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RESEARCH ARTICLE

FEASIBILITY STUDY FOR ENERGY RECOVERY OF PEELS RESULTING FROM CASSAVA PROCESSING INTO GARI: CASE OF THE MAWUDAGBA COOPERATIVE IN BENIN

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Abstract

In Bénin, cassava processing activities within Mawudagba cooperative enterprise generate significant wastes that are bulky and difficult to manage. In addition, Mawudagba Cooperative is dependent on thermal energy for cooking gari and gasoline supply to grating equipment. In order to reduce waste and the energy bill, a technical-economic and environmental study was carried out. The methodology used is based on energy needs analysis, energy recovery possibilities analysis and economico-environmental analysis. The results showed that the annual energy consumptions are 21.71 MWh and 3.10 MWh respectively for cooking gari and for fueling the grating equipment. The Gross Biomass Potential amounts to 187.792 T per year while that of the Net Biomass is 128.422 T per year. Analysis of energy recovery possibilities from cassava waste has retained pyrogasification as appropriate process for the energy recovery of cassava peels within the Mawudagba Cooperative.The economic analysis revealed that the investment cost for a period of 15 years is 3,690,000 FCFA and that of operation is 160,000 FCFA/year. In addition, the study made it possible to reduce the annual bill for firewood from 780,000 FCFA to 0 FCFA and that of gasoline from 520,000 FCFA to 0 FCFA. From an environmental point of view, a reduction of 26.61 tonnes CO_2/year is obtained from the emissions produced by non-recovered waste.

Introduction:-

In Benin, cassava is one of the main priority crops identified by Benin Government in the Strategic Plan for Agricultural Development. It represents 2.8% of national GDP and 8.3% of agricultural GDP (Agre et al., 2017) and is an important socio-economic issue in the country. It is the second most commonly crop grown after maize in Benin but it is the most important plant in multi-crop systems (Houngue and al., 2022). It is found in a wide range of markets and provides a stable source of incomeand food for many households Degnon et al. (2018). Cassava is a perishable product. Its degeneration starts 2-3 days after harvesting, hence, the need to process and convert the tubers to a more stable product with long shelf life (Ohimain and al., 2013). Currently, the global production of cassava is about 215,436,496 tons. Out of these, Benin produces only 4,161,660 tons (Zinsou and al., 2017). In terms of food, cassava is a staple food for about 500 million people in the tropical countries. In Benin, it represents the third largest staple food after maize and rice (Ahou and al., 2021). Ukwuru and Egbonu (2013) reported that cassava is a major source of energy for more than 2 billion people in the world especially in the tropical region.

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Cassava roots are processed into food derivatives such as tapioca, cossettes, lafun, fufu and chips with gari in mind, the quantity of which represents 65% of harvests (Adjovi and Madjri, 2016).Gari is one of fermented products made from cassava processing. Adegbite and al. (2019) define it as a creamy – white partially gelatinized roasted free flowing granular flour made from cassava roots. For Parmar et al. (2019), gari is an important staple in West Africa, where per-capita consumption is more than 120 kg per year. Cassava products are rich in carbohydrates (Kolawole, O.P., 2012), vitamins (mostly vitamins B and C), essential minerals and low in protein. The nutrient composition depends on the variety, age, and prevailing environmental condition including soil characteristics. Basically, cassava tuber contains about 70% water (Plevin and Donnelly, 2004).

In Benin, cassava processing are carried out at three levels of scale: small scale (Sonawane and al., 2011)medium scale processing (Aprajita and Harpinder, 2018) and Industrial scale processing (Augustin and al., 2016). For Godjo (2007), the common characteristic of those three sectors is to generate a finished product that will be consumed. Those different scales live in harmony, forming a continuum of activities with well-defined characteristics, responding to different market segments. At the artisanal level, the fact of carrying out the operations without the use of equipment makes the work difficult. The introduction of equipment at the medium scale improves the technical and economic efficiency of the process (Godjo, 2010). The Mawudagba Cooperative is one of Benin medium-scale enterprises. It specializes in cassava processing into gari. It is located in Lokossa, a commune in the south-west of Benin. Its annual processing capacity is 348.4 tons of cassava.

The cassava processing into gari requires a significant amount of energy. During the process, two sources of energy are used: a biomass energy (Janssen and al., 2012) made from the combustion offirewood for cooking the gari and a fossil (López-Gómez and al., 2021) energy consisting of gasoline to power the cassava root grating equipment. Unfortunately, access to those different forms of energy is difficult. In effect,in Benin, access to firewood is difficult because of measures against deforestation. In addition, the energy sector is experiencing major crises due to shortages of gas, oil and electricity (Akpassonou et al., 2022). Faced with the energy deficit, an alternative is to rely on the natural resources available to Benin to reduce its energy dependence. Regarding the cassava processing into gari within the Mawudagba Cooperative, the waste generated consists mainly of cassava peels and effluent. Although it is possible for the stakeholders of the Mawudagba Cooperative to sell part of the peels to breeders for cattle feed, the vast majority is left around the processing workshop with all the effluents thus generating nuisances in terms of health and the environment (carbon dioxide, methane, etc.).On human health, it has been widely proven that waste produces short, medium or long-term effects ranging from intoxication or asphyxia to chronic illness (asthma, hypersensitivity, etc.) or even carcinogenesis (Jaro and al., 2021). From an environmental point of view, it is undeniable today that waste has a strong polluting and harmful power for the components of ecosystems.

In view of the above, is it not imperative to make the Mawudagba Cooperative more competitive to recover energy from the waste within it in order to reduce its energy dependence and also the deposit of harmful and difficult to manage waste?To achieve that, this technical-economic and environmental study was carried out.

Cassava Processing Within The Mawudagba Cooperative

Within the Mawudagba Cooperative, the processing steps are described in Figure 1.

