Article

Energy Recovery Potential from Effluents in the Process Industry: System Dynamics Modeling and Techno-economic Assessments

Tofunmi Adepoju[1], Abiodun Momodu [2, *], Ibikunle Ogundari[3], Joshua Akarakiri[4]

[1] African Institute for Science Policy and Innovations, Obafemi Awolowo University, Ile-Ife, Nigeria; dtadepoju@pg-student.oauife.edu.ng / adepojutofunmi001@gmail.com

[2] Centre for Energy Research and Development, Obafemi Awolowo University, Ile-Ife, Nigeria; amomodu@oauife.edu.ng / abiodunmomodu8@gmail.com

[3] African Institute for Science Policy and Innovations, Obafemi Awolowo University, Ile-Ife, Nigeria; Ibikhunle_ogundari@oauife.edu.ng / ibikhunle@yahoo.co.uk

[4] African Institute for Science Policy and Innovations, Obafemi Awolowo University, Ile-Ife, Nigeria; jakarakiri@oauife.edu.ng / jakarakiri@yahoo.co.uk

* Correspondence: amomodu@oauife.edu.ng ; Tel.: +2348061399185

Abstract: This study quantified effluents generated during processing in three industry types, estimated the energy potential from the quantified effluents in form of biogas generation, and determined the economic viability of the biogas recovered. Data were procured from relevant scientific publications to quantify the effluents generated from the production processes in the industry types examined using industrial process calculations. The effluent data generated was used on the 2-module biogas energy recovery model to estimate the bioenergy recovery potential within it. Economic and financial analysis was based on cash flow comparison of all costs and benefits resulting from its activities. The effluents generated average daily biogas of 2559 Nm^3/gVS, having a daily potential combined heat and power of 0.52 GWh and 0.11 GWh respectively. The Life Cycle Analysis and cost-benefit analysis show the quantity of avoided emissions from using the effluents to generate heat and power for processes, and also the profitability of the approach. Conclusively, the study shows the use of biomass effluents to generate biogas for CHP is a viable one based on the technologies of a reciprocating engine, gas turbine, microturbine, and fuel cell. However, it is recommended that the theoretical estimation be validated using a field-scale project.

Keywords: System Dynamics; CHP; Energy Recovery, Effluents, Process Industry, Cost-benefits, LCA.

1. Introduction

Global desire is to reduce world temperature based on the 26th Conference of Parties (COP26) held in 2015 meeting that culminated in the Paris Agreement and the recent COP31, the Glasgow Climate Conference held in 2021 that built upon the gains of COP26. The goal of these efforts was principally to limit global warming to well below 2 degrees Celsius, preferably to 1.5 degrees Celsius, compared to pre-industrial levels. According to [1], industrial effluents, of which the food and beverage industry (F&Bi) is part, account for around 50% of the overall waste generated globally. Activities in the F&Bi, connect to three goals in the SDG, namely 7, 12 & 13, on clean and affordable energy, responsible consumption and production, and climate action. The process industry such as the F&Bi is usually accompanied by the generation of a large volume of effluents. Effluents are linked to methane generation, an influential greenhouse gas. Through improper handling, they could contribute to increased atmospheric temperature. Harnessing the effluents through conversion to biogas could be a means of producing clean and affordable energy, encourage responsible consumption and production, and could serve as a climate action

in the industry, hence this study. The specific study objectives are quantification of effluents generated during the process in these three industry types, estimation of the energy potential from the quantified effluents in form of biogas generation, and the economic viability of the biogas recovered.

Biogas is a good substitute for fossil fuels to be used for heat and electricity production in engines, microturbines, steam turbines, gas turbines, and fuel cells. Biogas used in this way is capable of creating further emission reductions, that could result in carbon-negative systems. Also, biogas as organic waste is capable of providing environmental protection, investment, and job creation in developing economies [2]. Figure 1 is a diagram of material flow in biogas production process and its uses.

Source: https://www.eesi.org/images/content/Figure1-Anaerobic-Digestion-Process.jpg
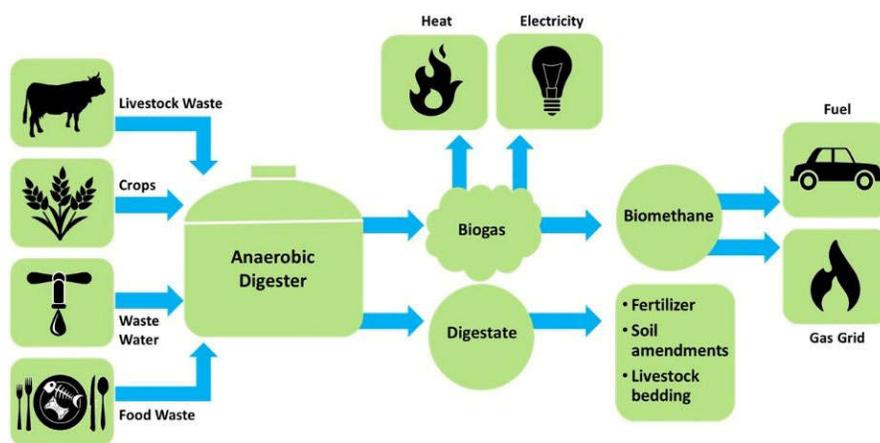
1.1 Process industry: economic importance and effluent generation in food and beverage production

