EFFECTIVENESS AND ENERGY EFFICIENCY OF SAVANNAH GRASS BRIQUETTES ALTERNATIVE TO WOOD ENERGY COMPARED TO BRIQUETTES OF RICE HUSKS, PLANING CHIPS AND SAWDUST.

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ABSTRACT

92% of Madagascar's energy supply is dominated by wood energy. Households are the major consumers of energy and are responsible for deforestation. Currently, only more than 21% of the country's surface area is covered by forest. To restore the country's image of the former "green island", the government has opted for a policy of diversifying energy sources by developing alternative energy sources such as the agrofuel sector for the production of bioethanol and biodiesel and the production of fuel briquettes from the energy recovery of rice waste, wood processing waste (planning chips, sawdust) and savannah grasses, which are invasive plants in the south of the country. These wastes are potential in three different study sites: rice husk in Morombe District, Atsimo Andrefana region, wood processing wastes (planning chips, sawdust) in Moramanga District, Alaotra Mangoro region, and finally, savanna grasses in Ihosy District, Ihorombe region.

The purpose of this research work is to determine the most suitable fuel to compete with or substitute for wood energy.

The methodology adopted is both qualitative and quantitative. Its long-term realization requires a priori by passing through the chronological order of the following activities: the collection of bibliographical data and webographies relating to the different types of recoverable biomass with a view to identifying potential waste that can be exploited, going down to the field to see first-hand the inventoried waste with its potential, collecting respective samples for experimental tests, making briquettes from the inventoried potential waste, to determine their physical-chemical character, to test the briquettes manufactured through the different universally recognized tests including those of water boiling, controlled cooking and energy efficiency in order to know respectively, the PCI, the boiling time per hour, the fuel consumption in kg/h, the power and the efficiency of each type of briquette manufactured. Knowledge of these parameters will make it possible to dictate which alternative fuel can compete with charcoal and firewood. The aim is therefore to find the manufactured briquette with the following criteria: suitable for firing, with an ICP

comparable with coal or wood, with a better output and power than coal and, finally, with a lower fuel consumption and boiling time compared to wood energy.
Previous research results have made it possible to determine the physical-chemical characteristics of fuel briquettes produced from rice husks, planning shavings, sawdust and recently savannah grasses. The variation in the binder (cassava starch) content and the granulometry of the fine particles making up the manufactured briquettes are the most studied parameters for the research work. The most convincing results from the different works carried out such as water boiling tests (fuel consumption, boiling time), energy efficiency (power, yield) and physical-chemical characteristics (PCI) for each type of fuel briquette manufactured make it possible to dictate the most efficient fuel able to compete with wood energy. In this context, the 10% savannah grass briquette in binder is the most energy-efficient fuel compared to briquettes made from rice husks, planning shavings and sawdust, as the savannah grass briquette not only has better fuel consumption, boiling time and yield than wood energy and the other briquettes studied. Moreover, the potentiality of the savannah grass resource is very significant with a dry matter content of about 10 to 15 t MS/ha/year. It is therefore the most appropriate fuel to substitute wood energy and to mitigate or even reduce deforestation in the country.

Key words*: waste, recovery, fuel briquette, energy efficiency,*

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1. INTRODUCTION

Energy is an important part of any development. Underdeveloped or non-oil-producing countries cannot emerge from this phase of underdevelopment until they have their own energy, because energy is the engine of development. The application of the policy of diversification of available energy sources is one of the best solutions to get out of this situation. In Madagascar, 92% of the energy supply is dominated by wood energy and 7% by imported petroleum products (Instat, 2013), (wwf, 2012). Domestic energy consumption is among the main reasons for this. In urban areas, the average annual charcoal consumption per capita is 125 kg/pers/year, i.e. 0.350 kg/pers/day, while in rural areas, this consumption is 110 kg/pers/year, i.e. 0.300 kg/pers/day. For wood, the consumption per capita per year is estimated at: 270 kg/pers/year in urban areas and 513 kg/pers/year in rural areas. For the year 2015, the demand for wood energy (18.3 million m3 per year) far exceeds the potential for sustainable production (9.169 million m3 per year). This situation is worsening over the years due to the increase in household energy needs and also to the high demand for wood by the population for various uses (construction, etc.). The deforestation rate is hovering around 1%, i.e. a loss of about 40,000 ha of forest per year, and the available forest resources now cover less than 21% of the island's surface area (World Bank, online).
Faced with this situation and aware of the importance of wood energy for the energy needs of the population, the Malagasy government has opted for this policy of diversification of energy sources through the adoption of alternative energy sources such as : the planting of sugar cane or jatropha carcass for the respective production of biofuel or biodiesel as well as the production of fuel briquettes from rice waste (rice husk, rice straw), wood processing waste (planning shavings, sawdust) and savannah grasses, invasive species occupying 2/3 of the surface area of the Ihorombe region.
For briquettes, studies have already been carried out and results have been obtained. Various questions arise, among others:
- firstly, is the rice waste (rice husk, rice straw) generated by rice cultivation not sufficient to meet domestic needs in the country?;
- Secondly, for wood processing wastes (planning chips, sawdust), are producing briquettes based on planning chips or sawdust more advantageous in terms of domestic energy instead of using the wood directly as domestic fuel?
- Thirdly, will cutting wood to obtain planning chips and sawdust not have an impact on deforestation?
- Fourth, what are the different advantages brought by the production and use of savannah grass briquettes instead of wood energy in households? and what strategies can be adopted to develop the planting of this invasive grass across the 22 regions of the country?
This research work tries to shed light on these different questions asked

2. METHODOLOGIES

2.1 Study areas

This research work covers three study areas: the District of Morombe, Atsimo Andrefana region, the District of Moramanga, Alaotra Mangoro region and the District of Ihosy, Ihorombe region.