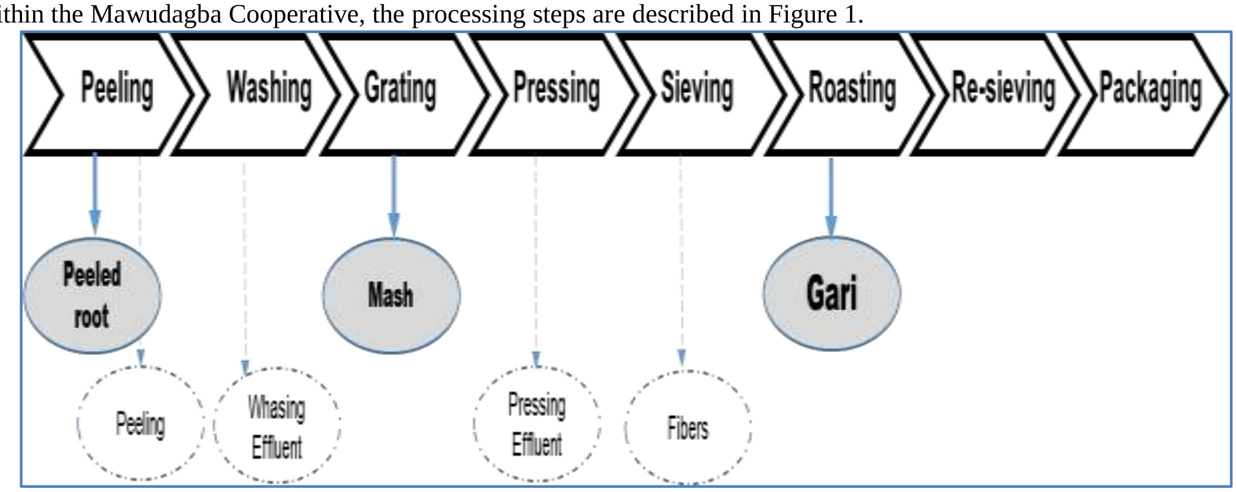

Figure 1:- Description of the sequential processing operations of cassava into gari.

The unit steps in this process are as follows: peel, washing, grating, pressing, sieving, garifying (toasting), re-sieving and packaging.Peeling is one of the most important unit operations. Its objective is to remove the periderm and cortex from the roots, so that the flesh obtained is as clean as possible. The technologies developed do not yet meet the needs of users because of the heterogeneous forms of the roots. Within the cooperative, this unit operation is performed entirely manually by operators simply using knives, which makes this unit operation restrictive in terms of productivity within this transformation process. The peel yield is about 68 % (Ajibola and al., 2016). The resultant peels are disposed into the environment without any form of treatment.The cyanide is reduced during cassava processing. The washing operation removes excess mud and sand and makes the roots clean. This operation requires a lot of water(Uchechukwu-Agua and al., 2015). It generates washing effluents. Within the cooperative, there is no waste water treatment or drainage. Sponges or scourers are used to wash the cassava clean, removing extra peel, spots, or dirt. This step of Garri processing is very important so that the quality of the final Garri is without sand.The need to grate cassava roots into mash is to remove some cyanide from the roots in the process. Within Mawudagba cooperative, two different types of cylindrical raspers, which have the ability to work in a continuous manner but differ in the rasping surface, are employed. The first type of rasper is with abrasive metal sheet and the second type is of rasper with serrated blades. Occasionally, the Cassava Mash obtained is is fermented to Remove Hydrocyanic Acid. The pressing operation consists in reducing the water content contained in the mash. Akosua and Bani (2007) reports that the losses that occur at the pressing stages in the processing of cassava into gari are 6.6%. Within the cooperative, the pressing stage is carried out by a mechanical twin-screw press. Comme dans l'étape de lavage, l'effluent de la presse, il n'y a pas de traitement ou d'évacuation des eaux usées. After draining the garri mash, the wet cake obtained is sifted. A sifter is used to remove the lumps and fibrous roots it contains. As waste, it results in fibrous debris.Finally, the cooking operation makes it possible to reduce the water content but also the rate of cyanidric acid contained in the gari(Izah et al., 2017).

Generally, cassava processing units generate large volumes of effluent, which contain highly lethal substances, affect biodiversity, human, animals, fauna and flora, and affect water and soil physicochemical parameters.Izah and al. (2018) reported that wastes from cassava processing can have adverse consequences on Human. Cyanide content could affect human. For Derek (1992), odour pollution may trigger unpleasant sensation which could have adverse physiological reactions and olfactory functions. He added that some of the adverse response associated with odour pollution include breathing and sleeping difficulty, coughing, stomach and loss of appetite, eye, nose and throat irritation, disturbance from external environment, annoyance etc. In point of view Socioeconomic Impacts, Odour from cassava processing mill has socioeconomic influence in the society. Izah and al. (2018) opined that odour from CME could worsen or down grade community pride especially in communities with high rate of cassava processing, interfere with human relation leading to unhealthy annoyance, discourage capital investment leading to slow growth in such community outside cassava processing.

Material And Methods:-

Study framework

This feasibility study for cassava peels energy recovery was carried out on the case of the Mawudagba cooperative. This cooperative is located in the South West of Benin, 110 km from the capital. The number of employees in the cooperative is 45 people including 41 women and 4 men. It is a predominantly female activity. The annual processing capacity is 348.4 tons of cassava. The processing activity is carried out on a semi-industrial scale with simple equipment, namely a grating machine for grating and a twin-screw mechanical press for pressing. The Mawudagba cooperative receives technical and financial support from Louvain Coopération, a Belgian international non-governmental organization.

Material:-

Peels generated from the process come "RB 89509" variety cassava roots processing.

