SAVANNAH GRASS BRIQUETTE, A REAL ALTERNATIVE TO WOOD ENERGY. CASE OF THE REALITIES OF THE IHOROMBE REGION IN MADAGASCAR

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ABSTRACT

Ihorombe, one of Madagascar's 22 regions, located in the southern part of the country. It is ranked among the poorest localities on the island, with 80.7 per cent of the population, slightly more than the proportion of poor people at the national level: 76.5 per cent. Moreover, it is an area with significant resources such as: the ecosystem, livestock, agriculture and special vegetation. For the ecosystem, it has a rich ecosystem, hosting a significant floristic and faunistic biodiversity, but it is subject to various pressures, all of them of anthropic origin, notably in the form of bush fires, wild fires, massive cutting for firewood and coal mining. It has 369,472 ha of natural forests, of which 49,959 ha are protected: the special reserve of Pic Ivohibe, the Kalambatritra nature reserve, part of the Andringitra National Park and part of the Midongy forest. The savannas of the plateaus occupy 2/3 of the whole area of the region and are mainly populated by grassy species: the andropogons (haidambo) and the Aristida (horona).

In terms of domestic energy, the majority of households still have a traditional way of life: more than 7 out of 10 households still use collected firewood as the main fuel for cooking. Charcoal is used by 16.1% of households where precious woods such as varongy and rotra are used for coal mining.

The results of various tests carried out at the laboratory of the energy department of the National Centre for Industrial and Technological Research (CNRIT) located in Fiadanana Antananarivo, showed that : firstly, cassava starch is the most interesting binder for agglomerating savannah grass; secondly, savannah grass has a biomass potential of around 10 to 15 t MS/ha/year; thirdly, savannah grass briquettes with 10% binder can compete with charcoal because they have respectively an average ICP of 5552.43 kcal/kg, a fuel consumption of 0.35 kg/h (0.36 kg/h for charcoal) less, a boiling time of 2.5 l of water 0.83 h (0.85 h for charcoal) faster and an efficiency of 29.84% higher than that of charcoal (23.74%). 60.5% of households, divided into three different socio-professional categories (well-off, medium, moderate) who participated in the acceptability test of savannah grass briquettes, are satisfied with the use of these savannah grass briquettes on its cooking capacity and convenience of use.

The substitution of annual charcoal consumption at the level of an urban household in Ihosy district, Ihorombe region by the savannah grass briquette can preserve 0.1 ha of eucalyptus forest, i.e. 908.8 ha/year for the 9088 urban households in Ihorombe region and 611,562, 30 ha/year for all of Madagascar's 611,523 urban households, *which greatly exceeds the forest area destroyed in 2017 according to Global Forest Watch of around 510,000 ha/year, i.e. the disappearance of 3.8% of Madagascar's forests.*

Keyword: *savannah grass, Ihorombe region, energy recovery, fuel briquette, energy efficiency, wood energy.*

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1. INTRODUCTION

In developing countries, the main sources of energy for domestic use are charcoal and firewood. Fuelwood accounts for a significant proportion of the energy consumed in the household. For Madagascar, (92%) of the energy supply is dominated by wood energy (Instat, 2013), (WWF, 2012) and imported petroleum products in their entirety (7%) which meet the three needs that are cooking (94%) of the energy consumed in Madagascar, lighting and electricity (5%) and industry and trade (1%). Moreover, only 15% of the population (5% in rural areas) has access to electricity, which is mainly produced by fossil and hydraulic energy.

Moreover, according to a report by Banjara Hills Consults and the New Energy Policy (NPE), average wood and charcoal consumption in rural and urban areas are not the same: in urban areas, annual charcoal consumption is 125 kg/pers/year, or 0.350 kg/pers/day, while in rural areas, this consumption is 110 kg/pers/year, or 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. From these estimates, an annual consumption of nearly 18.3 million m3 of wood in 2015 can be deduced, shared between

- 56% of firewood collected from natural forests;
- 44% transformed into charcoal through a low mass yield carbonization process (estimated at 12-15%).

At the national level, the demand for wood energy (18.3 million m3 per year) far exceeds the potential for sustainable production (9.169 million m3 per year). Thus, more than 60% of consumption is covered by overexploitation of forest resources. According to the PERR-FH7 REDD+ consortium (Eco-regional Project of the Program for Reducing Emissions from Deforestation and Forest Degradation) between 2005 and 2013, Madagascar would have experienced an annual deforestation rate of more than 1% (i.e. a loss of about 40,000 ha of forest per year), which ranks the country among the most affected by deforestation. Today, less than 21% of the island's surface area is still covered by forests (World Bank, online).

