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https://doi.org/10.5109/7151733

出版情報：Evergreen. 10 (3), pp.1835-1846, 2023-09. 九州大学グリーンテクノロジー研究教育センター
バージョン：

Economic Feasibility Study of Syngas-Derived Garden Waste Biomass as Liquified Petroleum Gas Substitute in Indonesia: A Case Study for 1-Megawatt Updraft Fixed Bed Gasifier

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(Received April 27, 2023; Revised September 4, 2023; accepted September 7, 2023).

Abstract: The price of international Liquified Petroleum Gas (LPG) has suffered in Indonesia, leading to its replacement with renewable ones, such as syngas. This study focuses on the techno-economic analysis of the 1-megawatt updraft fixed bed gasifier using a garden waste biomass. Three syngas price scenarios are considered, and the weighted performance index ranks the scenario and performs a sensitivity analysis on the best rank. The scenario of the 40% syngas price being less than the retail non-subsidized price fits and offers attractive economic feasibility to investors, balancing consumers' purchasing ability and government subsidies.

Keywords: biomass; gasification; garden waste; syngas; techno economic

1. Introduction

Indonesia is an LPG net importer and has recently suffered from increased international LPG prices. Indonesia's LPG imports have grown significantly since 2008, with an average annual increase of 8.1% from 2008 to 2020. In 2020, the volume of LPG that must be imported was 6.4 million tons[1]. One of the Indonesian government's policies to maintain the purchasing power of low-income people is to market 3 kg LPG at subsidized prices. Unfortunately, the LPG subsidy reached USD 3.8 billion in 2019[2] and is still increasing with the extent of use and price level of LPG.

Furthermore, LPG consumption in Indonesia directly contributed to a 7.7% increase in CO_2 emissions as a part of GHG between 2010 and 2018[3]. Increased CO_2 emissions will also affect future temperature increases in Indonesia. For this reason, it needs to replace LPG with other environmentally friendly fuels at an affordable price by considering the impact of reducing GHG emissions, LPG imports, and LPG subsidies. Moreover, it can sustain Indonesia's commitment to reach net zero emissions by 2060[4].

Biomass offers a promising and environmentally friendly alternative energy source with significant potential for development in Indonesia, leading to a reduction in fossil fuel consumption[5] [6]. This biomass can be derived from urban green space waste, such as leaves, twigs, and tree branches, commonly called garden waste. Importantly, this source does not require cutting down trees, as it can be obtained from living trees. A standing tree alone can yield more than 300 kg of dry biomass, including the stem, branches, twigs, and leaves[7]. This waste is typically dry, making it easily processed into biomass pellets. Research conducted by Pradhan et al.[8] on processing garden waste biomass (leaves, branches) demonstrated similar characteristics to typical wood biomass processing. As urbanization continues to grow worldwide, garden waste exhibits increased potential. In Indonesia, the Ministry of Environment and Forestry (KLHK) reported that approximately 22.42%, around 4,236,824 tons per year of the country's waste remains unmanaged as of 2022, with garden waste accounting for 13% of this total and showing a tendency to accumulate[9]. Law Number 26 of 2007 concerning Spatial Planning emphasizes maintaining at least 30% of the total area[10] as urban green open spaces, highlighting the significant potential for growth in urban biomass garden waste in Indonesia.

For converting biomass into fuel, it can be done by various processes, which include thermochemical and biochemical methods[11]. Since it may produce energy in solid biochar, liquid bio-oil, and gaseous producer or syngas, which are possible feedstocks for synthesizing chemicals such as methanol and ethanol, biomass-to-energy conversion appears to be the most efficient method[12]. For the effective utilization of biomass waste, biomass gasification emerges as a highly promising thermal conversion technology[13] compared to direct combustion and pyrolysis, resulting in lower emissions as a substitute for LPG. The product of biomass gasification comprises a mixture of inorganic gases (CO, H_2, N_2, CO_2) and light hydrocarbons (such as CH_4, C_2H_2, C_2H_6), along with tar, and unreacted ash or charcoal[14]. The gas fraction known as syngas is combustible and can be used in a conventional LPG stove. Moreover, syngas can be further purified to obtain valuable components[15].

Converting biomass into syngas provides an alternative to using biomass in areas that still use firewood in a traditional stove for cooking. Direct wood combustion releases harmful particulate matter, high emissions, and toxic gases, like volatile organic compounds, posing risks to household members while preparing food[16,17]. In contrast, the combustion of syngas is advantageous as it undergoes raw syngas processing, eliminating particulate matter, and emitting carbon dioxide and water, which are safer for humans and the environment[18]. However, biomass and syngas treatment considerations are recommended to make syngas production from biomass bearable, where the calorific value produced is equivalent to a higher price than subsidized LPG[19]. Therefore, along with increasing LPG prices, syngas can positively impact the future energy economy and increase energy security.