(a) Cassava roots of variety "RB 89509" (b) Cassava peels

Figure2:- Cassava roots of the “RB 89509” variety (a) and its peels (b).

After the cassava is processed, the majority of the peels are dumped on the village garbage heaps, usually resulting in an environmental hazard to well-being. This is therefore harmful waste which can be recovered as essential energy and which can be obtained at zero or low cost. Kayiwa and al., (2021) revealed that averagely cassava peels have a moisture content ranging from 9.93 to 11.46%, volatile matter ranged from 77.93 to 81.93%, the ash content ranged from 1.93 to 4.36% indicating low mineral contents in the peels . For Sudaryanto and al., (2006), analysis on cassava peel from other studies show the compositions of cassava peel in weight percentages as; 11–12%, 58–62%, 28–30%, and 0.2–0.4% for moisture content, volatile matter, fixed carbon, and ash content respectively.

Methods:-

Energy needs analysis

The method for determining Energy needs consists in evaluating energy consumption, biomass potential and finally carrying out an Functional Analysis of need. This last onehelps to define the need and more specifically the expected service functions.

Energy consumption evaluation Method

The method used to assess the energy consumption of Mawudagba Cooperative based on energy consumption evaluation Methodology (Zhao et al., 2016) summarized as follows:

1. inventory all energy sources of Mawudagba Cooperative;
2. compute the instantaneous absorbed energy of each device, $\mathbf{W_i(t)}$
3. and the total consumed energies as

$$WT(t) = \sum_{i=0}^{n} W_i(t)$$

Biomass Potential Evaluation Méthod

The Evaluation of the Biomass Potential of the Mawudagba Cooperative is based of a Participant observation (Seim, 2021) of the cassava processing within the cooperative.The raw biomass potential is the total quantity of waste resulting from the transformation of cassava into gari. The Net Biomass Potential is the difference between the amount of Gross Biomass and the amount of waste sold by the Mawudagba Cooperative.

Evaluation of Recovered energy from Net Potential of cassava peels

Recovered energy from Net Potential of cassava peels is the energy contained in the biomass. It is given by :

$E_{\text{biomass}} = Mass_{biomasse} * PCI_{biomass}$

$$E(kJ) = M\_Biomass\ (kg) \times PCI\_Biomass\ (kj/kg)$$

Where Massbiomasse is the quantity of cassava peels (kg)

PCIbiomass is the cassava peelslower calorific value(kj/kg)

The Lower Calorific Value that we have used is taken from the previous work of Kapepula et al. (2014) who noted that dried cassava peelings with a moisture content of 12% have a lower calorific value of 18 MJ/kg.

Functional Analysis of need

The Functional Analysis of Need is a standardized tool (NF X 50-150) constituting the reference in Industrial Engineering. It makes it possible to express expectations in terms of Services rendered. The philosophy of the Functional Needs Analysis consists in "Avoiding any first solution", i.e. not having in mind a technical solution but having a certain number of functions expected by the users, to clearly define what the product expected must be able to meet the expectations of users, in particular with a priority mission (Godjo, 2006). The external functional analysis expresses the need in the form of service functions by reasoning functions and not solutions. These functions highlight the relationships between the product and its environment (Yannou, 1997). The Functional Specifications presents this modeling of the need in the form of a set of validated, characterized and prioritized functions. It also represents the commitment document of a project of which it constitutes the "contract" throughout the duration of the project.The internal Functional Analysis makes it possible to graphically represent the logical sequence of the technical functions necessary to carry out the main function of the external functional analysis. The technical function is an action internal to the product (between its constituents) defined by the designer, as part of a solution, to ensure the service functions. A service function corresponds to a chain of technical functions. The "Functional Analysis System Technic (FAST)" is a tool for defining technical functions.

Economic study method

The economic study method includes the determination of the defined profitability criteria, namely: the Net Present Value of the project, the mode of use of this criterion is as follows, the Payback period of the invested capital and the internal rate of return.

Net Present Value of the project

The Net Present Value of the project (NPV) is given by the following formula:

$$NPV = -I + \sum (revenue \times (P/A, i\%, n)) - \sum (Costs \times (P/A, i\%, n))$$

With, I : Initial cost ;

Σ costs: Sum of discounted expenses (operating, renewal, upkeep and maintenance costs) over the lifetime of the project.

Σ revenue: Sum of profits made on electricity and fuel consumption

n = Duration of the project,

P = Present value of an amount.

A = present value of an amount in year n.

(P/A, i%, n) = calculation coefficient of P knowing A at rate i over n years.

The mode of use of this criterion is as follows:

1. If the NPV > 0, the project is profitable;
2. If the NPV < 0, the project is rejected.

Payback period of invested capital
Payback period (PP) is the time it takes for project revenues to balance the amount of capital expenditures.

$$PP = \frac{\text{Amountofexpenses}}{\text{Revenueperyear}}$$

Internal rate of return
The internal rate of return (IRR) is the rate at which the present value of income is equal to the capital invested.
• If the IRR is higher than the cost of capital by 10%; the project is accepted.
• If the IRR is less than 10%, the project is rejected.

Environmental study method
The method developed by the IPCC (Smith and al., 2009)makes it possible to estimate methane emissions from waste for one year. The equation used to perform the calculation is as shown below:

Emission of methane from the landfill $E_{methane}$

$$E_{met\,hane} = [(MSWT \times MSWF \times L_0) - (MSWT \times MSWF \times L_0 \times R)] \times (1 - OX)$$

With, $E_{methane}$: Amount of methane emitted for the specific year (Gg/year);
MSWT: amount of waste generated for the specific year (Gg/year)
MSWF: fraction of waste deposited in the dump
L0: methane production potential (Gg CH4/Gg of waste)
R: captured fraction of methane (Gg/year)
OX: oxidation factor
Gg: metric tonne, given that the values in the waste characterization report are expressed in kg.
One tonne of methane has a warming power equivalent to 25 tonnes of CO2.