The waste to be recovered is found in the districts of the three above-mentioned regions where rice husk is found in the District of Morombe, Atsimo Andrefana region, wood processing waste (planing shavings, sawdust) in the District of Moramanga, Alaotra Mangoro region and finally, savannah grasses in the District of Ihosy, Ihorombe region.

2.1.1. Morombe district, Atsimo Andrefana region

Located in the South-West of Madagascar, the Atsimo Andrefana Region is in the Province of Toliara. Stretching on a coast of 800 km, it is composed of 9 districts and 105 communes. Its regional capital is Toliara I which is located about 945 km from the capital of Madagascar. The other districts that make it up are the following: Toliara II, West Ampanihy, Ankazoambo, Benenitra, Beroroha, South Betioky, Morombe and Sakaraha.

It is limited by the following geographical coordinates:

- latitude: between 21°66' and 24°72' South;
- longitude: between 43°47' and 45°47' East.

It covers an area of 66,502 km2 , which represents 11.4 per cent of Madagascar's total surface area.

Table 1: Area of Morombe District

District	Area in km2
Ampanihy (Ouest)	13 253
Ankazoabo	8 834
Benenitra	4 741
Beroroha	6 723
Betioky (Sud)	10 079
Morombe	7 109
Sakaraha	8 160
Toliara I	282
Toliara II	7 321
Total region	66 502

The district of Morombe is the rice granary of the Atsimo Andrefana region with its 15,675-ha rice growing area and a production yield of 3t/ha.

Figure 1: Location map of the district of Morombe

2.1.2. Moramanga District, Alaotra Mangoro Region

The Moramanga district was chosen as the study area because of the importance of forest resources in the area on the one hand and the existence of the state-owned company FANALAMANGA and several free zone companies working in the timber and timber by-products sector on the other.

This section provides information on the geographical characteristics, climate, demographic situation and forestry in the Alaotra Mangoro region.

2.1.2.1. Geographical Location

The town of Moramanga is an essential stop on the National Road N°2. It is located in the Middle East region of Madagascar, in the south-central part of the Alaotra Mangoro region.

The Alaotra Mangoro Region is limited:

- To the North-East by the districts of Mandritsara, Port Berge and Befandria - North: Sofia Region;
- To the North-West by the District of Tsaratanana: Betsiboka Region;
- To the West by the Districts of Anjozorobe and Manjakandriana: Analamanga Region;
- To the South-West by the Districts of Andramasina and Ambatolampy: Analamanga and Vakinankaratra Regions;
- To the South by the District of Marolambo: Antsinanana Region;
- To the South-East by the Districts of Tanambao Manampotsy and Vatomandry: Antsinanana Region;
- To the East by the Districts of Brickaville and Toamasina II: Antsinanana Region;
- To the North by the Districts of Fenerive EST and Soanierana Ivongo: Analanjirofo Region.

The region as a whole represents 41% of the area of the Autonomous Province of Toamasina of which it is part and the 5.21% of the whole island. It is subdivided into two:

- the Alaotra including Ambatondrazaka, Amparafaravola and Andilamena.
- the Mangoro including Moramanga and Anosibe An'Ala

Table 2 presents the road map of the Alaotra Mangoro region.

Table 2: Road map of the Alaotra Mangoro region

District	Distance from Toamasina (km)	Distance from Antananarivo (km)	area (km2)
Anosibe an'Ala	441	186	2 660
Moramanga	254	115	8 954,5
Ambatondrazaka	411	272	6 492
Amparafaravola	437	298	4 947,5
Andilamena	553	414	7 526
TOTAL REGION	2 096	1 285	30 580

