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Chapter

Sustainable Energy Model for the Production of Biomass Briquettes Based on Rice Husks in Peruvian Low-Income Agricultural Areas

Juan Arévalo, Grimaldo Quispe and Carlos Raymundo

Abstract

An energy model focuses on the sustainability of environmental proposals that use clean biomass technology. In this case, briquette production seeks to generate socio-environmental development in agricultural areas contaminated by the burning of rice husks. However, this agricultural waste product has a large heating capacity and can be used as a raw material for briquette production, replacing conventional contaminant fuels such as firewood and reducing Peru's annual energy consumption by approximately 833,000 kg of CO_2 per year, considering the minimization of emissions from the felling of trees and the burning of rice husks. These rice husks are burned and generate pollutant gases, causing respiratory and pulmonary problems. Despite these negative effects, it is an agricultural waste product with great untapped energy potential and constitutes an opportunity to promote socio-environmental development based on economic valorization. The level of deforestation would decrease by approximately 2070 trees per year, 23% of a market population which consumes 10 kg of firewood per day. Unlike similar projects, briquette production sustainability may be achieved when economic, environmental and social aspects are included in energy model development, based on the application of clean technology and efficient management of energy supplies, such as husk supplies and corresponding briquettes.

Keywords: biomass, briquettes, circular economy, energy model, socio-environmental, heating capacity

1. Introduction

One problem in the rice industry is the accumulation of rice husks in high volumes, which are charred and thrown into rivers due to little interest in recycling these by-products for industrial sub-processes, thus constituting an opportunity to economically value an agricultural waste product within the value chain of paddy rice. The rice industry has a significant participation in the Peruvian economic sector, as the crop with the greatest contribution to agricultural development and GDP, producing approximately 44.7 million day wages and generating 161,300 jobs per year, representing its strong social and economic influence in rural areas. [1]. **Figure 1** shows the importance of the rice industry in Peru, which figures among the 20 countries with the highest production of paddy rice worldwide, processing a

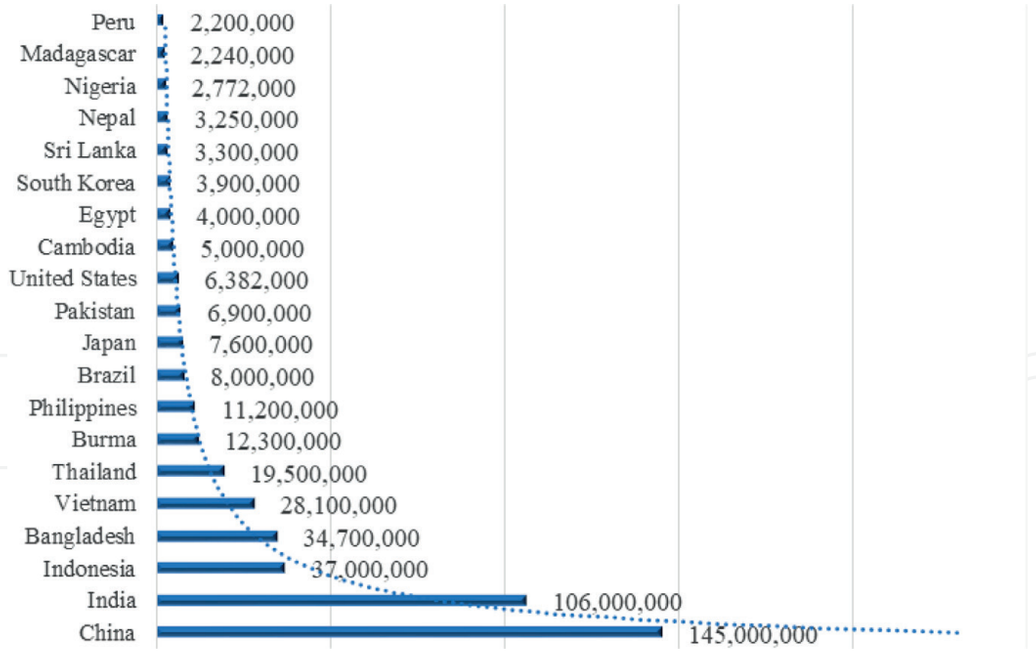


Figure 1.
Hectares of rice husk planted during the 2013–2014 agricultural campaign in Peru.

total of 2200 tonnes during the 2013–2014 agricultural campaign, the second Latin American country in this agricultural sector, since most of the production of this crop is found in Asian countries [2].

At the national level, San Martín is the region with the largest paddy rice area, annually reaching 86,053 hectares in the months of July and August [3]. Within this region, a rice industry company produces 45 tonnes of paddy rice daily; therefore, there is a large supply of rice husks around the mill or in the company's growing areas, many of which are dumped into rivers or nearby roads, harming the local environment and people.

