ENERGY AND ENVIRONMENTAL EFFICIENCY OF RICE HUSK FUEL BRIQUETTES. FACTORS INFLUENCING ICP/SCP: CASE OF MOROMBE DISTRICT, ATSIMO ANDREFANA REGION.

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ABSTRACT

The district of Morombe is the rice granary of the Atsimo Andrefana region with 15,675 ha of rice growing area for a production yield of 3t/ha. Paddy rice contains 21% rice husk, which represents a potential resource available at each harvest and which can be used for energy purposes. The rice husk has no particular use other than for cooking bricks for only 3% of these resources.

Given this observation and the high cost and even degradation of local forest resources, the use of rice husks for domestic energy purposes is a local priority. The present research work aims to provide the local population with an ecological, hygienic and alternative source of energy to wood energy from the local resources that is the rice husk.

The methodology adopted for the realization of this work consists of going through the following stages of activities: bibliographical and webographic research, field visits to see first hand the local reality on the availability of the resource to be exploited, surveys on local culinary habits and the processing and analysis of the data collected.

The result of this work has made it possible to have an annual resource of 9,875t in rice husks. The average monthly charcoal consumption per capita is 12.6 kg, or 63 kg/month/household of 5 people. Their culinary habits are very energetic (150 kg/year/capita in charcoal) compared to the national average (100 kg/year/capita in charcoal). The lower calorific value (LCV) of rice husk briquettes varies according to two important parameters: the binder and fine matter content. For a binder content varying from 4% to 10%, the minimum ICP increases from 3512.13 kcal/kg to 4284.77 kcal/kg, but the maximum ICP varies from 3542.13 kcal/kg to 5293.72 kcal/kg. The higher the binder content, not exceeding 10%, the higher the ICP. On the other hand, for fine material with a percentage varying from 25% to 75%, its optimal content is 50% to have a better PCI with a minimum and maximum PCI varying from 3704.73 kcal/kg to 5293.72 kcal/kg. The use of rice husk briquettes instead of charcoal for a household of 5 people will make it possible to preserve respectively every year: 1,008 ha, 0.89 ha and 0.43 ha of eucalyptus forest for rice husk briquettes with a binder content ranging from 4%,5% to 10% binder with an average ICP (4%,5%,10%) of 3452,415 kcal/kg, 3661,25 kcal/kg and 4789,24 kcal/kg respectively.

Keyword *Rice ball, Energy efficiency, Calorific value, Fuel briquette*

1. INTRODUCTION

The Atsimo-Andrefana region, one of the most energy-consuming regions in Madagascar, due to the energetic local dishes causing the high deforestation in this area, is the subject of a study on its energy potential, given that this region has a surface area of 66,236 km2 and has up to 1,247,663 inhabitants in 2011.

There is strong pressure on Madagascar's forests, where less than 10% of natural forests are preserved. The massive use of charcoal and wood fuels is the main cause. Indeed, 98% of Malagasy households use, exclusively or partially, charcoal for domestic needs. However, the imbalance between charcoal consumption and the renewal of ligneous resources through reforestation continues to grow. The phenomenon is particularly observed in the Boeny and Atsimo-Andrefana regions, where charcoal consumption is 50% higher than the national average: 150 kg per year per person in Atsimo-Andrefana, compared to 100 kg per year per person nationally, while reforestation activities are extremely rare. Eventually, wood resources will disappear: by 2030, Atsimo-Andrefana will have exhausted its wood resources.

The development of resources used for energy production contributes to the achievement of several key objectives of this study. These objectives include security of supply, the main goal being to reduce dependence on imported hydrocarbons (oil and gas) and exposure to economic risks; environmental protection by limiting deforestation, as the development of renewable energy is expected to propel Madagascar's industry into the rapidly expanding low-carbon technology sector.

The scientific and technical objectives of this study are respectively to determine: first, the energy and ecological efficiency and effectiveness of briquettes in relation to the use of wood energy; second, to characterize the factors that influence the ICP and PCS of rice husk briquettes; third, to evaluate the forest area saved in the Atsimo Andrefana region by the use of rice husk briquettes, as a source of domestic energy, instead of wood energy.

2. METHODOLOGIES

2.1. Databases and study area: Atsimo-Andrefana region, Morombe district

Located in the South West of Madagascar, the Atsimo Andrefana Region is in the Province of Toliara. Stretching over a coast of 800 km, it is composed of 9 districts and 105 communes.

Its regional capital is Toliara I, which is about 945 km from the capital of Madagascar. The other districts which make it up are the following: Toliara II, West Ampanihy, Ankazoambo, Benenitra, Beroroha, South Betioky, Morobe, 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 km^2, which represents 11.4% of Madagascar's total surface area.

Table 1: area of districts in the Atsimo Andrefana region

District	Area (km^2)
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 rice growing areas of 15,675 ha and a production yield of 3t/ha.

2.1.1. Situation of rice production in the Atsimo Andrefana region

The region's agricultural potential is measured by the availability of 140,800 ha of arable land distributed among the eight (08) districts: West Ampanihy (15 000 ha), Ankazoambo (18 000 ha), Benenitra (5000 ha), Beroroha (15 000 ha), Betioky Atsimo (22 000 ha), Morombe (30 000 ha), Sakaraha (15 000 ha) and Toliara II (20 800 ha). According to data from the 2009 monographic survey, the cultivated area in relation to the cultivable area varies from one district to another in the region. While in Betioky Atsimo District, 84.5% of the arable area is cultivated while in Ankazoabo District it accounts for only 59.4% of the arable area.
The ratio of cultivated area to cultivable area shows a relatively high proportion cultivated at the level of the region, with an average rate of 74.6% against a national average of 51.7%.

