5,400	7,700	9,200
Component	Flammable	%	26	34	40
	Moisture	%	60	55	53
	Ash	%	14	11	7
	Total	%	100	100	100

IV. MODEL DEVELOPMENT

A linear programming model is a mathematical method for finding the best outcome under a set of linear rules and relationships. To find the best possible solution, Linear Programming (LP) model is used to optimize the types of waste of waste to energy plant. The following mathematical formulations are used to develop (LP) model. The optimization model focuses on maximizing energy while monitoring emissions like SO_2, NO_x, and small particles. The study combines plant data, regulatory requirements, and computer simulations to determine the optimal material composition. This way, it regulates the optimal use of available resources. Tables 2, 3, and 4 provide salient information on the types of wastes, gas emissions, and their properties.

A. Data Collection and Parameter Validation

To establish the credibility and reproducibility of the LP model, operational parameter observations were made under the following The facility logs continuous daily receipts in the preliminary storage area, from which the maximum available fractions of municipal solid waste (MSW) and industrial wastes are drawn.

• Calorific Values: Under standard laboratory conditions, an experimental bomb calorimeter determined the low calorific value of each waste category. Realistic moisture content was considered, which could reach up to 60% during the local rainy season; therefore, detailed composite samples were analysed using standard scientific test methods.

• Emission Factors: Facility-specific emission factors for NOx, SOx, and PM were derived from historical continuous emissions monitoring systems (CEMS) data and taken as baseline values against published literature values. In this regard, the model's upper emission limits for domestic legislation, i.e., NOx ≤ 0.0015 kg/kg, SOx ≤ 0.001 kg/kg, and PM ≤ 0.0005 kg/kg, were calibrated according to the Myanmar National Environmental Quality (Emission) Guidelines.

Since the formulated Linear Programming model is complex, it will not be explained manually. Instead, it was coded and computationally executed using advanced mathematical optimization software. This software utilized a simplex linear programming algorithm to iteratively evaluate the established constraints and determine the global optimal objective value for maximum energy recovery.

B. Linear Programming Model

Linear Programming Model for Optimal Feedstock Blending in Yangon WTE Plant calculated as follows.

1. Objective Function:

Maximize total energy output (based on calorific values):

$$\text{Maximize } E = \sum_{i=1}^{n} x_i \, . \, CV_i \tag{1}$$

Where,

x_i=Fraction of waste type i in the blend ($0 \le x_i \le 1$)

CV_i = Calorific value of waste type i (MJ/kg)

n = Number of waste types

2. Constraints:

(a) Emission Compliance

For each pollutant j (Nox, SOx, PM):

$$\sum_{i=1}^{n} x_i \, . \, EF_{i,j} \le \text{Emission Limit j} \tag{2}$$

Where,

$EF_{i,j}$ = Emission factor of pollutant j for waste type i (g/kg)

Emission Limit j = Maximum allowed emission for pollutant j (g/kg)

(b) Waste Availability

$$x_i \le A_i \tag{3}$$

Where,

A_i = Maximum available fraction of waste type i (based on supply)

(c) Blending Ratio

$$\sum_{i=1}^{n} x_i = 1 \tag{4}$$

(Ensures all waste fractions sum to 100%)

(d) Non- negativity

$$x_i \ge 0 \; \forall i \tag{5}$$

TABLE 2. Waste types

Waste Type	Plastic	Paper	Organic Waste	Textile	Rubber	Wood	Metal
Max: waste (available)	0.45	0.35	0.5	0.2	0.15	0.1	0.05

TABLE 3. Emission gas limitations

Emission Gas	NOx (kg/kg)	Sox (kg/kg)	PM (kg/kg)
Limitation	0.0015	0.001	0.0005

TABLE 4. Waste types and properties

Waste Type	CV_i (Mj/kg)	NOx ($EF_{i,NOx}$,kg/kg)	SOx ($EF_{i,SOx}$,kg/kg)	PM
Plastic	32	0.002	0.0018	0.0006
Paper	16	0.0012	0.0008	0.0003
Organic Waste	10	0.0008	0.0005	0.0002
Textile	18	0.0015	0.0012	0.0004
Rubber	25	0.0018	0.0015	0.0005
Wood	15	0.001	0.0007	0.0003
Metal	0	0.0001	0.0001	0.0001

V. Results and Discussion

The linear programming (LP) model was described to control the optimal blend of waste fractions that maximize energy output while observing with emission regulations. The global optimum solution was 18.94615 MJ/kg, the maximum energy recovery within the constraints.