An economic feasibility study is required to understand the future financial benefits of the to-be-implemented plan[20]. Many researchers have reported the techno-economics of gasification of various biomasses and its utilization in various products and applications. For example, in the work reported by Mustafa et al.[21] downdraft gasifier of 6.0 MW with feedstock from forests and municipal solid waste for biofuel, the project's payback period could be achieved within four years. On the other hand, in work reported by Aguado et al.[22] downdraft gasifier of 125 kW with a feedstock of agricultural waste for electricity has a payback period of 5-9 years. Moreover, in work reported by Olupot et al.[23], a 250 kW downdraft gasifier with a feedstock of rice husk for electricity, the payback period is 2.5 years. However, Cardoso et al.[24] reported that bubbling fluidized bed gasifier with 100 kW capacities, utilizing feedstock from forest residue for electricity generation, were deemed economically unfeasible. The smaller project size failed to generate sufficient revenue to cover costs and provide a return on investment, making it economically unviable. The payback period for the 1000 kW project was found to be 7.4 years.

Furthermore, although many researchers have studied the techno economics of gasification, reports on the techno-economics of updraft fixed-bed gasifiers with raw materials like garden waste are scarce. This study aims to reveal the economics of syngas-derived biomass garden waste utilizing an updraft fixed bed gasifier to replace LPG in Indonesia. Even though the level of economic feasibility is still in the pre-study phase, it must be done to convince stakeholders of business development. In general, some economic feasibility studies use common assessments for a decision, such as PBP, NPV, IRR, and sensitivity analysis. In addition, this study also uses the weighting performance index for decision. As a result, a comprehensive approach combining techno-economic assessment and weighting performance index is presented in this study.

2. Methodologies

The research stages presented in this paper are shown in **Fig. 1**. The initial step involves properly handling biomass in urban areas, where garden waste is collected and sent to laboratories to explore its characteristics. Among various technologies available for biomass utilization, this study specifically focuses on updraft gasification. To assess the economic feasibility, investment and operational costs are collected and estimated for the selected capacities. Additionally, several schemes are proposed to determine the economics of urban waste biomass utilization in syngas production.

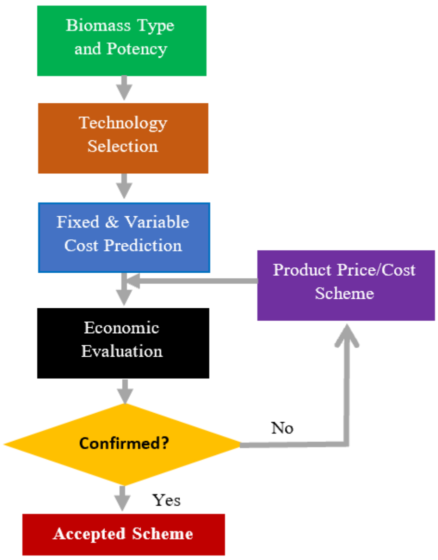

Fig. 1: Research procedure steps

2.1 Material and Technology Selection

This study utilized garden waste as raw materials, specifically twigs and leaves, commonly found as street shade trees in urban areas. The types of garden waste that are commonly found in Indonesia include Trembesi (Albizia saman), Neem (Azadirachta indica A.Juss), Mahogany (Swietenia mahagoni), and Ketapang (Terminalia catappa)[25]. Samples were collected from the BJ Habibie Science and Technology Park, Puspitek, Serpong, Tangerang, Indonesia. Next, the samples were dried, ground, and classified using a 60-mesh sieve. Following, the ultimate, proximate, and heat values of the -60 mesh sample were measured.

The proposed utilization scheme of syngas from garden waste gasification as a substitute for LPG is illustrated in **Fig. 2** Garden waste biomass is collected, conditioned, and then fed into the updraft gasification reactor (gasifier). The gasifier's schematic process is depicted in **Fig. 3**. The feedstock is charged from the top of the reactor, while steam is used as the gasifying agent[26] to generate syngas with a higher heating value[27] compared to air. As the gasifying agent flows through the biomass bed, it will consume biomass, produce heat, and change biomass composition by complicated oxidizing, reduction, pyrolysis, and water evaporation phenomena.

The updraft gasifiers can process biomass with a 5-100 mm size range. It can also handle biomass with a high moisture content[28], making them suitable for garden waste with varying biomass sizes and moisture levels. However, the updraft gasifier produces syngas in low-temperature pyrolysis and drying zones. Consequently, the resulting gas (syngas) will be contaminated with a significant amount of tar, which is unsuitable for gas turbines or internal combustion engines[29] but suitable for direct combustion applications such as fuel stoves. Next, the syngas is treated and distributed to household consumers for cooking and water heaters or collected to maintain supply. Moreover, it can be used as an alternative fuel for utility units in micro and small-scale businesses.