2.1.2. Local domestic energy source situation

With regard to the 2010 socio-sanitary indicators, 63.0 per cent of the region's population has access to controlled water. This level is 18.1 points higher than the country's rate of access to controlled water, which is 44.9 per cent. With regard to access to electricity, 12.2 per cent of the region's inhabitants use electricity as their main source of lighting. This is close to the national usage rate. However, with regard to the type of toilet, only 10.3 per cent of the region's population use a latrine (or better) compared to 39.8 per cent for Madagascar as a whole.
Table 2: Distribution of households by main type of fuel used for cooking

Fuel used by households	Atsimo Andrefana région (%)	Madagascar (%)
Collected wood	67,3	77,7
Wood purchased	12,2	4,5
Charcoal	20,1	17,1
Gaz	NS	0,2
Electricity	0,1	0,2
Oil	0,1	0,1
Others	0,2	0,2
Total	100	100

2.2. Laboratory work to determine Calorific Value (ICP/PCS):
2.2.1. Manufacture of briquettes from rice husk
The briquettes manufactured were based on two main factors:
- the variation in binder content ranging from 4%, 5% and 10%;
- the variation in the fines content of 25%, 50% and 75%. It should be remembered that rice husk has a high mineral matter content and a low dry matter content.

(a) The binder and choice of binders

Binders are used to agglomerate raw materials to facilitate compaction of solid fuel. Binders play an important role in fuel quality. They can make it more or less brittle, slow down combustion, increase smoke...
Generally, binders come from organic waste such as :
- Paper and cardboard waste,
-Flour waste,
-Cassava starch,
- Corn starch.

Clay can also be used, and synthetic binders such as paraffin, heavy oil, waste oil (by-product of the oil industry). But we choose the cheaper binders to avoid the blow up of our finished product.
Binders are only used for the manufacture of large solid fuels such as logs or chips, briquettes.
- Clay:
Clay is made up of minerals and trace elements such as: silica, aluminium silicate, magnesium, calcium, iron, phosphorus, sodium, potassium, copper, zinc, selenium, cobalt, manganese..., which it contains in varying proportions depending on the place of origin.
It comes in different colours: green, red, blue, yellow, grey, white, pink... its colour varies according to the iron oxides it contains. Some are used as natural medicines, for example green clays. And you can get it in the rice fields, in the riverside...

Taking the clay from the rice field does not pose a problem for the soil fertility because the proportion of its mass in relation to the mass of biquette is very small. The value of the "clay" binder is of the order of 10% in a briquette. In addition, the briquette ash will be valued as a fertilizer supplement for sandy soil.
The chemical characteristic of clay: it is a coagulating agent, and can obviously play the role of binder.

- Paper and cardboard:

Concerning paper and cardboard, it is also made up of celluloses and lignins, a natural wood binder. So they behave as a binder when water is added to them to form a paste. Cardboard is everywhere in household and industrial waste, municipal waste. In Madagascar, there are small and medium enterprises that treat paper and cardboard waste, but it is still unexpected because the population continues to throw them away in the surrounding area.
The use of this binder increases the calorific value but it also makes the presence of smoke in a carbonized fuel more or less the same. Indeed they contain volatile matter.

- Heavy oil, waste oil, other by-products of oil refining :

Oils, such as heavy oil, waste oil and other by-products of petroleum refining, can be used as binders or additives to increase the calorific value of the briquette. However, when used, they can cause disadvantages. Like all petroleum products, during the combustion reaction, they give off gases that can pollute the environment other than CO2.

- Wheat flour, maize, manioc starch :

It is a powder consisting of starches of 68 to 72%, water, then gluten, sugar, and fat, and a trace of cellulose. Thanks to the starches, this mixture has the ability to act as a binder when water is added. Wheat flour is sold at 2400 Ariary per kilo. Cassava starch is sold at 2300Ariary per kilo and maize flour at 2600Ariary per kilo. As this type of binder is not free, it is only used as an additive to optimize fuel quality.
Experience has shown that the presence of this product makes the briquette increasingly unbreakable, even when used in small quantities.
In our case, we chose cassava starch as a binder for our fuel briquette because of its availability and affordability.

2.2.2. Determination of the physico-chemical characteristics of manufactured briquettes made from rice husk

To determine the physico-chemical characteristics of a sample of briquettes, our approach is to calculate :
- the moisture (H);
- the ash content (Ce);
- the volatile matter (Vm) content;
- and by deduction the fixed Carbon content (F.C.).
- the determination of the Lower Calorific Value (LCV) and the PCS

Our objective is to know the physicochemical characteristics of these rice husk-based briquettes in order to be able to dictate the quality of the briquettes: a good fuel or not.

(a) Humidity (H):

Dry the container in an oven at 105°C and cool in the desiccator, then weigh.
20g (weighed to the nearest 0.1 mg) of charcoal are placed in a tare box previously dried at 105°C, cooled and weighed. Spread the coal evenly in the container, and place it in the oven heated to 105°C for 1 to 1.5 hours. Remove and place in the desiccator for 30 min and weigh to the nearest 0.1 mg.
Calculation of the humidity from the loss of mass in relation to the initial mass.