Our working definition of a process industry is an industry that is involved in the processing of bulk resources such as in food and beverage industries into other products. Examples will include turning cassava into cassava flakes for consumption, grains, and barley into beer, and refining sugarcane into sugar. Globally, one of the secondary industries critical to every economy is the food and beverage industry [3]. The food and beverage industry involves all manufacturing exercises concerning the processing of raw food materials, packaging, and distributing them, ranging from fresh, prepared foods as well as packaged foods, alcoholic, and nonalcoholic beverages [4]. The industry has two major segments, namely, production and distribution [5]. The production segment has to do with the processing of such items as meat, cheese, and the creation of soft drinks, alcoholic beverages, packaged food, and other modified food including food directly obtained from farming and other forms of agriculture. The distribution segment deals with transporting finished food products to the consumer [4]. According to [6], the industries in the food manufacturing subsector transform livestock and agricultural products into products for consumption, and this includes animal food manufacturing, grain and oilseed milling, sugar and confectionery product, fruit and vegetable preserving, and specialty food manufacturing, dairy product manufacturing, animal slaughtering and processing, seafood product preparation and packaging, bakeries and tortilla manufacturing and other food manufacturing. The beverage industry includes soft drink and ice manufacturing, alcoholic beverages, and tobacco products manufacturing. The food and beverage industry contribute significantly to the economy [7], for instance, in the United Kingdom, the food and beverage industry contributed more than 28 billion GBP to the economy, and exports more than 20 billion GBP worth of food and drinks to the rest of the world as at 2017 [6]. Similarly, in the United States, the food and beverage industry accounts for at

least 5% of the total gross domestic product and contributes at least 10% of the employ-ment rate, and more than 10% of consumers' disposable incomes [6].

Being an extremely productive sector, the food and beverage industry generally also produces large amounts of effluents in its processes [8]. Most procedures in the industry require water with the expectation that solid and gaseous waste residues are carried with this water, generating effluents or wastewater in the process [9]. The effluent produced varies quantitatively and qualitatively with the intrinsic characteristics of the process, the industrial facilities, and the operational practices of each production plant. These effluents pose threat to the environment, hence the need to minimize the environmental impacts [10]. The concept of food industry effluents and its treatment is viewed based on quanti-tative and qualitative characterization of the effluent, which is the main key to the treat-ment of effluents and the development of a logical and functional sequence of processes and operations which is the main tool for mitigating the environmental impact [9]. In an-other study, several eco-efficiency indicators are proposed in order to quantify industrial effluents in the food and beverage industries as a key step to the treatment of effluents and suggested an elementary index used in the sugar industry which is specific water consumption per ton of sugarcane [11].

A study on the management of effluents in the food and beverage industry in the South Western region of Nigeria indicates that 50% of its effluents are discharged into water bodies and septic tanks without treatment [12]. In particular, the brewery industry disposes their wastewater first by pumping it into a settling tank after which the superna-tant is treated separately, and prior to the construction of the settling tank, a disposal unit was in use but had to be abandoned owing to odor problems. The concept of clean tech-nology and water recycling was considered for effluent management and beneficial use of sludge of beverage industry in Pakistan and suggested as a low-cost wastewater treat-ment [13]. For the treatment concept, [14] examined integrated microfiltration and oil skimming for treatment of spent process water for product recovery and water use. Im-portantly, food and beverage industry effluents are biodegradable wastewaters that con-tribute as much as 6% of all anthropogenic methane emissions [15], suggesting the use of high-rate anaerobic digesters to treat such wastewaters efficiently as well as enable the capture of methane for use as a relatively clean energy source. In Nigeria, [12] reports that there is a gap in the treatment of effluent in the food and beverage industry in Nigeria for energy recovery purposes compared to some developing and developed countries.

1.2   Techno-economic assessment of energy recovery potential from effluents

Any energy recovery project is first and foremost an engineering project, and there-fore suitable to be evaluated using techno-economic assessment tools [16] such as the en-gineering economics approach. The engineering economics approach was applied for the techno-economic assessment in evaluating the design and engineering alternatives for en-ergy recovery potential from effluents generated from the process industry of the food and beverage industry. The techno-economic assessment examined the appropriateness of the project, estimated its value, and justified it from an engineering standpoint. The approach allowed for costs and expenses by assigning financial value to environmental as well as social benefits or costs. The parameters in engineering economics used for project evaluation include payback period, net present value, and internal rate of return, cost-benefit analysis, life cycle assessment, local economic impact, cost-effectiveness analysis, [17], comparative costs [18]. Among the mentioned economic analysis tools, the cost-ben-efit is the most widely used analysis due to its use in facilitating the aggregation of social, environmental, and economic benefits and costs [19]. The continual use of this analysis as a decision-making tool for the environmental project has led to the development of ap-proaches for effective evaluation of the economic performance of wastewater treatment

plants which include quantification of avoided environmental damages in monetary terms [19]. This methodology is very much applicable to energy recovery systems as they contribute to environmental and social benefits [20].

Some techno-economic assessment studies on bioenergy from different sources of effluent were examined. For instance, [21] conducted a techno-economic assessment of the feasibility of commercial waste biorefineries for cassava starch industries. The study considered different commercial viability scenarios and concluded that the integration of succinic acid production (6.9 Mg/h) in a biorefinery co-producing bioethanol and CHP is a potentially viable cassava waste biorefinery with economic and environmental benefits. In their study, [22] evaluated a long-term saving capability by conducting a techno-economic assessment of CHP installation at a case study of a wastewater treatment plant. The wastewater plant generates over 2 million cubic meters of biogas per year and utilizes over 36,000 GJ of natural gas per year. [23] suggested farm animal and meat processing industry effluent as a potential sustainable energy source because the effluents generated by this industry are critical sources for biogas production via anaerobic digestion. The study revealed that farm animal waste and meat processing industry effluent is advantageous sustainable and low-cost energy sources that can be efficiently utilized for the production of bioenergy and electricity and lower the GHG emission in the environment. [24] concluded that conventional treatment of winery waste is expensive, suggesting valorization of winery waste using the concept of biorefinery, that is, conversion of waste to produce biofuels, heat, and energy.