Emissions of oxidized methane $M_{oxidized}$

$$M_{oxidized} = [(MSWT \times MSWF \times L_0) - (MSWT \times MSWF \times L_0 \times R)] \times (OX)$$

$M_{oxidized}$: Emission of the fraction of methane produced by the landfill which oxidizes to give CO_2.

Emission of methane by decomposition of waste

$$CO2 = (MSWT \times MSWF \times L0)$$

Quantity of CO2 avoided by this anaerobic digestion project
Quantity of CO2 avoided by this anaerobic digestion project is calculated by:

$$C0_2\text{avoided} = M_{oxidized} + E_{methane} + CO2 - CO_2\text{emitted by the waste recovery system}$$

Carbon credit associated with the amount of CO2 avoided:

$$\text{Costs(FCFA)} = 10 \in \times 656 \times Q_{CO_2}\text{avoided per year} \times \text{project duration}$$

Results And Discussions:-

Energy Consumption Evaluation

The result of the Energy Consumption of the cooperative Mawudagba are presented in the Table 1.

Table 1:- Evaluation of Energy Consumption.

Energy inputs	Quantity used per year (Tons)	Energy supplied per year (MWh)	Energy consumed by the activity (MWh)	Yield (%)	Cost per year (F CFA)
Wood for cooking Gari	15.60	86.40	21.71	25	780 000
Fuel for Rasper operation	0.785	10.32	3.10	30	520 000

Firewood and fuel are the energy sources used by the cooperative to carry out its activities.Concerning gari cooking, the energy absorbed by the hearth is evaluated at 21.71 MWh. Regarding the Fuel for Rasper operation, the energy absorbed by the rapper equipment is evaluated at 3.10 MWh.

These results show that the firewood used for cooking gari is converted into gari cooking energy with a 25% energy efficiency. This performance is close to the results obtained by of Oluwole and al.(2005) and Akingbala and al.(2005) which respectively reported yields 24.9% and 29.9%.The low yield is due to the fireplace used which generates a lot of energy loss. Unfortunately, the Mawudagba cooperative, like most cassava-to-gari processing units in Benin, only uses firewood as an energy source for cooking gari. This practice causes environmental nuisances. Aware of the level of destruction of forest cover caused by this practice, improved stoves have been set up for the benefit of cassava processing cooperatives. However, all these technologies introduced could not help the cooperatives to reduce energy losses from the consumption of firewood for cooking gari. Furthermore, table 1 indicates that the quantity of wood used per year exceeds 15 tons. This quantity is high in terms of destruction of the forest cover.In terms of expenses, this is equivalent to 780,000 CFA francs. This amount seems to be high to allow famers to make a profit.As for fuel, the expenses related to the operation of the Râpeuse amount to 520,000 CFA francs per year.Faced with these problems, it is important to promote new energy-saving technologies within the processing units of cooperatives in the adoption of another cooking system, in order to reduce the cutting of firewood and protect forest cover. Also, support for cooperatives for the economic profitability and sustainability of their activities in connection with environmental protection is important.

Biomass Potential Evaluation of the Mawudagba Cooperative

Participant observation of the activity of processing cassava into gari with the Mawudagba cooperative allowed us to represent the mass balance of the product and derivatives resulting from the processing of cassava in Figure **3.**

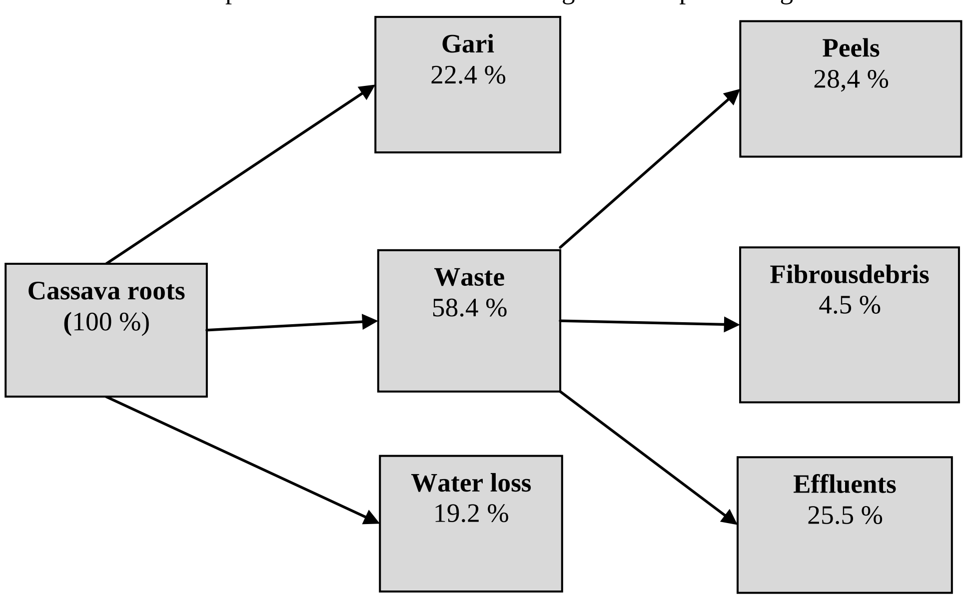

Figure 3:- Mass balance of cassava into gari within the Mawudagba cooperative.

