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Economic Perspective for Renewable Natural Gas from Food Waste

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In Malaysia, 45 % of total municipal solid waste is food waste in which government has mandated Act 672 to enforce food segregation approach for several states in Malaysia. Nevertheless, the segregated food waste is still not fully utilized and stick with the current practice of waste disposal. This practice leads to significant methane emissions, environmental pollution, and rising landfill management costs. To address this issue, conversion of food waste to Renewable Natural Gas (RNG) using anaerobic digestion (AD) serves as promising solution to produce clean energy substitute for natural gas. Life Cycle Cost Analysis (LCCA) and Levelized Cost of Methane (LCOM) is performed in this study to evaluate economic viability for two different RNG pathway which are RNG injection into the gas grid pipeline and RNG distribution via virtual pipeline (Bio-CNG). The system boundary includes the entire chain of RNG from food waste collection to RNG end-utilization. Based on this study, RNG injection into the gas grid pipeline presents the lowest annualized cost at 43.2 million MYR/y with an LCOM of 29.81 MYR/MMBtu, while the Bio-CNG pathway incurs higher costs at 64.1 million MYR/y and an LCOM of 44.23 MYR/MMBtu. Compared to the current fossil-based natural gas price of 40.34 MYR/MMBtu, RNG injection to gas grid pipeline shows competitive cost in replacing current natural gas. With additional support by government incentives, carbon credits, and green certificates, RNG production from segregated food waste will be the most viable option in solving the food waste accumulation issue while be competitive with current fossil-based natural gas in the market. This study will give valuable insights for policymakers and industry stakeholders in driving sustainable waste-to-energy strategies, enhancing food waste valorization, and advancing Malaysia's net-zero emission agenda.

1. Introduction

The swift urbanization and population growth in Malaysia has caused increase in municipal solid waste (MSW) generation. According to Ahmad et al. (2025), in 2021, Malaysia recorded 38,206.82 t of MSW per d, an increase of 83.54 t compared to 2020 with approximately, 45 % of the waste is food waste. In Kuala Lumpur, the rising volume of MSW has led to overloading at existing disposal sites, prompting the allocation of a new sanitary landfill at Bukit Tagar (Taib et al., 2017). Food waste disposal particularly in non-sanitary landfills contributes substantially to greenhouse gas (GHG) emission with nearly 47 % of total methane gas emission that drives the ozone depletion. To mitigate these issues, the Solid Waste and Public Cleansing Management Act 2007 (Act 672) has been introduced. This involves six states (Pahang, Johor, Malacca, Negeri Sembilan, Perlis, and Kedah) and two federal territories (Kuala Lumpur and Putrajaya) which mandates the separation of food waste from other types of solid waste (Nazibudin et al., 2025). Despite the implementation of Act 2007, the segregated food waste is still end up to be dumped in the landfill together with other mingled waste. This raises critical question about the effectiveness and the purpose of doing food waste segregation if no subsequent utilization pathway. Food segregation alone will not solve this issue and it must be complemented with waste reduction or food reduction step.

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Globally, various food waste reduction approaches have been explored, including anaerobic digestion (AD), incineration, composting, and use as animal feed (Ra-Ibnulamin et al., 2025). According to Ahmad et al. (2025), incinerator is the most recognized technology that can convert waste to energy in Malaysia. It provides an effective solution in reducing waste as well as land acquisition for landfill disposal. Despite these advantages, incinerator involves high capital investment and generates flue gas that consist of nitrogen, sulphur dioxide and carbon dioxide, raising environmental concern. In contrast, anaerobic digestion (AD) has gained traction internationally as a sustainable alternative for food waste treatment. Anaerobic digestion converts biodegradable substrates like food into biogas in the absence of oxygen (De Crescenzo et al., 2023). Biogas produced derives its heating value primarily from methane (CH_4), while carbon dioxide (CO_2) is non-combustible and dilutes the energy content (López et al., 2024). In China, anaerobic digestion of separated food waste produces biogas, a renewable energy source, and digestate, which can be used as a fertilizer (Ra-Ibnulamin et al., 2025). According to Triviño-Pineda et al. (2024), Anaerobic digestion decomposes organic matter such as food without oxygen using microorganism. This converts it into biogas and digestate. This process reduces food waste, emission and produce sustainable energy source. Anaerobic digestion offers similar waste to energy technology as incineration. In all, anaerobic digestion poses a valuable technology where it has numerous advantages such as producing bioenergy sources that can replace current fossil fuel, reduce food waste in landfill, capture CO_2, and financially lower than incinerator. Nonetheless, Anaerobic digestion in Malaysia faces challenged such as higher cost compared to current waste treatment (landfill disposal), lack of local technology (mainly imported from Germany) and lack of skilled workers (Ahmad et al., 2025).

