Journal Homepage: -www.journalijar.com

INTERNATIONAL JOURNAL OF ADVANCED RESEARCH (IJAR)

Article DOI: 10.21474/IJAR01/16070
DOI URL: http://dx.doi.org/10.21474/IJAR01/16070

RESEARCH ARTICLE

AN ANALYSIS OF THE USE OF BIOCHAR TECHNOLOGY IN BENIN

Thierry Godjo, Raoul Comlan Tossou and Mintodê Nicodème Atchadé
Laboratoire des Sciences de l'Ingénieur et de Mathématiques Appliquées, Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques, B.P. 2282 Goho, Abomey, Bénin.

Manuscript Info

Manuscript History
Received: 25 November 2022
Final Accepted: 27 December 2022
Published: January 2023

Keywords:-
Renewable Energy, Biomass, Biochar, Multiple Correspondence Analysis, Multinomial Logistic Regression Model, Benin

Abstract

Fossil fuels are the primary sources of energy used in the world. They are polluting and detrimental to the environment. To meet this challenge, renewable energies with a better environmental footprint and that are inexhaustible have been developed. This is the case with biochar, an intriguing alternative to the unsustainable use of traditional energy (firewood, charcoal, and natural gas) in developing nations. Biochar is a clean and sustainable energy source. Unfortunately, this technology needs to be used more in Benin. In order to understand the low level of use of biochar in Benin, this research was carried out. A semi-directive survey of Benin's biochar producers and consumers was conducted as the first step in the approach used to identify and analyze the factors that influence the adoption of biochar. The purposive sampling technique was used to select three towns in Benin republic with large populations and where biochar factories are located (Porto-Novo, Cotonou, and Abomey-Calavi). In the second step, the manufacturing process of biochars was analyzed. The findings showed that 56% of surveyed households had adopted biochar compared to 44% who had not. Low ignition and combustion, crumbling, and late delivery of biochars are factors in the need for more adoption. The reasons for the non-adoption are low ignition and combustion, crumbling, and late delivery of biochars.

Introduction:-

Fossil fuels are the primary energy used in the world to meet the ever-increasing demand for energy (Kumar et al., 2021). Unfortunately, these energies are depleted daily, and their costs fluctuate continuously due to geopolitical issues (Aberilla et al., 2019). In addition, they are cited as responsible for socio-environmental problems: air pollution, global warming, health impacts, worsening of respiratory conditions, and exacerbation of cardiovascular conditions (Li et al., 2017; Lott et al., 2017). Indeed, burning fossil fuels produces significant harmful greenhouse gases, including carbon dioxide (CO2), sulfur dioxide (SO2), nitrogen oxides (NOx), and other particulates (Karmaker et al., 2020). The concentration of CO_2 in the upper atmosphere is cited as the leading cause of the greenhouse effect and the rise in atmospheric temperature (Aba et al., 2017), causes of global climate change with its adverse effects on resources. Water, agriculture, health, and increased natural disasters (tropical cyclones, typhoons, hurricanes, and tornadoes) are indicators (Nicholls & Cazenave, 2010). These greenhouse gases contribute

Corresponding Author:- Thierry Godjo
Address**:-** Laboratoire des Sciences de l'Ingénieur et de Mathématiques Appliquées, Université Nationale des Sciences, Technologies, Ingénierie et Mathématiques, B.P. 2282 Goho, Abomey, Bénin.

to the destruction of the ozone layer and expose humans to ultraviolet (UV) radiation. UV exposure is associated with damage to the eye's cornea, lens, retina, and skin cancer (Aba et al., 2017).

Globally, 41% of households depend on solid fuels (wood and charcoal) for cooking and heating (Amegah et al., 2020). Wood energy is mainly used in developing countries with inefficient conversion technologies (Mugabi & Kisakye, 2020), which leads to deforestation, pollution, a threat to human health, and climate change (Mbamala, 2019). Large-scale charcoal production and use due to its low cost and high rates of population growth and urbanization remain a growing concern due to the threat of deforestation, land degradation, and climate change (Mekonnen et al., 2018; Zulu & Richardson, 2013). Traditional charcoal production processes lead to high CH_4 and CO_2 emissions with low yields, around 16% (Lohri et al., 2016).

More than half of the biomass produced annually is directly burned in agriculture. Kang et al. (2018) reported that in 2010, about 280 million tons of agricultural waste out of the 711 million collectibles in China was burned in the fields, causing severe problems of energy loss and contamination of the water. Apart from being burned without heat recovery, these residues are also left to rot, emitting greenhouse gases (GHG) (Dasappa, 2011).

Renewable energies with a better and inexhaustible environmental footprint have been developed to meet all these challenges. This is the case with biochar, clean and sustainable energy about current and future socio-economic and environmental needs. It is identified as a plausible and close alternative to commonly used fuels such as charcoal and firewood, whose prices are rising due to dwindling natural wood resources (Mugabi & Kisakye, 2020). Bonsu et al. (2020) observed that biochars produced from palm kernel shells are clean fuels and less expensive to produce. Biochar technology uses biomass residues generated as waste from the commercial, agricultural, and industrial forestry sectors (Njenga et al., 2009). The growing interest in converting biomass into fuels is its ability to reduce reliance on fossil fuels, its carbon-neutral effect on the atmosphere, and its less toxic nature to the environment (Zhang et al., 2018). Indeed, the CO_2 released during its combustion corresponds to the quantity of CO_2 absorbed by photosynthesis for plant growth (Missaoui, 2018). In addition, the low sulfur and nitrogen content of biomass reduces the emission of gaseous pollutants (García et al., 2014a; 2014b; Saqib et al., 2017). The conversion process, based on the thermochemical decomposition of biomass in an anaerobic or slightly oxygenated environment at temperatures between 300 and 500°C, eliminates volatile matter (Bustos-Vanegas et al., 2019). The efficiency of the process can go up to 30% when operating at low temperatures with a long residence time (Bridgwater & Peacocke, 2000; Czernik & Bridgwater, 2004). Biochars have a high density (729 to 986 kg/m3) and compressive strength (8.32MPa maximum) (Aransiola et al., 2019); they are flammable and do not emit smoke, therefore non-polluting with a high calorific value (24.9MJ/kg, Akogo, 2021). The thermochemical process of upgrading biomass into biochar is a valuable and feasible way to reduce the emission of pollutants (Li et al., 2017). To Ajimotokan et al. (2019), biochars are renewable energy and have low moisture (5-10%and ash (1.4-6%), compared to other solid fuels, making them economical and allowing them to offer much higher boiling efficiency. Their combustion is uniform compared to that of coal. Biochars are usually produced close to consumers to avoid long-distance transport constraints (Sharma et al., 2015).