As shown in Figure 3, the waste resulting from the cassava processing into gari, within the Mawudagba cooperative, represents 58,4% of the mass of cassava roots. They consist of peels (representing 28.4% of the mass of cassava roots), fibrous debris (4.5%) and effluents (25.5%).Ozoegwu et al. (2017),reported similar proportions. For Elijah and al. (2014), several wastes by-products are derived including cassava peels (21.8%), cassava mill effluents (16.2%), fibrous debris (7.5 %) and air emission (19.8%). In Benin as in many subsahara countries, those by-products are discharged into the ecosystem without treatment.The average quantities of cassava processed per day and per year by the Mawudagba Cooperative are respectively 1.34 T and 348.4 T. In addition, the cassava peels from this processing per day and per year are respectively 0.38 kg and 98.95T. Concerning cassava effluents from the processing of cassava into gari, they amount to 0.34 kg per day and 88.842 T per year.

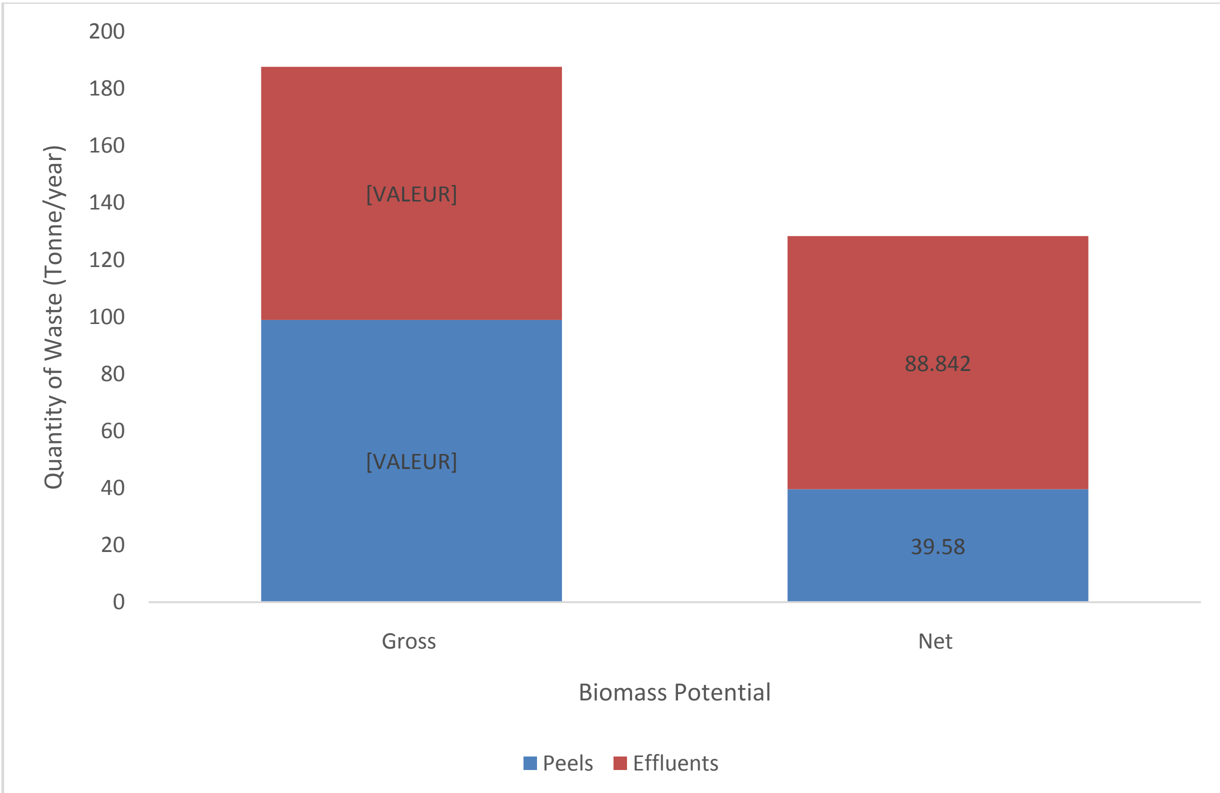

Figure 4:- Evaluated Biomass Potential per year within Mawudagba Cooperative.

Based on the waste resulting from processing and the quantity of cassava peels sold, which represents 40% of the cassava peels generated by the cooperative, the estimated Gross Biomass Potential amounts to 187.792 T per year including 98.95 T of peels and 88.842 T of effluents. The Net Potential meanwhile amounts to 128.422 T per year including 39.58 T of peels and 88.842 T of effluents.

Possibilities and analysis of energy recovery from cassava waste within the Mawudagba Cooperative

Possibilities of energy recovery from cassava waste

The Cassava peels can be recovered into useful forms of energy using a number of different processes. Factors that inffluence the choice of conversion process are: the type and quantity of biomass feedstock; the desired form of the energy,i.e. end-use requirements; environmental standards; economic conditions; and project specific factors (McKendry, 2002). The cassava waste recovery possibilities are presented in Table 2.

Table 2:- Possibilities of energy recovery from cassava waste.

Biomass	**Recovery Processes**					
	Biochemical	**Thermochemical**				
	Anaerobic digestion	Comb-ustion	Carboni-zation	Pyrolysis	Pyro-Gasification	Gasification
Liquid Waste : Effluent	**Biogaz**(heat, electricity, biofuel) **Digestate** (Fertization)					
Solid Waste : Cassava Peels + Fibrous	**Biogaz**(heat, electricity, biofuel) **Digestate**(Fertization)	**Steam**(Heat, Electricity) **Heat**	**Charcoal**(Heat)	**Gas**(heat, electricity) **Oil**(brake oil, paint, varnish,	**Syngas** (heat, electricity,biofuel) **Biochar**(activated carbon, soil fertilization fertilizer, Heat)	**Syngas** (heat, electricity,biofuel **Ash**(hydraulic and bituminous concrete, fertilization,

by-products from crushing and sieving				electrical insulation, biofuel, etc **Biochar** (activated carbon, soil fertilization fertilizer, Heat)	**Ash**(hydraulic and bituminous concrete, fertilization, pottery) **BioHydrogen**ization	pottery) **BioHydrogen**ization