2. Concept, materials, and methodology

The concept of this study is predicated on the principle that effluents from the processes in F&Bi are capable of generating biogas for energy recovery [25] if handled properly. The processes are described using two causal loop diagrams for biogas production and energy recovery potential for CHP use. Figure 1 shows the causal loop diagram (CLD) for biogas production process showing our understanding of the AD process that effluents undergo for biogas production, while Figure 2 is the adapted CLD [26] for energy recovery potential from the biogas produced from the effluents generated in the processes of the three F&B industry types.

Specific materials of interest are cassava used in making cassava flakes or *garri*, millet/sorghum adjuvants used in breweries that serve as malted grain in place of barley for beer production, and sugar cane refined to sugar.
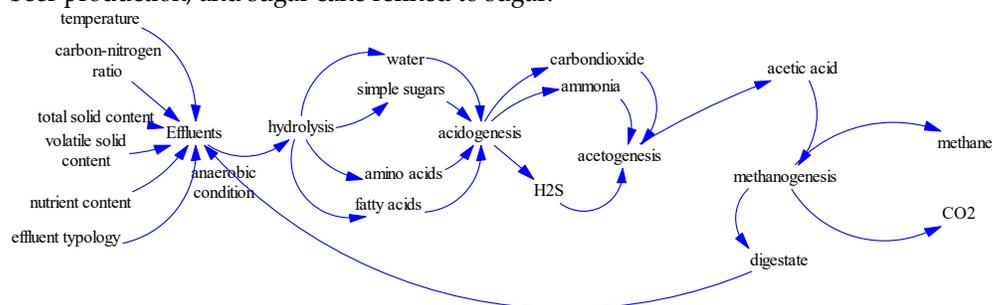

Figure 1. Adapted causal diagram of anaerobic digestion of effluents used for biogas production [26]
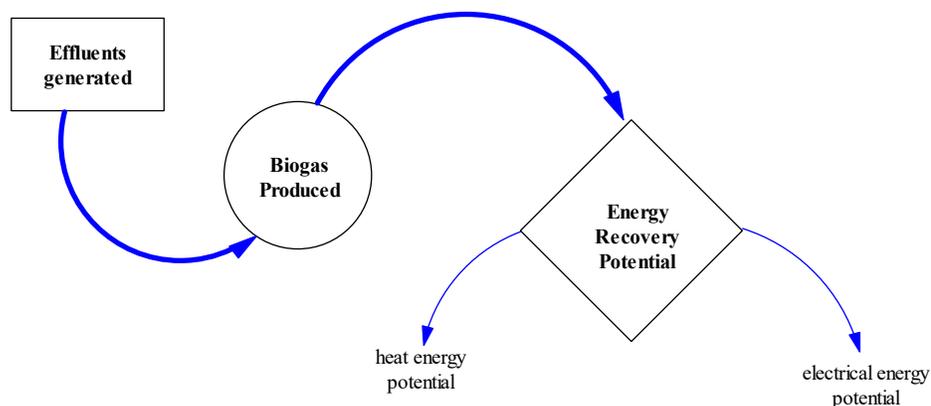
Figure 2. Causal diagram for effluents, biogas production and energy recovery for CHP use

The stock and flow diagram (SFD) in System Dynamics explains the structure and behaviour of the adapted model depicted in Figure 3. This stock and flow (or level and rate) diagram (SFD), represents the structure of the 2-module biogas energy recovery model for CHP purposes. The model is adapted from [26], and then coupled to the energy recovery potential to the biogas production module. SFD is the most common first step in building a simulation model showing a more detailed information for the system than the causal loop diagram. SFD defines variable types that are important in the structure of the model. The SFD also describes the way of material flow in the system, while the model behavior is given using equations that govern the direction that material can flow when the model is simulated Math_representation.ppt (live.com).

Data on these materials were procured from relevant scientific publications as well as such reports from the Food and Agricultural Organization (FAO) on the Cassava Industrial Revolution [27, 28], grain (millet and sorghum) usage in the production of beer in Nigeria [29], and the National Sugar Master Plan of the Nigeria Sugar Development Council [30]. These data formed the bedrock of quantifying the effluents generated from the production processes of cassava flakes, beer making, and sugar refining using industrial process calculations.   Next, the effluent data generated was fed into the 2-module model - biogas energy recovery model – (see Figure 1) to estimate the bioenergy recovery potential within it. The behaviour of SD models is driven by equations. So, equation 1 gives the equation for simulating the kinetics of the biogas produced from effluents generated from production processes in the F&B industry.

$$G_{t=} \ A\{ \ 1 - \exp[\ (m - 1)(\frac{t}{t_0})^{\left(\frac{1}{m}\right)}] \quad \} \quad \text{Eqn 1}$$