In view of the above, why are biochars validated by research and developed are not used enough to replace traditional energies in households? To answer this question, we conducted this study with the objective to contribute to the sustainable development of biochar technology in Benin through surveys of producers and users of biochar.

State of the Art

Biochar

It is difficult to separate biochar from biocharcoal. Biochar is densified biochar (Nanda, 2018). Biochar is the char freed of impurities after one of the thermochemical decompositions of carbonization, pyrolysis, and pyrogasification (Couhert et al., 2009). Carbonization is a slow decomposition that occurs at temperatures between 300 and 500°C (Bustos-Vanegas et al., 2019) and mainly leads to char. The latter is often called coal because it does not undergo or is not obliged to transform (densification) before being used. Also, it is often not called biochar or biochar when it comes from carbonization because this thermochemical process does not necessarily contribute to neutralizing all impurities. Pyrogasification consists of a biomass conversion in the presence of a reactive agent (air, oxygen, water vapor, or a mixture of these gases) (Radanielina, 2018) at temperatures between 550 and 1600°C in syngas. The syngas obtained results from the oxidation of the char, oil, and gas fractions formed during the pyrolysis phase. When it is free of any impurity, the char resulting from pyrolysis and pyrogasification is called biochar, and char in the opposite case. This is why several authors, such as Lehmann et al. (2012) and Weber et al. (2018), advocated pyrolysis or pyrogasification as a technique for the thermochemical conversion of biomasses into biochars. Indeed, under a limited supply of oxygen (O2) and at temperatures approaching 700°C, the thermal decomposition of organic matter is complete with a carbon-rich and non-toxic char (Godjo & al, 2022).

During the production of biochar, after the thermochemical decomposition, the resulting biochar undergoes a series of transformations, as shown in Figure 1 below. This is the grinding into fine particles of a size of 0.1 to 0.3 mm (Kang et al., 2018). The ground biochar is mixed with water and binder. It is generally used as a binder in cassava starch in proportions of 8-12% (Godjo, 2017) or very rarely pyrolysis oil in proportions of 6% (Riva et al., 2021). The homogeneous mixture obtained is introduced into a press to be densified. The briquettes produced are dried (in the oven or the sun) to reduce their moisture content to less than 8% or 2.2–15.9% according to the SNI 016235-2000 and ISO 17225 standards, respectively (Ifa et al., 2020).

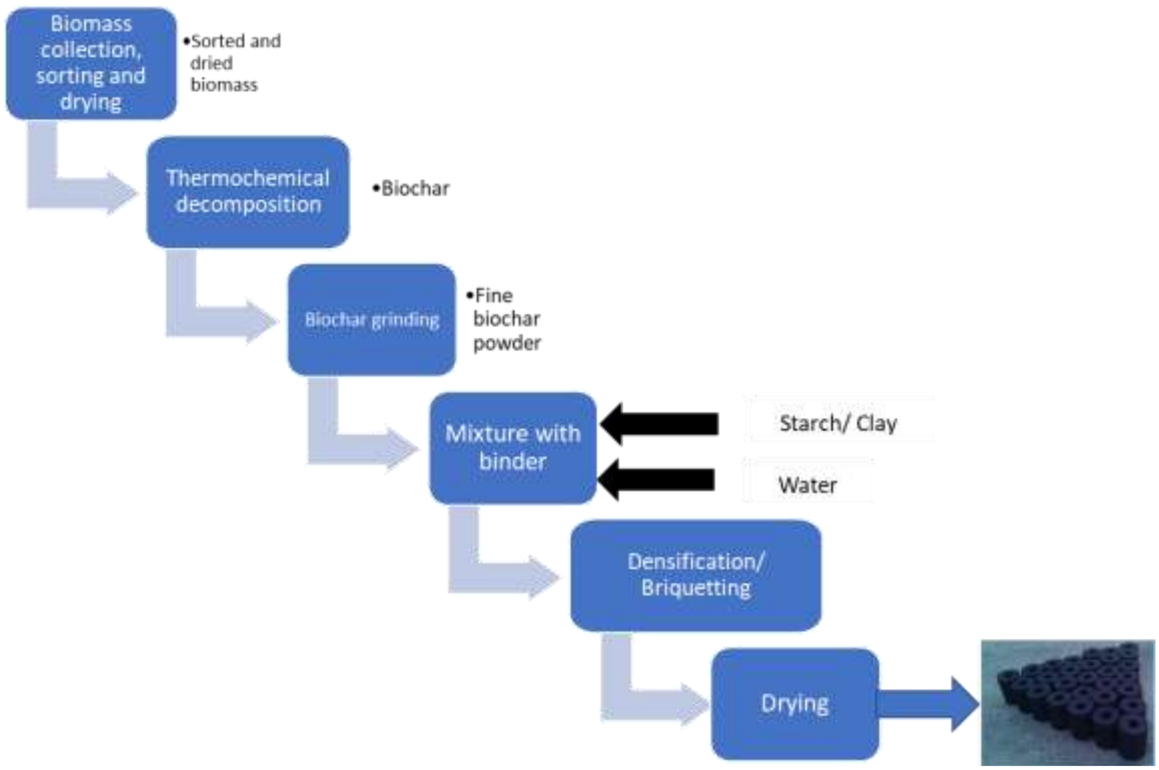

Figure 1:- Biocharcoalproduction diagram.

