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Energy and economic assessment of mixed palm residue utilisation for production of activated carbon and ash as fertiliser in agriculture

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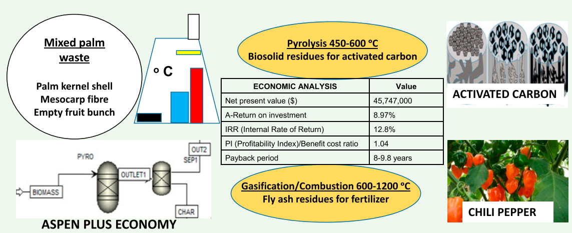
ABSTRACT

The resultant residues after thermal processes can be reused in the form of activated carbon (AC) production or used for soil amelioration. However, the economic and energy optimisation of the waste revaluation process is necessary for the prediction of technology requirements, investment boundaries and cost–benefit analysis. Mass, energy and cost estimation of the entire process were systematically executed relative to equipment sizing and type of product, as major factors in the evaluation. The economic analysis and process optimisation were quantified and evaluated with the Aspen Plus economy and an SPSS statistical tool for economic analysis. Simulation results were concomitant with economic analysis to determine the approximate annualised return on investment, profitability index and payback period, using optimised variables in the process. The four processes examined: process scenario 1–4 (pyrolysis, gasification, combustion and combined) have 16, 17, 14 and 17.2% return on investment for the 8.5, 8.2, 9.8 and 8-year payback period, respectively. The results provide a technology assessment and economic guide for investors and policymakers among others. This work is also useful for researchers in achieving the goal of efficient biomass utilisation. Palm waste ash as a potential alternative to chemical fertiliser, especially for the treatment of ultisol and acidic soils, were evaluated and it was confirmed that it is a good alternative to typical inorganic fertiliser. Finally, the results indicate that using such wastes in the AC market is a viable business option, though with high initial capital investment even though palm waste ash can be produced locally.



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Introduction

The enormous increase in solid waste generation emanating from agriculture, through direct production and processing, has created global environmental challenges [1]. This is one of the major environmental problems yet to be addressed in most developing countries [2]; although, adequate awareness has resulted in the development of measures to mitigate the adverse effects [3]. Oil palm waste (OPW) is one of these solid wastes with major disposal challenges and which can cause environmental pollution [4]. Landfill sites are an inappropriate solution due to resulting greenhouse gas emissions. The importance of the environment and human health relative to waste management in the agricultural sector has also stimulated waste utilisation attention in developing countries [5].

Based on waste revaluation principles, OPW can be applied in several ways. Empty fruit bunch (EFB) is useful for the following: mulching, cooking fuel and soap production. Mesocarp fibre (MF) is widely used for heating, mulching and soil fertilisation. Palm oil mill effluent are used for pig alimentation and soil fertilisation. Palm kernel shell (PKS) is widely applied in energy, activated carbon (AC) and locally for heating [6]. Gasification and pyrolysis are promising thermal technologies for converting OPW into energy and

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other valuable products for economic and environmental benefits [7]. Typically, biomass gasification occurs in three stages, namely drying, pyrolysis and char gasification. The three major processes to generate either char or ash are combustion, gasification and pyrolysis. These processes are related; however, pyrolysis is the initial stage of both gasification and combustion but can be regarded as an independent thermal treatment and is characterised by zero supply of oxygen or other oxidising gases to the wastes being processed [8].

The thermal conversion of carbonaceous feedstock into other useful products with a useable heating value is a good option [6]. Therefore, thermal and thermochemical utilisation of biomass is an environmentally friendly route to produce clean and sustainable products [9]. The gasification of biomass is very efficient, resulting in 90–97% conversion of feedstock into syngas [10]. This process can generate solid residues that are further processed into AC or fertilisers. The use of fly and bottom ash from thermal conversion of the waste could be a substitute for chemical fertilisers for soil with high acidity and low fertility [11], although the primary benefits of NPK fertilisers are crop quality improvement and improved plant growth through soil enrichment. However, typically the fertility and soil resilience begin to decline with time due to the application of these chemical nutrients [12].

The heavy use of NPK and other chemical fertilisers has been reported to produce a negative impact on the soil and the ecosystem [13]. These adverse effects are observed in soil and crop health. In some cases, they are severe and can cause an imbalance in the ecosystem. For every metric tonne of chemical fertiliser, Nigeria spends more than $500 above the cost of organic fertiliser [14]. The use of biomass gasification by-products could bridge the gap for quality, locally produced and environmentally friendly option. Fertiliser importation status in Nigeria are: NPK 64%, NP compounds 19%, ammonium sulphate 5%, phosphate fertilisers 4%, urea 4% and other fertilisers 4% [15]. Though, there are several factors affecting the efficient production and distribution, which is the reason Nigeria consumes about 12–15 kg of nutrient per hectare against the global average usage of 100 kg/hectare [16].

Due to the challenges of chemical fertiliser, farmers have shifted their focus to organic fertilisers. Chemical fertilisers are effective; however, they pose some challenges such as acidification of land and water. Therefore, biomass ash as a fertiliser is considered to be a sustainable option with minimal or no negative impact and no apparent unwanted effect on the soil and crop. It is a strategy to maintain the available phosphorous [17].

The analysis of oil palm waste ash (OPWA) showed that it contains ∼0.18, 27–28, 6–8, 3% of available P, Total P, K, Ca and Mg 0.19%, respectively [18]. The influence of PWA on soil structure is also necessary in ultisol soils [19]. OPWA application rate could be flexible and application beyond the average range has not been verified to have a negative impact. OPW ash effect on the soil is improvement of water-holding capacity, reduction of soil acidity and increase in microbial activities of the soil. The effect on crop yield has been demonstrated in several research studies, for the growth of cassava [18] and pepper [19].

OPW is also proven to be a promising raw material for the production of highly adsorptive AC with well-defined pore structures and good surface area [20]. Several OPW could be used individually for the AC production. These are effective in the adsorption of methyl blue, heavy metals and in purification [21]. The availability of raw materials is a primary factor in the use of biomass for AC production. AC market and supply chain in Nigeria and Africa are growing at 7.5% annually, about 80% of AC used in Nigeria are imported while 70% used in Africa are imported [22].