The excessive and inefficient consumption of wood energy, coupled with insufficient production and low carbonization, as well as the search for new agricultural land and mining contribute to the degradation of forest ecosystems (erosion, drying up of water reserves, loss of biodiversity, etc.) and contribute greatly to the increase of the country's greenhouse gas (GHG) emissions.

Given the seriousness of the situation in Madagascar regarding the energy issue on the one hand and the disappearance of forest resources in record time on the other hand, the present research work focused on savannah grasses due not only to its potentiality reaching 10 to 12 t MS/ha/year but also to its invasive character which occupies 2/3 of the surface area of the Ihorombe region.

Ihorombe is one of the 22 regions of Madagascar, located in the southern part of the country. It is a poor region where poverty affects 80.7% of the population. However, it has significant resources that differ from the other regions of the big island, including: the ecosystem, livestock, agriculture and special vegetation.

In terms of domestic energy, the majority of households in the Ihorombe Region still have a traditional way of life. Thus, more than 7 out of 10 households still use firewood collected as the main fuel for cooking. For coal mining, precious woods are used such as varongy, rotra etc. Coal is used by 16.1% of households. Savanna grasses are burnt every year to provide food for cattle, to grow other food crops such as cassava and to remove the traces of zebu thieves after committing acts. Among the questions that arise are the following:

- Savanna grasses have a high rate of dry matter per hectare per year. Is it not possible to use it for energy recovery in the form of fuel briquettes to meet local domestic needs?
- What is the appropriate technology to have fuel briquette, which is ecological, able to substitute wood energy and accepted by all social classes?
- What is the appropriate binder for agglomerating savannah grasses and what is the most significant binder content?
- Can the new energy source resulting from the energy recovery of savannah grasses compete with wood energy?
- What are the various advantages brought by the penetration of this fuel briquette, a new source of energy at the household level in the Ihorombe region and throughout the country?

2. METHODOLOGIES

2.1 Study area: Ihosy district, Ihorombe region

2.1.1. 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

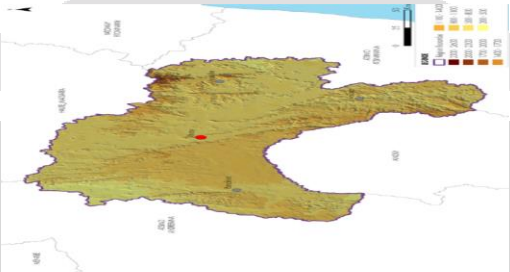

Figure 1: Location of the Ihorombe Region

2.1.2. The climate

There are three types of climate in the Ihorombe Region:

- a humid tropical climate all year round, on its eastern part (districts of Iakora and Ivohibe);
- a semi-humid tropical climate (tending towards semi-arid) on its western part;
- a humid tropical climate with low precipitation in the central part, i.e. in the district of Ihosy.

2.1.3. Plant formations

Three types of vegetation can be found in the region: natural forests, savannahs and vegetation specific to rocky massifs.

a) Natural forests

Natural forests are found in the north-eastern and south-eastern sectors of the region, in the Ivohibe and Iakora districts. These are strips of forest attached to the eastern forest corridors (Vondrozo Forest Corridor and South Midongy Forest). However, these forests, which are confined to the far east of the region, occupy only a small part of the territory. These strips of forest are mostly populated by bryophytes, lichens, ferns or large trees depending on the altitude and relief.

b) Savannahs

The savannah covers most of the region, from the foot of the Vohibory Mountains in the east to the Isalo Plateau in the west. The savannas of the plateau are mainly populated by grassy species: the andropogons (haidambo) and the Aristida (horona). The river beds and wetlands are mainly populated by phragmite bamboos (bararata) and cypressus.

c) Special vegetation

The massifs of Isalo are populated by a rather peculiar vegetation mainly consisting of Uapaca Bojeri (tapia). Other types of special vegetation are found in the gallery forests along the river beds and in the swampy areas.

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 2: Result of comparative study on binders

Parameters	**Cassava flour**	**Cassava starch**	**Clay**
Method of production	Medium	Medium	Easy
Availability	National	Régional	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 demoulding is then carried out thanks to a demoulding 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:

$$\mathrm{MOV} = \frac{\mathrm{M}_{105} - \mathrm{M}_{505}}{\mathrm{M}_{\mathrm{seche}}} \times 100$$

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:

$$\mathrm{TC} = \frac{\mathrm{M}_{850}}{\mathrm{M}_{\mathrm{seche}}} \times 100$$

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

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.