Composition, characteristics, and physicochemical properties of biochar

The biochar composition is related to the biochar from which it is derived. Biochar is composed of organic (C, H, O, N, S) and inorganic (Si, K, P, Ca, Na, Mg) elements (Radanielina, 2018). This elemental composition depends on the biomass and the conditions (temperature, residence time, etc.) in which the thermochemical process occurs. However, carbon remains the main element. In addition to the elemental composition, biochar has several physicochemical characteristics, including moisture, volatile matter, fixed carbon, and ash.

Moisture content is defined as the ratio of moisture to dry weight of solid fuel; the quality of biochar depends on its moisture content. Indeed, part of the energy is used for water evaporation to the detriment of the calorific value of biochar (Aina et al., 2009). Ash is the constituent obtained after heating to a constant weight of solid fuel (Ifa et al., 2020). It decreases the calorific value of the fuel (Missaoui, 2018) and increases the resistance to heat transfer (García et al., 2014a; Smith et al., 2016). This is the reason why the standard requires an ash content of less than 7% for biofuels (Ifa et al., 2020). The volatile matter fraction represents the share of combustible (CxHy, CO, and H2) or non-combustible (CO2, SO2, NOx, H2O, and SO3) organic and inorganic components released during heat treatment under an inert atmosphere at high temperatures solid fuel (García et al., 2014b). A solid fuel with a high volatile matter fraction reduces combustion efficiency and increases the emission of pollutants (Liu et al., 2013; Smith et al., 2016). However, the volatile matter composition of biochars facilitates their flammability (Ifa et al., 2020). As for the fixed carbon rate is the fraction remaining after the volatile matter is wholly released, except humidity and ash (García et al., 2014b). A high fixed carbon content would improve the calorific value of biochar (Ifa et al., 2020). The calorific value, expressed in MJ.kg-1, represents the net enthalpy released during the reaction of solid fuel with oxygen under isothermal conditions (Missaoui, 2018). It is a significant property because it represents the energy contained in biochar (Aina et al., 2009). Table 1 presents the immediate analysis of biochars from different types of biomass with their calorific value. The humidity rate varies from 4 to 12%, the ashing rate from 2.48 to less than 18.5%, the volatile matter rate from 17 to nearly 80%, the fixed carbon rate from 5 to less than 73%, and the calorific value varies from 10.30 to 29.6 MJ/kg. Let's recall that biochars from cashew nut shells and cotton stalks have a higher calorific value than charcoal.

Finally, biochar is assessed based on its physical and mechanical properties, such as density, densification rate, impact resistance, and resistance to water penetration, allowing the handling and transport of biochar briquettes (Godjo, 2017). Impact resistance is used to determine the hardness of biochars. Water penetration resistance, measured as a percentage, represents the amount of water absorbed when the fuel is immersed. The densification rate represents the ratio of the difference between the density of the briquette and that of the biochar about the latter's density.

Material and Methods:-

Areas Studied

The study was conducted in Porto-Novo, Cotonou, and Abomey-Calavi in Benin. Porto-Novo is the country's administrative capital, Cotonou is the economic capital and the main commercial center of the country, and Abomey-Calavi is one of the biggest Beninese cities with an estimated population density of 1010 per/km². These cities were chosen because of their high population density, which leads to high charcoal consumption. In addition, these cities have more biochar consumers than other regions of the country. Finally, the producers still in operation are in Abomey-Calavi and Porto-Novo.

Material:-

Data collection material

The survey was conducted through two semi-structured questionnaires:

1. Questionnaire targeting the Biochar producers: production, industrialization, Difficulties, Constraints, and Producers' Expectations
2. Questionnaire targeting the Biochar users: Use, Difficulties, Constraints, and Expectations of Direct Users"

Data analysis material

R software and Excel 2016 were used to process and analyze the survey data. We used methods such as descriptive analysis, multiple correspondence analysis (MCA), and multinomial logistic regression. The MCA has been implemented to study the association between the qualitative variables. The logistic model was computed to identify the factors influencing the adoption of biochar.

Methods:-

Sampling and Data Collection

The snowball method was used to identify producers and direct and indirect users of biochar, as they are very few and difficult to find. In total, 03 producers and 27 direct users were identified. The survey was conducted through two semi-structured questionnaires developed, tested, and administered to these three categories of actors in person and by telephone: the first one for the producers on "Biochar production in Benin: Industrialization and Difficulties, Constraints and Expectations of the Producers"; the second for direct users on "Use of Biochar in Benin: Difficulties, Constraints, and Expectations of Direct Users."

Multiple Correspondence Analysis

The MCA is usedtovisualisethedatasetintermsofdependencybetween rows objects. The MCA analyzes a set of observations described by a set of nominal variables. Each nominal variable comprises several levels, and each is coded as a binary variable. Technically, MCA is obtained using a standard correspondence analysis on an indicator matrix (i.e., a matrix whose entries are 0 or 1). Corrections must be made to the explained variance percentages, and the correspondence analysis's interpretation of interpoint distances must be appropriate.

Be a set of Knominal variables; each nominal variable has $J_k$levels, and the sum of the $J_k$is equal to$J$. There are Iobservations. Let us denote X the $I \times J$indicator matrix. Performing the correspondence analysis on the indicator matrix will provide two sets of factor scores: one for the rows and one for the columns. These factor scores are generally scaled so that their variance equals their corresponding eigenvalue (Abdi et al., 2014).