(b) Volatile matter (VMI) :

Determine the volatile matter index or VMI, which is the percentage loss in mass, obtained under standard conditions, after pyrolysis heated in the absence of air, excluding the loss in mass due to evaporation at 550°C.

(c) Ash content (C):

Combustion of a test sample in a muffle furnace at 850°C. The ash content is the amount of residue, relative to the mass of the test sample.

(d) Fixed carbon rate (FCR):

It is the percentage of the remainder between ash content, moisture content and volatile matter index.

TCF= 100-(H+C+IMV)

(e) Lower Calorific Value (LCV):

Adoption of the CASSAN empirical formula:
ICP= (100-C)* 80 in kcal/kg

2.4. Efficiency and energy efficiency of rice husk briquettes of 4%,5% and 10% in binding compared to wood energy (coal, wood)

In order to determine the effectiveness and energy efficiency of the bale briquettes, it is necessary to pass through the following tests: Drop test, rotating drum test, shear test, flammability test and water boiling test (WBT).

- **Drop test**: This test is a simulation of the stresses to which the fuel is subjected during transport and handling. It is a universally recognised test for assessing the friability of fuels. This test shows a clear correlation between the binder content and the fuel's ability to resist spalling.
The test consists of dropping all the fuels to be tested from several heights and determining the behaviour of each fuel from each drop height.
- **Rotating Drum Test** : This test is a simulation of the shocks that can occur to the fuel regardless of the rotational movement the fuel undergoes and the conditioning mode adopted before the fuel flows from production to consumers.
This test consists of introducing the fuel into a rotating drum device by varying the number of revolutions of the device while setting the test duration at 1 minute.
- **Shear test**: The shear test is the ability of the briquettes to be fractionated. It is a convenience of use and an important parameter for consumers.
This test consists in fractionating the fuel whatever the desired size.
- **Flammability test**: The flammability test consists of assessing the flammability of briquettes compared to other common fuels. The flammability test is a technical parameter that allows the fuel to be judged in advance on its calorific value. The better the fuel burns, the more correctly the fuel burns and the flames are predominantly blue in colour showing that the fuel is well consumed and the unburned and losses are only very small. On the other hand, if the flame is yellowish and with a small proportion of bluish colour, which shows that the unburned is important and other factors must be taken into account to avoid this situation.
It is from the boiling water test that the above situation can be assessed.
- **Water Boiling Test (WBT)** : In order to evaluate the performance and energy efficiency of briquettes alone or in relation to other commonly used fuels such as charcoal and firewood, it is necessary to carry out water boiling tests at high and low power (actual condition of use of fuels and fireplaces per household) and to assess from these tests the flammability time (ignition time) of each fuel, their behaviour in relation to the fire and the fireplace used (improved fireplace) as well as the possibility of using the unburnt fuel (fuel remaining during a TEE) for a new firing.
Fuels (wood waste briquettes, charcoal and firewood) were tested with the most widely used fireplace in Madagascar: improved fireplace (fatana mitsitsy medium model). The performance of the briquettes will be deduced from the results of the tests, taking into account the different assessments made concerning the flammability time, their behaviour in front of the fire and the hearth as well as their aptitude to be able to reuse the unburnt material from each water boiling test.
- **Controlled Cooking Test (CCT):** This is a test used universally to determine the ability of briquettes to cook the various culinary dishes most consumed in the country.

2.4.1. The energy efficiency of rice husk briquettes of 4%, 5% and 10% in binding compared to wood energy (coal, wood)

2.4.1.1. Calculation method for the determination of fuel consumption (in kg/h) rice husk briquette, charcoal, firewood

2.4.1.2. Approach adopted for evaluating the effectiveness and energy efficiency of rice husk briquettes in relation to a well-defined improved hearth.

The effectiveness and energy efficiency of the rice husk briquette compared to other fuels depends on the result of Water Boiling Tests (WBT) which determine the consumption of briquette and other usual fuels (charcoal and firewood) by using the most commonly used fireplace: the Fatana Mitsitsy (Improved Fireplace) using the same kettle under the same operating conditions (same amount of briquette and the same kettle for each test).
Moreover, it is from this Water Boiling Test (WBT) that the parameters for each fuel can be evaluated:
o Flammability test or ignition time ;
o Fire behaviour;
o The duration of water boiling ;
o The possibility of using the unburnt fuel (fuel remaining during a TEE) for a new firing.
The methodology adopted for carrying out Water Boiling Tests (WBT) using the most commonly used furnace (Fatana Mitsitsy) consists of carrying out Water Boiling Tests (WBT). These WBTs allow to evaluate the consumption of coconut wadding briquette and wood waste briquette compared to other commonly used fuels (charcoal, firewood).
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 :