Source: Madagascar, road map at 1/2 000 000; Atlas of Madagascar

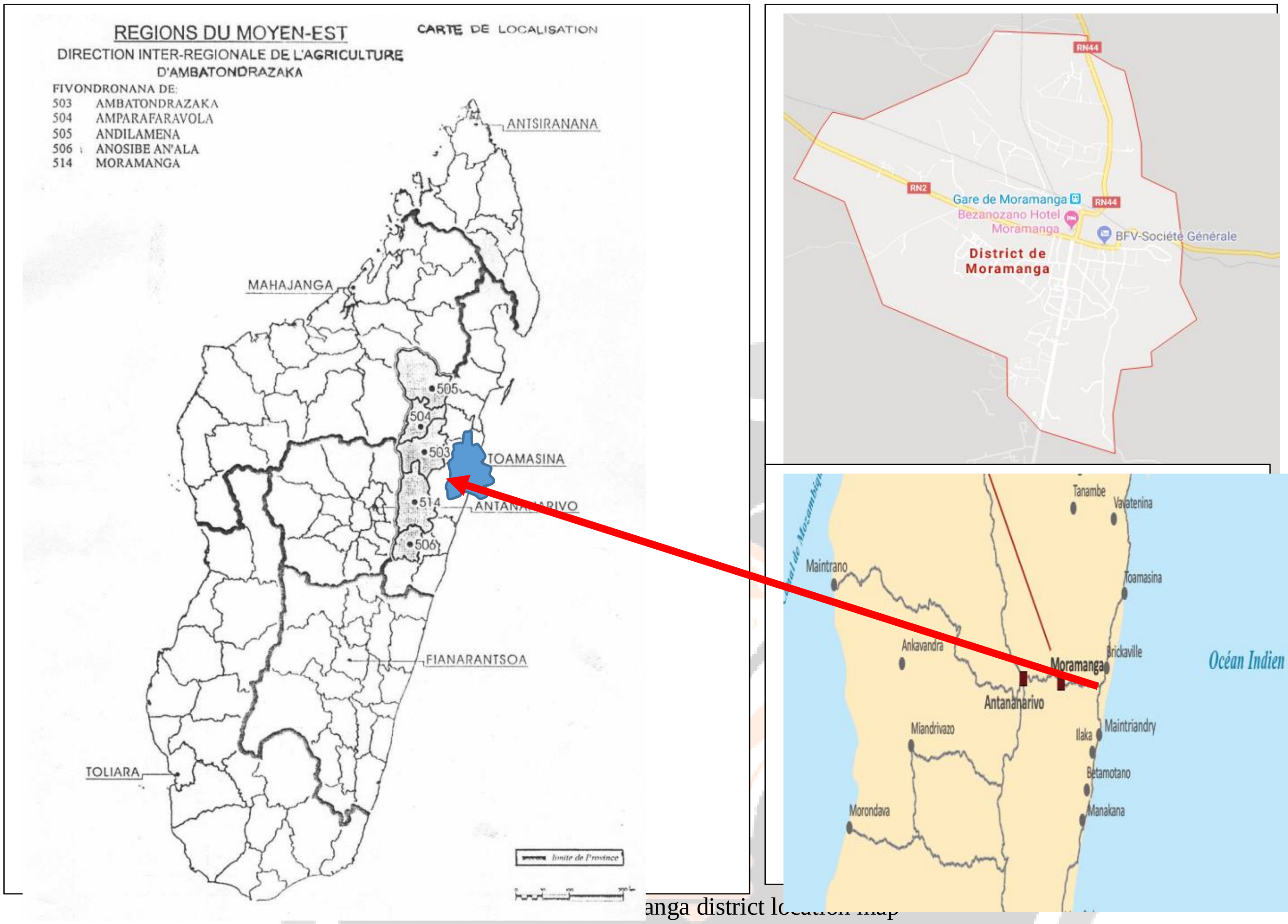
2.1.2.2. Location of the Moramanga district

Table 3 below shows the geographical location of the town of Moramanga.

Table 3: Geographical location of the town of Moramanga.

Country	Madagascar
Region	Alaotra Mangoro
Province	Toamasina
District	Moramanga
Contact details (GPS)	18°57' sud, 48°14' Est
Altitude	980 m

This table 3 informs the geographical parameters allowing to locate geographically the district of Moramanga.



anga district lo... map

2.1.3. Ihosy district, Ihorombe region

Location

The Ihorombe Region is located in the south-central part of Madagascar and is part of the province of Fianarantsoa. It is delimited in the North by the Haute Matsiatra Region, in the South by the Anosy Region, in the East by the Atsimo Atsinanana Region, and in the West by the Atsimo Andrefana Region. It extends geographically between longitudes 44°98' and 46°62' and latitudes 21°61' and 23°10', over a length ranging from 100 km to 120 km, a width of about 200 km and an area of 26 930 km2.

The Ihorombe Region is made up of three districts: Iakora, Ihosy and Ivohibe, with respective areas of 4,258 km2, 18,372 km2 and 4,300 km2. Its capital is the city of Ihosy, which is located 602 km south of the capital Antananarivo, via the RN 7.

The following figure illustrates the location of the Ihorombe region

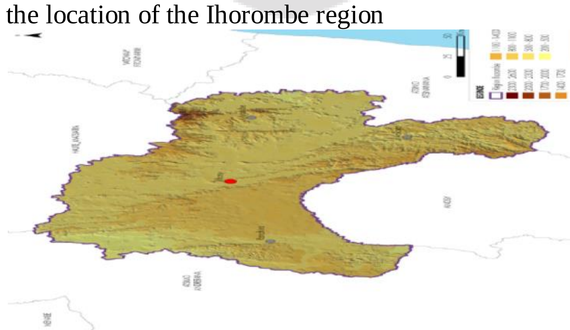


Figure 3: Location of the Ihorombe Region

2.2. Laboratory work

2.2.1. The choice of binder

By definition, a binder is a substance used to agglomerate several components of a material. The mass of the binder shall not exceed 10% of the total mass of the agglomerated material.