2.2 Economic Analysis

The feasibility analysis in this study considers some parameters consisting of NPV, IRR, and PBP. The NPV shows the amount of collected money at present value. It is calculated by subtracting total cost from total revenue as long as the project life cycle (Eq. 1). When the NPV is zero on bank interest, the time when that condition is reached is the payback period and can be calculated using Eq. 2. However, the interest is IRR when the NPV is zero on non-bank interest. The IRR refers to the extent of using Eq. 3.[30]. all calculation apply an exchange rate in July 2022 of IDR 15,066/USD.

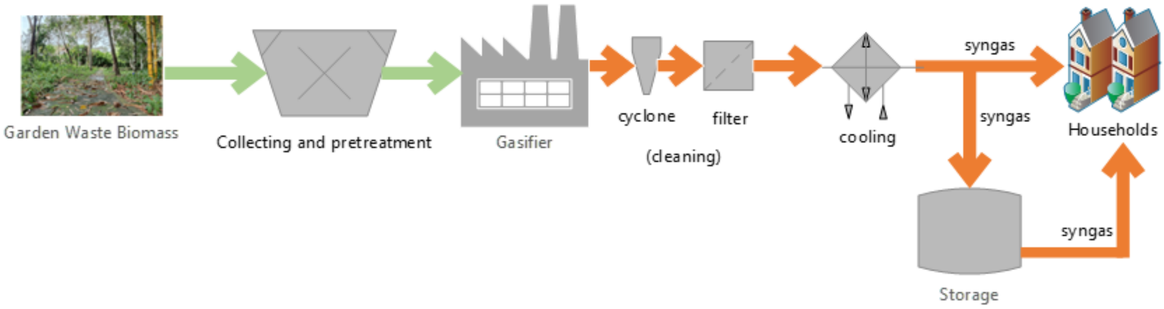

Fig. 2: The utilization of the syngas from biomass waste as an LPG Substitute

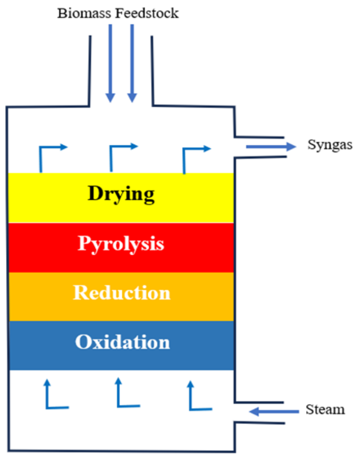

Fig. 3: Schematic of Updraft type gasifier[28]

$$NPV = \sum_{t=0}^{n} (C_b - C_c)_t (1 + i))^{-t} \quad (1)$$

$$PBP = \sum_{t=1}^{Pt} (C_b - C_c)_t (1 + i)^{-t} = 0 \quad (2)$$

$$IRR = \sum_{t=0}^{n} (C_b - C_c)_t (1 + irr)^{-t} = 0 \quad (3)$$

2.3 Product Cost Scenario

The primary project revenue comes from product sales; the cost determines the total project revenue. In the typical case of gasification, the project's feasibility could not be capital return. It is stated in percentage and calculated attractive because of the low NPV and IRR and the long PBP. Therefore, we propose three scenarios of syngas price in calculating the economics of biomass waste gasification, as shown in **Table 1**, to evaluate its proper price. Case 1 states that the syngas price equals non-subsidized LPG, USD 1.16/kg. However, case 2 takes the syngas price equivalent to subsidized LPG, which is USD 0.48/kg.

Moreover, case 3 takes the syngas price 40% lower than non-subsidized LPG, at USD 0.69/kg. It may still need government subsidies but lower than it is in case 2. Case 3 gives insight into alternative product prices in the event of any adjustment.

Table 1. Proposed Product Cost Scenario

Parameter	Case 1	Case 2	Case 3
LPG Price, USD/kg	1.16	0.48	0.69
Subsidized	No	Yes	Yes
Price ratio	1.0	0.4	0.6

2.4 Decision-Making Analysis

This study applies a weighted performance index to make a decision[31)]. The following procedures are included in the stages of the analysis process:

a. Formulate the requirements parameter.
b. Establish a weighting index.
c. Determine the index of performance

Equation 4 describes the total number of weighting index combinations (N) when evaluating x parameters. These combinations of parameters and conceivable weighting indexes are tabulated in **Table 2**. Subsequently, the two parameters in each possible weighting index combination are compared: the essential parameter is assigned a value of 1, while the less significant parameter is assigned 0. The scores are then calculated by adding the parameter values (Eq. 5). Finally, to obtain the percentage index, each score is divided by the sum of the scores (Eq. 6).