Environment and economics of OPW are required for fulfilment of zero-waste economy target in the palm industry [23]. Due to the environmental need for OPW utilisation and the resultant benefits of the products, economic analysis is recommended to guide investment [24]. Some utilisation techniques are environmentally damaging and economically poor [25]; therefore, a combined approach to meet the biofuel target is considered a vital approach [26]. Further call for demonstrative projects in order to strengthen investment focuses and develops a tool for waste utilisation policies in Africa [27]. This is a primary drive for this study. Hence, this study focused on an economic quantification and its utilisation approaches relative to, production, availability, need and market value. The novelty of this study is to evaluate the economic relationship and value impact of OPW utilisation. This work leverages on the experimental data of a pilot plant located at Cranfield University (England).

The Aspen plus model applied for the conversion of OPW into value-added products is used in evaluating thermal processes and economic resource conversion. The residues are quantified relative to syngas production and overall market value of the products. Hence, the economics of OPW for effective utilisation, which enables adequate estimation of production cost and optimisation of application route. The comparative study of the economic processes for PWA relative to soil amelioration and char for AC production was accessed. The choice of combined OPW for AC production and soil amendment requires a technical and economic framework; for ideal development and optimum revaluation. A comprehensive sensitivity analysis was performed. The vital factors influential to the feasibility of the process systems were used to propose cost-reduction techniques.

Materials and methods

The methodology of this study was modelled and outlined with a concept for determining the economic boundaries and optimised range of combine palm waste (CPW) utilisation. The scenarios for the analysis are dependent on the procedures and parameters applied for the simulation (pyrolysis, gasification, combustion and the combined process; is due to the combination of three processes, integrated in the system to run simultaneously). The estimation for mass, energy and economic balances were outlined using Aspen plus V.10 including Aspen Economy (under an academic license) for pyrolysis, gasification and combustion. Table 1 describes the combustion parameters and biochemical properties of CPW [18,24,28]. The simulation and general analysis were performed with PKS, MF and EFB as an unconventional material; in a single and combined stream. Pyrolysis, gasification and combustion experiments were performed; focusing on AC production through pyrolysis, and fly ash production through combustion.

Mass and energy balance

In energy systems, material quantification is necessary and governed by mass conservation, which is relevant in the industries for the control of yields and overall process. This is important in thermal conversion due to the energy and mass relations in determining the product and how temperature variation influences the process outcome; this is a cost–benefit determinant. In Equations (1)–(3), M represents mass, E stands for energy, S represents store, P for product and L means losses [8]. R is the quantity received in the process, and mw is the mass of waste generated from a single process

$$M_{\text{store}} = M_{\text{out}} - M_{\text{in}} \tag{1}$$

$$\sum^{\text{mR}} = \text{mP} + \text{mW} + \text{mS} \tag{2}$$

$$\sum^{\text{ER}} = \text{EP} + \text{EL} + E_{\text{store}} \tag{3}$$

Figure 1 shows the mass–energy relativity and resultant products. This also outlines the procedure for designing the thermal process model for biomass conversion.

This process described by [8] considers heat energy based on the temperature and other energy inputs

$$\Delta Q = Q_{\text{out}} - Q_{\text{in}} \tag{4}$$

The heat calculation is based on enthalpy operation and heat loss. Using the pyrolytic assumptions

$$E_{\text{thermal process}} = E_{\text{drying}} + E_{\text{products}} + E_{\text{reaction}} \tag{5}$$

The energy efficiency, which measures the performance of the system, is calculated thus

$$\Delta_{\text{energy}} = \frac{E_{\text{product}}}{E_{\text{feedstock}} + E_{\text{pyrolysis}}} \tag{6}$$

Equation (4)–(6) are used to evaluate the energy requirement of the proposed process. In Equation (5), pre-process energy was considered. Hence, milling and drying consume energy and considered in both simulation and cost estimation. This is considered based on physical and mechanical properties, e.g. material breakage, as the fracture reaction is contingent on impact frequency, energy, moisture content and biomass properties. Vogel and Peukert [29] summarised the phenomenon of energy expenditure as in Equation (7)

$$S = 1 - \exp\{-f_{\text{mat}} xk(W_{m,\text{kin}} - W_{m,\text{min}})\} \tag{7}$$

X represents the initial particle size, and k and $W_{m,\text{kin}}$ are the impact frequency and specific kinetic energy of the impact, respectively. $W_{m,\text{min}}$ is the threshold energy. The material properties in terms of its resistance and minimum specific energy are relevant to determine the fracture and breakage factor which define the milling rate [6].

Table 1. Chemical and biochemical properties of CPW

Proximate analysis (%w/w)	Moisture	4.05
	Ash	5.20
	Volatiles	74.50
	FC	16.25
Ultimate analysis (%w/w)	C	44.60
	H	6.35
	N	0.80
	S	0.15
	O[a]	48.10
Lignocellulosic composition	Cellulose	30.8
	Hemicellulose	23.5
	Lignin	40.2
Thermal and energy properties	Organic content	91.8
	Inorganic content	8.2
	Combustion rate, C_R (10 kg/s)[b]	3.8–4.2
	Specific heat, c, (J/kg K)[b]	2832–3231

[a]Oxygen by difference include moisture and ash.
[b]Data from Bevan et al. [24]. CPW comprises: palm kernel shell, Mesocarp fibre, empty fruit bunch at 3:2:1 ratio, respectively.