The total of the table is noted as N, and the first step of the analysis is to compute the probability matrix $Z = N^{-1}X$. We denote ***r***the vector of the row totals of $\boldsymbol{Z}$ (i.e., $r = ZI$, with **1** being a conformable vector of 1's); cthe vector of the totals of the columns, and $D_c = diag\{c\}$, $D_r = diag\{r\}$. The factor scores are obtained from the following singular value decomposition:

$$D_r^{-\frac{1}{2}}(Z - rc^T X)D_c^{-\frac{1}{2}} = P\Delta Q^T \qquad (1)$$

$\Delta$is the diagonal matrix of the singular values, and Δ^2 is the matrix of the eigenvalues.

Logistic regression

In order to establish the theoretical framework for logistic multinomial regression, we will begin by formulating the model, estimating its parameters, and testing its goodness of fit.

Let $X_1, X_2, \dots, X_n$be a set of variables observed, and let us consider *n*observations of such variables that will be resumed in the matrix$X = x_{ij}{}_{(n \times p)}$.

Be Ya variable with $m$modalities$u_1, u_2, \dots, u_m$. For $k\in$ {2, · · ·, m} let us notify that $p_1(x) = 1 - \sum_{k=2}^{m} p_k(x)$ such that $p_k(x)$is the probability that $Y = u_k$given that $(X_1, \dots, X_p) = (x_1, \dots, x_p)$, and $p_1(x)$the probabilitythat $Y = u_1$given that$(X_1, \dots, X_p) = (x_1, \dots, x_p)$. For $k\in$ {2,…,m}, we have:

$$log\left(\frac{p_k(x)}{p_1(x)}\right) = \beta_0{}^{(k)} + \beta_1{}^{(k)}x_1 + \cdots + \beta_p{}^{(k)}x_p \qquad (2)$$

Thus, we have

$$p_k(x) = \frac{exp\left(\beta_0{}^{(k)} + \beta_1{}^{(k)}x_1 + \cdots + \beta_p{}^{(k)}x_p\right)}{1 + \exp(\beta_0{}^{(k)} + \beta_1{}^{(k)}x_1 + \cdots + \beta_p{}^{(k)}x_p)} \qquad (3)$$

The parameters are obtained by maximum likelihood estimation. In our study, the variable of interest is biochar users' perceptions. The explanatory variables are as follows: gender, level of education, age, level of urbanization of the residence locality, price, and quality of biochar.

Results and Discussion:-

The Stakeholders in the biochar value chain in Benin

The actors in the biochar value chain in Benin are numerous and diversified, with poorly consolidated relationships between them. The chain includes four links: specific inputs, production, marketing, and consumption (Figure 2).

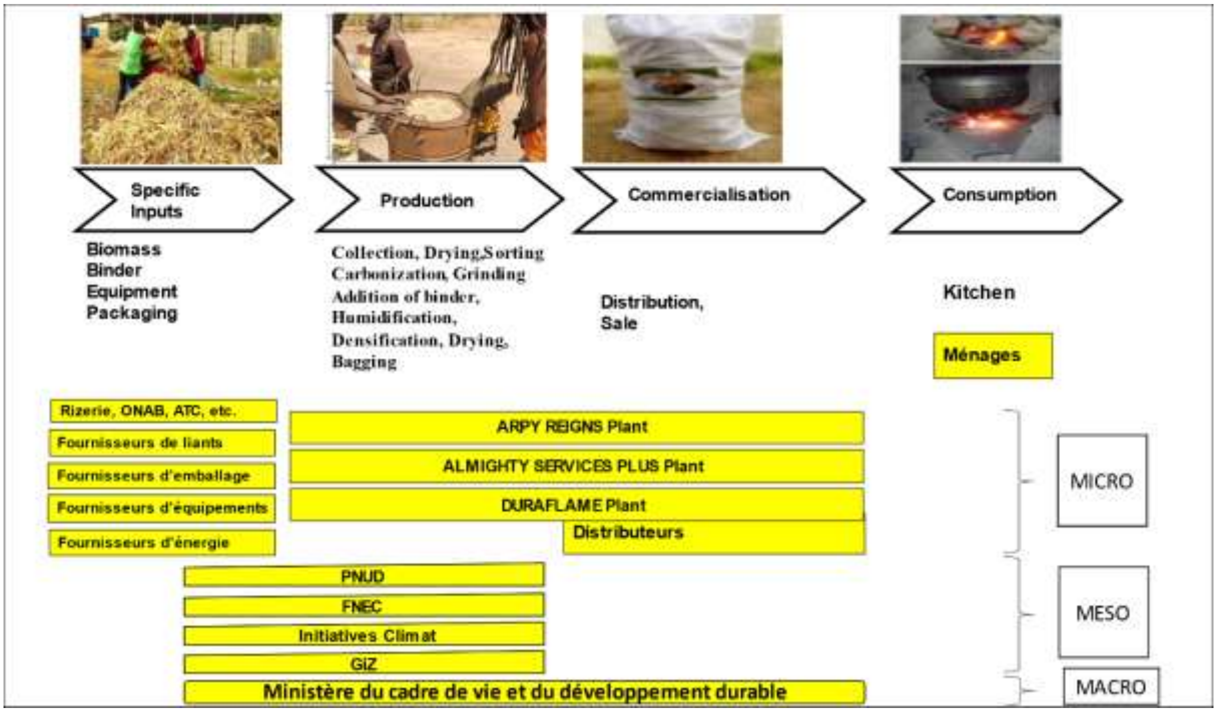

Figure 2:- Stakeholders in the biochar value chain in Benin.