$$N = x\frac{(x-1)}{2} \tag{4}$$

$$S_j = \sum_{1-2}^{(x-1)-x} P_j \tag{5}$$

$$WI_j = \frac{S_j}{S_T} = \frac{S_j}{\sum_1^x S_j} \tag{6}$$

Table 2. Weighting Index

P	1-2	1-3	1-x	2-3	2-x	3-x	S	Index (%)
1	0/1	0/1	0/1				S1	S1/ST
2	0/1			0/1	0/1		S2	S2/ST
3		0/1		0/1		0/1	S3	S3/ST
x			0/1		0/1	0/1	Sx	Sx/ST
Total							ST	100

Furthermore, the weighted performance index is tabulated to compare the scenarios to the percentage weighting index. Each case is ranked based on four parameters in the weighting index. Each scenario is ranked based on its effect on the weighting index so that the highest total score for the selected scenario comes out. Finally, in each case, five rankings are assigned based on different parameters in **Table 3**. Finally, to get a total score for each case in Weighted Performance Index, multiply each point obtained from the ranking by the percentage each parameter in the weighting index yielded (Eq. 7).

Table 3. Weighted Performance Indeks Rank

Value	Description
1	Highly insignificant
2	Insignificant
3	Neutral
4	Significant
5	Highly significant

$$WPI = \sum_{k=1}^{y} WI_k \ r_k \tag{7}$$

2.4 Sensitivity Analysis

Sensitivity analysis on economic evaluation is critical to understand the level of influence of the variables that determine its feasibility. It was carried out by varying the operational costs (such as feedstock, maintenance, salary, and electricity), investment, and operating hours.

3. Result and Discussion

3.1 Feedstock Characteristic

Table 4 shows the characteristics of garden waste biomass divided into leaves and twigs. The humidity of these two types of biomass is similar because the biomass taken is dry and detaches on its own. The volatile matter content of the two biomasses is almost similar. However, the ash content of leaves is more than twice as high as that of twigs. Although the fixed carbon in the twigs is higher, it contains more oxygen than in the leaves. Moreover, the biomasses have calorific values ranging from 14.5 to 18.4 MJ/kg, higher than the average value for municipal solid waste and the minimum amount of energy advised by the World Bank for waste-to-energy applications[32,33)].

Table 4. Fallen Leaf and Twig Proximate, Ultimate, and Calorific Value Analysis

Parameter	Method	Leaf		Twig	
		AR	DB	AR	DB
Proximate (%Weight)					
Moisture	ASTM D3173	9.52	-	9.69	-
Ash	ASTM D3174	12.90	14.25	5.22	5.89
Volatile Matter	ASTM D3175	61.66	68.17	65.52	72.55
Fixed Carbon	ASTM D3172	15.90	17.57	19.47	21.56
Ultimate (% Weight)					
Carbon	ASTM D5373	49.33	54.52	45.17	50.02
Hydrogen	ASTM D5373	6.43	5.93	6.12	5.58
Nitrogen	ASTM D5373	2.61	2.89	1.23	1.36
Sulphur	ASTM D4239	0.15	0.17	0.14	0.15
Oxygen	ASTM D3176	28.57	22.23	42.02	37.00
Calorific Value (MJ/kg)					
HHV	ASTM D5865	14.50	16.10	16.60	18.40

3.2 Economic Assessment

The economic feasibility calculation in this paper uses the basis data presented in **Table 5**. The data are based on general financial data and experience with similar projects. However, depreciation is calculated using the straight-line method for 20 years.

Table 5. Economic Feasibility Basis

Parameter	Value	Unit
Project Life	20[34]	years
Depreciation	Straight-Line[35]	-
Interest	8[36]	%
Tax	25[37]	%
Operation Time	8760[38]	hours/year

3.2.1 Investment

This study utilizes data from the HQ-SR2400 gasifier, a commercial updraft fixed-bed gasifier with a capacity of 1 MW produced by Haiqi, China[26]. The technical data of it is shown in **Table 6**. The listed values are subject to change depending on the local conditions where the gasifier is located. Based on it, the garden waste from the Serpong office meets the manufacturing requirements, i.e., moisture content below 15% and size less than 100 mm, as we conducted pretreatment in this study.