This research work has made it possible to study seven varieties of binder that can be used to make fuel briquettes, namely: paper and cardboard, cassava flour, cassava starch, clay, heavy oil, waste oil and maize starch. Eight parameters were studied to determine the most suitable binder for use in fuel briquettes. After the test carried out at the CNRIT energy laboratory, three of the seven types of binders were found to be best suited for use: cassava flour, cassava starch and clay. The results of these tests and analyses are summarized in the table below.

Table 4: Result of comparative study on binders

Parameters	Cassava flour	Cassava starch	Clay
Method of production	Medium	Medium	Easy
Availability	National	Regional	National
Ease of use in hot and cold conditions	Medium	Easy	Medium
Cost of finished product (Ar/kg)	60	258	40
Food competition	Yes	Yes	No
Efficiency scale	80	100	70
Strong point	Relative price affordable	Adhesive strength high	Widely available
Weakness	Adhesive strength mediocre	High cost	Resistance to low compression
Resistance to stress (MPa)	3,8	6,0	2,9

Source: CNRIT lab test, April 2017

The results of the tests summarized in the table above show that cassava starch is in a good position compared to other binders. The starch is then transformed into a starchy substance before being used.

2.2.2. Proportions in binder and fine material

The proportions of binder and fine material for the production of savannah grass briquettes are as follows:

- Binder: 5%, 7%, 8% and 10%;
- In fine matter: 25%, 36%, 50%, 73% and 80%.

2.2.3. The mixture

Once the proportion is complete, we mix all the compositions. The whole is then manually placed in the matrix, the piston compresses the materials until it feels a counter movement. The demolding is then carried out thanks to a demolding device.

2.2.4. Physical and chemical characteristics of combustible briquettes

The efficiency of a briquette depends on its physical-chemical characteristics such as: moisture, ash content, volatile matter content, fixed carbon content and net calorific value (NCV). The objective is to be able to compare the results with those of charcoal.

2.2.4.1. Moisture content

The moisture content of a combustible briquette represents its water content in relation to its wet mass. It should be noted that drying briquettes cannot remove all the water contained in a briquette. The moisture thus obtained is the amount of water remaining after drying the briquettes. It is a decisive parameter for the combustion of briquettes: if it is high, combustion is almost impossible.

Measuring principle: The sample is heated in a CARBOLITE R38 oven at 105°C and weighed after 24 hours. Determination is carried out according to the European standard EN 14774. The moisture content is obtained by the following formula:

$$TH = \frac{M_{humide} - M_{seche}}{M_{humide}} \times 100$$

With TH: moisture content expressed in (%)
M_wet: mass of the sample
M_dry: mass obtained after heating to 105°C.

2.2.4.2. Volatile Matter Content (VOCs)

The volatile matter of a fuel is that part of the Organic Matter (OM) that escapes as a gas during combustion. The level of MOV supports the flammability of the fuel.

Principle of measurement: The same sample used to find the moisture content is heated in a Naberthern B180 muffle furnace at a temperature of up to 550°C. Its determination follows the French standard NF, 1985. The volatile matter content is determined by the loss of mass during heating. The following formula is used to calculate the volatile matter content:

$$MOV = \frac{M_{105} - M_{505}}{M_{seche}} \times 100$$

With:
MOV: Volatile matter content,
M_105: Mass obtained after heating to 105°C,
M_505: Mass obtained after heating to 550°C.
M_dry: Mass of the sample

2.2.4.3. Ash content (TC)

The ash content represents the amount of mineral matter contained in a fuel. It is important for the appreciability of the fuel because when it is very high, this ash becomes an obstacle to the progress of combustion.

Measuring principle: The ash content is obtained by heating the sample to 850°C in a Naberthern B180 muffle furnace. Its determination follows the European standard EN 14775. The ash content is determined by the mass of the residue after incineration. The result is obtained with the following formula:

$$TC = \frac{M_{850}}{M_{seche}} \times 100$$

With:
TC: Ash content
M_850: Mass obtained after heating to 850°C
M (dry): Mass of the sample

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$$TC = \frac{M_{850}}{M_{seche}} \times 100$$

With:
TC: Ash content
M_850: Mass obtained after heating to 850°C
M_(dry): Mass of the sample

2.2.4.4. Fixed carbon (FC) rate

Generally, if the carbonization is well conducted, the tank contains about 80% fixed carbon. An indispensable element in the composition of briquettes and other fuels, fixed carbon has great energy potential. It is the amount of carbon remaining after the removal of volatile matter, ash and moisture. It is different from total carbon which is the sum of the fixed carbon and the carbon contained in the volatilized part.

The level of fixed carbon can be determined either:
- by following the ASTM standard and it is calculated with the following formula:

- $$CF = \frac{M_{550} - M_{850}}{M_{550}}$$

- by applying the following formula: TCF= 100-(TH+Ce+MOV)
With: TH: Moisture; CF: Fixed Carbon; MOV: Volatile Matter Content.

2.2.4.5. Calorific Value

The calorific value of a fuel represents the amount of energy contained in a unit of mass of that fuel. It is expressed in terms of energy per unit mass (for solids: MJ/Kg) and per unit volume (for gases: MJ/m3).