At the micro level, there are four categories of input suppliers. The first is made up of suppliers of biomass from agricultural and agri-food waste (rice husks, cassava peelings, coconut shells and husks, and corn cobs), leaves of herbaceous plants (leaves of quackgrass), and wood residues (sawdust and chips and coal dust). Suppliers of agricultural and agri-food waste biomass are mainly made up of agri-food processing plants: "Rizerie de Glazoué," located in the center-west of the country in Glazoué, 230 km from Cotonou and "Riz Délices" located in the southwest in Lalo, 143 km from Cotonou and the cassava, coconut and maize processing cooperatives located around the biochar production units. This category of biomass suppliers also includes farmers located in the vicinity of biochar production units, which supply the leaves of herbaceous plants such as quackgrass leaves and industrial units for processing wood into furniture: ONAB located in Cotonou, the capital and Bohicon, 120 km from Cotonou; ATC located in Allada, 70 km from Cotonou. The second category of suppliers is made up of suppliers of binders made of clay, wheat flour, cassava, and corn starch. Agri-food processing cooperatives provide these binders. The third category of suppliers comprises packaging suppliers for packaging biochar. The fourth category comprises suppliers of production equipment (ovens, grinders, mixers, presses) and packaging. The equipment used is mostly made locally. For the operation of the engines of the equipment, the producers of biochars use gasoline, motor oil, and butane gas (for the drying oven) from companies selling petroleum products (TOTAL, BP, ORYX, JNP, etc.) as well as electricity supplied by Beninese Company of Electric Energy (SBEE).

Biochar production is mainly ensured in Benin by three production plants:ARPY REIGNS Plant, ALMIGHTY SERVICES PLUS Plant, and DURAFLAME Plant. ARPY REIGNS and ALMIGHTY SERVICES PLUS are located in the city of Abomey-Calavi in Southwest Benin, while DURAFLAME is located in the city of Glazoué. The main activity of these plants is the production of biochar briquettes from agricultural residue waste: agricultural and agri-food waste, leaves of herbaceous plant leaves, and wood residues. The market of the three companies is located at the national level.ARPY REIGNS Plant and ALMIGHTY SERVICES PLUS Plant ensures the distribution and marketing of biochars themselves. However, distributors based in major urban centers (Porto-Novo, Cotonou, Abomey-Calavi) deliver biochar directly to consumers.Regarding the consumption link, the surveys revealed that the biochar produced by the three production units is used exclusively for cooking. Biochar users are, therefore, households.

At the meso level, we find development partners such as the United Nations Development Program (UNDP), the National Environment and Climate Fund (FNEC), Swiss cooperation, Canadian cooperation, German cooperation

(GiZ), the Dutch cooperation (SNV) and the French Development Agency (AFD). These institutions support initiatives to create biochar production. There are also NGOs such as Climate Initiatives.

The Ministry of Living Environment and Sustainable Development is at the macro level.

The analysis of the different categories of actors involved in the biochar value chain shows that many more actors are at the micro and meso levels. This means there are very few facilitation structures promoting the business climate, communication, and legislation supporting the biochar development policy. Indeed, the Ministry of the Living Environment, through the Department of the Environment, carries out political actions about the preservation of the environment, but specifically, the policy on the development of biochar still needs to be perceptible; also, the sector needs to be organized.

Biochar production in Benin

The biochar production activity in each of the three production plants is described as follows.

Arpy Reigns Plant

The agricultural residues consist of corn husks and cobs, cassava peelings, coconut shells, quackgrass leaves, and charcoal dust. These plant biomasses collected from farmers, agribusinesses, and sawmills in the towns of Abomey-Calavi, Cotonou, and the surrounding area are crushed into compressible fragments using a plant crusher with hammer knives driven by an electric motor of 2.2kW. The residue obtained is mixed with water (15% of the mass of biomass) and binders. Cassava starch (10% of biomass mass) or maize starch (15% of biomass mass), or wheat flour (8% of biomass mass) are used as a binder. The mixture is compacted using a semi-automatic screw expeller press driven by an electric motor with a power of 5.5 kW. The briquettes obtained then undergo a thermochemical treatment by carbonization for about 120 min. After cooling, they are bagged.

Almighty Services Plus Plant

This factory uses rice husks collected from rice mills, cotton flower stalks collected from cotton fields, coconut husks collected from coconut-to-oil processing units, and sawdust and wood chips collected from timber sawmills. The collected agricultural and agri-food waste undergoes a thermochemical treatment by carbonization for about 120 min. Then, the carbonaceous residues obtained are cooled and crushed using a plant crusher with hammer knives driven by a 2.2 kW electric motor. The residue obtained is mixed with water (15% of the mass of biomass) and binders. Cassava starch (10% of biomass mass) or maize starch (15% of biomass mass), or wheat flour (8% of biomass mass) are used as a binder. The mixture is compacted using a semi-automatic screw expeller press driven by an electric motor with a power of 5.5 kW. The briquettes obtained are dried in the sun and then bagged.

Duraflame Plant

DURAFLAME Plant is a factory specializing in transforming rice husks into biochars. The biomass used consists solely of rice husks collected from rice mills in the town of Glazoué. The production process is similar to that of the ARPY REIGNS Plant.

Different user perceptions and adoption rates of biochar

Figure 3 below shows the distribution of biochar users' perceptions. These are Biochar Spalling, Late Ignition, High Ash, Non-Reuse of Biochar, and Late Delivery. 44.44% of respondents pointed out that biochar crumbles at the slightest shock. 75% found the ignition to be late. 27.77% indicated that coal produces much ash after burning. 8.33% of respondents mentioned the impossibility of reusing charcoal once it is ignited. The quality of these biochars still needs to meet the aspirations of users. Difficulties mentioned, such as late ignition and high ash content, are examples of this. Some producers use clay as a binder. As the latter is a thermal insulator, its use can reduce the product's energy efficiency. The high ash content may be due to the lack of control over carbonization and the choice of biomass. For example, rice husks have a high ash content (21.30%) related to the presence of inorganic matter and processing conditions (Radienielina, 2018).