Table 6. The HQ-SR2400 Gasifier Technical Data

Parameter	Value	Unit
Feedstock	1250	Kg/h
- Size	< 100	mm
- Moisture	< 15	%-weight
Electricity consumption	58	Kw/h
Maintenance	3	% of equipment cost
Gasification Efficiency	≥ 75	%
Gas Production	2100 to 3150	Nm^3/hour
Gas Composition		
- O_2	2.3	% volume
- N_2	48	% volume
- CH_4	5	% volume
- CO	10.5	% volume
- CO_2	21.3	% volume
- H_2	11.8	% volume
- C_mH_n	1.1	% volume
Calorific Value	5.2	MJ/m^3
Relative Density	97.32	%

A 1 MW commercial updraft fixed bed gasifier combined with the electricity generating system costs USD 1,470,862[26]. However, this study focused only on syngas production, excluding the electricity generation system. Therefore, the capital cost for the gasifier system is 2/3 of the initial gasifier investment cost, or USD 980,552. In addition, the capital cost for the pipeline and syngas storage is 30% of the gasifier price, which is USD 294,173, and working capital for the initial three months of activity is USD 152,572. Finally, the total investment cost is USD 1,579,869. The price was converted from RMB to USD at the USD 0.147/RMB exchange rate in July 2022. **Table 7** summarizes the investment components used in this paper. The investment parameter formula derivates from product information, the author's decision based on the Indonesia case, and the general rule of thumb.

Table 7. Investment Cost

Parameter	Formula	Value (USD)
Gasification system	2/3 of the original price	980,552
Pipeline and storage	30% of the gasifier price	294,173
Working capital	3 months of operational cost	152,572
Total Investment Cost		1,579,869

3.2.2 Operational and Maintenance Cost

The operating and maintenance costs are listed in **Table 8**, totaling USD 610,288 annually. It is customized for Indonesia and calculated yearly. The gasifier needs 1250 kg/hour[26], or 10,950 tons/year, of biomass at USD 0.042/kg[39] covering raw biomass, pretreatment, handling, and transportation to the location. However, the raw biomass price is about USD 0.02/kg[40]. Based on Machado et al.'s[41] research, an area of 45 km^2 can produce 3 kg/m^2 of garden waste annually. Therefore, to provide 1 MW of gasification, an area of 3,650,000 m^2 is needed.

Moreover, the gasification system requires 2 leaders and 2 HSE Engineers to supervise the plant using an ON-OFF work system. The monthly salary for this position is USD 531.05. Additionally, the plant requires 3 mechanical technicians and 3 electrical technicians with a monthly salary of USD 332. Lastly, there are 3 helpers required for the plant with a monthly salary of USD 287.3. They will work in a 3-shift work system. Further, the electricity consumption of 58 kW/hour at USD 0.113/kW[42] and maintenance costs about 3% of the gasifier price.

Table 8. Operational and Maintenance Cost

Parameter	Formula	Value (USD)
Feedstock	USD 0.042/kg x 1250 kg/hour x 24 hour x 365 days	454,978
Electricity	USD 0.113/kW x 58 kW/hour x 24 hour x 365 days	57,330
Salary	- 2 leaders x USD 531.05 x 12 months - 2 HSE x USD 531.05 x 12 months - 3 Mechanical Technicians x USD 332 x 12 months - 3 Electrical Technicians x USD 332 x 12 months - 3 Helper x USD 287.3 x 12 months	59,737
Maintenance Cost	3% of the investment	38,242
Total O&M Cost		610,288

3.2.3 Syngas Production

From a 1 MW updraft biomass gasifier, 1250 kg of biomass per hour, estimating the expected quantities of syngas, will produce 8,838,700 kJ/hour syngas or 77,427,012,000 kJ/year syngas with composition listed in **Table 6**. About 28.4% of syngas are comprises CH_4, CO, H_2, and C_mH_n, and it is flammable[43]. Furthermore, compared to LPG with a heating value of 46,100 kJ/kg[44], the annual syngas equals 1,679,544 kg of LPG and the annual revenue from the sale of syngas is shown in **Table 9**.

Based on the research on the behavior of LPG usage in Indonesia, Pranadji et al.[45], a 3-kg LPG cylinder can be utilized for seven days per household. Therefore, the syngas produced by a 1 MW biomass gasifier can supply 10,736 households. Assuming that the syngas, as a substitute for LPG, will be applied at the location where the raw biomass is produced, which is in Serpong with a population density of 5400 people per km^2[46], the distribution radius would be approximately 3 km^2.

Table 9. Syngas Yearly Revenues

Case	Price	Revenue (USD/Year)
1	1.16	1,948,272
2	0.48	806,181
3	0.69	1,170,531

3.2.4 Analysis of Feasibility

Table 10 displays the economic feasibility indicator, and **Fig. 4** shows the cash flows of the three proposed syngas price scenarios. All cases have NPV positive and the IRR is higher than bank interest. However, although the NPV is positive, Case 2 results in a low IRR, almost the same as the bank interest, which is not interesting for investors. Among the three cases, Case 1 gives the best option with the highest return and quickest payback time, but the price for the community is high.