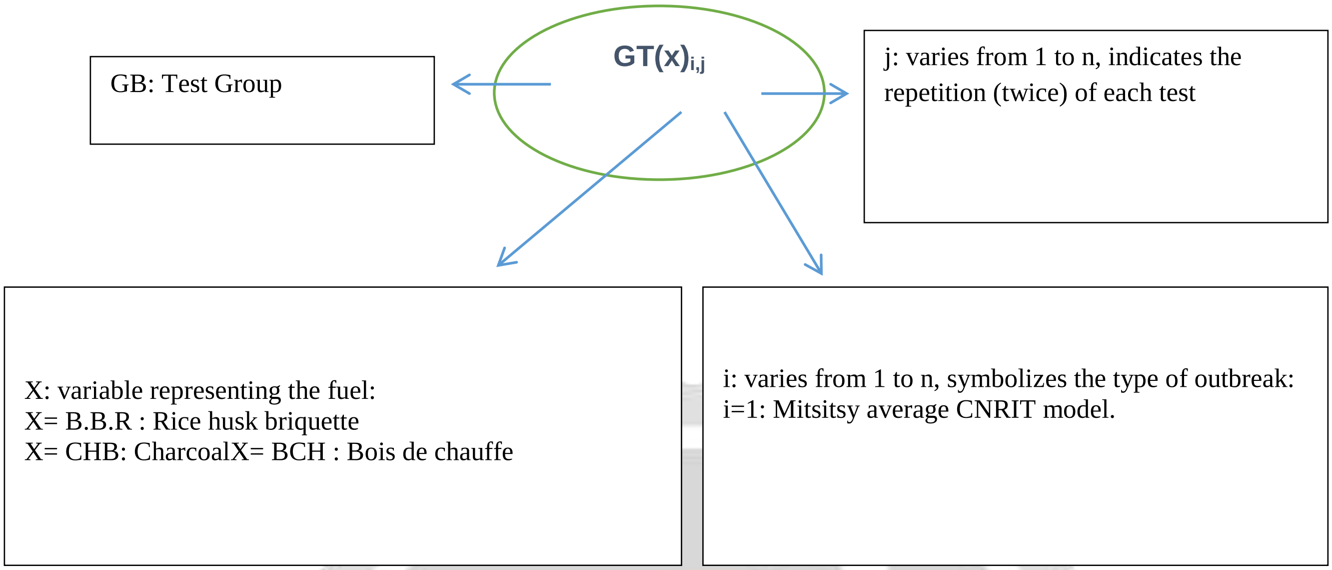

Figure 1: Rice husk briquettes Test Group

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

- The test group using the Rice Ball Briquette [GT(R.B.B.B.) i, j] with the Mitsitsy focus comprising: GT (R.B.B. (4%))1, j composed by the two tests GT (C.B.B. (4%))1,1 to GT (C.B.B. (4%))1,2.
- The test group using the Rice Ball Briquette [GT(R.B.B.B.) i, j] with the Mitsitsy firebox comprising: GT (R.B.B. (5%))1, j composed by the two tests GT (R.B.B. (5%))1,1 to GT (S.B.B. (5%))1,2
- The test group using the Rice Ball Briquette [GT(R.B.B.B.) i, j] with the Mitsitsy firebox comprising: GT (R.B.B. (10%))1, j composed by the two tests GT (R.B.B. (10%))1,1 to GT (R.B.B. (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

Table3: Matrix representation of the 5 test groups, fuels and fireplaces

Foyer / Fuel	Mitsitsy Moyen Model (CNRIT)
B.B.R (4%)	GT (B.B.R (4%))$_{1,j}$
B.B.R (5%)	GT (B.B.R (5%))$_{1,j}$
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 made for 5 test groups with two replicates each,

a) Calculation method for the determination of the fuel consumption (kg/h) of rice husk briquette of 4%, 5% and 10% binder as well as charcoal and firewood

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

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

AVERAGE FUEL CONSUMPTION = 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 furnace by using the composition briquettes by binding 4%, 5% and 10%;
- The efficiency or yield of each furnace by using rice husk briquettes of 4%, 5% and 10% binding composition.
- fuel consumption (in kg/h) of rice husk briquettes and charcoal and 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.

- The power of each hearth is increased by using rice husk briquettes with a binding composition of 4%, 5% and 10%:

Power is defined as the derivative of energy versus 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 temperature 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:

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

Where:

C_{eau}	Mass heat of the water	4180 J/kg. °C
L_{eau}	Latent heat of vaporization of water	2260000 J/kg
$M_{eau\ initiale}$	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	Seconde
P	Power of the hearth	Watt

- The efficiency (yield) of each household through the use of rice husk briquettes with a binding composition of 4%, 5% and 10% :

The evaluation of the efficiency of the household is based on the yield calculation.

By definition, the efficiency is the ratio between the energy transmitted from the furnace to the kettle and the energy contained in the fuel burned.

Let it be:

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

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

3. RESULTS

3.1 Results

3.1.1. Minimum and maximum net calorific value (net calorific value (NCV))

According to the different binder contents (4%, 5%, 10%) of the rice husk briquettes, the ICP (min, max) per binder composition is summarized in the following table

Table 4: ICP (min, max) of different compositions when binding rice husk briquettes

Designation	**PCI min**	**PCI max**	**PCI min**	**PCI max**	**PCI min**	**PCI max**
Binder content	4%		5%		10%	
Ash content (%)	58%	55,72	57%	51,86	46%	33,82
PCI (min, max) kcal/kg)	3362,7	3542,13	3471,50	3851,00	4284,77	5293,72

This table informs the minimum and maximum ICP of rice husk briquettes according to the ash and binder content of each briquette. It should be remembered here that the rice husk has a high mineral content, which is why briquettes with a high binder content have a high ICP. This is why the ICP (10%) is higher than the ICP (5%) and the ICP (4%).

3.1.1.1. Average ICP briquettes and ratio of ICP charcoal to ICP of rice husk briquettes to (4%,5%,10%) by binding

According to the experimental tests carried out in the laboratory of the Energy Department of the National Centre for Industrial and Technological Research (CNRIT), the composition of each sample is not the same from one test to another, therefore, two values (minimum, maximum) were obtained for the result of : PCI

The following table also informs about the average minimum and maximum ICP.