Where,
G_t is the accumulative biogas yield at digestion time t
A is the biogas yield potential of substrates
m is an intermediate constant
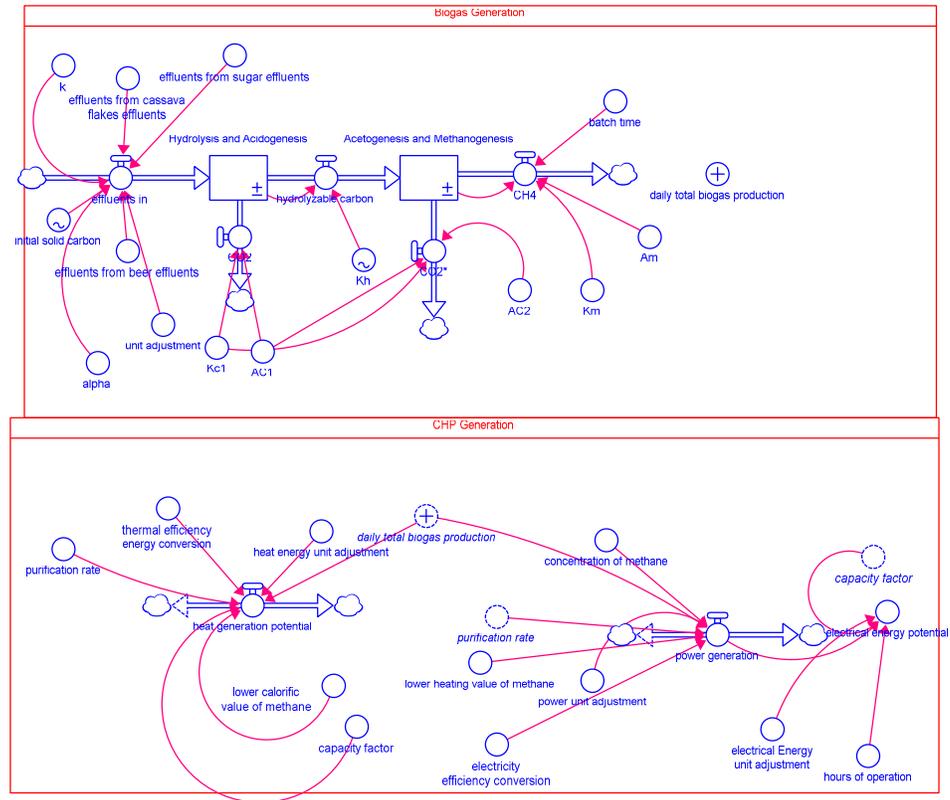t_0 is the time when the biogas rate reaches a maximum

Figure 3 System Dynamics Biogas Energy Recovery Model for CHP

Equation 1, the basic equation in the model, was complemented with equations 2, 3 and 4 respectively to estimate the electric power, electric energy generation potential and the heat energy generation potential from the biogas produced.

$$P = \frac{LHV \times \eta \times Q \times CCH4}{31536} \quad \text{Eqn 2}$$

Where
P- electric power
LHV - Lower heating value of methane (MJ/m3)
η - Efficiency of the energy conversion technology (%)
Q - Biogas yield (m3/day)
CCH4 - Concentration of methane in biogas (%)
Factor for unit adjustment- 31536

$$E = \frac{P \times \Delta t \times fc}{10^6} \quad \text{Eqn 3}$$

Where
E – Electric energy generation potential (GWh/day)
Δt - Annual hours of operation (hours/day)
Fc-   capacity factor of the plant

$$E_{th} = \frac{LHV \times \eta \times Q \times f_c}{10^6} \quad \text{Eqn 4}$$
  Where
Eth – thermal energy generation potential (GWh/day)

Q – biogas yield (m3/day)
LHV – Lower calorific value of biogas (MJ/m3)
η – thermal efficiency of energy conversion technology (%)
fc – capacity factor

The final step involves technoeconomic analysis of the processes, namely, avoided emissions given by equation 5 and 6

$$E_{av,el} = E \times E_f \qquad \text{Eqn 5}$$

Where,
Eav, el - emissions avoided using recovered bioenergy for electricity generation per year (tCO2eq/yr);
E - annual electricity generation from the bioenergy (GWh/yr);
Ef - CO2 emission factor of the grid electricity matrix in Nigeria (tCO2/GWh)

$$E_{av,th} = E_{th} \times EF_{ff} \qquad \text{Eqn 6}$$

Where,
Eav, th - emissions avoided from use of bioenergy for thermal energy (tCO2/yr);
Eth is the annual thermal energy generation potential (GWh/yr);
EFff is the emission factor of the specific fossil fuel per unit of energy (tCO2/GWh)

Estimating the cost of energy from the energy recovery potential project using biogas from the effluents in the process industry involves the total present value of cash outflow divided by the total energy generated in a fixed period. This is represented in Eqn 7.

$$Levelised\ cost\ of\ electricity\ (LCOE) = \frac{Total\ Cost\ over\ a\ period}{Total\ Energy\ over\ the\ same\ period} \qquad \text{Eqn 7}$$

The economic and financial analysis of the project is based on the comparison of the cash flow of all costs and benefits resulting from the project's activities [31]. There are four common methods of comparing alternative investments: (1) discounted cash flow/net present value, (2) Rate of Return, (3) profitability index/Benefit-Cost analysis, (4) return on investment, and (5) Pay Back Period. Each of these is dependent on a selected interest rate or discount rate to adjust cash flows at different points in time. The explanation of these four methods is given below as deployed for project selection [32].