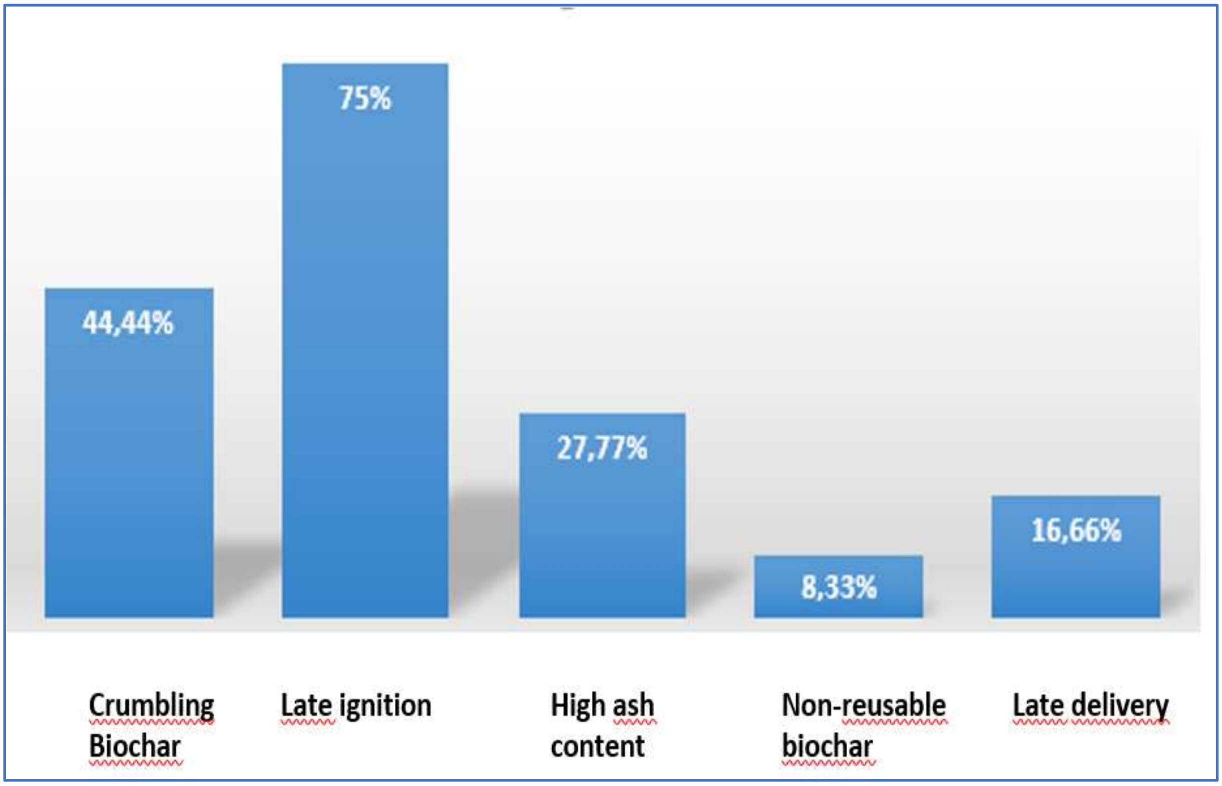

Figure 3:- Distribution of biochar users' perceptions.

Another area that could be mentioned is the crumbling of the briquettes. If the biochars crumble, they can be due to the mixture with the binder and the compaction pressure. Formulations (10%) of cassava starch as a binder (Aransiola, 2019) produced impact-resistant biochar, while producers indicated a formulation ranging from 4 to 7% binder for 6 to 8% water. In this case, the compaction pressure must be high to obtain resistant briquettes (Kang et al., 2018). Unfortunately, the presses used are unsuitable for these formulations because of the low output pressures, the values of which still need to be discovered by the producers, whether the press is locally manufactured or imported. The crumbling of biochar means that its combustion is only done with suitable stoves, which could negatively influence its adoption by a potential user with limited income. Users have also indicated that biochars are difficult to ignite (late ignition). This is due to their high humidity. Indeed, drying in the sun and the oven still needs to be more efficient, which does not allow obtaining biochar with a moisture content of at most 10% (Pallavi et al., 2013). Drying in the sun is restrictive. Every evening, the briquettes have to be picked up to protect them from humidity or to stop production in the rainy season, which is an obstacle to production on an industrial scale. The non-reuse of biochars hinders its adoption. Late delivery is often due to the unavailability of the product, and users are forced to resort to other fuels. This is also the case with the late ignition of biochar. Some users have positive perceptions of biochar. They mentioned that biochar is very economical, does not emit fumes, does not crackle or blacken the pans, and has advantages confirmed by (Sharma et al., 2015).

The adoption rate analysis showed that 56% of surveyed households adopted biochar against 44% who did not.

The multiple correspondence analysis revealed proximity between the modalities of the variables studied and the individuals (Figure 4).