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$$\mathrm{TC} = \frac{\mathrm{M}_{850}}{\mathrm{M}_{\mathrm{seche}}} \times 100$$

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:

$$\mathrm{CF} = \frac{\mathrm{M}_{550} - \mathrm{M}_{850}}{\mathrm{M}_{550}}$$

- 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 [23]. 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 savannah grass compared to charcoal and firewood and for a binder content of 5%, 7%, 8% and 10% depending on the raw material to be agglomerated.

In order to determine the efficiency and energy efficiency of savannah grass briquettes, it is necessary to go through:

- the following different tests: drop test, rotating drum, secability test, flammability test, controlled cooking test and water boiling test;
- determination of the consumption of savannah grass briquettes, charcoal and firewood by using an improved fireplace with a well-defined efficiency;
- determining the power of the improved fireplace by using each savannah grass briquette with a binder content of 5%, 7%, 8% and 10%;
- the efficiency (yield) of the improved fireplace by using each savannah grass briquette with a binder content of 5%, 7%, 8% and 10%.

2.2.5.1. Tests of efficiency and energy efficiency of savannah grass briquettes for binder contents of 5%, 7%, 8% and 10%.

Tests of efficiency and energy efficiency of savannah grass briquettes requires six universally known tests, these are:

- The Drop test;
- The Rotating Drum Test;
- Shear Test;
- The Flammability Test;
- The Water Boiling Test (WBT);
- The Controlled Cooking Test (CCT);

2.2.5.2. Approach adopted for the evaluation of the efficiency and energy efficiency of savannah grass briquettes with a binder content of 5%, 7%, 8% and 10% in relation to an improved hearth with a well-defined yield.

The effectiveness and energy efficiency of each savannah grass briquette compared to charcoal and firewood depend on the result of Water Boiling Tests (WBT) to determine the consumption of each savannah grass briquette and charcoal and firewood by the most commonly used fireplace: the Fatana Mitsitsy (Improved Fireplace) by using the same kettle under the same operating conditions (same quantity 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, he duration of water boiling and 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 WBTs allow to evaluate the consumption of savannah grass briquettes compared to other commonly used fuels (charcoal, firewood).

a) Boiling Water Briquette Water Test with Savannah Grass (B.H.S)

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

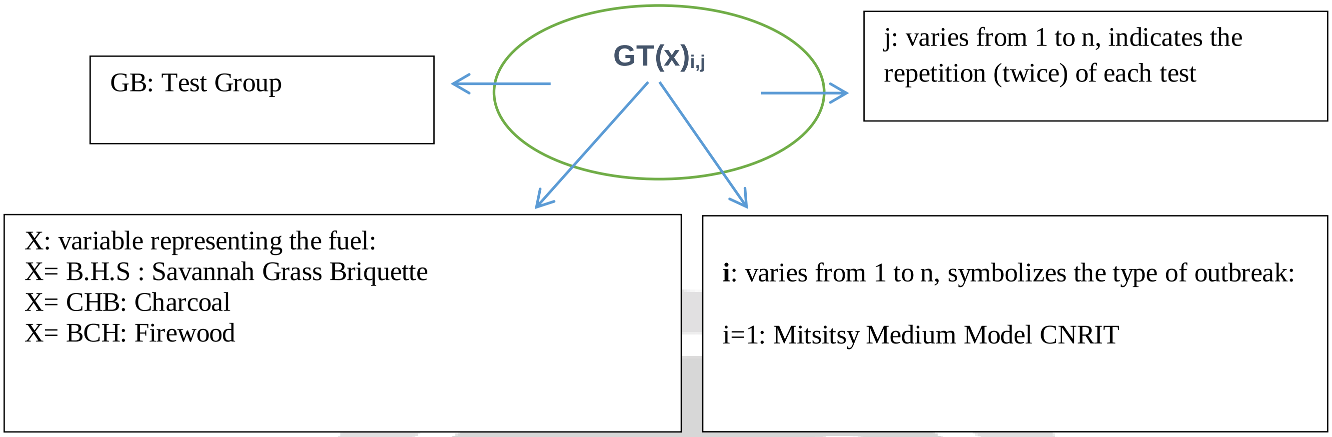

Figure 2: Test group for savannah grass briquettes

These test groups [GT(x)i, j] are distributed as follows:

- The test group using the Savannah Grass Briquette [GT(B.H.S) i, j] with the Mitsitsy firebox comprising: GT (B.H.S (5%))1, j composed by the two tests GT (B.H.S (5%))1,1 to GT (B.H.S (5%))1,2 ;
- The test group using the Savannah Grass Briquette [GT(B.H.S) i, j] with the Mitsitsy heater comprising: GT (B.H.S (7%))1, j composed by both tests GT (B.H.S (7%))1,1 to GT (B.H.S (7%))1,2 ;
- The test group using the Savannah Grass Briquette [GT(B.H.S) i, j] with the Mitsitsy heater comprising: GT (B.H.S (8%))1, j composed by both tests GT (B.H.S (8%))1,1 to GT (B.H.S (8%))1,2 ;
- The test group using the Savannah Grass Briquette [GT(B.H.S) i, j] with the Mitsitsy heater comprising: GT (B.H.S (10%))1, j composed by both tests GT (B.H.S (10%))1,1 to GT (B.H.S (10%))1,2;
- 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 ;
- 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
-

These tests are represented in the form of a matrix table as follows

Table 3: Matrix representation of the 6 test groups, fuels and the Mitsitsy heater

Stove Fuel	Mitsitsy Medium Model (CNRIT)
B.H.S (5%)	GT (B.H.S (5%))$_{1, j}$
B.H.S (7%)	GT (B.H.S (7%))$_{1, j}$
B.H.S (8%)	GT (B.H.S (8%))$_{1, j}$
B.H.S (10%)	GT (B.H.S (10%))$_{1, j}$
CHB	GT(CHB)$_{1, j}$
BCH	GT(BCH)$_{1, j}$

According to this matrix table, the tests are done for 6 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:

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

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 savannah grass briquette of the composition by binding 5%, 7%, 8% and 10%;
- The efficiency or yield of each fireplace by using each savannah grass briquette of 5%, 7%, 8% and 10% binding composition;
- The fuel consumption (in kg/h) of each savannah grass briquette and that of charcoal and firewood.

The realization of each activity will depend respectively on the study materials, the raw materials (fuel, water) available and the technicians for the realization.

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

Power is defined as the derivative of energy over time.

$$P(t) = \frac{dE\ (t)}{dt}$$

-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:

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

And as a result:

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

Table 4: 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 savannah grass briquette as fuel with respective contents of : 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 :

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

For the savannah grass briquette, we will have the following table

Table 5 : Parameter values for the savannah grass briquette

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

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%, 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

3.1. Savannah grass briquette

a) According to binder contents: 5%, 7%, 8% and 10%.

3.1.1. The ICP (min, max) of Savannah Grass briquette according to the binder composition of 5%, 7%, 8% and 10%.

To see the influence of the binder on ICP, four binder compositions were tested in the CNRIT laboratory. The results of these laboratory tests are summarized in the following table.

Table 6: ICP (min, max) of the different binder compositions of savannah grass briquettes

Binder (%)	PCI Min	PCI Max
5	5009,20	5997,67
7	5210,74	5754,31
8	5118,75	5882,75
10	5400,78	5704,07

3.1.2. Average PCI Savannah Grass briquettes at 5%, 7%, 8% and 10% in binder

The following table gives the value of the average ICP of the briquette at 5%, 7%, 8% and 10% in binder.

Table 7: Average ICP of different compositions in binder for savannah grass briquettes

Binder (%)	PCI Min	PCI Max	PCI average
5	5009,2	5997,67	5503,44
7	5210,74	5754,31	5482,53
8	5118,75	5882,75	5500,75
10	5400,78	5704,07	5552,43

This table shows that the higher the binder content, the better the average ICP.

b) According to the fine matter content

3.1.3. The ICP (min, max) of Savannah Grass briquette according to the fine matter content of 25%, 36%, 50%, 73% and 80%.

To see the influence of fine matter on the ICP of savannah grass briquettes, grass briquette samples with five fine matter compositions were made. The following table summarizes the results of the laboratory work

Table 8: ICP min/max of the five fine material content values

Fine Matter (%)	PCI Min	PCI Max
25	5009,18	5701,28
36	5210,74	5754,31
50	5327,74	5704,07
73	5118,75	5882,75
80	5380,21	5997,67

This table informs the value of the PCI Min, Max for the five fine material values

3.1.4 The average ICP of Savannah Grass briquette according to the fine matter content of 25%, 36%, 50%, 73% and 80%.

The following table gives the value of the average ICP of the briquette at 25%, 36%, 73%, 8% and 10%) in fine matter.