1.   *Discounted Cash Flow* or net present value (NPV) method, the discounted cash flow method determines the net present value of all cash flows by discounting them by the required rate of return (also known as the hurdle rate, cutoff rate, and similar terms) as follows:

$$NPV = \sum_{t=0}^{n} \frac{R_t}{(1+i)^t} \qquad \text{Eqn 8a}$$

Where
NPV = Net Present Value
Rt = net cash inflow-outflows during a single period t
i = discount rate or return that could be earned in alternative investments
t = number of time periods

2.   The *internal rate of return* (IRR) is a metric used in financial analysis to estimate the profitability of potential investments. IRR is a discount rate that makes the net present value (NPV) of all cash flows equal to zero in a discounted cash flow analysis. It should be noted that IRR calculations rely on the same formula as NPV does, where the

annual return that makes the NPV equal to zero. Generally speaking, the higher an IRR, the more desirable an investment is to undertake. Being uniform for varying project types, IRR can be used to rank multiple prospective investments or projects on a relatively even basis. In general, when comparing investment options with other similar characteristics, the investment with the highest IRR probably would be considered the best.

$$0 = NPV = \sum_{t=0}^{T} \frac{C_t}{(1+IRR)^t} \qquad \text{Eqn 8b}$$

Where,

    C = Cash flow at time t

    IRR = discount rate/internal rate of return expressed as a decimal

    T = time period

To include the impact of inflation (or deflation) where pt is the predicted rate of inflation during period n, we have

$$NPV = \sum_{n=0}^{N} \frac{C_t}{(1+r+p_t)^n} \qquad \text{Eqn 8c}$$

3.   *Profitability Index* Also known as the benefit-cost ratio, the profitability index is the net present value of all future expected cash flows divided by the initial cash investment. (Some firms do not discount the cash flows in making this calculation.) If this ratio is greater than 1.0, the project may be accepted.

$$\frac{Net\ Present\ Value + Initial\ cash\ investment}{Initial\ cash\ investment} \qquad \text{Eqn 9}$$

4.   *Return on investment* (ROI) Return on investment (ROI) is a performance measure used to evaluate the efficiency or profitability of an investment or compare the efficiency of a number of different investments. ROI tries to directly measure the amount of return on a particular investment, relative to the investment's cost. To calculate ROI, the benefit (or return) of an investment is divided by the cost of the investment. The result is expressed as a percentage or a ratio.

$$Return\ on\ investment = \frac{Net\ Present\ Value}{Cummulative\ Cash\ outflow} \qquad \text{Eqn 10}$$

5.   *Payback Period* for a project is the initial fixed investment in the project divided by the estimated annual net cash inflows from the project. The ratio of these quantities is the number of years required for the project to repay its initial fixed investment. This method assumes that the cash inflows will persist at least long enough to pay back the investment, and it ignores any cash inflows beyond the payback period. The method also serves as an (inadequate) proxy for risk. The faster the investment is recovered, the less the risk to which the firm is exposed.

$$\frac{Initial\ fixed\ investment}{Estimated\ annual\ net\ cash\ inflows + Salvage\ value} \qquad \text{Eqn 11}$$

3. Findings and Analysis

The result of industrial process calculations shown in Table 1 indicates that effluents generated are highest from the processing of cassava into cassava flakes in terms of nominal value. This is quite understandable considering the volume of cassava processed in this region annually. The second highest effluents generated come from beer production processed from malted grains using millet/sorghum characteristics with sugar being a very distant third. However, considering the input-output ratio, beer production from unmalted grain and barley generated the highest effluents at 74% as compared to cassava flakes at 24% and sugar processing effluents at about 4%. This is because more than 90% of input for beer production is water, and an efficient brewery will typically use between 4-6 liters of water to produce 1liter of beer [29].

Table 1 Estimates of effluents from the process in the production of cassava flakes, beer and sugar in southwestern Nigeria

Effluents production from	Amount (m³/day)
Cassava flakes	9,554
Beer from un-malted grain and barley	4,805.77
Sugar refining	2,767.67

Model simulation results show that the average daily biogas generated from the effluents would be 2558 Nm³/gVS (Figures 4 and 5). The potential combined heat and power this could produce is 0.52 GWh/day and 0.11 GWh/day respectively. Theoretically, these results show that effluents from the processing of cassava, sorghum/millet, and sugar refinement of these industries could produce enough methane to adequately support their CHP needs. In terms of viability, the techno-economic analysis using LCA and cost-benefit analysis (profit and Rate of Returns) respectively show the quantity of avoided emissions from using the effluents to generate heat and power for processes and also the profitability of the approach.
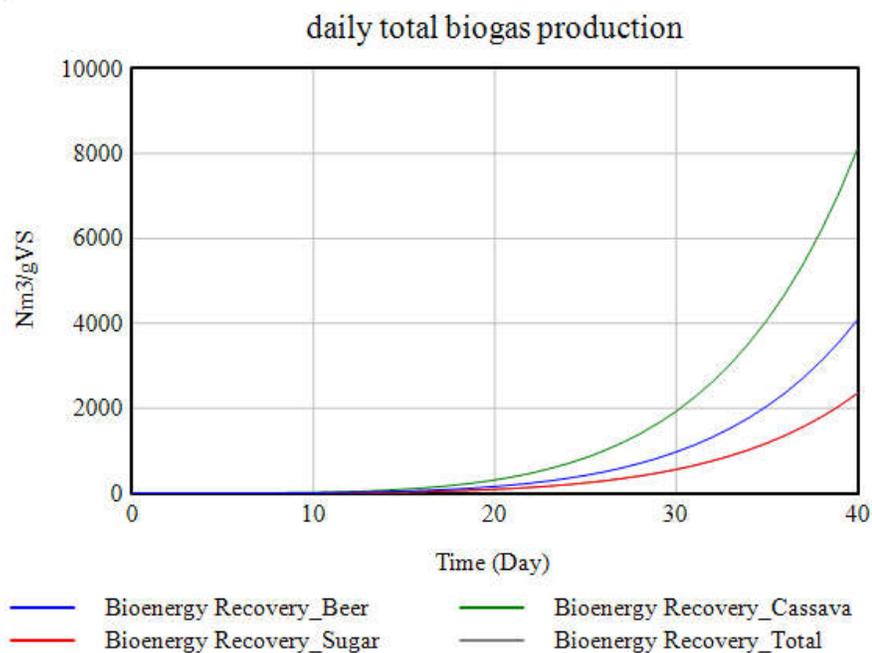