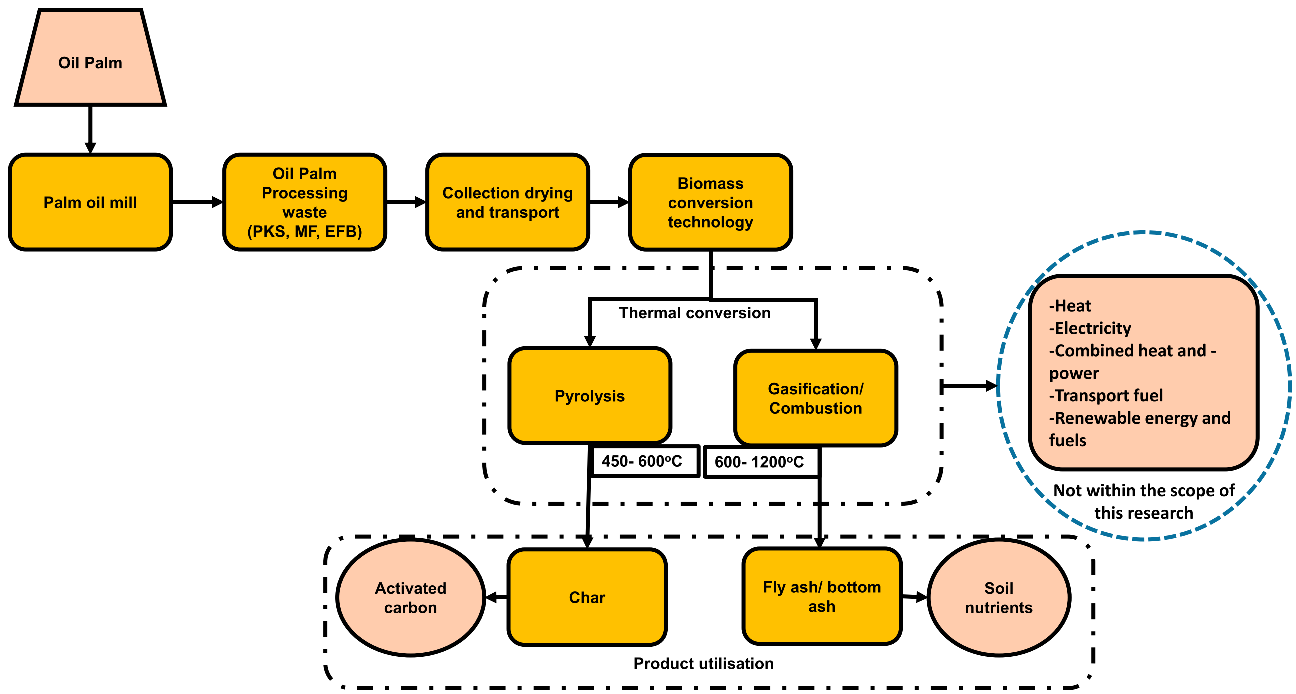

Figure 1. Mass and energy relativity for the OPW thermal process.

AC production process modelling

Data collected from 10 palm oil mills relative to mill capacity and quantity of waste generated in southern Nigeria with boundary consideration of EFB, MF and PKS were used as initial conditions for the model development. These companies produced yearly at an average of 800, 480 and 250 tonnes of EFB, MF and PKS, respectively. A tonne of oil palm fresh fruit bunch yields, an average of 720 kg of fruit, 255 kg of EFB and 50 kg of palm kernel cake, 60 kg for PKC, 115 kg of MF, 230 l of POME and 150 l of crude palm oil. An overview of the process line for AC and PWA is outlined in Figure 1. Some studies were carried out to determine the estimated pre-processing expenses [30].

The three modes of simulation were considered – combustion, gasification and pyrolysis and activation process. The sensitivity analysis was based on temperature, flow rate, pressure and their variation effect on the output yield [10].

Aspen plus (Figure 2) was adopted for the simulation and sensitivity analysis, while Microsoft excel and SPSS were used for mathematical calculations. The thermodynamic models selected defined the appropriate liquid and vapour phases and prediction by the Peng–Robinson model was used. This process was structured based on the municipal solid waste pyrolysis and gasification study by Deng et al. [31].

Economic assessment and sensitivity analysis

Aspen economic analyser is a new costing module that evaluates economics based on Icarus technology. The technique is independent on capacity-factored curves for equipment sizing and not influenced by factors to

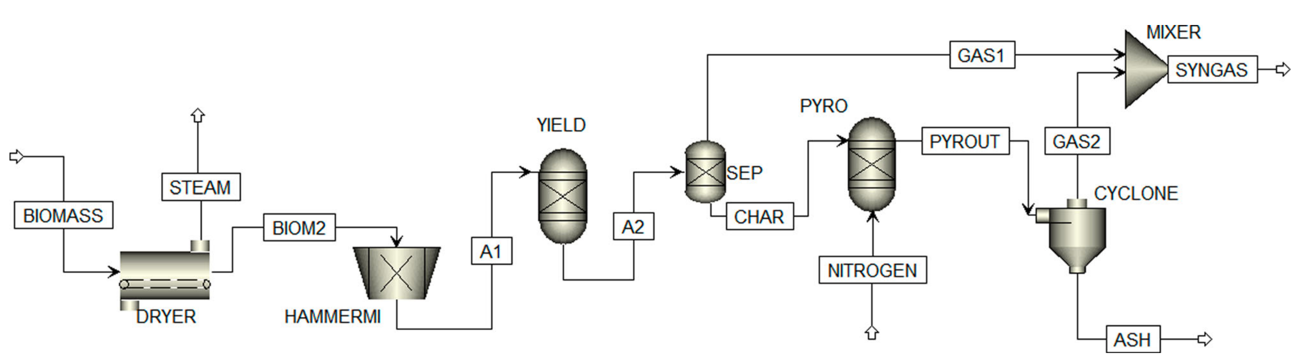

Figure 2. Thermal combined processes of pyrolysis, gasification and combustion.

estimate installation quantities. The principles of operation are based on integrated economic evaluation by activating the costing engine, mapping unit operations to equipment, sizing equipment, economic evaluation and reviewing results. However, in this project, auto evaluation was adopted based on default-assigned mappings and sizing algorithms and the terms expressed in Table 2.

The economic analysis was executed using mathematical tools, combined with Aspen Economic Analyser. All financial estimation was in US dollar ($), modelled for a 20-year period at an annual interest rate of 10% and 2.3% income tax. The basic principles of biomass conversion technology are based on capacity and production context. The application of economic analysis of the process corresponds with the price/kg of chemical fertiliser in Nigeria N300–500 and £1–5 in international market. There are several ways of evaluating the cost and profit of agricultural crops, shown as Equations (7)–(9)

$$\mathrm{GM} = \mathrm{TR} - \mathrm{TVC} \tag{8}$$

$$\mathrm{NR} = \mathrm{TR} - \mathrm{TC} \tag{9}$$

$$\mathrm{TC} = \mathrm{TVC} + \mathrm{TFC} \tag{10}$$

where TR is the total revenue in US dollar ($), GM is the gross margin and TVC is the total variable cost, which includes cost of labour, and raw material is represented by TVC. Net returns that are based on total investment cost are denoted by NR. Total cost is the sum of fixed and variable costs.

For economic analysis relative to mass and energy relationship are the principal derivatives of economic assessment. The investment cost is relative to the fixed capital investment on equipment and process cost. Other operating costs and annual cost are considered [32]. These include the cost of equipment as described by Jahirul et al. [8] (Equation (10)).