Renewable Natural Gas (RNG), upgraded biogas from anaerobic digestion holds significant potential in addressing both waste management inefficiencies and energy decarbonization. Beyond serving as a renewable substitute for fossil-based natural gas, RNG production from food waste can mitigate methane emissions from landfills and valorize policy-mandated segregation efforts. In Malaysia, the concept of virtual pipeline delivery (Bio-CNG) has been preliminarily validated for industrial clusters using POME-derived biogas (Lee et al., 2019), yet no study has assessed its economic viability for food waste-derived RNG, particularly under the enforcement of Act 672. In this paper, Life Cycle Cost of Analysis (LCCA) and Levelized Cost of Methane (LCOM) are conducted to assess their economic viability for two different pathway which are RNG injection to gas grid pipeline and RNG via virtual pipeline (Bio-based Compressed Natural gas (Bio-CNG)). The study covers the entire chain from food waste collection up until the RNG utilization where it includes biogas production, biogas pre-treatment and biogas upgrading. While anaerobic digestion and RNG have been studied globally, this work presents the first comparative economic assessment of RNG end-use pathways, includes grid injection versus virtual pipeline (Bio-CNG) specifically for Malaysia's segregated food waste stream under Act 672. By integrating localized cost data from Kuala Lumpur's Taman Beringin transfer station, development cost from local industry players, and national infrastructure, this study identifies grid-injected RNG as a near-term viable alternative to fossil gas, offering a practical solution to the underutilization of policy-mandated food waste segregation.

2. Problem Identification

In 2007, Malaysia has implemented Act 672 in mandating food waste segregation. Despite this effort, the management of segregated food waste remains inefficient as it still disposed in the landfill. To efficiently benefits from food waste segregation approach, proper food reduction approach and utilization strategy need to be done. At present, there are two known approach that has been implemented in Malaysia, which are composting and incineration.

Composting, while environmentally friendly, it faces limitation in managing large scale food waste, which make it less practical as nationwide solution. Incineration, on the other hand, require a large capital investment and produces harmful flue gas. Rendering it misaligned with the current Net Zero Emission aspiration.

These challenges of managing waste while maintaining sustainable approach, has highlight anaerobic digestion to be of the viable alternatives. Despite having several biogas plants with feedstock of Palm Oil Mill Effluent (POME). The potential of utilizing food waste for similar technology has not been studied in Malaysia, evaluating the viability of this technology in utilizing segregated food waste. Nonetheless, the adoption of anaerobic digestion in Malaysia faces significant barriers, including the lack of local technological expertise and reliance on imported systems, which increase investment costs. Driven by this, life cycle cost analysis (LCCA) needs to be performed to ensure the economic viability of several utilization pathway of RNG from food waste via anaerobic digestion.