The term "Lower Calorific Value (LCV)" is used when combustion takes place at a constant pressure, i.e. in the open air. This means that the latent heat (which is difficult to recover) of the water vapor is not recovered at this time. It is this ICP value that is recoverable as energy by the user.

Measuring principle: The ICP can be determined in two different ways:

- using a calorimetric bomb (PHYWE B1245) in the presence of oxygen and a temperature monitoring every 30 sec must be carried out until stabilization. Its determination follows the French standard NF ISO 1928, 2004;
- from the following CASSAN formula: PCI= (100-TC) * 80 in kcal/kg

where: TC: Ash content

2.2.5. Tests of the effectiveness and energy efficiency of briquettes made from rice husks, planning shavings, sawdust and savannah grass compared to charcoal and firewood and for a binder content of: 4%, 5%, 7%, 8% and 10% depending on the raw material to be agglomerated.

In order to determine the efficiency and energy efficiency of these briquettes with different binder content, each briquette must pass the following tests: drop test, rotating drum, shear test, flammability test, controlled cooking test and water boiling test in order to determine respectively their energy efficiency (power, yield), boiling time, respective average fuel consumption (briquette, coal and firewood) through the use of an improved fireplace with a well-defined yield.

2.2.5.1. Approach adopted for the evaluation of the effectiveness and energy efficiency of briquettes made from rice husks, planer shavings, sawdust and savannah grass and with a binder content of 5%, 7%, 8% and 10% compared to an improved fireplace with a well-defined yield.

The effectiveness and energy efficiency of each savannah grass briquette in relation to charcoal and firewood depend on the result of Water Boiling Tests (WBT) to determine the consumption of each rice husk, planning chips, sawdust and savannah grass briquette, charcoal and firewood by the most commonly used firebox: the Fatana Mitsitsy (Improved Fireplace) by using the same kettle under the same operating conditions (same amount of briquette and the same kettle for each test).

Furthermore, it is from this Water Boiling Test (WBT) that the parameters for each fuel can be evaluated:

- Flammability test or ignition time;
- Fire behavior;
- The duration of water boiling;
- The possibility of using the unburnt fuel (fuel remaining at the time of a TEE) for a new firing.

The methodology adopted for the realization of the Water Boiling Tests (WBT) by using the most commonly used fireplace (Fatana Mitsitsy) consists in carrying out the Water Boiling Tests. These TEEs allow to evaluate the consumption of briquettes made of rice husks, planning shavings, sawdust and savannah grass compared to other commonly used fuels (charcoal, firewood).

(a) Briquette Water Boiling Test with rice husk, planning shavings, sawdust and savannah grass

The realization of these water boiling tests consists in grouping the activities to be undertaken in the form of Test Groups [GT(x)i,j] where :

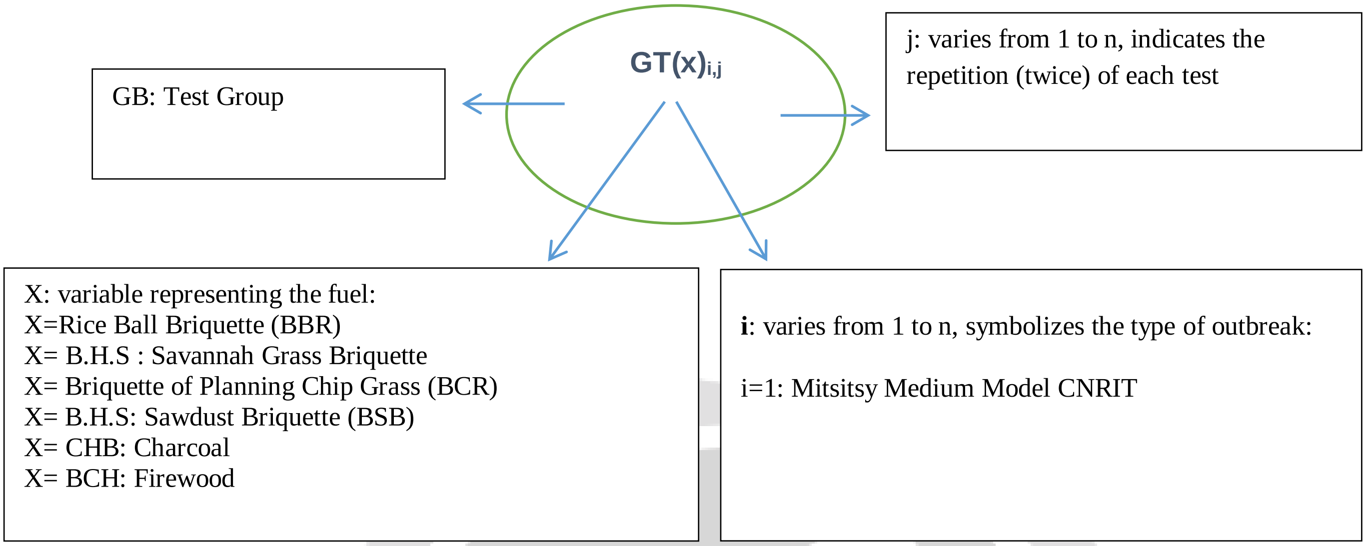

Figure 4: Test group for fuels (briquettes, coal, firewood)