Case 3 reveals a reasonably short payback period that is sufficiently attractive to investors, and it brings some relief to the government as it reduces subsidies compared to the previous scenario due to a slightly higher syngas price. Nevertheless, consumers must pay higher fuel prices than in Case 2. However, the government could subsidize the price at a 70% reduced amount, from USD 1.16/kg to USD 0.48/kg, to keep the syngas price equal to subsidized LPG.

However, this study's fixed-bed gasifier results in a shorter PBP than a 60 kW gasification power plant for electricity constructed at Oklahoma State University (OSU)[34] for Case 1 and Case 3.

Table 10. Syngas-Derived Biomass Waste Using Fixed Bed Gasifier Economics

Case	Capacity (MW)	NPV (USD)	IRR (%)	PBP (Years)
1	1	7,857,091	65	1.8
2	1	104,251	9	17.2
3	1	2,536,515	28	4.5
OSU[34]	0.06	84,550	10.9	7.7

3.3 Weighted Performance Index

A weighted performance index is calculated to determine which scenario to select[31]. Four variables are adopted as the weighting index:

1) purchasing power of consumer,
2) economic feasibility,
3) raw material source, and
4) government subsidies.

Then, the two weighting indexes are compared; the more critical variable is assigned a value of 1, while the less important is 0. The score, which is the sum of awarded points, and the percentage of each parameter are shown in **Table 11**.

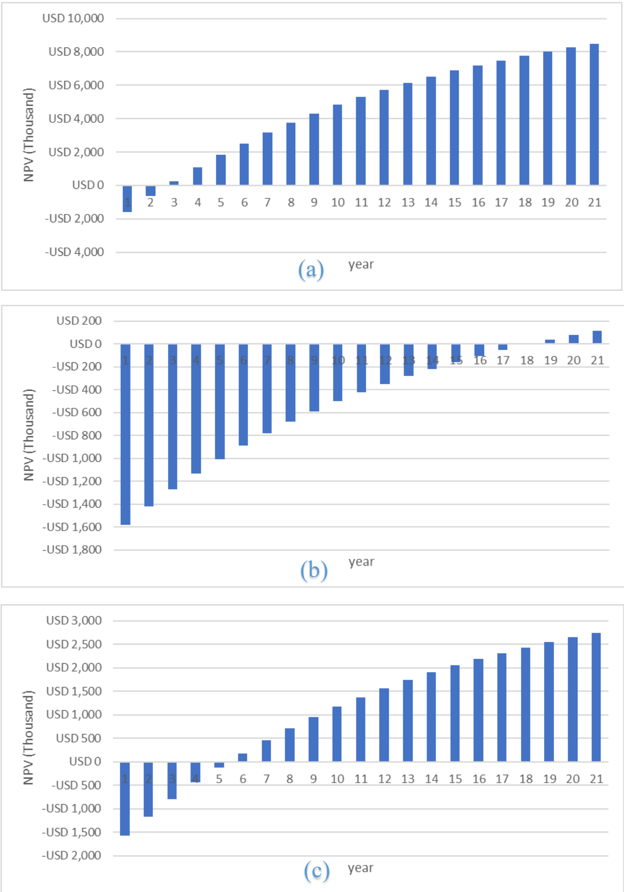

Fig. 4: Cash flow (a) Case 1, (b) Case 2, and (c) Case 3

Table 11. Weighting Index

P	1-2	1-3	1-4	2-3	2-4	3-4	S	Index (%)
1	0	1	1				2	33
2	1			0	1		2	33
3		0		1		0	1	16
4			0		0	1	1	16
Total							6	100

The purchasing power of consumers (1) is more important than the availability of raw materials (3)[47] because sufficient raw materials have no impact if nobody can buy them. In addition, the purchasing power of consumers (1) is more important than government subsidies needed (4) because the existence or necessity of government subsidies depends on the community's purchasing power[48]. Moreover, the project's economic viability (2) is prioritized over consumers' purchasing power (1)[49] and government subsidies needed (4)[50], so economic attractiveness (2) is more important. Furthermore, the availability of raw materials (3) is more critical than economic viability (2) because a project will only proceed if resources are available[51]. Finally, government subsidies needed (4) prioritized over the availability of primary materials (3) because subsidies can impact cost curves in decentralized reverse supply chains[52].

The weighted performance index is presented in **Table 12**, ranking all cases based on their parameter influence. The ranking for each parameter influence was obtained through purposive sampling with knowledgeable experts target sampling for each parameter[53]. The first parameter, consumer purchasing power, was derived from consumer or user sampling. The second parameter, economic feasibility and raw material source, was obtained from business operators or entrepreneurs, and the fourth parameter, government subsidies, was acquired from government officers. For the first parameter, Case 1 receives the lowest rank with a value of one, Case 2 receives the highest rank with a value of five, and Case 3 is assigned four points, considering the community's purchasing power for each case. Additionally, for the second parameter, Case 1 is given five points, Case 2 receives two points, and Case 3 gets four points based on the calculated economic viability. The third parameter awards four points to each case, as the availability of raw materials significantly impacts all scenarios, not dependent on syngas prices. Lastly, Case 1 receives five points for the fourth parameter as it requires no government subsidies. In contrast, Case 2 and Case 3 get one and two points, respectively, as they rely on government subsidies.