Table 2. Project profile and schedule used in the project simulation

Project name	Combine thermal plant
Plant process capacity	1500 kg/h
Plant location	Nigeria, Africa
Brief description	Pyrolysis project
Schedule	
Start date for engineering	9 Sep 2019
Duration of EPC phase	16 months
Completion date for construction	Tuesday, 31 December 2021
Economic parameters	
Country	Nigeria, Africa
Units of measure	Metric
Currency (cost) symbol	US Dollar
System cost base date	1Q 16
Project type	Grass roots/clear field
Design code	ASME

Total investment cost (C)

$$C = \text{Capital cost} + \text{Operational cost} \tag{11}$$

Net present value (NPV)

$$\mathrm{NPV} = \sum_{n=1}^{T} \frac{\mathrm{CF}_n}{(1+n)^n} - I_0 \tag{12}$$

CF_n is the annual cash flows, I_0 is the initial total capital investment and T is the project life.

These evaluations are based on the discount rate, r=10% and the rate of cash outflows corresponds to the value of inflows for breakeven discount rate. The percentage interest yield from the investment is the internal rate of return as illustrated in Equation (11).

Annualised return on investment (A-ROI)

The challenges of the traditional return on investment metric are that it does not consider time periods. Hence, to overcome this issue, an annualised ROI formula is used. Periodic cash flow is relative to a payback period of an investment.

Table 3. Project summary for the proposed biomass thermal process plant

Capital cost evaluation basis		
IF (ROR interest factor)		1.2
ECONLIFE (Economic life of project)	Period	10
DEPMETH (Depreciation method)		Straight line
DEPMETHN (Depreciation method Id)		1
ESCAP (Project capital escalation)	Per cent/ period	5
ESPROD (Products escalation)	Per cent/ period	5
ESRAW (Raw material escalation)	Per cent/ period	3.5
ESLAB (Operating and maintenance labor escalation)	Per cent/ period	3
ESUT (Utilities escalation)	Per cent/ period	3
START (Start period for plant startup)	Period	1
PODE (Desired payout period (excluding EPC and startup phases))	Period	10
POD (Desired payout period)	Period	8
DESRET (Desired return on project for sales forecasting)	Per cent/ Period	10.5
END (End period for economic life of project)	Period	10
GA (G and A expenses)	Per cent/ Period	8
DTEP (Duration of EP phase before start of construction)	Period	0.27
Input parameters		**Value (Million $)**
Capital investment cost (CIC)		280.4
Annual labour cost		18.5
Annual repair and maintenance		5.5
Total cost of biomass per year		4.8
Depreciation	(20% of CIC)	52
Interest rate	(10% CIC)	2.8
Discount rate	(10% CIC)	2.8
Salvage value	(10% CIC)	2.8
Insurance and taxes	(10% CIC)	2.8

The economic constraints and theories are based on parameters in literatures and known factors [32]. The sensitivity analysis was hinged on three factors, operating temperature, input oxidants flow and type of feedstock and output streams of syngas and biosolids. The factors were equated to plot the optimum temperature and conditions for expected output. Table 3 is the summary of the economic input data for Aspen economic analysis.

For environmental and economic impact using the combinational techniques of Lenzen et al. [33] based on the uncertainty analysis for multi-region input–output models – a case study of the UK's carbon footprint and Chertow and Lombardi [34] which centres on environmental costs with less attention to benefits. The environmental benefits of industrial symbiosis are quantified by measuring the changes in the consumption of natural resources, and in emissions to air and water, through increased cycling of materials and energy. The economic benefits are quantified by determining the extent to which companies cycling by-products can capture revenue streams or avoid disposal costs; those businesses receiving by-products gain advantage by avoiding transport fees or obtaining inputs at a discount.

Results and discussion

Mass and energy balance of thermal processes

Based on the design calculations, for 500 kg/h of biomass could produce about 75 kg/h of AC. The thermogravimetric analysis (TGA) is implemented to define the variations in the weight of a sample relative to temperature through the pyrolysis of PKS, MF and EFB. This thermal behaviour emphasises the heat requirement for the type of process for CPW and the reaction zones are defined and differentiated by the derivative thermogravimetric analysis (DTA) expressed in Figure 3(a).

Pyrolysis/gasification simulation with Aspen plus are helpful in determining the fraction of syngas components and their relationship at different temperature phases. The Gibbs reactor is based on the principle of controlling chemical and thermodynamic equilibrium of the processes. Sensitivity analysis for the product gas composition has been performed with respect to the flow rate and reaction temperature. CO_2 and CH_4 decrease whereas the concentration of CO and H_2 increases with increasing the reaction temperature.

Economic analysis

Adopting a model developed by Porcu et al. [35], the economic and financial assumptions are based on cost and itemised indicators of production. The profit and investment output are predicted relative to the global market and gross domestic product of the location. These processes are the outline for AC production and the factors are determined based on proposed contracts and valuation by consulting company for Energy and construction firm. The benefit–cost ratio (BCR) is calculated by dividing the proposed total cash benefit of a project by the proposed total cash cost of the project.

Time period and economic assumptions, operating hours per year (7500), length of Startup period (4 months), duration of construction phase (15 weeks), interest rate (10%), plant depreciation period (10 years) and project life (20 years). The four streams established in the simulation, as represented in Table 4, show the variations of economic values. These variations have a direct impact on the price of the output. The economic outcome of each process is directly influenced by capital, operational and product prices. The plant is targeted to process 2000 tonnes/day of mixed waste, 6–8% feedstock ash and an approximate yield of 66,000 tonnes/year of AC and 180,000 litres/year of bio-oil are also produced with the same feedstock applying scenario 1 (Table 4). Table 4 is formulated based on the economic assumptions by Davis et al. [36] and Akorede et al. [37].

Scenario 1 (S1) represents Pyrolysis process where char production is favoured and there is minimal use of oxygen in the process. Scenario 2 (S2) is a gasification process for the production of syngas. The process of biofuel production is preferred and characterised. Scenario 4 (S4) is a more complex and combined process, where the system operations can be altered to favour a particular scenario.

Using descriptive statistics and quantitative analytical techniques, the application of system models is relative to the economic analyses with 2.5% income tax rate and 10% interest rate. The direct and indirect capital costs were measured relative to estimated variables for maintenance cost, and the other operational cost [36] as outlined in Figure 4(a,b).