Table 9: Average ICP of different fine matter compositions of savannah grass briquettes

Fine Matter (%)	PCI Min	PCI Max	PCI Average
25	5009,18	5701,28	5355,23
36	5210,74	5754,31	5482,53
50	5327,74	5704,07	5515,91
73	5118,75	5882,75	5500,75
80	5380,21	5997,67	5688,94

This table shows that the higher the binder content, the higher the average ICP.

3.1.5. Curves of variation of minimum and maximum ICP of Savannah Grass briquettes according to binder and fine material composition.

a) Influence of the binder on the ICP

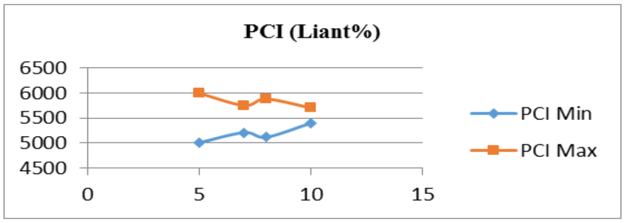

Figure 3: Influence of binder on ICP

b) Influence of fine matter on ICP

The following figure shows the influence of fine matter on the ICP of savannah grass briquettes.

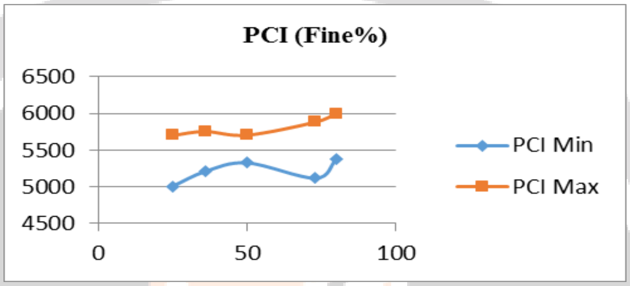

Figure 4: Influence of fine matter on ICP

This figure informs whether it is PCI Min or PCI Max, the higher the fine matter content, the higher the PCI.

c) Influence of Binder Content on Volatile Matter and Fixed Carbon

The binder contents have an influence on the volatile matter and the fixed carbon. Table 13 informs about this influence.

Table 10: Influence of binder contents of savannah grass briquettes on volatile matter and fixed carbon.

Binder (%)	CF Max	CF Min	IMV Max	IMV Min
5	52,17	41,28	26,10	19,01
7	48,08	41,20	31,53	25,82
8	43,09	39,81	27,18	22,72
10	51,58	47,39	21,95	18,76

The influence of binders on volatile matter and fixed carbon is shown in Figure 5 below.

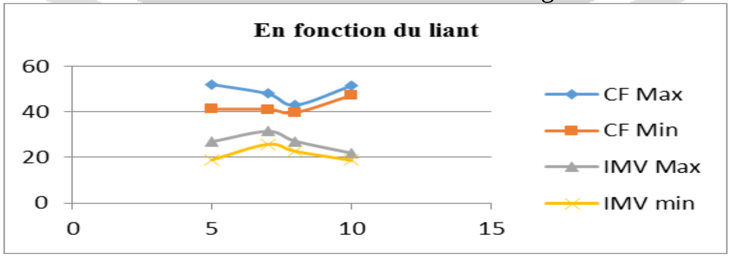

Figure 5: Influence of fine matter on ICP

This figure shows that the variation in binder content has an influence on fixed carbon and volatile matter. A binder content of around 8% is the worst value for fixed carbon. On the other hand, a binder content of 7% results in a poor fuel with a high volatile matter content.

d) Influence of Fine Matter Content on Volatile Matter and Fixed Carbon

The fine matter content has an influence on the Volatile Matter and Fixed Carbon. The following table informs about this influence.

Table 11: Influence of the fine matter content of savannah grass briquettes on volatile matter and fixed carbon.

Fine Matter (%)	CF Max	CF Min	IMV Max	IMV Min
25	49,06	41,28	24,29	20,38
36	48,08	41,20	31,53	25,83
50	51,58	43,67	23,45	18,76
73	43,09	39,81	27,18	22,72
80	52,17	47,78	25,99	20,53

Figure 6 shows the influence of fine matter on volatile matter and fixed carbon.