Table 12. Weighted Performance Index

Case	**Parameter**				**Total Score**
	1	**2**	**3**	**4**	
	Weighting Index				
	33%	**33%**	**16%**	**16%**	
1	1	5	4	5	3.42
2	5	2	4	1	3.11
3	4	4	4	2	3.60

Case 3 has the highest total score in the weighted performance index tabulation. It attracts due to its favorable economic feasibility, balanced consideration of consumers' purchasing power, and the reduced government subsidies. Therefore, a sensitivity analysis was performed on case 3, where the selling price of syngas was set at USD 0.69/kg.

3.4 Sensitivity Analysis

Fig. 5 shows the sensitivity analysis of the proposed scenario, baseline Case 3. In exploring investment risk opportunities, the variables that affect investment feasibility are varied. Therefore, the analysis result are compared with the baseline IRR to show the project's feasibility after making changes. Fluctuations in the cost of biomass directly affect the IRR; the higher cost tend to reduce the IRR, while the lower cost result in a high IRR. Changes in ongoing maintenance expenses are also considered, and higher costs might lead to a decrease in the IRR, while lower costs could positively affect project profitability.

The sensitivity analysis also assesses the contribution of salary expenses to overall operating costs. Higher salaries may negatively impact the IRR, while lower salaries could positively influence project profitability. Additionally, fluctuations in electricity prices are studied, as higher electricity prices may improve the IRR, considering their direct impact on revenue from energy sales.

In addition, the sensitivity analysis covers the variation in the initial capital investment required for a gasification project. Higher investment costs can result in a lower IRR, while cost-saving measures can improve it. Finally, the effect of reduced operating hours is explored, whereby fewer hours can reduce revenue and negatively impact IRR, mainly if fixed costs are not distributed adequately.

Rising biomass and investment cost reduce IRR while adding operating hours increases it. If the cost of biomass increases by more than 75%, the project will no longer be economically viable. 200% is the maximum additional investment that remains financially sustainable. Moreover, a decrease of 53% in annual operation hours is not permitted. In contrast, increasing electricity costs, salaries, and maintenance expenses does not substantially impact the feasibility level of biomass gasification's IRR compared to the cost of biomass, investment, and operating hours changing. It is primarily because electricity costs, salaries, and maintenance expenses typically constitute a smaller portion of the total operating costs than the significant cost elements of biomass, investment, and operating hours.

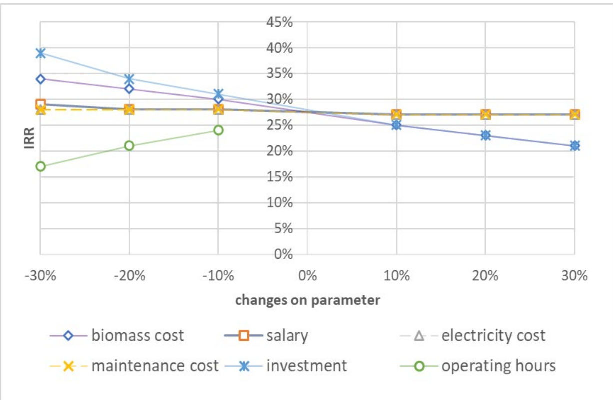

Fig. 5: Project economic sensitivity analysis

Moreover, effective cost optimization strategies can better manage operational factors. As a critical input, the cost of biomass significantly influences production expenses and revenue generation. At the same time, the initial capital investment and the number of operating hours play vital roles in determining the project's financial viability. Therefore, addressing the cost of biomass, investment, and operating hours becomes crucial for ensuring the economic feasibility and overall success of the biomass gasification project.

By conducting a sensitivity analysis of these cost elements, decision-makers can identify the critical factors that significantly impact the BEP. It allows them to make informed decisions about cost management, production levels, and investment strategies to ensure the project's financial viability and aim for a lower BEP, making it more resilient to market fluctuations and potential risks.

3.5 Expected Investment for Gasifier Substitute LPG at a Subsidized Price

In their journal, Chanthakett et al.[54] concluded that investing in a fixed-bed gasifier would be economically feasible if the NPV is positive and the PBP is around 7-9 years, considering a system life of 20 years. However, the calculation results for Case 2 showed positive NPV but a PBP of 17.2 years, which does not meet the economic feasibility criteria. Therefore, reducing investment costs to sell syngas at the same price as subsidized LPG is essential.