Table 5: Average PCI briquettes and ratio between PCI briquettes and PCI charcoal

Designation	**Charcoal**	**Rice husk briquette**	**Percentage of ICP rice husk briquette versus ICP charcoal**	**Ratio PCI briquettes/PCI charcoal**
PCI (kcal/kg) min (4%)		3362,7	50,19	0,50
PCI (kcal/kg)max (4%)		3542,13	52,87	0,53
PCI moyen (4% by binding) (kcal/kg)	**6700**	**3452,415**	**51,53**	0,52
PCI (kcal/kg) min (5%)		3471,5	51,81	0,52
PCI (kcal/kg)max (5%)		3851	57,48	0,57
PCI moyen (5% by binding) (kcal/kg)		**3661,25**	**54,65**	0,55
PCI (kcal/kg) min (10%)		4284,77	63,95	0,64
PCI (kcal/kg)max (10%)		5293,72	79,01	0,79
PCI moyen (10% by binding) (kcal/kg)		**4789,24**	**71,48**	0,71
Average				**0,59**

This table also shows the ratio of ICP briquette to average charcoal. It should be noted that the average of this ratio PCI briquette /PCI charcoal is: 0.59, i.e. the PCI briquette is 0.59 times the PCI charcoal.

3.1.1.2. Comparative study of ICP and fuel consumption (charcoal, rice husk briquettes)

a) Initial (zero) status of charcoal consumption per household

In its initial state (zero), local households in Morombe district use charcoal as a source of domestic energy. On average, a person consumes 12.6 kg of charcoal per month. The following table summarizes the average monthly and annual consumption of a household of the same size as : 5 (national average).

Table 6: Initial charcoal consumption per person per household per month and per year

Designation	**charcoal**
Monthly consumption per person (kg/person/month)	12,6
Monthly consumption per household (kg/month)	63
Annual consumption per household (kg/year)	750
Average charcoal ICP (kcal/kg)	**6700**

b) Current status: Replacement of charcoal by rice husk briquettes

In the present state where coal is replaced by rice husk briquettes, the consumption per person per day, per month and per year has changed according to the binder content varying from 4% to 10%.the following table informs about the related consumptions.

Table 7: Consumption of charcoal equivalent in a 5-person household by replacement of charcoal in rice husk briquettes of different composition '4%, 5% and 10%'

PCI briquette (min, max)	**PCI min**	**PCI max**	**PCI min**	**PCI max**	**PCI min**	**PCI max**
Binder content	4%		5%		10%	
Equivalent monthly charcoal consumption per person (kg/person/month)	25,10	23,83	24,32	21,92	19,70	15,95
Equivalent monthly charcoal consumption per household (kg/month)	125,52	119,17	121,59	109,61	98,512	79,74

Equivalent annual charcoal consumption per household (kg/men/year)	1494,33	1418,64	1447,50	1304,86	1172,76	949,24

This table shows that if a person has used rice husk briquettes with 4% binder content and with an ICP min as fuel instead of charcoal, he or she consumes 25.10 kg charcoal equivalent instead of 12.6 kg (initial state), i.e. substituting 12.6 kg charcoal per month by 25.10 kg will result in monthly savings of wood corresponding to these 12.6 kg, i.e. 126 kg if the carbonization yield is 10%.

3.1.1.3 Environmental impact (preservation of forest resources) through the use of rice husk briquettes instead of charcoal for a household of 5 people living in the study area

Charcoal substitution at the household level has several advantages in several areas :

- At the household level, the budget allocated to domestic fuel will be reduced and this will enable them to improve their source of income and their living conditions by eliminating the smoke emitted by the use of wood energy;
- At the study area level, the forest resources still available in the study area will be preserved;
- At the national level, the environment in general is healthy and ecological.

The following table tries to provide information on the preservation of forest resources due to the replacement of wood energy by rice husk briquettes for a household of five people for a period of one year, taking into account the carbonization yield (10%) and the eucalyptus wood productivity (7000 kg/ha).

Table 8: Annual forest conservation by a 5-person household using rice husk fuel briquettes instead of charcoal

Designation	Forest area (ha)	Eucalyptus wood productivity (kg)
Annual forest loss per household using charcoal	1,071	7500
Annual forest preserved per household using medium-ICP rice husk briquette (4%) (ha)	1,008	7055,03
Annual forest preserved per household using medium-ICP rice husk briquette (5%) (ha)	0,89	6224,82
Annual forest preserved per household using medium-ICP rice husk briquette (10%) (ha)	0,43	2992,26

This table shows that if the 5-person household uses only charcoal, it destroys 1,071 ha of eucalyptus forest each year. On the other hand, if it substitutes charcoal with rice husk briquettes with 4%.5% and 10% binder, it will preserve 1.008 ha, 0.89 ha and 0.43 ha of eucalyptus forest each year, respectively, taking into account that 1 ha of eucalyptus forest contains 7000 kg of wood and the charcoal equivalent consumption of the average ICP briquettes in the following Table 6,

Table 9: Summary

Designation	charcoal	**Rice husk briquette with a binder content**		
		medium PCI (4%)	Average PCI (5%)	Average PCI (10%)
onsumption/pers/month (kg)	12,6	24,45	23,06	17,63
consumption/household/month (kg)	63	122,26	115,29	88,13
consumption/household/year (kg)	750	1455,50	1372,48	1049,23
PCI average (kcal/kg)	**6700**	**3452,415**	**3661,25**	**4789,245**
Annual area of forest destroyed (ha) per year by charcoal/household use	**1,071**			
Annual area of forest preserved/household using rice husk briquette (ha)		10008	0,89	0,43

3.1.1.4. Factors affecting the ICP of rice husk briquettes

Three different factors were studied to determine their effect on the ICP of rice husk briquettes. These are the binder, the fine matter content and the volatile matter content.

a) Fine matter content

As the rice husk contains a high mineral content, which means low levels of lignin, cellulose and hemicellulose. The Dry Matter content is very low. Therefore, the incorporation of fine matter with rice husk briquettes is very important to have a good quality rice husk briquette. The question is: is there a limit to the amount of fine matter that can be added to a rice husk briquette?