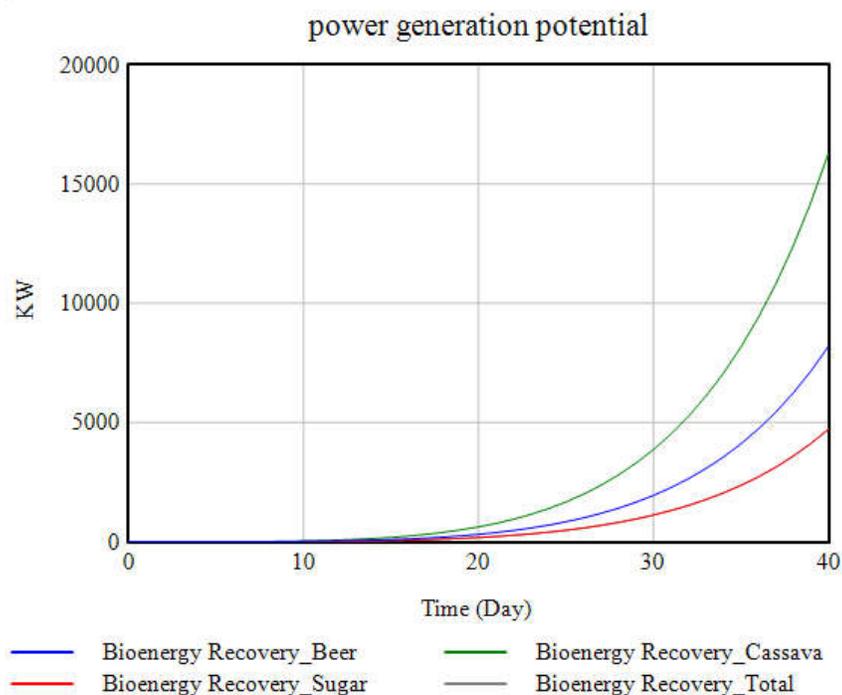Figure 4 Estimated Biogas produced daily – Cassava flakes-Sugar-Beer and Total

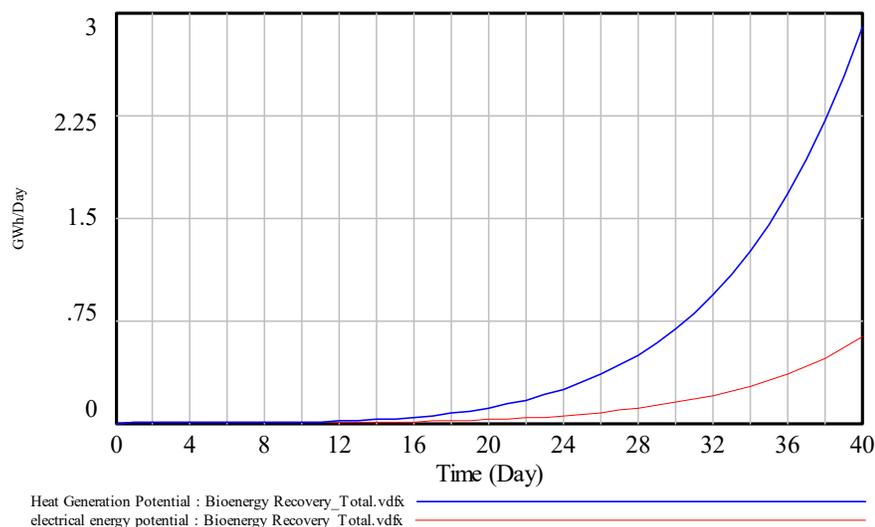**Figure 5 Power generation potential from Effluents produced**

Figure 6 Heat and Electrical energy potential from the biogas recovered from the effluents

The result from the LCA shows the total avoided emissions from average daily electricity generated from the effluents is shown in Table 2. The first step in the LCA was to estimate energy recovery potential to handle the average daily methane generated from the effluents. Next is to estimate the power capacity of the generator for the potential energy recovered. This was then followed by calculation for the avoided emissions or fossil fuel displaced generating electricity and heat from the effluents.

Table 2 Life Cycle Assessment of Avoided Emissions from generated effluents

Source of effluents	Average daily heat generation potential (kWh/day)	Average daily electricity generation potential (kWh/day)	Total Avoided Emissions yearly (tCO2eq)
Malted Grains	127,924.80	27,648.89	17,264.55
Cassava	254,311.00	54,965.20	34,321.36
Sugar	73,657.78	15,919.94	9,940.76
All effluents	455,893.58	98,534.03	61,526.67

Usually, in the early life of any engineering project, including the energy recovery project considered, the net cash flow is negative because the major outflow was the initial investment in the project. For instance, in the three types of turbines and fuel cell (FC) considered as alternatives, for RE the net cash flow was negative for the first two years and was three years for GT and 5 years for MT. However, the three alternatives became ultimately successful projects as the cash flows became positive in the third, fourth, and sixth year respectively, making the project *acceptable*, with the sum of the net present values of all estimated cash flows over the life of the project being positive for each of the type considered. That for a fuel cell technology was however different, being negative all through the ten-year cycle. It was observed that with a fuel cell capacity of about 40% of the generation capacity of the other technologies (i.e., 2.0 MW), the cash flow situation changed significantly, where it was negative till the 6th year and became positive in the 7th year.