We distinguish two categories of waste. The first category includes liquid waste called effluents which consist of wastewater from the operation of washing the peeled cassava roots and the liquids from the pressing of the cassava pulp obtained after the rapping of the cassava roots. Considering the level of technology scale in the sub-Saharan countries, two main ways are used for the recovery of waste from cassava processing: the biochemical way and the thermochemical way. The thermochemical wayincludes several processes based on the cracking of biomolecules under the effect of heat. (Couhert and al., 2009). These are combustion, carbonization, pyrolysis (Godjo et al., 2015), pyro-gasification andgasification (Rajvanshi, 2014). The combustion of cassava peels makes it possible to obtain Steam usedas Heat(Bantacut and Romli, 2020)or Electricity. Carbonization of cassava peels and Fibrous by-products often remained in the biochar production process (Tippayawong and al., 2017). Valorization of cassava peels by pyrolysis makes it possible to obtain Pyrolysis Gas used as heat or Electricity, Pyrolysis Oil (Ki and al, 2013) used as brake oil in aeronautics (Ağbulut and al. 2021), paint and varnish (Guilhaume and al. 2021), electrical insulation (An-Xin and al., 2013), tiles (Jungmeier, 2017) and biofuel (Okekunle and al., 2016). Biochar is also obtained from the pyrolysis of cassava peels. Biochar is used for such as for the production of activated carbon, combustion and soil fertilization (Co and al., 2012). Pyrogasification (Okoro and l., 2022) is at the crossroads between pyrolysis and gasification. The products obtained are syngas and biochar. The syngas used as heat, electricity and biofuel. Andika and al. (2020) reported the gasification of cassava peels. This process makes it possible to obtain syngas and recoverable ashes in hydraulic concrete (Anagonou et al., 2020a) and in bituminous concrete (Anagonou and al., 2020b).The biochemical pathway consists of anaerobic digestion processes. Effluents can be biochemically recovered. Biogas is obtained there which is used as heat, electricity or biofuel and Digestate used as fertilizer for soil regeneration.Cassava Peels and Fibrous by-products from crushing and sieving can be recovered by Anaerobic digestion and by al Thermochemical pathway. Cassava Peels and Fibrous by-products biodigestion makes it possible to obtain Biogaz that cbe used asheat, electricity or biofuel and Digestate which is a very good soil fertilizer. Nevertheless, Ubalua (2007) pointed out that utilization of the peel is limited by its low digestibility and toxicity from extremely high levels of hydrocyanic acid. Fermentation not only reduces toxicity, but the enzyme-resistant lingo-cellulose material is converted into a more digestible substrate.A Comparative Study of Biogas Production from Anaerobic Bio-Digestion of Peels and Effluents from Cassava Processing Factories in southern Benin (Tchanou and Godjo, 2022)showed that the bio-digestion of cassava effluents can be considered as the best system to imprive the production of biogas between the two biomass wastes from cassava processing in southern Benin.

Analysis of Possibilities of energy recovery from cassava waste

With regard to the recovery possibilities presented above, it appears thatCassava Peels andibrous by-products from crushing and sievingoffer more opportunities for recovery than effluents.Indeed, effluents can only be recovered by the methanation process.By the process of methanation, it is necessary to pre-treat the peels in order to reduce their size to facilitate the digestion process. This would require the purchase of a mechanical crusher which entails additional expenses. Moreover, biomethanation does not make it possible to obtain biochar as the end product. The option of selecting an anaerobic digestion process is therefore excluded from the analysis. By proceeding through combustion, we obtain heat and electricity. Since gasification does not produce biochar, the final choice of process would be either pyrolysis or pyrogasification. From the final product point of view, it appears that pyrogasification offers more possibilities for final products.In short, Pyrogasification appears to be the appropriate process for the valorization of cassava peels for cooking gari. Indeed, the use of this type of process does not require enough pre-treatment of the waste.In order to retain a recovery technology taking into account not only the possibilities of energy recovery from cassava waste but also the users expectations, brinstomings with them made it possible to draw up the functional specifications of the device enabling cassava peels to be converted into energy within the Mawudagba Cooperative.

Technical feasibility analysis

The envisaged application for the syngas obtained is the production of thermal energy by direct combustion for the cooking of gari and by combustion in a gas thermal engine for the cassava grater.The envisioned supplied energy from cassava peelings amounts to 197.9 MWh per year. Referring to the work of Kapepula et al. (2014), the PCI of the syngas obtained by the valorization of cassava peelings is estimated at 6.2 MJ/kg. The gross energy of the syngas in our case is then evaluated at 245,396 MJ per year or 68.17 MWh per year. The share of energy losses by combustion in the pyrogasifier gas furnace is estimated at 40% of the energy of the syngas obtained.Therefore for cooking with syngas, the net energy that can be obtained amounts to approximately 40.9 MWh per year. The activity of cooking gari requires 21.71 MWh per year, so the recovery of cassava peelings by pyrogasification therefore makes it possible to fully meet the thermal energy demand of the cooperative for cooking gari. The residual thermal energy amounts to 18.9 MWh corresponding to 32 MWh of syngas energy upstream of the gas fire. This energy would then be used in a heat engine to meet the energy demand upstream of the cassava grator, estimated at 10.32 MWh. Thus, the final residual energy of the syngas amounts to 21.5 MWh. The graph in figure 5 summarizes the energy profit of the project constituted by the pyrogasification unit.