A validation with a similar project although manually calculated shows a similarity. However, the results indicate that the complexity of the processes system relative to the product sales is the major determinant to BCR. The multi-operational technique of the design in this study to achieve the process of ash, AC and syngas productions justifies high profit. Sobamowo and Ojolo [38] in their study did target the production of electricity. Hunpinyo et al. [10] confirmed their result using Aspen but with 30% uncertainty. The advancement of thermal processes which focus on direct use in electricity may fall short but the integration of all aspects of utilisation will enable non-financial benefits.

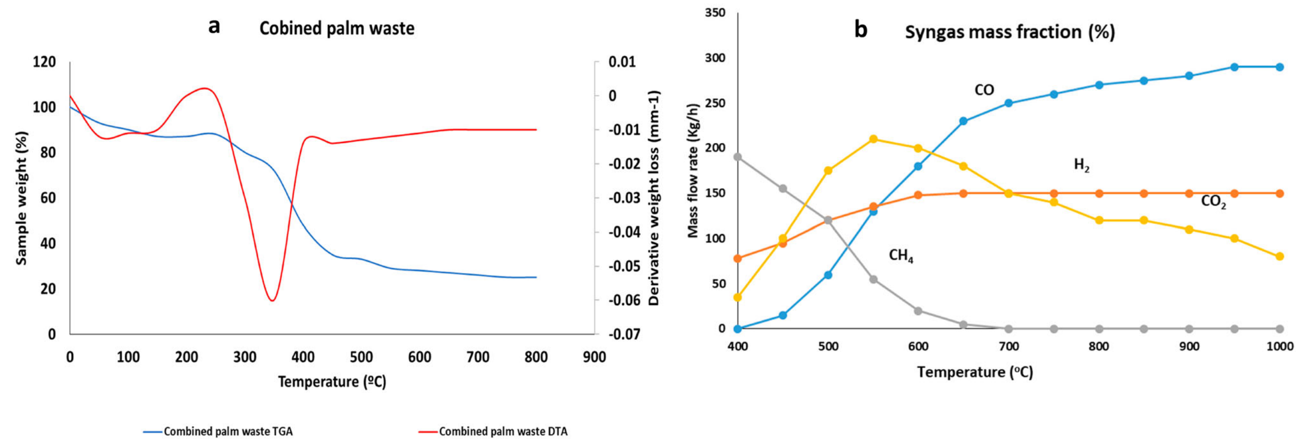

Figure 3. (a) TGA and the DTA of CPW used in the experiments. (b) Mass flow relationship relative to the influence of temperature change on the composition of syngas.

The demand for energy in developing countries is increasing and the greenhouse gas emission is greatly influencing the utilisation of biomass. Economic investment on biomass gasification is lower than coal gasification system [39]. Biomass energy can also contribute economically and generate wealth through different processing levels. Under the same operational condition, the economic performance of biofuel production and pyrolysis varies relative to energy requirements and equipment setup.

An independent economic analysis was conducted for the selling price, and the influence of the price on the economic status of the feedstock. The global AC demand is expected to rise to 3800 kilotonnes in 2021 with the economic value of $8 billion [22]. The bio-oil production cost is dependent on the capacity of the processing plant and it is represented by the product sales with a relative payback period of 6.2 years. And for the pyrolysis process with the primary target of generating biochar for AC production considers the price of AC by mass. The annual operating hour considered to be about 7500. The cost of biomass is based on the logistics and transport of the materials to the plant location. The handling capacity of the design is 1500 kg/h and considered in the simulation. For the pyrolytic products, about 10–120 kg/h of biochar was produced. The capital cost has equipment as the highest percentage expenditure. Labour is the highest for operating cost and cost of input based on the process. The project payback period and profitability index are determined based on the product sales and overall cost of the process.

Table 4. Economic analysis of thermal processes and investment summary

	Scenario 1	Scenario 2	Scenario 3	Scenario 4	[38]
Annual production sale of bio-products (Million $)	125	128	110	130	123.8
Net present value of profit (Million $)	1,062	1,091	937	1,105	528.8
Net present value of operation and maintenance cost (Million $)	297	297	297	297	348
Accumulated net present value of all cost (Million $)	669	669	669	669	833
Net present value of the project (Million $)	1010	104	885	1,053	-
Benefit–cost ratio	1.3	1.4	1.3	1.4	0.4
Payback period (years)	8.5	8.2	9.8	8	10.1
Internal rate of return (%)	16	17	14	17.2	17.5

S1, Pyrolysis, char production favoured; S2, gasification, syngas production favoured; S3, combustion, production of ash favoured; S4, combined process

Figure 5 clearly summarises the energy, economic and environmental benefits of the entire processes, using OPW for bio-oil and syngas production yield great economic results in the first few years likewise the use of biosolids for AC production. The indication of linear increase in economic and environmental benefits of the processes and products is based on the value input–output data; CO_2 emissions data; producer price indices to be used as deflators to accommodate structural change; CO_2 emissions data and international trade data.

The use as a fertiliser alternative has the lower economic impact. However, the environmental benefit and long-term influence is encouraging. The two processes have a relative balance in application despite the target output. This was analysed based on variable subsets and environmental and product benefit analysis setup. The factors are dependent on the economic