Table 3 shows the project specifications based on the turbine selected and Table 4 shows the economic and financial analysis of the project. Table 3 shows that the power capacity for each of the technology examined is the same for three of the turbine types and different for fuel cell while the energy cost varies. The first step to estimating these indicators was to calculate the levelised cost of electricity (LCE). Four different generation technologies, namely, reciprocating engine (RE), microturbine (MT), gas turbine (GT), and fuel cell were considered as project types. Shown in Table 4 are five methods by which the alternative investments are compared, namely, net present value (NPV), internal rate of return (IRR), profitability index/benefit-cost analysis, return on investment (ROI), and payback period (PP). The power generating capacity for each of the three turbines is 5.2 MW as determined by the gas flow generated from the effluents and that of fuel cell was put at 2.3MW i.e., approximately 40% of the gas flow capacity. The levelised cost of energy (LCE) in $/kWh for the turbines is respectively 0.06, 0.07, 0.08, and 0.09 for RE, GT, MT, and FC, with the highest being fuel cells, followed by microturbines and lowest for reciprocating engines. All prices are however higher than what is currently charged for residential tariffs by electricity distribution companies in Southwest Nigeria. This implies that the project is financially viable. The net present value (NPV) of profit for the turbines is respectively $7.9, $6.79, $3.59 and $2.42 million for RE, GT, MT, and FC.   This implies that any of the technology considered is capable of generating a net return of profit from the investment. In terms of return on investment, RE faired best at 46%, GT next at 41%, MT at 16%, and FC at 10%. The IRR also followed the same trend at 45%, 36%, 34%, and 32% respectively. The payback period is respectively 6.09, 6.63, 8.09 and 7.69 years for RE, GT, MT, and FC.

Table 3 Project specifications of energy recovery potential from process industry effluents

Turbine type Project Indicators	Reciprocating Engine (RE)	Gas Turbine (GT)	Micro Turbine (MT)	Fuel Cell
Power Generating Capacity needed (MW)	5.2	5.2	5.2	2.0
Levelised Cost of Energy (LCE) ($/kWh)	0.06	0.07	0.08	0.09

Table 4 Economic and financial analysis of energy recovery potential project specifications

Project type Economic and financial indicators	Reciprocating Engine (RE)	Gas Turbine (GT)	Micro Turbine (MT)	Fuel Cell
NPV of Profit Margin (Millions of Dollars)	7.9	6.79	3.59	2.42
ROI (%)	46	41	16	10
IRR (%)	45	36	34	32
Payback period (years)	6.09	6.63	8.09	7.69
Profitability index (cost-benefit ratio)	1.50	1.39	1.17	1.12

3.2   Limitations of the study

The scope of the study is theoretical, therefore having its inherent limitation, making it important to go through an empirical or evidence-based process to validate its findings. The empirical approach will involve a detailed analysis of how wastes, particularly those from cassava processing, would be collected from various sources in southwest Nigeria. Cassava processing is the most decentralized processing industry that was examined. Data paucity is also an issue being a theoretical approach that was not also subjected to site selection processes for the gathering of effluents from the various process industry examined.

4.0   Conclusion and recommendation

In considering the input-output ratio, beer production from un-malted grain and barley shows the highest effluents generation at 74% as compared to cassava flakes at 24% and sugar processing effluents at about 4%. In conclusion therefore, the study indicates the use of effluents for generating biogas to be used for CHP to be a viable one based on the technologies of a reciprocating engine, gas turbine, micro turbine, and fuel cell. The fuel cell was made viable in the 10-year cycle used for the financial assessments by reducing the capacity of the power generator to about 40% of what it is capable of supporting. Using a combination of the economic/financial indicators used, the reciprocating engine appears to be the most viable of all the technologies considered. However, it is recommended that the theoretical estimation be validated using a field-scale project.

Author Contributions: Conceptualization, Adepoju. and Momodu; methodology, Momodu.; software, Adepoju; validation, Ogundari, Akarakiri, and Momodu; formal analysis, Adepoju and Momodu; investigation, Adepoju.; resources, Adepoju, Momodu; data curation, Adepoju, Momodu and Ogundari; writing—original draft preparation, Adepoju; writing—review and editing, Momodu, Ogundari and Akarakiri; visualization, Momodu; supervision, Momodu, Ogundari and Akarakiri; project administration, Momodu. All authors have read and agreed to the published version of the manuscript.