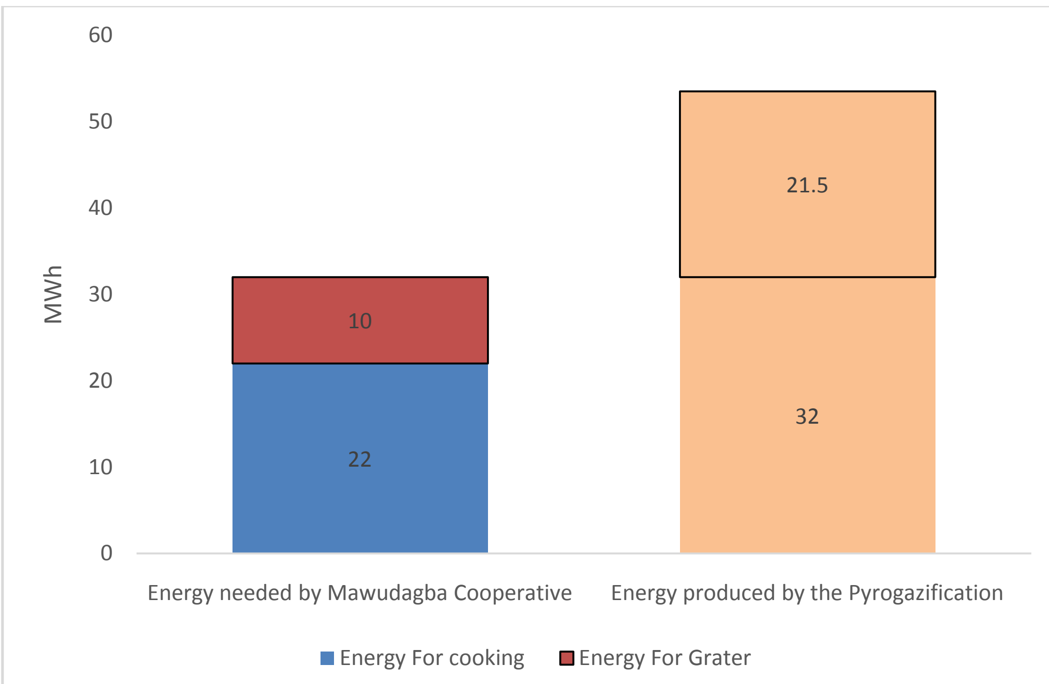

Figure 5:- Energy benefit of the project.

From this graph, we see that the energy recovery of waste peelings within the Mawudagba Cooperative makes it possible to provide all the energy necessary for cooking (22 MWh) and that for feeding the cassava grator (10 MWh). In sum,the project will reduce to 0 MWh the equivalent annual thermal energy consumption for cooking gari and that of the motorized grater of the Mawudagba Cooperative. The residual syngas energy after the energy satisfaction of the cooperative amounts to 21.5 MWh per year. This energy can be used for other purposes.

Functional Specifications of Mawudagba Cooperative Needs

The Functional Specifications of Mawudagba Cooperative Needs, in terms of energy recovery from cassava peels, is presented in Table 3.

Table3:- Functional Specifications of Mawudagba Cooperative Needs.

Functions	Criteria	Levels	Flexibility
FP1: The device must transform	Relative humidity of peels	≤ 12 %	

cassava peels into gas and biochars	% Gas mass	≥ 45 %	
	Lower Calorific Value of Gas	> 4 MJ/kg	
	% Mass of biochar	≥ 8%	
	Lower Calorific Value of biochar	28,1 MJ/kg	±10%
	Operating temperature	300°C à 900°C	
	Operating mode	Continued	
	Reactor dimensions	Ø500 x 1000	
	Hourly capacity	10 kg/h	±5%
FC2: The device must be handled by an operator	Thermal insulator	Clay	
	Height of the hopper above the ground	1,5m	
FC3: The device must comply with the standards (environmental, agri-food and safety)	No smoke emission		
	Reduction of health nuisance (odors from wet peels)		
FS4: The device must be purchasable by processors	Design cost	≤ 600 000 F	
FS5: The device must be reproduced by a local manufacturer	Availability of technicality	Local	
	Availability of materials	Local	
FS6: Device must be maintained locally	Periodicity of preventive maintenance	1 time per trimester	

The functional analysis defined six service functions including one main (FP1), two constraints (FC2 and FC3) and three secondary (FS4, FS5 and FS6). The various criteria used to assess the functions and their levels have been defined. As pointed out by Rivier (2017) and Boroze (2011), equipment intended for use in countries in Sub-Saharan Africa generally has a service function because it is simple equipment. The price must be low to allow low-income users in these countries to be able to buy.

This functional specification represents the characteristics of future equipment.

Functional block diagram of the device to be designed

The FAST diagram corresponding to the device to be developed is presented in figure 5. In this figure, the first column (on the left hand side) corresponds to principal service function defined in the Functional Specifications. The deployment of the analysis system technic around the service function made it possible to identify various technical functions presented broken down into three levels (three columns). At the end of this deployment, the technical solutions representing the functional entities of the device emerged. It is a reactor, burner, grate, blower, outer cylinder, thermal insulation and air duct.