Positive NPV and a 7-year PBP can achieve a 46.5% investment reduction (USD 845,230). It can be accomplished through tax and loan interest exemption, utilization of domestic materials, and promoting of domestic production. Furthermore, the government can offer subsidies related to renewable energy development or investment incentives amounting to USD 734,639, provided once, eliminating the need for an annual subsidy (USD 945,271). It comes from savings on LPG subsidies implemented thus far. The production of 1,679,544 kg of syngas annually results in USD 945,271, considering the difference between the LPG price and the non-subsidized LPG prize system of USD 0.56/kg. This charge is lower than the support required for gasification investment subsidies. Consequently, in the following years, the government will no longer need to issue 1,679,544 kg/year of subsidies for each 1 MW gasifier capacity. A comparison of the government expenditure for LPG subsidies with the investment incentives for a 1 MW syngas project as an LPG substitute can be seen in **Table 13**.

Table 13. Comparison of LPG Subsidies with Investment Incentives

Scenario	PBP (year)	NPV (USD)	Incentive/Subsidized (USD)	
			Yearly	Total
LPG Subsidy	4.5	7,857,091	945,271	18,905,420
Investment Incentive	7	700,989	-	734,636

Additionally, city or village can independently plan garden waste collection. In that case, there is no need to buy raw biomass for USD 0.02/kg anymore. It will reduce operating expenses, lowering the investment value that the government will need to subsidize.

4. Conclusion

Gasification presents an attractive option for producing syngas-derived biomass waste using an updraft fixed bed gasifier as a substitute for LPG in Indonesia. The investment in the syngas-derived biomass gasifier project offers an appealing prospect with a payback period of 1.8 years, an NPV of USD 7,857,091, and an internal rate of return of 65% based on the retail non-subsidized fuel gas prices, making it a highly profitable venture. However, utilizing subsidized prices extends the payback period to 17.2 years, with an NPV of USD 104,251 and an IRR of 9%, making it unattractive to private investors. Offering syngas at 40% less than retail non-subsidized prices result in a payback period is 4.5 years, an NPV of USD 2,536,515 and an IRR of 28%. Still, government subsidies remain necessary to enhance investor appeal for prices below the non-subsidized scenario. The weighted performance index analysis indicates that setting the syngas selling price of 40% less than the retail non-subsidized prices (0.69/kg) offers an economically feasible option for investors, aligning consumers' purchasing capacity with government subsidies and making it an attractive and sustainable investment choice. Additionally, sensitivity analysis identifies biomass costs, investment, and operating hours as crucial factors affecting feasibility, necessitating measures to maintain these parameters at optimal levels.

This research focuses on the economic pre-feasibility study of syngas-derived garden waste biomass as a potential LPG substitute in Indonesia. While providing valuable insights into the viability of using garden waste biomass for syngas production, the study did not include simulations or laboratory runs to validate and optimize the gasification process, potentially affecting the accuracy and reliability of the findings and economic projections. Further simulations are needed to comprehensively understand the gasifier's behavior under various operating conditions and address potential challenges. Future research should consider incorporating gasification simulations or laboratory tests to determine the capacity requirements of gasifiers for different regions based on the potential of garden waste biomass in urban areas.

Acknowledgements

This research is a part of the "Waste to Energy" Research Group activity at the Research Centre for Energy Conversion and Conservation, National Research and Innovation Agency, and Degree by Research in the Mechanical Engineering Department, University of Indonesia.

Nomenclature

LPG	Liquefied Petroleum Gas
GHG	Greenhouse Gas
PBP	Payback Period
BEP	Break-even Point
NPV	Net Present Value
IRR	Interest Rate of Return
AR	As Received
DB	Dry Basis
LHV	Low Heating Value
HHV	High Heating Value
CO	Carbon Monoxide
H_2	Hydrogen
N_2	Nitrogen
CO_2	Carbon Dioxide
CH_4	Methane
C_2H_2	Ethyne
C_2H_6	Ethane
C_mH_n	Hydrocarbon
MW	Mega Watt
kW	Kilo Watt
MJ/Kg	Megajoule/Kilogram
WI	Weighting Index
S	Score
ST	Total Score
P	Parameter
WPI	Weighted Performance Index
HSE	Health, Security, and Environment

Subscripts

C_b	cash benefit of the investment
Cc	cash cost of the investment
$(C_b - C_c)_t$	net cash flow in year
n	project lifecycle
i	cut-off discount rate
N	weighting index combination
x	total number of parameter in weighting index
j	number of parameter in weighting index
y	Total number of case being considered
k	number of case being considered
r	points obtained from the ranking assigned to case

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