References

1. UNESCO, 2019. *World Water Assessment programme: The United Nations World Water Development Report 5, Water in Changing World part,* London Eathscn: s.n.
2. Mang, H. et al., 2013. Biogas Production, Developing Countries. In: T. N. B. L. S. L. V. L. (. Kaltschmitt M., ed. *Renewable Energy System.* New York(New York): Springer, pp. 216-246
3. Moomaw, W. & Barthel, M., 2012. *The Critical role of global food consumption patterns in achieving sustainable food systems and food for all.* s.l.:A UNEP discussion paper
4. globalEDGE, 2021. *Food and Beverage.* [Online] Available at: https://globaledge.msu.edu/industries/food-and-beverage/memo/ [Accessed 13 September 2021].
5. Belyaeva, Z., Rudawska, E. D. & Lopatkova, Y., 2020. Sustainable business model in food and beverage industry–a case of Western and Central and Eastern European countries. *British Food Journal.*
6. CED, 2017. *Economic Contribution of the Food and Beverages Industry,* Arlington, VA: Wilson
7. Valta, K. et al., 2015. Overview of water usage and wastewater management in the food and beverage industry.. *Desalination and Water Treatment,* 53(12), pp. 3335-3347.
8. Khedkar, R. &. & Singh, K., 2018. Food industry waste: A panacea or pollution hazard?. In Paradigms in Pollution Prevention. *Springer, Cham.,* pp. 35-47.
9. Tommaso, G., 2011. Effluents from the food industry. *Woodhead Publishing Series in Food Science, Technology and Nutrition,* pp. 606-622.
10. Hanjra, M. A. et al., 2012. Wastewater irrigation and environmental health: Implications for water governance and public policy.. *International journal of hygiene and environmental health,* 215,(3), pp. 255-269.
11. Maxime, D., Marcotte, M. & Arcand, Y., 2006. Development of eco-efficiency indicators for the Canadian food and beverage industry. *Journal of Cleaner Production,* Volume 14, p. 636.
12. Kayode, O. F., Luethi, C. & Rene, E. R., 2018. Management recommendations for improving decentralized wastewater treatment by the food and beverage industries in Nigeria. *Environments,* 5(3), p. 41.
13. Hussain, R., Sattar, S., Khan, M. H. & Nafees, M., 2013. Low Cost Wastewater Treatment at Beverage Industry, Hattar Industrial Estate, Pakistan-A Case Study. *International Journal of Environmental Protection,* 3(11), p. 23.
14. Chmiel, H. et al., 2003. Concepts for the treatment of spent process water in the food and beverage industries. *Desalination,* 152 (1-3)), pp. 307-314.
15. Tauseef, S. M., Abbasi, T. & Abbasi, S. A., 2013. Energy recovery from wastewaters with high-rate anaerobic digesters.. *Renewable and Sustainable Energy Reviews,* Volume 19, pp. 704-741.
16. Zimmermann, A. et al., 2020. Techno-economic assessment guidelines for CO2 utilization. *Frontiers in Energy Research,* p. 5.
17. Mohammed, M. et al., 2017. Feasibility study for biogas integration into waste treatment plants in Ghana. *Egypt. J. Pet. ,* Volume 26, p. 695–703.
18. Tomei, M. et al., 2016. Techno-economic and environmental assessment of upgrading alternatives for sludge stabilization in municipal wastewater treatment plants.. *J, Clean. Prod.,* Volume 112, pp. 3106-3115.
19. Garrido-Baserba, M. et al., 2016. Application of a multi-criteria decision model to select of design choices for WWTPs. *Clean Technol. Environ. Policy,* Volume 18, p. 1097–1109.
20. Svanström, M. et al., 2014. Method for technical, economic and environmental assessment of advanced sludge processing routes.. *Water Sci. Technol.,* Volume 69, , p. 2407–2416.
21. Padi, R. K. & Chimphango, A., 2020. Feasibility of commercial waste biorefineries for cassava starch industries: techno-economic assessment.. *Bioresource technology,* Volume 297, p. 122461..
22. Riley, D. M. et al., 2020. Techno-Economic Assessment of CHP Systems in Wastewater Treatment Plants. *Environments,* 7(10), p. 74.
23. Mofijur, M. et al., 2021. Bioenergy recovery potential through the treatment of the meat processing industry waste in Australia.. *Journal of Environmental Chemic,* 9(4), p. 105657.
24. Zacharof, M. P., 2017. Grape winery waste as feedstock for bioconversions: applying the biorefinery concept.. *Waste and biomass valorization, ,* 8, (4), pp. 1011-1025.
25. Sawatdeenarunat, C. et al., 2019. Biogas production from industrial effluents. In Biofuels: Alternative Feedstocks and Conversion Processes for . In: A. L. C. a. R. S. e. Pandey, ed. *Biofuels: Alternative Feedstocks and Conversion Processes for the Production of Liquid and Gaseous Biofuels (Second Edition).* s.l.:Elsevier, pp. 779-816.
26. Momodu, A. S. & Adepoju, T. D., 2021. System dynamics kinetic model for predicting biogas production in anaerobic condition: Preliminary assessment.. *Science Progress,* 104(4, 00368504211042479.).
27. FAO, 2010. *Cassava Development in Nigeria,* s.l.: Department of Agriculture, Federal Ministry of Agriculture and Natural, Resources.
28. FAO, e. a., 2020. *The State of Food Security and Nutrition in the World 2020, Transforming food systems for affordable healthy diets,* Rome: Food and Agriculture Organization of the United Nations.
29. Adewumi, I., Oyebode, O., Igbokwe, K. & Aluko, O., 2011. Water footprints in four selected Breweries in Nigeria. *In Towards life cycle sustainability management , Springer, Dordrecht.,* pp. 171-181.
30. NSDC, 2021. *National Sugar Master Plan,* Abuja: National Sugar Development Council.

31.   Mahmoodzadeh, S., Shahrabi, J., Pariazar, M. & Zaeri, M., 2007. Project selection by using fuzzy AHP and TOPSIS technique..
        World Academy of Science, Engineering and Technology, 30(1), pp. 333-338
32.   Meredith, J. & Mantel, S., 2009. *Project Management: A Managerial Approach.* s.l.:(W/Cd). John Wiley & Sons.