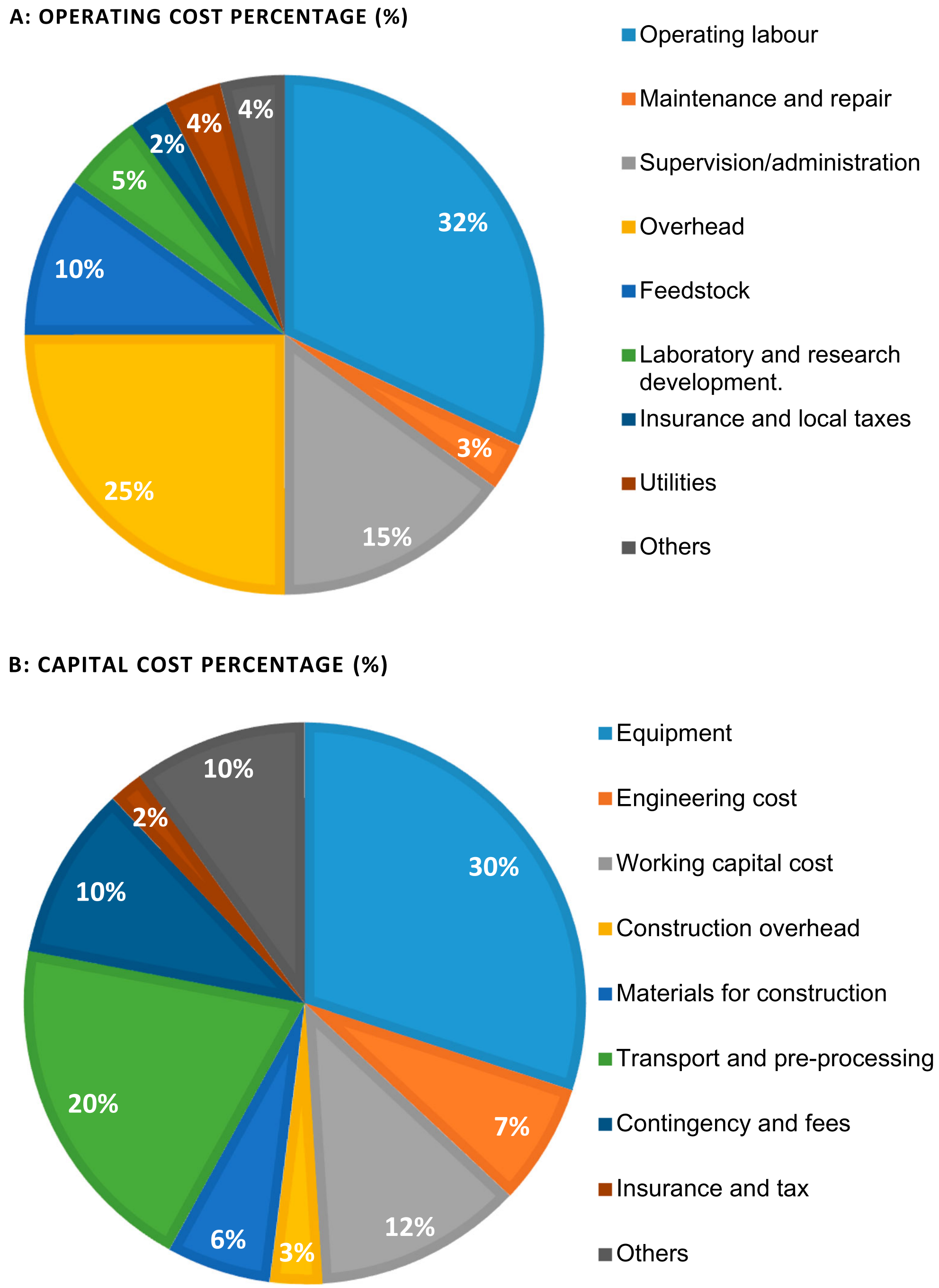

Figure 4. (a) Operating and (b) capital cost for combined thermal processes.

analysis of this study and assumptive factors relative to energy projects.

Relative to the basic assumption, there are factors responsible for how these utilisation techniques could affect the economic and environmental projections. The natural and climatic conditions, governmental policies and regulations and restrictions, energy content of the feedstock, OPW generation and quantification techniques were accounted for in the theoretical potential. Geographic potential is relative to land use and constraints of area availability which impact the quantity of waste projected to generate. Sustainable potential is an important factor due to the environment and dependence on recovery factor. Technical, economic and market potentials are valued for system sizing and performance, technology cost, energy demand, competition and investment capacity.

Sensitivity analysis for AC production

This technique is based on analytical assumptions of the variation of dependent values and the resultant impact

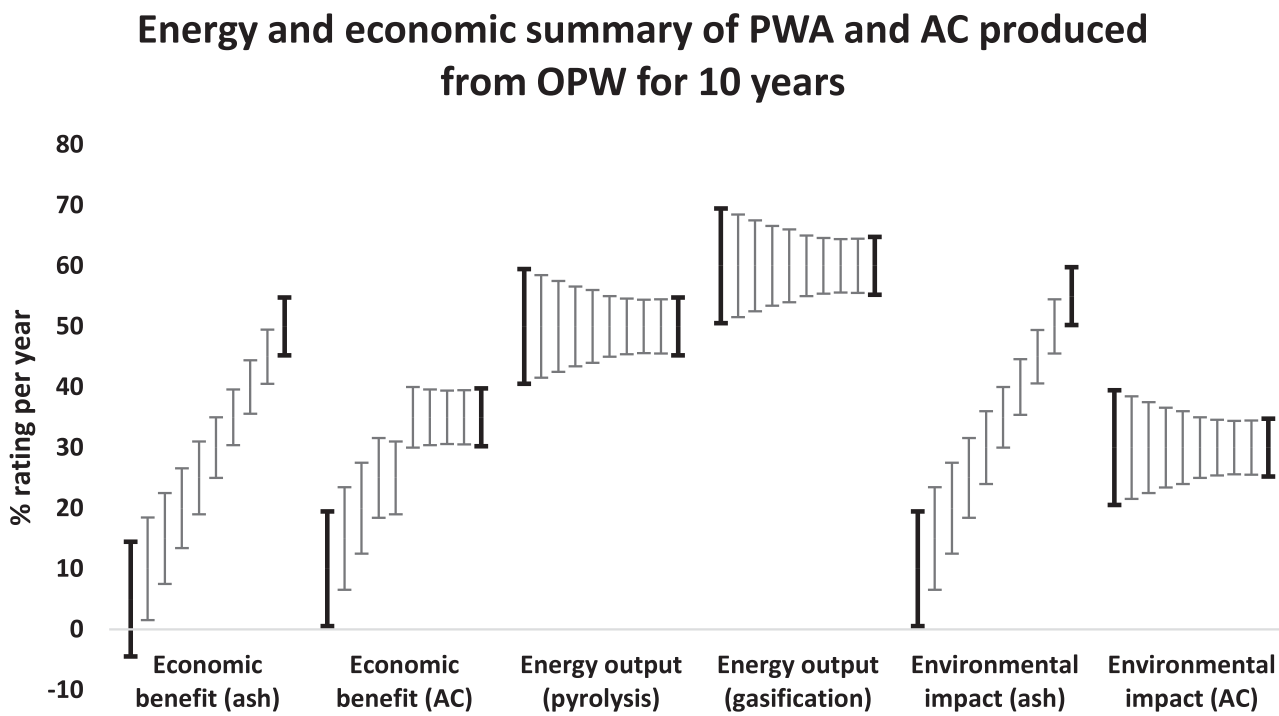

Figure 5. Summary of energy, economic and environmental benefits of the processes.

relative to independent variables. This quantifies single or multiple variables within the specific boundaries. In this study, the biochar yield is considered as AC yield. Temperature, pressure, biomass flow rate, N_2/steam flow rate and O_2 flow rate are input factors. These were compared with literatures and experimental studies to validate the output. The syngas composition obtained through pyrolysis and gasification Figure 6 is varied at different temperatures and flow rates. The current prediction by Aspen plus was compared with experimental analyses in this study. Only four components are considered in the syngas stream; other minor gases were accounted as being negligible. The sensitivity analysis at difference temperature ranges shows the effect on syngas compositions and the variations in mass flow rate. The increase in gasification temperature increases mass flow rate of the output except for CH_4. At 800°C and 120 kg/h mass flow rate of feedstock, every product is at optimum. For AC production, only pyrolysis mode is considered. Figure 6 represents the outcome of the variable input in the Aspen simulation and show the composition of syngas relative to temperature variations and mass flow rate. Most of the operations are estimated to operate at an optimum condition within the temperature range below 1000°C.