These test groups [GT(x)i, j] are distributed as follows:
o The test group using respectively the fuels (X1, X2, X3, X4, X5, X6) [GT(X) i, j] with the Mitsitsy heater comprising the: GT (X (4%))1, j composed by the two tests GT (X (4%))1.1 to GT (X (4%))1.2 ;
o The test group respectively using the fuels (X1, X2, X3, X4, X5, X6) [GT(X) i, j] with the Mitsitsy heater comprising: GT (X (5%))1, j composed by the two tests GT (X (5%))1.1 to GT (X (5%))1.2;
o The test group respectively using the fuels (X1, X2, X3, X4, X5, X6) [GT(X) i, j] with the Mitsitsy heater comprising: GT (X (7%))1, j composed by the two tests GT (X (7%))1.1 to GT (X (7%))1.2;
o The test group respectively using the fuels (X1, X2, X3, X4, X5, X6) [GT(X) i, j] with the Mitsitsy heater comprising: GT (X (8%))1, j composed by the two tests GT (X (8%))1.1 to GT (X (8%))1.2;
o The test group respectively using the fuels (X1, X2, X3, X4, X5, X6) [GT(X) i, j] with the Mitsitsy heater comprising: GT (X (10%))1, j composed by the two tests GT (X (10%))1.1 to GT (X (10%))1.2.
o The charcoal test group [GT(CHB) i, j] with the Mitsitsy fireplace comprising: GT(CHB)1, j composed by the two tests GT(CHB)1,1 to GT(CHB)1,2
o The firewood test group [GT(BCH)i,j] comprising the:GT(BCH)1,j composed by the two tests GT(BCH)1,1 to GT(BCH)1,2
For each X fuel used, these tests are represented as a matrix table. Taking X1 = Rice Ball Briquette (BBR), the matrix table is as follows:

Table 5: Matrix representation of the 5 test groups, the fuels and the Mitsitsy fireplace.

Stove / Fuel	Mitsitsy Medium Model (CNRIT)
B.B.R (4%)	GT (B.B.R (5%))$_{1,j}$
B.B.R (5%)	GT (B.B.R (7%))$_{1,j}$
B.B.R (10%)	GT (B.B.R (10%))$_{1,j}$
CHB	GT(CHB)$_{1,j}$
BCH	GT(BCH)$_{1,j}$

According to this matrix table, the tests are done for 5 test groups with two replicates each.

2.2.6. Calculation method for the determination of the consumption (kg/h) of charcoal, firewood and savannah grass briquettes with 5%, 7%, 8% and 10% binder.

The average fuel consumption (kg/h) shall be determined from the average values of the water boiling test groups [GT(x)i,j].

The formula used to calculate the average fuel consumption (kg/h) shall be as follows:

$$\textbf{AVERAGE FUEL CONSUMPTION} = \textbf{Fuel consumed: Duration of combustion}\left[\frac{Kg}{h}\right]$$

FUEL CONSUMED = original fuel - fuel (uneaten + nested)

DURATION OF COMBUSTION = Boiling time + 1//4 of an hour

The average fuel consumption (kg/h) is therefore equal to the value of the ratio of the average quantity of fuel consumed to the average boiling time of water plus 15 minutes. Thus, each test group will have its own average fuel consumption per unit of time.

At each test, we will try to determine:

- The power of each fireplace by using each type of fuel (briquette, coal, firewood) of composition by binding 4%, 5%, 7%, 8% and 10%;
- The efficiency or output of each fireplace by using each type of fuel (briquette, coal, firewood) with a composition of 5%, 7%, 8% and 10%;
- The fuel consumption (in kg/h) of each type of fuel (briquette, coal, firewood). The realization of each activity will depend respectively on the study materials, the raw materials (fuels, water) available and the technicians for the realization.

2.2.7. Calculation method for the determination of the Power (Watt) of the fireplace improved by using charcoal, firewood and each type of briquette as fuel for the binder contents of 4%, 5%, 7%, 8% and 10%.

Power is defined as the derivative of energy over time.

-In our case, it is a question of determining a constant heat output value. We can therefore write;

$$P(t) = \frac{Q}{t}$$

Where: Q: represents the useful energy, i.e. the energy transmitted from the hearth to the pot,
and "t": the time or total duration of the test.

The useful energy is a function of the amount of heat accumulated by the water between its initial temperature and boiling point and the latent heat of the evaporated water:

$$Q = C_{eau} \times M_{eau initiale} \times (T_{ébullition} - T_{initiale}) + L_{eau} \times (M_{eau\ initiale} - M_{restante})$$

And as a result:

$$P = \frac{C_{eau} \times M_{eau\ initiale} \times (T_{ébullition} - T_{initiale}) + L_{eau} \times (M_{eau\ initiale} - M_{restante})}{t}$$

Table 6 : Value of power determination parameters

C_{eau}	Mass heat of the water	4180 J/kg. °C
L_{eau}	Latent heat of vaporization of water	2260000 J/kg
$M_{eau\ initial}$	Initial mass of water	2,5kg
$M_{eau\ restante}$	Mass of water remaining after the test	Kg
Q	Energy transmitted by the hearth to the kettle	Joule
t	Total test time	Second
P	Power of the hearth	Watt

2.2.8. Evaluation of the efficiency (yield) of the improved fireplace by using charcoal, firewood and each type of briquette with respective contents of: 4%, 5%, 7%, 8% and 10%.