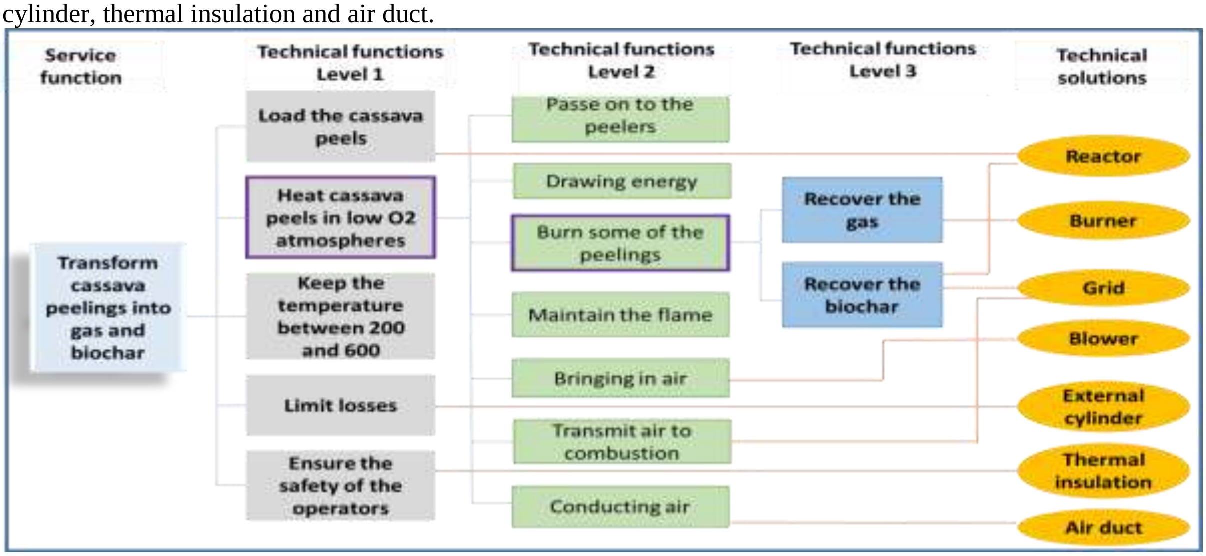

Figure 6.:- FAST diagram obtained for device to be designed.

The model of the device shown in Figure 5 is a fixed-bed, countercurrent pyrogasifier. The solid fuel (cassava peels) is introduced into the reactor to then be burned at the top of the bed surface. The air required for the conversion process is introduced into the lower part of the reactor through the air line. This air passes through the grate and crosses the entire biomass bed to the combustion zone. The gas produced is channeled to the burner. The air blower (0.24 A, 12 V) supplies the reaction with air, thus improving the combustion of the gas produced and raising the gas to the burner. Biochars are collected from the grid.

Economic study
Economic indicators are presented in Table 4.

Table4:- Economic indicators of the study.

		Period Duration	Annual Value (FCFA/year)	Present Value (FCFA)
I	Initial investment			3 690 000
II	Operating cost discounted over 15 years	15 years	17 627	160 000,00
IV	Revenue cost discounted over 15 years before tax	15 years	2 230 000	20 241 710
	Straight line depreciation		385000	
	Taxable income		1 845 000	
	Taxes paid		608 850	
	Cost revenue after tax		1 621 150	14 715 178,55
	Net Present Value of the project (NPV)			10 865 178,55
	Payback period (PP)			2,374857354
	Internal rate of return (IRR)			38%
	TRE			35%
	IR			3,822124299

As shown in Table 4, the economic study noted that the initial investment cost for this energy recovery study amounts to 3,690,000 FCFA. The operating cost is estimated at 17,627 FCFA per year. We deduce that the cost of processing one ton of waste is 445 FCFA per year. The recovery will save, after tax, 1,621,150 FCFA per year. The Capital Recovery Duration Invested is 2.37 years, i.e. a duration of approximately 2 years 4 months 13 days.
From the results obtained, we can conclude that the project is very profitable because the discounted savings it generates after tax, which amounts to 14,715,178.55 FCFA during the life of the project, exceeds the initial investment (3,690,000 FCFA) and the updated operating cost (160,000.00 FCFA) of the project. The Net Present Value amounting to approximately 10,865,178.55 FCFA being greater than zero confirms the profitability of the project. The internal and external rate of return estimated at 38% and 35% respectively are higher than the discount rate of 10%. These economic indications of the project prove that the project is profitable and economically feasible.

Environmental Study
Table 5 presents the results of the environmental study.

Table5:- Methane emissions from the landfill.

	Unité	Valeur
Waste produced	ton/year	187, 792
Deposited in the dump	ton/year	128,42
L0		74
R	-	0
OX	-	0,36
MSW_T	ton/year	187,792
MSW_F	ton/year	0,68
Direct emission from the dump		
CO2 Emissions	$tonCO_2$	69,45
Emission by methane oxidation		
CO2 Emissions	$tonCO_2$	4,3

Emission by waste decomposition		
CO2 Emissions	$tonCO_2$	11,94
Emission from the reactor facility		
CO2 Emissions	$tonCO_2$	60,5

The recovery of cassava waste in the pyrogasification unit leads to a reduction in the quantity of waste that can decompose to produce greenhouse gases. The results of the environmental study (Table 5) show that the amount of waste generated (MSW_T) within the cooperative amounts to 187.792 tons per year and that the amount of net waste represents approximately 68% of the amount of waste generated. This waste generates methane emissions due to the dump itself, to the oxidation of the methane produced by the waste and to the decomposition of the waste, which amount respectively to 69.45 tonnes of CO_2 per 4.3 tonnes of CO_2 per year and 11.94 tonnes of CO_2 per year. In addition, the pyrogasification unit produces an emission of around 60.5 tonnes of CO_2 per year.

The amount of CO2 avoided by this anaerobic digestion project per year using formula (7) is:

$$C0_2\text{avoided} = 25{,}19\ \text{tonnes/year}.$$

This quantity of CO_2 avoided could constitute a Clean Development Mechanism (CDM) project and could therefore be a carbon credit that can be sold on the Kyoto market. It would cost: 1,637,522.264 FCFA, which will allow project financing of 44.38% of the initial investment.

Conclusion:-

This study shows that it is possible to recover energy from waste peels resulting from cassava processing into gari within the Mawudagba cooperative.This energy recovery will make it possible to fully supply the energy needed for cooking gari and gasoline supply to grating equipment within Mawudagba Cooperative with a Energy benefit amounts to 21.5 MWh per year.

From the economic study, the financial indicators are very favorable for the project, which proves its economic feasibility. In terms of the environment, this project has made it possible to reduce GHGs as well as odors and nuisances generated by waste on the environment. Thus an emission of 25.19 tonnes C0_2 is avoided on average each year.

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