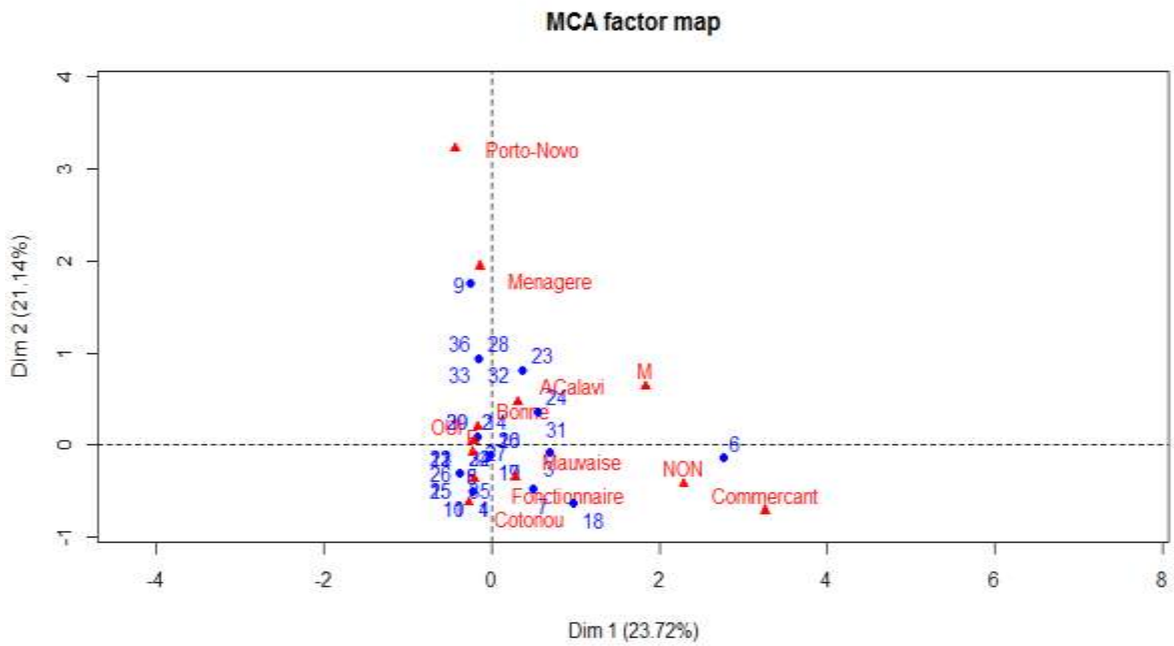

Figure 4:- Overlay graph of modalities and direct users.

From figure 4, users in Abomey-Calavi have an excellent perception. These are homemakers who have biochar delivered directly to them. On the other hand, users based in Cotonou need a better perception of using biochar. The multinomial logistic regression model estimation showed that the perception is not significantly influenced by gender, level of education, age, level of urbanization of the locality of residence, price, and quality of biochar. Also, households that have already and those who have not yet adoptedbiochar are similar concerning the locality of residence, level of education, delivery method, and purchase price compared to the price of traditionally used energy. The analysis of the results revealed a need for more qualifications for biochar production techniques in the production units (high moisture and ash content, crumbling products, etc.).

Conclusion:-

This study carried out showed that biochar is produced and used in Benin. Its use in households is an alternative to energy unsuitable for the environment. The study also showed the different perceptions of users of the biochar produced: Biochar crumbling, Late Ignition, High Ash, Non-Reuse of Biochar, and Late Delivery. From the analysis of these perceptions, there is a gap between the quality of the biochars produced and users' expectations. Analyzing user needs and optimizing the quality of biochar, considering the identified needs, will contribute to the better adoption of biochar technology in Benin.

References:-

1. Aba, S. C., Ndukwe, O., Amu, C. J., & Baiyeri, K. P. (2017). The role of trees and plantation agriculture in mitigating global climate change. African Journal of Food, Agriculture, Nutrition and Development, 17(4), 12691–12707. https://doi.org/10.18697/ajfand.80.15500
2. Abdi, H., & Béra, M. (2014). Correspondence Analysis.
3. Aberilla, J. M., Gallego-Schmid, A., & Azapagic, A. (2019). Environmental sustainability of small-scale biomass power technologies for agricultural communities in developing countries. Renewable Energy, 141. https://doi.org/10.1016/j.renene.2019.04.036
4. Aina, O., Adetogun, A., & Iyiola, K. (2009). Heat Energy From Value-Added Sawdust Briquettes Of Albizia Zygia. Ethiopian Journal of Environmental Studies and Management, 2(1). https://doi.org/10.4314/ejesm.v2i1.43501
5. Ajimotokan, H. A., Ibitoye, S. E., Odusote, J. K., Adesoye, O. A., & Omoniyi, P. O. (2019, December). Physico-mechanical characterisation of fuel briquettes made from blends of corncob and rice husk. In Journal of Physics: Conference Series (Vol. 1378, No. 2, p. 022008). IOP Publishing.