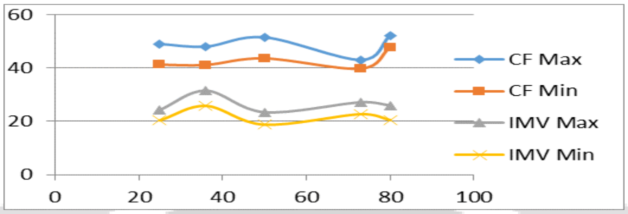

Figure 6: Influence of fine matter on volatile matter and fixed carbon.

3.1.6. The curves of variation of the minimum and maximum PCS of Savannah Grass briquettes according to the binder and fine material composition.

a) Variation of the PCS for 5%, 7%, 8% and 10% in binder

The variation of binders influences the PCS. The following table informs about this influence.

Table 12 : Influence of binders on PCS

Binder (%)	PCI Min	PCS Max	PCS Average
5	6001,59	6914,41	6458,00
7	6500,80	6522,55	6511,68
8	6104,46	6169,12	6136,79
10	6680,33	6884,64	6782,49

The following figure informs about the influence of binders on PCS

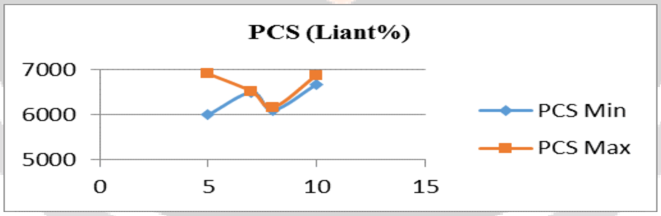

Figure 7: Influence of binder on PCS

b) Change in PCS for 25%, 36%, 50%, 73% and 80% in Fine Matter

Fine matter influences the PCS. Table 13 provides information on these influences.

Table 13: Influence of fine matter composition on PCS

Fine Matter (%)	PCS Min	PCS Max
25	6001,59	6057,56
36	6500,80	6522,55
50	6680,33	6884,64
73	6104,46	6169,12
80	6832,18	6914,41

Figure 8 shows the influence of fine materials on the PCS.

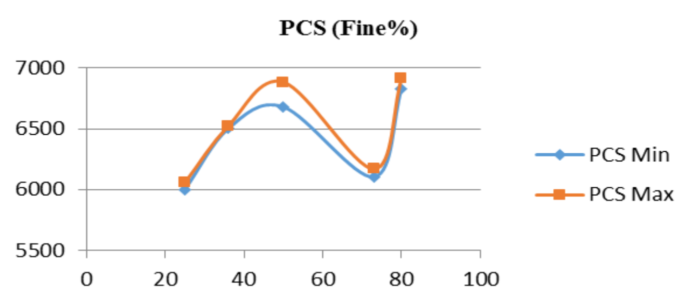

Figure 8: Influence of fine materials on PCS

3.1.7 PCS/PCI ratio Average

Table 14 summarizes the PCS/PCI ratio by binder content.

Table 14: PCS/PCI ratio by binder content

Liant (%)	PCI Min	PCI Max	PCI Average	PCS Average	PCS/PCI Average
5	5009,2	5997,67	5503,44	6458,00	1,17
7	5210,74	5754,31	5482,53	6511,68	1,19
8	5118,75	5882,75	5500,75	6136,79	1,12
10	5400,78	5704,07	5552,43	6782,49	1,22

This table shows that the average PCS/PCI ratio is in the range of 1.12 to 1.19.

3.1.8. Energy efficiency of 5%, 7%, 8% and 10% savannah grass briquettes in binding compared to charcoal and firewood.

This section informs the results of the different tests and energy efficiency of savannah grass briquettes in relation to charcoal and firewood. The following table summarizes the respective results:

- of the fuel consumption test of savannah grass briquettes with a binder content of 5%, 7%, 8% and 10%;
- of the power of each fireplace by using savannah grass briquettes with a binder content of 5%, 7%, 8% and 10%;
- of the output of each fireplace using the 5%, 7%, 8% and 10% binder content savannah grass briquettes.

In addition, the table highlights the comparison of the performance of each fuel including savannah grass briquettes as well as charcoal and fuel wood.

Table 15: Summary of the results of the different energy efficiency tests of savannah grass briquettes with charcoal and firewood.