Prospects of biomass utilisation and non-economic value

PWA as organic fertiliser has been tested in some studies [40] and there was a prominent indication of about 10% increase in yield in relation to mineral fertilisers [41]. However, there are nutrient imbalance challenges with organic fertilisers [42]. The cost of fertiliser is one of the highest factors in production cost in agriculture; the total production cost is also affected hugely by pesticides and other chemicals. However, it is possible to grow crops without those. In practice, the cost of input of fertiliser affects the general yield of crops [43]. Relative to production cost, a field study by Mohammed et al. [44] was compared with assumed and projected of the production costs in this project are outlined in Figure 7.

OPW is available at zero cost; however, the cost of gathering, transport and logistics could contribute to the overall cost of revaluation and utilisation. This factor can be input in the cost analysis calculation and process quantification. The cost analysis of the two process show that energy equivalence is interrelated and depend on the size of the equipment, production capacity and output price range. Using Aspen economy analysis, non-economic valuations were non-inclusive in the analysis. Biomass energy complements other renewable energy systems, technological improvement in biomass setup helps improve agricultural and industrial revolutions. The focal points of biomass utilisation are low economic value, environmental impact and multiple application capabilities. This would create jobs for skilled and non-skilled workers [45]. The challenges of collections, pre-processing and drying vary and could be key factors in the overall analysis.

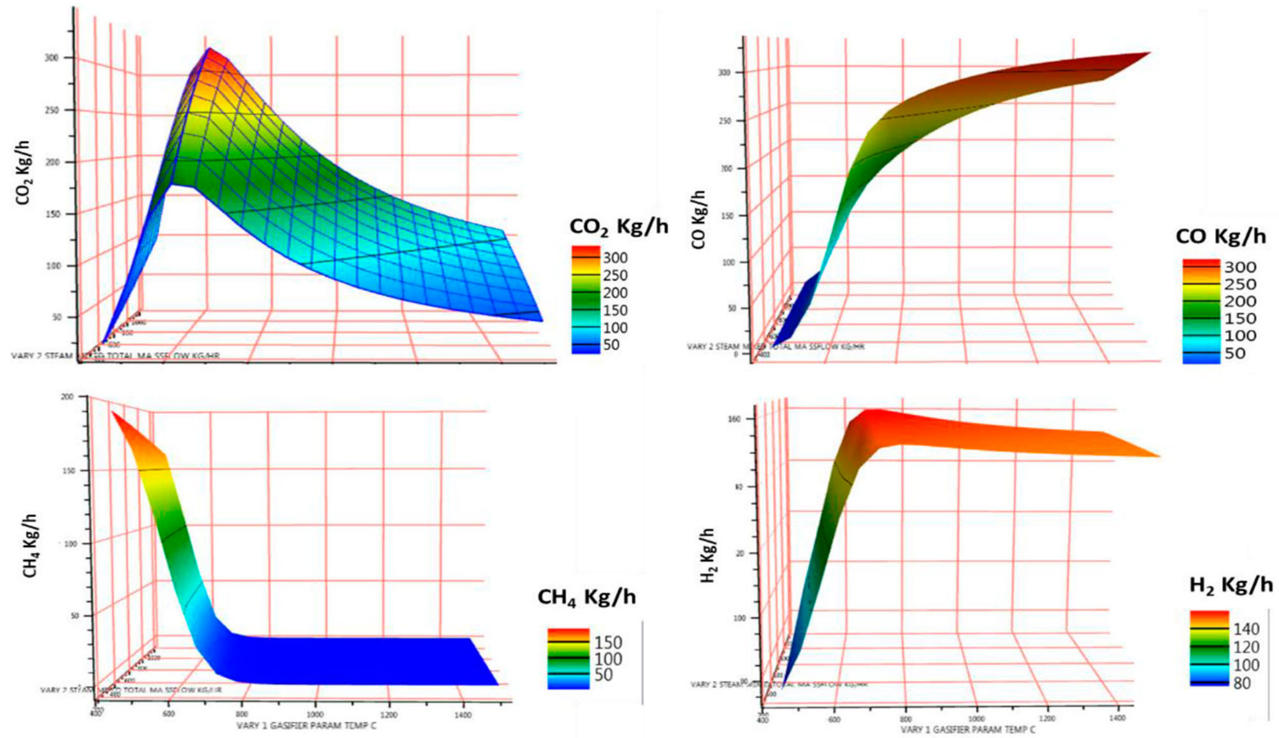

Figure 6. The relationships between flow rate, temperature and syngas produced in the thermal process.

OPW is available in mostly in large particle sizes and lump form; therefore, size reduction is crucial to utilise in AC production. This is done by milling, which requires high energy for operation. Particle size is one of the key factors in thermochemical process, physical conditions of OPW biomass notwithstanding the method influences activation rate and other production parameters [46]. There is difficulty in milling MF and EFB rather than