The evaluation of the efficiency of the improved fireplace is based on the yield calculation.

By definition, the efficiency is the ratio between the energy transmitted by the fireplace to the pot and the energy contained in the burnt fuel.

Let it be:

$$\eta = \frac{Q}{PC_{Combustible} \times P_{Combustible}}$$

By replacing Q, by its above value, we have the following result

$$\eta = \frac{C_{eau}\ x\ M_{eau\ initiale}\ x\ (T_{ébullition} - T_{initiale}) + L_{eau}\ x\ (M_{eau\ initiale} - M_{restante})}{PC_{Combustible} \times P_{Combustible}}$$

Table 7: Parameter values for each type of briquette Xi at 4%,5%,7%,8% and 10%.

PC_{Fuel}	Calorific value of the fuel; or: PC_{Xi} (4%) --- ▪ PC_{Xi} (5%) --- ▪ PC_{Xi} (7%) -- ▪ PC_{Xi} (8%) --- ▪ PC_{Xi} (10%) --	**Kcal/kg**
P_{Fuel}	Weight of fuel consumed, i.e. :PC_{Xi} (4%) --- ▪ PC_{Xi} (5%) -- ▪ PC_{Xi} (7%) -- ▪ PC_{Xi} (8%) -- ▪ PC_{Xi} (10%) --	kg
η	Stove efficiency	(%)

2.2.9. Method for determining Gross Calorific Value (GCV)

By definition, Gross Calorific Value (GCV) is a quantity that represents the absolute value of the enthalpy variation (amount of heat at constant pressure) of the total (and air) combustion reaction of a hydrocarbon compound with formation of water vapor.

The Gross Calorific Value (GCV), at constant volume, of a fuel represents the amount of heat released by the combustion of the unit of mass of the fuel:

-In oxygen saturated with water vapor, the products reacting and the products formed being at the same temperature,

- In the same enclosure, the water formed being liquid.

2.2.9.1. Approach adopted for the calculation of the SGP of savannah grass briquette

There are several methods to determine PCS, but in this research work we will use the PCS prediction methods developed by Thipkhunthod et al. 2005; Chang et al. 1997, taking into account the MS content of 4%, 5%, 7%, 8% and 10% briquettes in the binder. The correlation between MS content and PCS is as follows:

PCS= 0.006 M. S + 15.20 (MJ)

3. RESULTS

The results summarized are the most convincing results for each type of briquette regardless of the binder content. Table 8 below summarizes the results of all the different tests carried out.

Table 8. Summary of laboratory results

Fuel	**PCI moyen (kcal/kg)**	**PCS moyen (kcal/kg)**	**Average consumption (kg/h)**	**Boiling time (h)**	**Power (W)**	**energy transmitted by fireplace (j)**	**Efficiency (%)**
1) RICE HUSK							
BINDER							
4% rice husk briquette	3452,41	4225,46	0,38	0,79	660,99	1883835	22,07
5% rice husk briquette	3661,25	4224,15	0,42	0,71	738,76	1883835	39,27
10% rice husk briquette	**4789,24**	**4224,33**	**0,36**	**0,75**	**697,72**	**1883835**	**31,53**
2) PLANING SHAVINGS							
a) BINDER							
Briquette of planning chips 5%.	6043,42	6793,99	0,4	0,84	745,7	1883835	39,5
Briquette of planning chips 7%.	5887,51	6824,18	0,41	0,83	624,65	1883835	28,3
Briquette of planning chips 8%.	5700,75	6431,78	0,39	0,83	657,92	1883835	29,7
Briquette of planning chips 10%.	**6252,42**	**7075,48**	**0,36**	**0,80**	**686,72**	**1883835**	**30,5**
3) SAWDUST							
a) BINDER							
5% Sawdust Briquette	**6008,98**	**6698,63**	**0,45**	**0,83**	**632,43**	**1883835**	**24,1**
10% Sawdust Briquette	4917,77	5636, 50	0,43	0,85	621,87	1883835	25,4
4) SAVANNAH GRASS							
a) BINDER							
5% savannah grass briquette	5503,44	6458,00	0,35	1,08	627,95	1883835	58,49
7% savannah grass briquette	5482,53	6511,68	0,37	1	523,29	1883835	51,38
8% savannah grass briquette	5500,75	6136,79	0,365	0,92	570,86	1883835	45,52
10% savannah grass briquette	**5552,43**	**6782,49**	**0,35**	**0,83**	**627,95**	**1883835**	**29,84**
5) CHARCOAL	**6700**		**0,36**	0,85	636,23	**1943824**	**23,74**
6) FIREWOOD	**4350**		0,54	0,84	574,73	1744196	21,04

This table summarizes the results of the various tests carried out in the laboratory to characterize the energy performance of the fuels (briquette with different binder content, charcoal, firewood) studied. Reading the values of the results in this table coupled with databases obtained on the potentiality and durability of the resource (waste to be briquetted) will be sufficient to dictate the appropriate fuel to compete with coal or wood.