3. Methodology

A structured methodology was developed to conduct Life Cycle Cost Analysis (LCCA) and Levelized Cost of Methane (LCOM) for two different RNG pathway entirely from its source to end RNG utilization as illustrated in

the superstructure in Figure 1. This evaluation requires all cost related data that are found from literature review, pilot plant data and industry expert. This data is then standardized in term of its unit at MYR/y in which capital expenditure (CAPEX) need to be annualized. The LCCA is then evaluated with basis of 1350 t of food waste /d, replicating the amount of food waste in Taman Beringin, Kuala Lumpur. This methodology is structured into three stages which are data collection of cost components, LCCA calculation and economic evaluation.

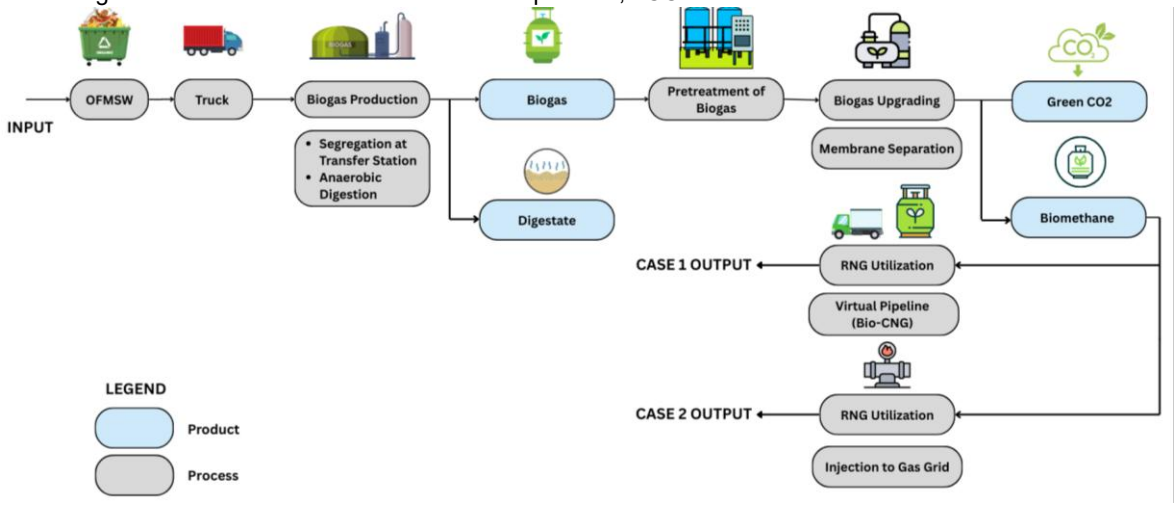

Figure 1: Superstructure of the RNG Pathway from Food Waste Source to RNG Utilization

3.1 Data Collection of Cost Components

The data collection was obtained from several sources namely Tenaga Nasional Berhad Research Sdn Bhd. (TNBR) pilot plant, industry experts and literature review. The data has been tabulated according to its category make it readable for LCCA calculation. Cost components is categorized according to its pathway as shown in superstructure in Figure 1, which highlights the process category which require data on costing.

3.2 LCCA Calculation

For Life Cycle Cost Analysis (LCCA) computation, it is essential to standardize the final unit to ensure consistency across all calculations. In this study, all costs are expressed in terms of MYR/y, encompassing both capital expenditure (CAPEX) and operational expenditure (OPEX). To annualize the CAPEX, the capital recovery factor method was applied, which converts the total investment cost into an equivalent annual value. The formula is presented as follow where r is the discount rate and n is the lifetime in years.

$$CRF = \frac{r(1+r)^n}{(1+r)^n-1} \quad (1)$$

The data obtained need to be standardized. To achieve this, the sixth-tenth factor rule was applied to scale the values relative to a base reference. The formula is shown as follows where C_1 is known cost at base capacity, Q_1 and C_2 is the estimated cost at new capacity, Q_2.

$$\frac{C_2}{C_1} = \left(\frac{Q_2}{Q_1}\right)^{0.6} \quad (1)$$

To determine the capital and operating costs, interest rate, i need to be assumed. For this LCCA, inflation rate, i is taken to be 3 % (assumption from TNBR) with average lifetime of 20 years based on the equipment lifetime. The final calculation is carried out by summing all the cost components within the defined system boundary for each case study in unit MYR/y. These boundaries are based on the respective superstructures developed for the analysis in which the overall superstructure can be seen in Figure 1.