6. Amegah, A. K., Boachie, J., Näyhä, S., & Jaakkola, J. J. K. (2020). Association of biomass fuel use with reduced body weight of adult Ghanaian women. Journal of Exposure Science & Environmental Epidemiology, 30(4). https://doi.org/10.1038/s41370-019-0129-2
7. Missaoui, A. (2018). Etude de la conversion de la biomasse en energie par unprocédé hydrothermal de carbonisation - Caractérisationdes produits issus des grignons d'olive. Doctoral dissertation, Université d'Orléans.
8. Bridgwater, A. v., & Peacocke, G. V. C. (2000). Fast pyrolysis processes for biomass. Renewable and Sustainable Energy Reviews, 4(1). https://doi.org/10.1016/S1364-0321(99)00007-6
9. Bustos-Vanegas, J. D., Martins, M. A., Freitas, A. G., & Mellmann, J. (2019). Experimental characterization of self-heating behavior of charcoal from eucalyptus wood. Fuel, 244. https://doi.org/10.1016/j.fuel.2019.01.136
10. Czernik, S., & Bridgwater, A. v. (2004). Overview of applications of biomass fast pyrolysis oil. Energy and Fuels, 18(2). https://doi.org/10.1021/ef034067u
11. Dasappa, S. (2011). Potential of biomass energy for electricity generation in sub-Saharan Africa. Energy for Sustainable Development, 15(3). https://doi.org/10.1016/j.esd.2011.07.006
12. García, R., Pizarro, C., Lavín, A. G., & Bueno, J. L. (2014a). Spanish biofuels heating value estimation. Part I: Ultimate analysis data. Fuel, 117(PARTB). https://doi.org/10.1016/j.fuel.2013.08.048
13. Godjo, T. (2017). Densification and analysis of the physical properties of bio-coal produced from the pyrolysis cashew nut shells in Benin. International Journal of Innovation and Applied Studies, 19(3), 614–620. http://www.ijias.issr-journals.org/
14. Ifa, L., Yani, S., Nurjannah, N., Darnengsih, D., Rusnaenah, A., Mel, M., Mahfud, M., & Kusuma, H. S. (2020). Techno-economic analysis of bio-briquette from cashew nut shell waste. Heliyon, 6(9). https://doi.org/10.1016/j.heliyon.2020.e05009
15. Kang, K., Zhu, M., Sun, G., Qiu, L., Guo, X., Meda, V., & Sun, R. (2018). Codensification of Eucommia ulmoides Oliver stem with pyrolysis oil and char for solid biofuel: An optimization and characterization study. Applied Energy, 223, 347–357. https://doi.org/10.1016/j.apenergy.2018.04.069
16. Karmaker, A. K., Rahman, M. M., Hossain, M. A., & Ahmed, M. R. (2020). Exploration and corrective measures of greenhouse gas emission from fossil fuel power stations for Bangladesh. Journal of Cleaner Production, 244. https://doi.org/10.1016/j.jclepro.2019.118645
17. Kumar, J. A., Kumar, K. V., Petchimuthu, M., Iyahraja, S., & Kumar, D. V. (2021). Comparative analysis of briquettes obtained from biomass and charcoal. Materials Today: Proceedings, 45, 857–861. https://doi.org/10.1016/j.matpr.2020.02.918
18. Lehmann, J., & Joseph, S. (2012). Biochar for environmental management: An introduction. In Biochar for Environmental Management: Science and Technology. https://doi.org/10.4324/9781849770552
19. Li, S., Feng, K., & Li, M. (2017). Identifying the main contributors to air pollution in Beijing. Journal of Cleaner Production, 163. https://doi.org/10.1016/j.jclepro.2015.10.127
20. Liu, Z., Quek, A., Kent Hoekman, S., & Balasubramanian, R. (2013). Production of solid biochar fuel from waste biomass by hydrothermal carbonization. Fuel, 103. https://doi.org/10.1016/j.fuel.2012.07.069
21. Lohri, C. R., Rajabu, H. M., Sweeney, D. J., & Zurbrügg, C. (2016). Char fuel production in developing countries – A review of urban biowaste carbonization. Renewable and Sustainable Energy Reviews, 59. https://doi.org/10.1016/j.rser.2016.01.088
22. Lott, M. C., Pye, S., & Dodds, P. E. (2017). Quantifying the co-impacts of energy sector decarbonization on outdoor air pollution in the United Kingdom. Energy Policy, 101. https://doi.org/10.1016/j.enpol.2016.11.028
23. Mbamala, E. C. (2019). Burning Rate and Water Boiling Tests for Differently Composed Palm Kernel Shell Briquettes. IOSR Journal of Environmental Science, Toxicology and Food Technology, 13(3).
24. Mekonnen, M. M., Romanelli, T. L., Ray, C., Hoekstra, A. Y., Liska, A. J., & Neale, C. M. U. (2018). Water, Energy, and Carbon Footprints of Bioethanol from the U.S. and Brazil. Environmental Science & Technology, 52(24). https://doi.org/10.1021/acs.est.8b03359
25. Mugabi, P., & Kisakye, D. B. (2020). Status of production, distribution and determinants of biomass briquette acceptability in Kampala City, Uganda. Maderas. Ciencia y Tecnología, 23. https://doi.org/10.4067/S0718-221X2021000100413
26. Nicholls, R. J., & Cazenave, A. (2010). Sea-Level Rise and Its Impact on Coastal Zones. Science, 328(5985). https://doi.org/10.1126/science.1185782
27. Njenga, M., Karanja, N., Prain, G., Malii, J., Munyao, P., Gathuru, K., & Mwasi, B. (2009). Community-based energy Briquette production from urban organic waste at Kahawa Soweto Informal Settlement, Nairobi. In Urban Harvest (Vol. 5).

28. Bonsu, B. O., Takase, M., & Mantey, J. (2020). Preparation of charcoal briquette from palm kernel shells: a case study in Ghana. Heliyon, 6(10). https://doi.org/10.1016/j.heliyon.2020.e05266
29. Radanielina, M. H. (2018). Co-valorisation énergie et matière des résidus agricoles par pyro-gazéification (Doctoral dissertation, Université d'Antananarivo).
30. Riva, L., Wang, L., Ravenni, G., Bartocci, P., Buø, T. V., Skreiberg, Ø., Fantozzi, F., & Nielsen, H. K. (2021). Considerations on factors affecting biochar densification behavior based on a multiparameter model. Energy, 221. https://doi.org/10.1016/j.energy.2021.119893
31. Saqib, N. U., Oh, M., Jo, W., Park, S. K., & Lee, J. Y. (2017). Conversion of dry leaves into hydrochar through hydrothermal carbonization (HTC). Journal of Material Cycles and Waste Management, 19(1). https://doi.org/10.1007/s10163-015-0371-1
32. Sharma, M. K., Priyank, G., & Sharma, N. (2015). Biomass Briquette Production: A Propagation of Non-Convention Technology and Future of Pollution Free Thermal Energy Sources. American Journal of Engineering Research (AJER), 04(02).
33. Smith, A. M., Singh, S., & Ross, A. B. (2016). Fate of inorganic material during hydrothermal carbonization of biomass: Influence of feedstock on combustion behavior of hydrochar. Fuel, 169. https://doi.org/10.1016/j.fuel.2015.12.006
34. Weber, K., & Quicker, P. (2018). Properties of biochar. In Fuel (Vol. 217, pp. 240–261). Elsevier Ltd. https://doi.org/10.1016/j.fuel.2017.12.054
35. Zhang, Y., Qu, S., Zhao, J., Zhu, G., Zhang, Y., Lu, X., Sabel, C. E., & Wang, H. (2018). Quantifying regional consumption-based health impacts attributable to ambient air pollution in China. Environment International, 112. https://doi.org/10.1016/j.envint.2017.12.021
36. Zulu, L. C., & Richardson, R. B. (2013). Charcoal, livelihoods, and poverty reduction: Evidence from sub-Saharan Africa. Energy for Sustainable Development, 17(2). https://doi.org/10.1016/j.esd.2012.07.007.