3.1 Commentary on this summary table by fuel type

This table informs all the results of the different tests carried out in the laboratory and explains the performance of each fuel (briquette, coal, wood). We will see one by one each fuel:

3.1.1. Rice husk briquette

Three rice husk briquettes with different binder content (4%, 5% and 10%) were manufactured and passed the various tests of water boiling, controlled cooking (boiling time, average fuel consumption), energy efficiency (power, yield, etc.) and determination of physical-chemical characteristics (moisture content, volatile matter, fixed carbon, ash content and deduction of Lower Calorific Value). For these three fuels, the most interesting one is the 10% briquette in binder for the following reasons: it has a high PCI (compared to 4% briquette, 5%), a fuel consumption of 0.36 kg/h (identical with coal), a power and efficiency better than coal but average compared to rice husk briquettes at 4% and 5% in binder. Finally, its boiling time is average compared to briquettes with 4% and 5% binder. Taking these results into account, the rice husk briquette with 10% binder is better than the 4% and 5% binder briquettes. Moreover, its low ICP (4789.24 kcal/kg) compared to that of medium charcoal (6700 kcal/kg) justifies that the 10% rice husk briquette with binder will never be able to compete with charcoal.

3.1.2. Briquettes of planning chips

Four briquettes of planning shavings with different binder content (5%, 7%, 8% and 10%) were manufactured and passed the various tests of water boiling, controlled cooking (boiling time, average fuel consumption), energy efficiency (power, yield, etc.) and determination of physical-chemical characteristics (moisture content, volatile matter, fixed carbon, ash content and deduction of Lower Calorific Value). For these four fuels, the most interesting one is the 10% planning chip briquette in binder for the following reasons: it has a high PCI (compared to briquette at 5%, 7% and 8%), a fuel consumption of 0.36 kg/h (identical with coal), better power, efficiency and boiling time compared to coal and to briquettes of planning chips at 5%, 7% and 8% in binder. Taking these results into account, the 10% planning shavings briquette with binder is better and more efficient compared to charcoal than the other three 5%, 7% and 8% planning shavings briquettes with binder. On the other hand, the purpose of the planning chips depends on the cutting of the wood. As long as the wood is not cut, there is no wood chips and the planning chip briquette does not exist. In short, the planning chip resource is not sustainable and, in this context,, the planning chip briquette cannot compete with coal and wood even if it performs better because its existence is dependent on wood.

3.1.3. Sawdust briquette

Two sawdust briquettes with different binder content (5% and 10%) were manufactured and passed the different tests of water boiling, controlled cooking (boiling time, average fuel consumption), energy efficiency (power, yield...) and determination of physical-chemical characteristics (moisture content, volatile matter, fixed carbon, ash content and deduction of Lower Calorific Value). For these two fuels, the most interesting one is the 5% sawdust briquette in binder for the following reasons: it has a very high PCI (6008.98 kcal/kg) than the 10% (4917.77 kcal/kg), a boiling time (0.83 h) identical to that of coal, a high power compared to coal but a fuel consumption of 0.45 kg/h higher than the 10% (0.43 kg/h) and coal, a power and efficiency better than coal. Taking these results into account, sawdust briquette with 5% binder is better than sawdust briquette with 10% binder. On the other hand, the purpose of sawdust depends on the cutting of the wood. As long as the wood is not cut, there is no sawdust and there is no such thing as a sawdust briquette. In short, the sawdust resource is unsustainable and in this context sawdust briquettes cannot compete with coal and wood itself because its existence depends on wood.

3.1.4. Savannah grass briquette

Four savannah grass briquettes with different binder content (5%, 7%, 8% and 10%) were manufactured and passed the different tests of water boiling, controlled cooking (boiling time, average fuel consumption), energy efficiency (power, yield...) and determination of physical-chemical characteristics (moisture content, volatile matter, fixed carbon, ash content and deduction of Lower Calorific Value). For these four fuels, the most interesting one is the 10% savannah grass briquette in binder for the following reasons: it has a high ICP compared to other briquettes with 5%, 7% and 8% in binder, a boiling time (0.83 h), a fuel consumption and a better efficiency than coal. Taking these results into account, the 10% savannah grass briquette in binder is better than charcoal. Moreover, the potentiality of the savannah grass resource is significant with a dry matter content reaching 10 to 15 tMS/ha/year. It is therefore a sustainable resource. In short, it is the savannah grass briquette that can compete with charcoal and wood not only because of its energy performance but also because of the potentiality of the resource as an invasive species that has no specific use.

4. CONCLUSION

Compared to the current government's policy of applying the policy of diversification of energy sources, the result of this research work proves that the 10% savannah grass briquette in binder is the most efficient compared to energy wood and briquettes of rice husk, planning shavings and sawdust. Replacing wood energy at household level with 10% savannah grass briquettes in binder is possible because of its energy performance in terms of fuel consumption, power, yield and boiling time. Strategies must be adopted to achieve this, among others: household awareness raising, transfer of briquette production technology, and the implementation of a government policy that would make it possible to combine the planting of these savannah grasses with reforestation with a view to restoring the country's image of the former "green island".

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