Fuel	**PCI (kcal/kg)**	**PCS (kcal/kg)**	**Average consumption (kg/h)**	**Boiling time (h)**	**Power (W)**	**Energy transmitted by the stove (j)**	**Efficiency (%)**
SAVANNAH GRASS							
- BINDER CONTENT							
5%	5503,44	6458,00	0,35	1,08	627,95	1883835	58,49
7%	5482,53	6511,68	0,37	1	523,29	1883835	51,38
8%	5500,75	6136,79	0,365	0,92	570,86	1883835	45,52
10%	**5552,43**	**6782,49**	**0,35**	**0,83**	**627,95**	**1883835**	**29,84**
WOOD CHARCOAL	**6700**		**0,36**	0,85	636,23	**1943824**	**23,74**
FUEL WOOD	**4350**		0,54	0,84	574,73	1744196	21,04

Taking into account this summary table and analyzing these parameters one by one, we can say that :

- Firstly, from an ICP point of view, charcoal has a higher ICP than that of the savannah grass briquette and firewood regardless of the binder content;
- Secondly, from the fuel consumption point of view, it is the savannah grass briquette with 5% and 10% binder that is the most interesting (0.35 kg/h) compared to charcoal (0.36 kg/h);
- Thirdly, the boiling time of 10% savannah grass briquettes with binder is faster (0.83 h) and very efficient compared to 5% savannah grass briquettes with binder (1.08 h). This puts the 10% savannah grass briquette with binder in 1st place even though the 5% savannah grass briquette has a high ICP.
- Fourthly, from the point of view of life and yield, the 10% savannah grass briquette with binder is the most interesting compared to charcoal and firewood.

In short, the 10% savannah grass briquettes in binder are the best placed to compete with charcoal and fuelwood because they have a fast boiling time, low fuel consumption and high efficiency respectively compared to charcoal and fuelwood. In this context, the 10% savannah grass briquette in binder is the fuel that can compete with charcoal.

4. Advantages brought by the penetration of savannah grass briquettes in urban households in Ihosy district, Ihorombe region.

Benefits may be in both quantifiable and non-quantifiable forms. From the quantifiable point of view, the respective assessment of the weight equivalent of annual charcoal consumption for a single household and the area of forest preserved by this substitution will provide the quantifiable benefits. In this part, we will try to evaluate the equivalent weight of charcoal substituted by all the households of the Ihorombe region as well as the forest preserved in one year by these households.

4.1 Equivalent in weight of the annual charcoal consumption per household substituted by the savannah grass briquet

Taking into account respectively that:
- the average per capita consumption of charcoal at the national level is estimated at 100 kg/year, i.e. an average of 600 kg/household/year;
- the average Lower Calorific Value (LCV) of eucalyptus charcoal is 6700 kcal/kg;
- the average Lower Calorific Value (LCV) of the savannah grass briquette is 5552.43 Kcal/kg;
- the following relationship: $m1*PCI1 = m2*PCI2$, where:
  - m1= mass of eucalyptus charcoal consumed/year by 1 household and;
  - m2 = equivalent mass of eucalyptus charcoal consumed/year by 1 household and substituted by the savannah grass briquette;
  - ICP1 = Average Lower Calorific Value (LCV) of eucalyptus charcoal;
  - ICP2 = Average Lower Calorific Value (LCV) of the savannah grass briquette.

Thus, after calculation, it was found that: $m2 = 6700*600/5552.43 = 724.01$ kg/year/household.

This means that the charcoal equivalent mass is: 724.01 kg/year/household. This means that if a household uses savannah grass briquette instead of charcoal, this household needs 724.01 kg/year of savannah grass briquette for its annual energy needs.

4.2. Area of forest preserved corresponding to the equivalent in weight of the annual charcoal consumption per household substituted by the savannah grass briquet

Taking into account:
- data from the Taolagnaro Forest Center (TFC) in 2005 where: "1 ha of eucalyptus forest produces 200 35 kg bags of charcoal" i.e.: 200 kg*35 kg = 7000 kg of charcoal;
- that the yield of traditional millstone charcoal is 10%, i.e. for 100 kg of green wood, there will be 10 kg of charcoal.

Thus, taking into account these data, we can draw that:

-for 1 hectare of eucalyptus forest, we will have 70,000 kg of green wood.

Referring to the previously obtained result that the equivalent mass of eucalyptus charcoal consumed/year by 1 household and substituted by the savannah grass briquette is 724.01 kg/year/household, the area of forest preserved can be estimated from the above-mentioned data. After calculation, we found: 0.10 ha/year/household.

In short, the substitution by a household of its charcoal consumption of 600 kg/year by 724.01 kg/year can preserve 0.10 ha of eucalyptus forest/year.