3.3 Economic Evaluation (LCCA and LCOM)

The result from LCCA were then compared in graphical form, pie chart. This helps to illustrate the cost breakdown or distribution for each case study at 1,350 t of food waste/d basis. Then, a further comparison is done to compare Levelized Cost of Methane (LCOM) between these two case studies while also check on their viability on replacing fossil-based natural gas. LCOM is calculated by using the following formula:

$$LCOM = \frac{Total\ yearly\ cost\ of\ Case\ 1}{Total\ Methane\ Content} = \frac{Total\ yearly\ cost\ of\ Case\ 1}{RNG\ Produced \times RNG\ conversion\ to\ MMbtu} \quad (1)$$

RNG produced for case study 1 and case study 2 is assumed to be the same as it uses similar route and feed

4. Results and discussions

The cost breakdown from Life Cycle Cost Analysis (LCCA) is shown in Table 1. This highlights the exact expenses by summing annualized CAPEX and OPEX, considering 20 years lifetime of the technology. The results from Figure 2 shows that at basis 1350 t/d, case study 1 (RNG to Virtual pipeline) has higher cost compare to case study 2 (RNG to gas grid pipeline). Case study 1 has LCCA of 34,684,805 MYR/y while case study 2 with LCCA of 19,120,394 MYR/y. This expenses gap is due to the additional expenses of 15,564,411 MYR/y for case 1 which is the cost for virtual pipeline utilization whereas case study 2 incurs no additional cost for gas grid injection as seen in Table 1 and Figure 3a-b. This scenario is because gas distribution pipeline cost is fully covered by Gas Malaysia through government tax. Cost of waste transportation for both case study is MYR0.00. This is because the investment cost is viewed as the cost bear by transfer station operator, BSI or investor, in which the current waste transportation cost is covered by the local authorities or Industrial, Commercial, and Institutional (ICI).

In terms of Levelized Cost of Methane (LCOM), Case Study 1 records a higher value of 32.31 MYR/MMBtu compared to 17.81 MYR/MMBtu for Case Study 2. The difference in term of Life Cycle Cost Analysis (LCCA), making case study 2 gives a cheaper option even though both have the same volume of RNG production. When benchmarked against the current natural gas price from Gas Malaysia (40.337 MYR/MMBtu), the results indicate that RNG competitiveness depends on aligning its cost closer to that of fossil-based natural gas. To consider it competitive, the RNG price should be close or same as fossil-based natural gas, in which can only be achieved if the investment cost or LCOM is low enough to give sufficient profitThrough incorporation of carbon credit and government incentives, it could lower the LCOM of current RNG production.

Table 1: Cost Breakdown for Case Study 1 and Case Study 2

Cost	Case 1 (Food Waste to RNG to Virtual Pipeline)	Case 2 (Food Waste to RNG to Grid Injection)
Waste Transportation (MYR)	0.00	0.00
Biogas Production (MYR)	4,305,268	4,305,268
Pretreatment Biogas (MYR)	4,495,055	4,495,055
Biogas Upgrading (MYR)	10,320,071	10,320,071
Grid Injection RNG (MYR)	N/A	0.00
Virtual Pipeline RNG (MYR)	15,564,411	N/A
Total Yearly Cost (MYR/y)	34,684,805	19,120,394
LCOM (MYR/MMBtu)	32.31	17.81