The results of the tests have shown that: a fine matter content of 50% is the maximum limit not to be exceeded. Below or above this value (50%), the ICP of rice husk briquettes is low. The following graph provides information on this situation;

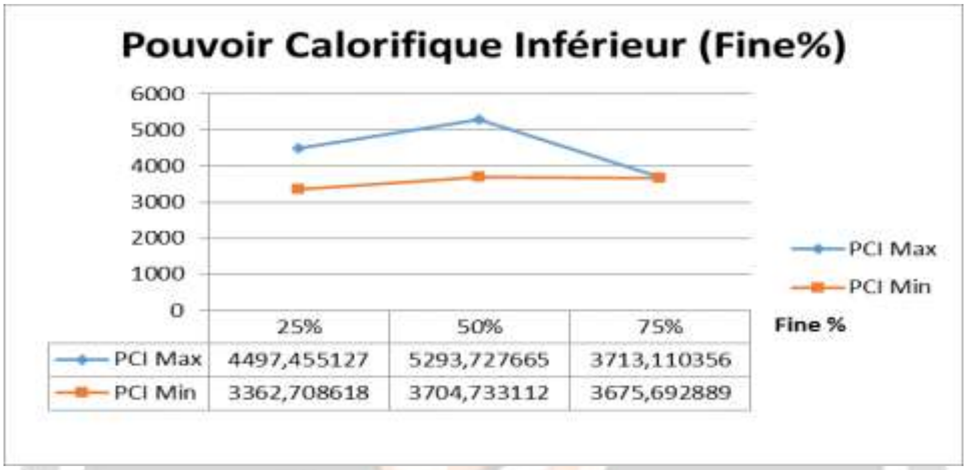

Figure 2: Evolution of the ICP of rice husk briquettes as a function of fine material.

b) Binder content

Three experimental tests by variation of the binder content were carried out at the CNRIT laboratory. The results of these tests showed that the higher the binder content, the higher the ICP of the corresponding rice husk briquettes. This justifies the low dry matter content of the rice husk. In short, if the raw material lacks dry matter, it is the binder content that influences the performance of the fuel in terms of cohesive quality. The following graph justifies this situation.

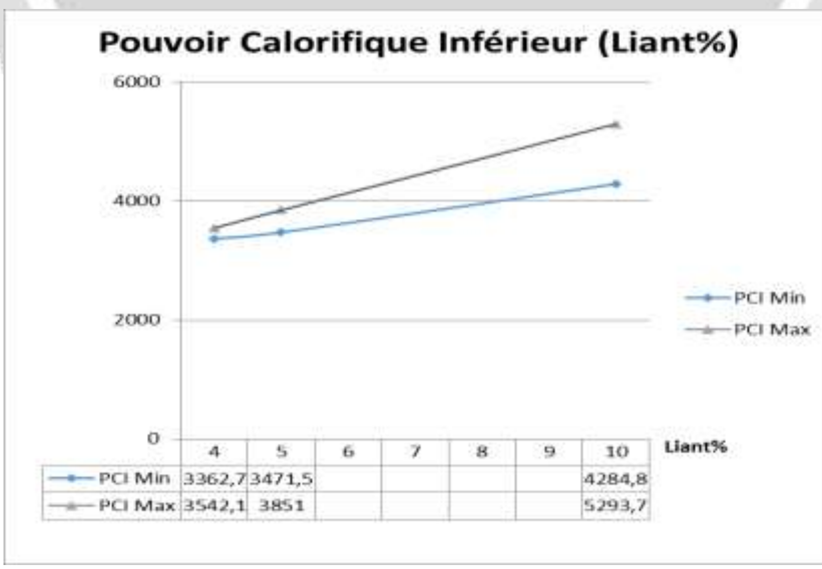

Figure 3: Evolution of the ICP of rice husk briquettes as a function of binder.

c) Volatile Matter Content

From a practical point of view, volatile materials are the products that pollute the environment. The more volatile matter in a fuel, the more harmful it is to the environment. All greenhouse gases (GHGs) are found in volatile matter. The most efficient way to use it is to reduce its volatile matter content. The result of this research work has shown that the higher the binder content, the higher the volatile matter content. The following table and graph informs about this situation

Table 10: Evolution of Volatile Matter as a function of binder content.