4.3. What are the benefits brought by the penetration of this savannah grass-based briquette at the respective level of households, the commune affected by the project and at the level of the nation as a whole?

Initially, it is the households in the Ihorombe region that first obtain the savannah grass briquettes, as it is in their homes that these savannah grass resources are in abundance, as 2/3 of the area is covered by this biomass.

a) at the household level

Benefits may be in both quantifiable and non-quantifiable forms. From the quantifiable point of view, we have already evaluated the equivalent weight of annual charcoal consumption for a single household and the area of forest preserved by this substitution. In this section, we will try to evaluate the equivalent weight of charcoal substituted by all households in the Ihorombe region as well as the forest preserved in one year by these households.

- **Weight equivalent of charcoal consumed by all households in the Ihosy district of Ihorombe region.**

The National Institute of Statistics (Instat) of Madagascar has given the distribution of households by region in Madagascar for the year 2018, according to the following table:

Table 16: Number and average size of households

Region	Number of households			Average household size		
	Residence Environment			Residence Environment		
	Urban	Rural	Total	Urban	Rural	Total
Ihorombe	9 088	83 410	92 498	4,3	4,6	4,5
Total Region	1 309 912	4 805 711	6 115 623	3,8	4,3	4,2

Source: Provisional Results RGPH-3, INSTAT- CEC, 2018

This table shows that the Ihorombe region comprises 9088 urban households. These households use charcoal for their daily energy needs. According to the result found earlier, one household consumes 724.01 kg/year of savannah grass briquettes instead of 600 kg/year of charcoal. In rural areas, firewood is the most consumed fuelwood in the said region. The following table summarizes the environmental gain by substituting charcoal for the savannah grass briquette.

Table 17: Environmental gain by substitution of charcoal by briquettes of savannah grass by all urban households in the Ihorombe region

Fuel		charcoal	Savanna grass briquette
consumption/year/household (kg/year)		600	724,01
Number of urban households in the Ihorombe region	9 088		
consumption/year/total urban household (kg/year)		5 452 800,00	6 579 802,88
Forest destroyed by coal/household/household/year consumption (ha)	0,086		
Forest destroyed by coal consumption/all urban households/year (ha/an)		781,57	
Preserved forest/household/year (ha)	0,1		
Environmental gain: Forest preserved by use of savannah grass briquette/total urban household/year (ha/an)			908,8

This table shows that an urban household in the Ihorombe region destroys 0.086 ha of forest to meet its annual charcoal needs of 600 kg of charcoal, if the 10% carbonization yield is taken into account. Thus, for the 9088 urban households in the said region, the forest destroyed is 781.57 ha/year. On the other hand, substituting charcoal with savannah grass briquettes will make it possible to preserve 0.10 ha for a single household. Thus, if the 9088 households in the region no longer use charcoal, the preserved forest will be 908.8 ha.

In short, the volume of forest preserved depends on the penetration rate of the savannah grass briquette at the level of each household on the one hand, and on the level of awareness received by each household on the importance of the environment which plays an important role in the life of the population on the other hand.

CONCLUSION

It must be said that the initial objective set has been achieved. Savanna grasses with a high dry matter content in the order of 10 to 15 tMS/ha/year can be valorized in the form of savanna grass briquettes and can be used at household level as a substitute for wood energy. The appropriate technology to dispose of the savannah grass briquettes is densification with the incorporation of manioc starch-based binder. The most popular is the 10% savannah grass briquette in binder, cylindrical in shape, with a diameter of 42 mm, a height of 60 mm and a mass of 80 g. 60.5% of the social strata in Ihosy district are satisfied with its use for their daily culinary habits. The savannah grass briquette is suitable to substitute wood energy because it has the following energy performances: an average ICP of 5552.43 kcal/kg, a fuel consumption of 0.35 kg/h (0.36 kg/h for charcoal) less, a boiling time of 2.5 l of water faster than 0.83 h (0.85 h for charcoal) and an efficiency 29.84% higher than that of coal (23.74%).

The substitution of charcoal by these 10% savannah grass briquettes by binding to an urban household in Ihosy district can preserve 0.1 ha/year of eucalyptus forest, or 908.8 ha/year for the 9088 urban households in Ihorombe region. The questions that arise:

- Firstly, how can this technology be disseminated at the household level throughout the region in the short and medium term, and throughout the country in the long term?
- Second, do all households across the island agree to the use of this briquette? What strategies can be adopted because the greater the penetration rate of this fuel, the more tangible the benefits are.

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