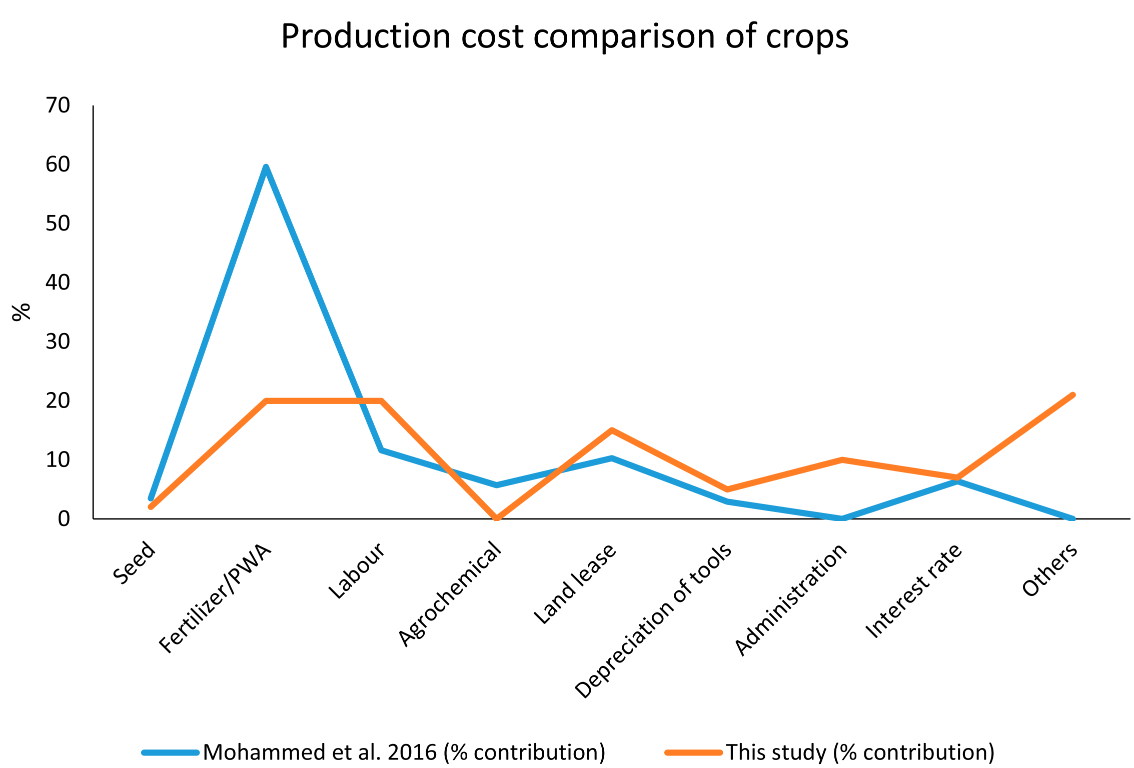

Figure 7. Percentage production cost of crop production.

PKS due to low brittleness. OPW could be crushed when dry, sieved and graded into different uniform sizes of <2.0 mm using a milling machine [47], to ensure uniform distribution of heat. This process requires energy and could result in material wastage in the form of dust and so in order to minimise loss of biomass, a dust collector is installed, which aids in throughput flow and overcome air flow resistance [48]. Pre-treatment such as drying and sieving also occasionally play a role in determining energy consumption. Establishing uniformity of particle sizes largely depends on the physical properties of biomass. Brittleness, hardness and elasticity affect the energy requirement in milling. Philips et al. [49] studied the mechanical and physical influence of PKS, and showed that aggregate crushing value is 5.3% and flakiness index 63.2%, indicating that PKS has a good milling effect. The efficiency of hammer mill operation is factorised by the nature of the biomass. Due to the several types of OPW with varied sizes and shapes, their milling tendencies vary widely. Material breakage as the fracture reaction is contingent on impact frequency, energy, moisture content and biomass properties [50]. The material properties in terms of its resistance and minimum specific energy are relevant to determine fracture and breakage factor which would define the milling rate. The energy requirement increases with reducing particle size; however, it is also observed that physical properties influence feeder design, biomass flow rate and reactor performance [51].

Environmental assessment

The reutilisation of PWA in soil amendment can be a good option for phosphorous and other key mineral input other than from finite sources; however, dumping of ashes in river can upset the balance of ecosystem and landfilling may result in environmental pollution due to particle flows into the air. In the experimental study, the yield due to PWA application equates to the inorganic option of fertiliser. They are not economically exploited despite the large quantity produced. Managing these wastes for pollution and environmental health safety has to be the principal goal. The use of biosolids has range of benefits which include carbon sequestration [52].

The use of biomass thermal by-products could reduce loss of nutrients through leaching improve soil characteristics, reduce non-CO_2 greenhouse gas emission and remediate contaminated soils. The feasibility of breakeven cost of biochar production depends on location, biomass availability and technology [53].

Assessing the two-utilisation route of AC and PWA, few environmental factors are necessary for consideration. The impact can't be directly quantified; however, impact in substituting chemical fertiliser and impact in avoiding pollution are trackable.

The increased soil carbon due to PWA addition to the soil contributes to the reduction of atmospheric carbon intensities. These play a major role in minimising erosion and runoffs by binding the soil structure. The nitrate leaching experienced in sandy soil is greatly reduced by the application of PWA. The high natural gas-intensive due to nitrogen fertiliser production is reduced.

About 60% of the fertiliser are imported and Nigeria requires varieties of fertilisers to meet the growing demand. However, the country remains a major importer of fertiliser. Crop yield has a massive influence on the revenue and economy of every society. Agriculture contributes meaningfully to rural occupation and provides substantial non-oil foreign exchange incomes. Organic fertiliser comparative study with chemical fertiliser shows that it enhances soil structure, increase nutrient and water retention, increased the microbial activities of the soil. The excess application does not have harmful effects on crops and it prevents erosion. However, chemical fertilisers are harmful to crops and human, excess application destroys soil structure, leads to soil acidity and harmful to plants. Organic fertiliser is about 40% cheaper than other potassium fertiliser, 100% organic and eco-friendly, recommended for all kinds of plants, very effective for neutralising acidic soils.

Conclusions

The energy and economic analyses for the utilisation of oil palm waste show that, AC production has higher technical and cost requirement than palm waste ash utilisation. However, the application of palm waste ash has relatively high environmental benefits because it can substitute chemical fertiliser. Palm waste ash is alternative to chemical fertiliser, especially for the treatment of ultisol and acidic soils, this is most useful where the fertiliser market is not easily accessible. AC market is a viable business; although, it has a high initial capital investment with an estimated capital expenditure of $280M for biomass thermal processing plant; here, the payback period was evaluated at 8.2–9.8 years. The general efficiency of the two processes depends on requirements and demand. Scenario 1 pyrolysis option which favours char production a BCR of 1.34 against 1.25 of scenario 3 combustion which favours ash production. Scenario 2 gasification has the highest economic benefit and the best payback period compared to other scenarios. Advancing research on multiple utility and compound wastes will further boost the annualised return on investment. Biomass thermal plants should be established in an area with a good road network, available electricity and should be designed to take multiple processes simultaneously.

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