Liant (%)	Matière Volatile Max (%)	Matière Volatile Min (%)
4	9,9	7,95
5	11,28	8,19
10	**30,83**	**10,76**

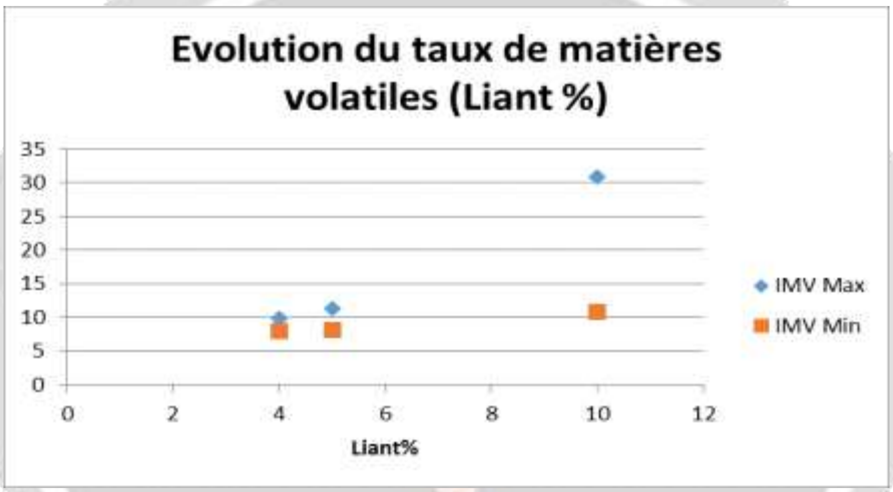

Figure 4: Evolution of volatile matter as a function of binder content

3.1.2. Superior Calorific Pouvoir (PCS)

By definition, the 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 quantity of heat released by the combustion of the unit mass of the fuel:

- In oxygen saturated with water vapor,
- The reacting and formed products are at the same temperature,
- In the same compound,
- The water formed being liquid.

3.1.2.1. Approach adopted for the calculation of the PCS of rice husk briquettes

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(Dry Matter) content of the 4%, 5%, and 10% briquettes in the binder. The correlation between MS content and PCS is as follows:

PCS= 0.006 MS + 15.20 (MJ)

a) Calculation of the PCS value (min, max) of the briquettes according to the binder content of: 4%, 5% and 10% binder content

Depending on the binder content (4%, 5%, and 10%), the different PCS values (min, max) are summarized in the following table.

Table 11: PCS (min, max) for 4%, 5%, and 10% in binding rice husk briquettes

4% in binders	5% in binders			10%in binders	
4225,479	4223,792	4224,516	4223,702	4223,320	4225,150
4225,456	4224,243	4224,699	4223,724	4223,348	4225,444
4225,473	4224,309	4223,904	4223,628	4223,243	4225,499
4225,487	4224,247	4224,628	4223,812	4223,165	4225,005
4225,565	4223,732	4224,663	4223,861		4225,299

This table shows the different PCS values for each binder content.
From this table, the respective values of PCS min and PCS max for each binder content of each fuel were derived.
Table 12: Values of PCS min and PCS max for each binder content of rice husk briquettes
Binder PCS Max PCS Min

% Binder	PCS Max	PCS Min
4	4225,565	4225,456
5	4224,699	4223,702
10	4225,499	4223,165

This table shows the minimum and maximum PCS of rice husk briquettes for binder compositions of 4%, 5% and 10%. It can be seen that regardless of the binder content, the value of the PCS min and PCS max is almost the same with some error.
In short, regardless of the value of the binder content of the rice husk briquettes, this has no influence on the value of the PCS min or PCS max. The following figure shows the small change in the PCS (min, max)

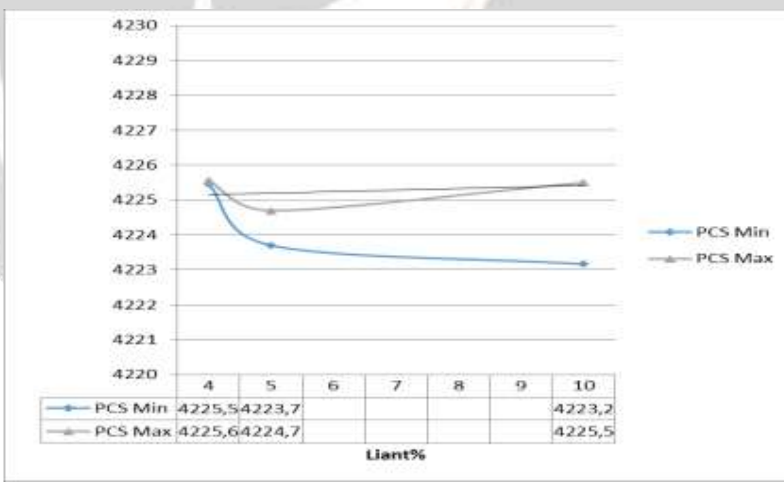

Figure 5: Evolution of PCS min and PCS max according to the binder content of the briquettes

b) Calculation of the PCS value (min, max) of the briquettes according to the fine particle content of 25%, 50%, and 75%.

For contents of fine particles in rice husk briquettes, the results of the laboratory tests are summarised in the following table
Table 13: PCS value according to fine particle content: 25%, 50%, and 75%.

Fine %	PCS Max	PCS Min
25%	4224,309	4223,165
50%	4225,499	4223,904
75%	4223,861	4223,628

This table shows the minimum and maximum PCS of rice husk briquettes for binder compositions of 4%, 5% and 10%. It can be seen that regardless of the binder content, the value of the PCS min and PCS max is almost the same with some error.