The rice husk represents 20% of total paddy rice production [4]. Approximately 9 tonnes of this agricultural waste accumulates daily [5]. Thus, rice industry companies seek opportunities to recycle these waste products, with the purpose of converting their lineal production into a circular economy, based on the economic valorization of the rice husk through the elaboration of ecological products using clean technology, which does not generate additional costs with respect to obtaining raw material.

Within the concept of a sustainable energy model, several alternatives for rice husk recycling should be analyzed, which is why it analyzed the current situation of the area, where this agricultural waste product is abundant. One of the factors with the greatest environmental impacts is the use of firewood for cooking, exacerbating local pollution, which is currently damaged by burning rice husks. Therefore, biofuels are being developed through scientific research to replace firewood. It was determined that briquettes and pellet biofuels, also known as "ecological coal," have the highest energy efficiency. Both resources have been developed worldwide for projects with similar criticality to the current situation in San Martín regarding deforestation and high firewood consumption in rural and agricultural areas.

The present case determined that the briquette is the best option to replace firewood. Unlike pellets, briquettes may be used in domestic activities, notably in individual boilers, traditional ovens, or fireplaces. These briquettes generate greater opportunities for new markets, since they can be elaborated in different forms and sizes, unlike pellets which are necessarily cylindrical and smaller [6].

Briquette development is by no means a new technology in agricultural areas, where there are many types of biomass or resources for biofuel material. Projects with similar characteristics have already been implemented, from an environmental perspective and with a vision to maximize energy resource use. However, some did not achieve successful results, and not necessarily because of product quality but because of the way in which the proposal was developed. Others were successful but could have had greater economic impacts.

Among the most important aspects regarding briquette proposals is the determination of raw material costs assumed by rice companies and the way in which it would impact their current budget. For example, "Corinay Briquettes" is a producer, exporter, and marketer of coal briquettes, whose initial objective was to exploit the abundance of this resource in rural areas. In addition, it would substitute domestic use of firewood, thus reducing the rate of deforestation in the region [7]. One of the main problems is the increase in the cost of coal, since "Corinay Briquettes" increased its installed capacity to 5000 tonnes per year [8], due to the large supply of briquettes that exists in rural areas, where production is concentrated. In comparison with the present proposal for briquette production under a sustainable energy model, the difference is that the rice husk will have zero costs, at least in the first years of operation.

Another important aspect from other projects is the determination of different briquette production programs. For example, the company "North Wood" established different production scenarios for sawdust briquettes, focusing its business on an analysis of supply and demand, providing knowledge regarding the number of briquettes necessary to satisfy current consumption of the population using firewood in a certain area [9]. Thus, energy model sustainability will focus on the fulfillment of short- and medium-term demands so that different production scenarios may be established which respond to demand variability for this innovative ecological product, as it may succeed based on market acceptance.

Energy model sustainability also focuses on societal acceptance and perception of briquettes. For example, the company "Eco Amazonia" did not succeed in its coconut husk briquette business because the biofuel was sold under the name of "Ecocarbón," with a coal shape and color. For this reason, society perceived that it was not an ecological product, since it was composed of charred coconut husk, which would later generate a large amount of volatile matter [10]. Therefore, the present proposal considers the inclusion of non-charred rice husks for briquette production.

Additionally, one of the main factors within the energy model is determining a specific place where the proposal will be developed. As mentioned above, the San Martín region is an ideal place for briquette production due to its great potential for growing rice husks coupled with high levels of firewood consumption. In this region, the sector with the highest quantity of processed rice is central Huallaga, with a total of 73,343 tonnes, divided between the provinces of Picota, Huallaga, Bellavista, and Mariscal Cáceres. However, the high volume of rice husks is not the only factor for determining the location; it is also necessary to consider environmental awareness of disadvantaged residents. For example, the municipality of San Hilarión, located in the central sector Huallaga, established Municipal Ordinance No. 013-2004/MDSH/A, which prohibits the burning of husks by mill owners. The economic sanction is valued at 2 UIT [11]. The opportunity to invest in clean technology becomes an obligation for several mills in the area; hence, they seek alternatives to recycle rice husks, economically valuing the produced biomass. **Figure 2** presents the regions with the highest rates of environmental pollution due to rice husk burning.