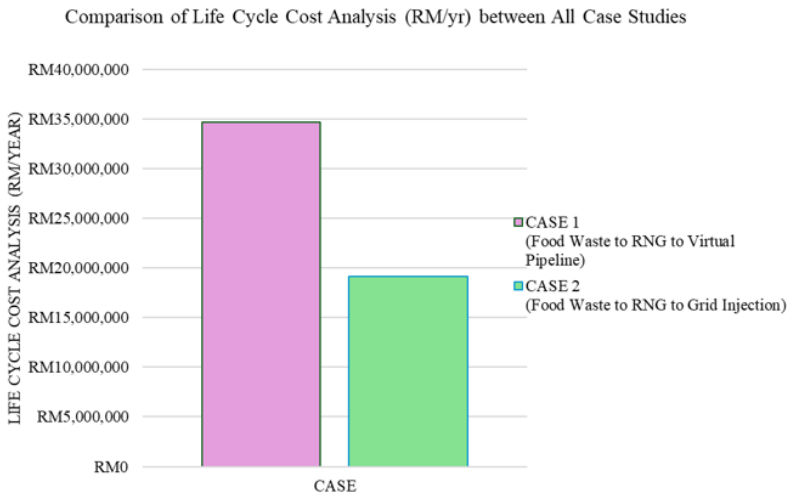

Figure 2: Comparison of Life Cycle Cost Analysis of Case 1 and Case 2 in Annualized CAPEX

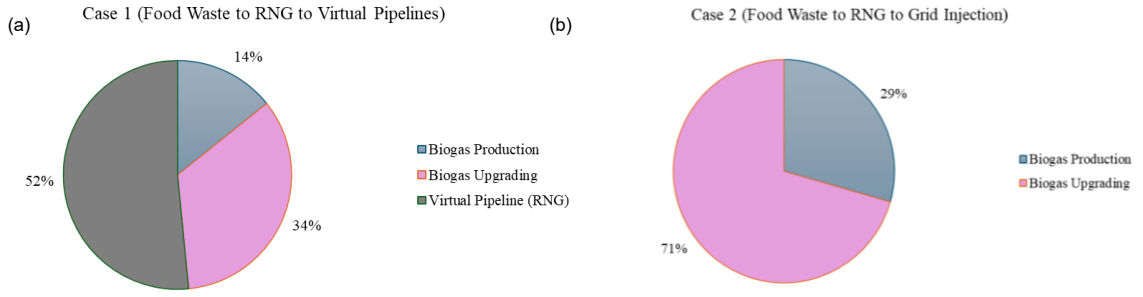

Figure 3: Illustration of Percentage Cost Breakdown for (a) Case Study 1, and (b) Case Study 2