In short, regardless of the value of the binder content of the rice husk briquettes, this has no influence on the value of the PCS min or PCS max. The following figure shows the small change in the PCS (min, max)

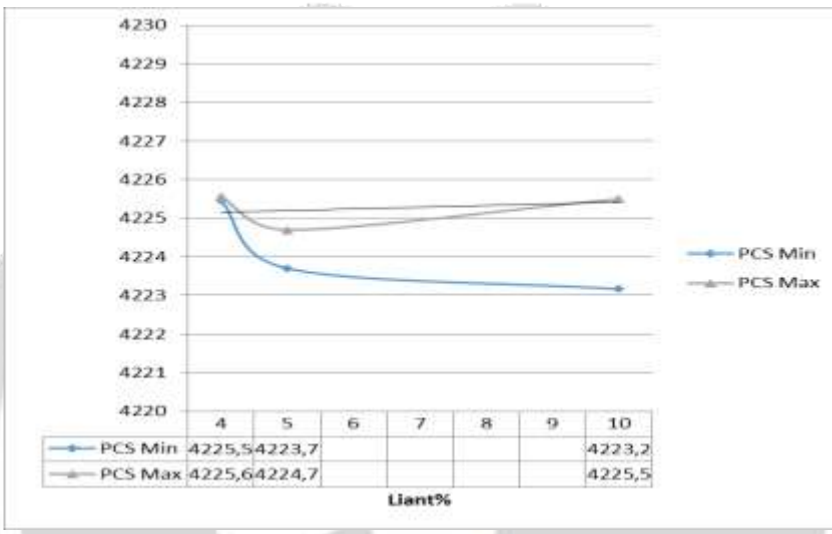

Figure 6: Evolution of PCS min and PCS max according to the binder content of the briquettes

3.2 Energy efficiency of rice husk briquettes compared to charcoal and firewood

This part tries to show the efficiency of rice husk briquettes at different concentrations compared to charcoal and firewood. To do this, you have to go through the following different activities:

- make a fuel consumption test (BBR 4%, 5% and 10 %.);
- calculate the power of each fireplace using rice husk briquettes at 4%, 5% and 10% ;
- Evaluate the efficiency of each household using the 4%, 5% and 10% rice husk briquettes.
- To make a comparative study of the results obtained allowing to classify each rice husk briquette of different compositions by binding (4%, 5%, and 10%) with wood energy.

The following table tries to summarize the results of the fuel consumption test (rice husk briquette, charcoal, firewood), the power of the fireplace by the use of each type of fuel as well as the energy transmitted to the fireplace by the fuel as well as the respective yield.

Table 14: Summary of the results of the different tests: consumption, power, efficiency and transmitted energy

Fuel	average consumption (kg/h)	Boiling time (h)	Power (W)	Energy transmitted by the hearth (joule)	Yield (%)
4% rice husk briquette	0,38	0,79	660,99	1883835	22,07
5% rice husk briquette	0,42	**0,71**	**738,76**	1883835	**39,27**
10% rice husk briquette	0,36	0,75	697,72	1883835	31,53
Charcoal	**0,34**	0,85	636,23	**1943824**	**23,74**

Firewood	0,54	0,84	574,73	1744196	21,04

This table presents respectively:
- Average fuel consumption: Compared to the five fuels, charcoal consumes the least fuel, followed by rice husk briquette with 10% binder, then rice husk briquette with 4% binder and finally firewood. In short, it is fuelwood that is the largest consumer of fuel;
- the boiling time which informs the time it takes for each type of fuel to boil the 2.5 kg of water. The 5% briquette which has the best performance with 0.71 h ;
- The 5% rice husk briquette has the highest power with 738.76 watt; Taking into account the high value of the fire power of the 5% binder briquette, we can say that the fact of having this power has allowed this briquette to have the 1st place, i.e. the fastest boiling time;
- the energy transmitted by the hearth of which charcoal has the highest energy compared to other fuels ;
- the efficiency of the hearth whose first place is for the rice husk briquette 5%.

3.3. PCS/PCI ratio

The following table summarizes the relationship between PCS and ICP.

Table 15: PCS/PCI ratio

% Binder	PCS Max	PCS Min	PCI Max	PCI Min	PCSMax/PCI Max	PCSMin/PCI Min
4	**4225,56**	**4225,45**	**3542,13**	**3362,70**	**1,192**	**1,256**
5	4224,69	4223,70	3850,97	3471,47	1,097	1,216
10	4225,49	4223,16	5293,72	4284,77	0,986	0,985

This table shows that the PCS/PCI ratio decreases as the binder content increases.

CONCLUSIONS

Taking into account the results of this research work, the substitution of wood energy, particularly charcoal, at the household level is beneficial in several areas not only for the households themselves but also for the study area and the country as a whole. For the households affected by the use of rice husk briquettes, the substitution of charcoal by this fuel is interesting because it will make it possible to preserve 1,008 ha, 0.89 ha and 0.4.3 ha of eucalyptus forest per year and per household of 5 persons respectively, depending on the binding agent content of each rice husk briquette. This is a significant advantage for them as it is a forced saving that affects their living conditions. For the study area, the valorization of rice husks, which has no previous use, has a particular advantage because it is not only an alternative fuel to wood energy but also a contribution to the reduction of greenhouse gases emitted by cooking with wood energy in households. It is therefore a contribution of the population residing in the study area to the reduction of Global Warming Potential (GWP) on the one hand, and on the other hand to the preservation of forest resources that can initiate the abundance of rainfall in the study area. Finally, for the country, this preservation of forest resources ranging from 1.008 ha to 0.4.3 ha reduction per household and per year according to the composition of the binder, is of particular interest because the environment and energy go hand in hand and in synergy. Preserving the environment is one of the priorities for the country with a view to restoring Madagascar's image of yesteryear: "Green Island, island of fragrance".

5. REFERENCES

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