A. *Optimal Waste Blend Composition*

Modelling results thus give the following proportions as optimal for each waste type:

- Plastic: 28.85%
- Paper: 35.00%
- Organic Waste: 26.15%
- Wood: 10.00%
- Textile, Rubber, and Metal: 0%

Such a combination ensures the highest calorific value within the constraints of NOx, SOx, and particulate matter (PM) emissions. Textiles, rubber, and metal wastes have been eliminated due to their high emission factors or low energy contributions, either breaching regulatory limits or reducing energy efficiency.

B. *Key Findings*

(1) Energy Maximization:

High calorific values for plastics (32 MJ/kg) and paper (16 MJ/kg) strongly underpin energy output.

Organics (10 MJ/kg) and wood (15 MJ/kg) are included in reasonable proportions to balance moisture content and combustion stability.

(2) Emission Compliance:

The blend contains all the following emission constraints.

- NOx: ≤ 0.0015 kg/kg
- SOx: ≤ 0.001 kg/kg
- PM: ≤ 0.0005 kg/kg

No rubber and textile waste avoid unnecessary NOx and SOx emissions, which would otherwise be close to the limits.

(3) Sensitivity Analysis:

Variability in waste availability, such as seasonal variations in the moisture content of organic waste, may also require blending adjustment.

Industrial wastes, such as rubber and textiles, can be considered when pre-treatment reduces their emission factors or when regulatory limits are eased.

(4) Limitations of the LP Model:

Although the LP model produces an optimal composition, some critical limitations must be considered. The most crucial is the assumed linearity of combustion dynamics and emission generation. Total energy and emissions are thus treated as a strictly proportional sum of the individual fractions. In a real physical thermal treatment process, co-combustion of various waste streams may have non-linear synergistic or antagonistic effects, such as when high moisture content in organic waste directly affects combustion efficiency and temperature profile in plastics. This optimization framework should be followed by NLP or CFD, which can better represent the complex thermodynamic interactions inside the hyper grate stoker furnace.

C. *Practical Implications*

- Operational Strategy: The plant should focus on sourcing plastics, paper, and organic waste, thus minimizing textile and rubber inputs.
- Pre-treatment: Organic waste drying and segregating high-emission materials, such as rubber, would increase efficiency.
- Policy Alignment: The results provide Myanmar's emission standards and stress the need for adaptive waste management policies.

VI. Conclusion and Future Research

This study shows that a 28.85% plastic, 35% paper, 26.15% organic, and 10% wood blend improve energy recovery (18.95 MJ/kg) at the Yangon WTE Plant, complying with emission regulations. Important activities in this regard include the following:

i. Strategic Blending: Plastics and paper with high calorific values are at the forefront of the optimal mix, supplemented with organic waste and wood to ensure combustion stability.

ii. Emission Control: Wastes with high emissions, such as textiles and rubber, must be excluded to comply with the law.

iii. Adaptability: Seasonal variation in waste requires real-time monitoring and dynamic blending changes.

With an eye toward the future, advanced pre-treatment methods, such as torrefaction, may prove promising. Expanding the optimization framework to incorporating multi-objective approach that economic and environmental trade-offs would provide a comprehensive decision-making tool. Expand the model to include emerging pollutants such as per- and polyfluoroalkly substances (PFAS) and carbon footprint analysis to get better assess the overall environmental impact. This research provides an actionable framework for Yangon's WTE plant and similar facilities in developing regions to achieve sustainable waste management and energy generation.

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AUTHOR CONTRIBUTIONS

Wint Khant: Conceptualization, Data Curation, Methodology, Validation, Writing – Original Draft Preparation;

Aung Myo Lwin: Project Administration, Supervision, Writing – Review & Editing.

CONFLICT OF INTERESTS

No conflict of interests was disclosed.

ETHICS STATEMENTS

Ethical approval was not applicable to this research since it did not involve human participants, animals, or sensitive data.

DECLARATION OF AI-ASSISTED TECHNOLOGIES IN THE WRITING PROCESS

No artificial intelligence tools were used in the research or writing of this article.

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