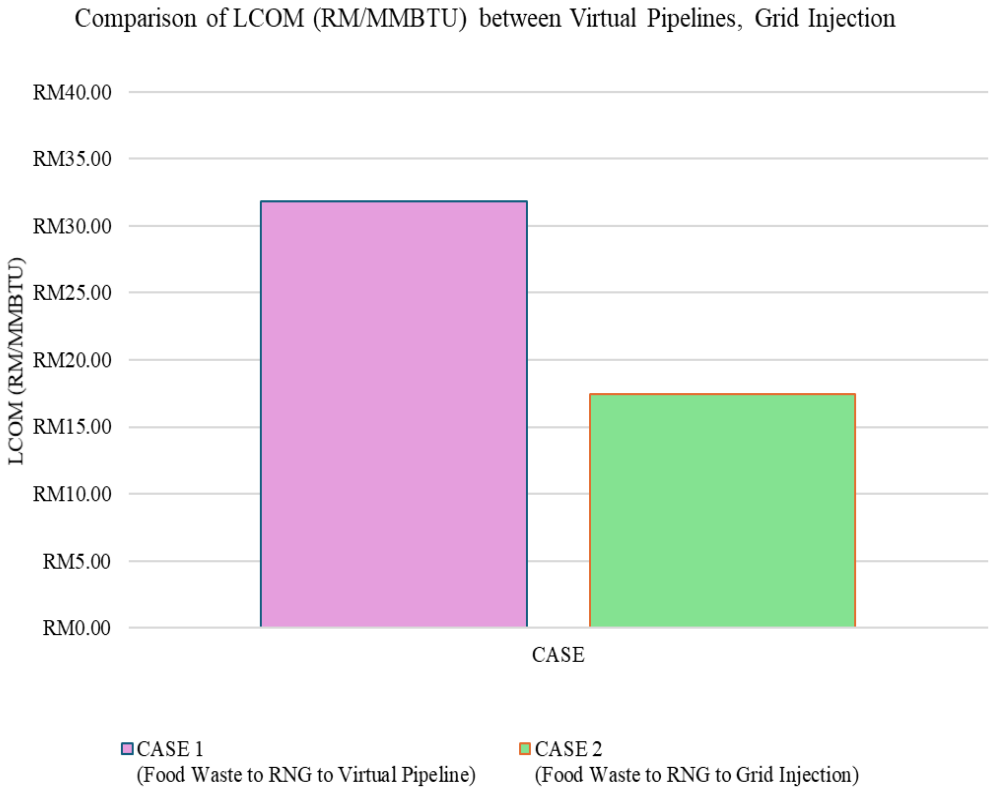

Figure 4: Comparison of Levelized Cost of Methane (LCOM) between Case 1 and Case 2

Figure 2 and Figure 4 shows consistent results where Case Study 2 (RNG grid injection) has lower life cycle cost (LCCA) and levelized cost of methane (LCOM) than Case Study 1 (Bio-CNG). This difference arises from the additional cost of Bio-CNG infrastructure which comprises compressor, storage, cylinder tank and transport, required in Case Study 1. As illustrated in Figure 3, Case Study 2 includes only two major cost components: biogas production and biogas upgrading. In contrast, Case Study 1 includes a third component: the virtual pipeline system for Bio-CNG distribution. Both pathways share similar costs for biogas production and upgrading, so the added expense of Bio-CNG infrastructure accounts for the higher total cost in Case Study 1.

5. Conclusions

This paper highlights the potential of renewable natural gas (RNG) production from segregated food waste, with reference to the transfer station at Taman Beringin, Kuala Lumpur. The study demonstrate that this approach is not only reducing the volume of food waste and prevent greenhouse gas emission from landfill disposal but also contributes to clean energy generation. This study covers the entire chain of cycle from segregated waste collection to its end utilization which is RNG injection to gas grid pipeline and RNG distribution via virtual pipeline

(Bio-CNG). The Life Cycle Cost Analysis (LCCA) indicates that RNG injection to gas grid pipeline is the most cost-effective option with LCCA of RM19,120,394/y while virtual pipeline (Bio-CNG) is at RM34,684,805/y. Similarly, the Levelized Cost of Methane (LCOM) supports this conclusion, with RM17.81/MMBtu for gas grid injection and RM32.31/MMBtu for virtual pipeline, compared to the current natural gas market price of RM40.337/MMBtu set by Gas Malaysia. Even though, RNG utilization is seems to be costly, RNG costing from food waste can be cost competitive if considering supporting mechanism such as government incentives, green certificates and carbon credit in which will lessen the burden of the cost. Beyond the economic perspective, this study underlines the broader sustainability benefits of RNG. Utilizing segregated food waste through anaerobic digestion offers a practical alternative to incineration, which is less suitable for wet waste streams. By adopting RNG pathways, Malaysia can move closer to achieving its net-zero emission targets while providing industries with renewable and low-carbon energy sources. The current issue of this approach would be the potential of continuous food waste feedstock to continuously running the anaerobic digester allowing it to continuously producing biogas for further upgrading to RNG. Moving forward, the government should play an important role in driving this approach and boost the adaptation and implementation of this technology in our country by providing incentives and promotes waste segregation approach by providing dedicated bin and collection truck for food waste. This approach will further entice the industry player to venture towards this technology, reducing the waste, emission as well as producing renewable energy sources for the industry.

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