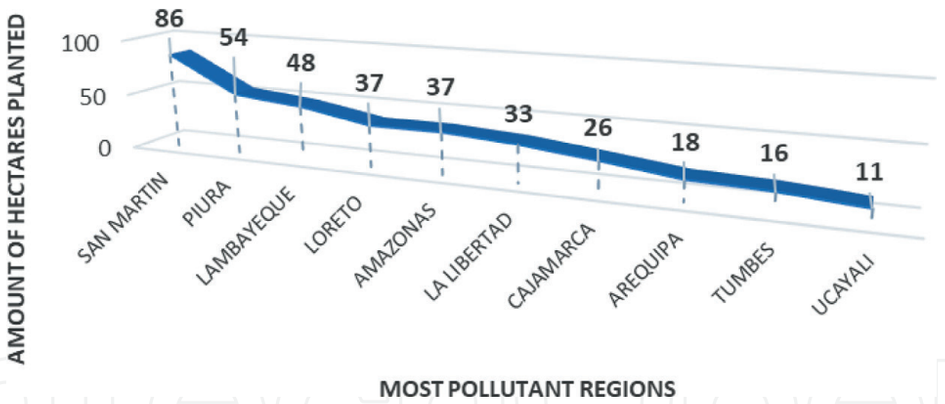


Figure 2.
Environmental pollution due to rice husk burning during 2013–2014 agricultural campaign in Peru.

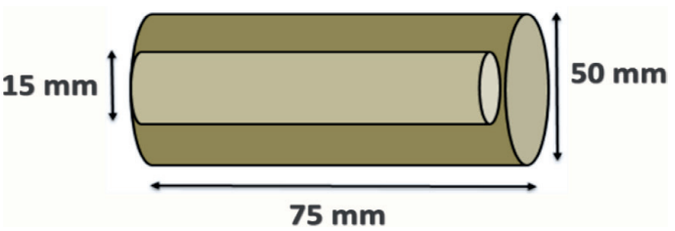


Figure 3.
Dimensions of rice husk briquettes.

As mentioned above, the briquette is not a new technology, so determining briquette design will depend on product use and specifications of the briquette machine. For industrial processes or businesses, lengths vary between 300 and 1000 mm, for producers length varies between 100 and 500 mm, and for domestic sector, length varies between 30 and 80 mm. **Figure 3** shows the ideal prototype of briquettes for domestic use.

The inclusion of an interior hole will endow the briquette with greater oxygenation capacity but could increase volatile matter, so the shape of the product will depend directly on its use, be it industrial or domestic. Another variable is the market approach to briquette production, since it will not necessarily be used as fuel but can also act as a heating resource in locations with low temperatures or may be exported to the European market. Density is another main characteristic, since as it becomes denser; less volume will be occupied, which will mean easier handling, optimum storage, and easier transport, compared to firewood. Its weight should be 1000 kg/m3 [12], and this depends mainly on rice husk density and the pressure exerted by briquette machines. Finally, humidity directly influences heating capacity, for they contain a large percentage of moisture and the energy released is lower during combustion, causing evaporation to consume heat. Humidity should vary between 8 and 10% [13].

2. Method

Within the methodology, the goal is to develop the energy model, which is mainly based on the use of renewable energy and the search for energy efficiency, with the purpose of ensuring sustainability in the proposal, satisfying economic, environmental, and social aspects.

The model begins with the search for alternatives for recycling biomass as an alternative resource to firewood, which is why briquettes emerge as the ideal

biofuel in the environmental proposal development. Briquettes are formed from the conglomeration of various types of waste, may it be forestry, agricultural, or industrial [14], mixed with binders such as cassava starch or bentonite, in order to optimally compact the mixtures. The choice of agricultural waste or biomass as raw material for the briquette was rice husk, due to the high rate of charred husk on location, which will allow for a large supply of this waste, reducing the population's social cost.

Having selected the clean technology, it is necessary to perform a technical evaluation of the briquette based on energy efficiency, which includes calculations of heating capacity and efficiency during combustion. The rice husk briquette has 4040 kcal/kg heating capacity, that is, the amount of heating capacity used per kilogram burnt [15]. Its combustion energy efficiency obtained a value of 80.39%; in comparison to firewood, fewer kilograms of briquettes are needed to heat or prepare food in a shorter time. Additionally, it is important to set out the development method within the technical product evaluation, in order to meet certain technical requirements, such as moisture measurement, through the drying method, which uses the "Colombian technical standard for domestic use briquettes," permitting a value between 9 and 10%. Furthermore, there are two important aspects that were investigated to obtain an optimal briquette, based on adequate biofuel combustion: granulometric analysis and agglomeration analysis. Granulometric analysis is used to achieve a resistant briquette with sound composition, analyzing different sizes of husk particles with metal sieves. On the other hand, agglomeration analysis, using cassava starch as a binder, will be important in balancing mixture resistance and moisture. Various forms have been used, the first of which compresses the briquette with a piston and the second by manual press compression. Thus, a briquette with high quality standards, based on the percentage of moisture, ash, and volatile matter, was obtained.

To ensure the energy model—designed specifically for biomass briquette production proposals—is developed successfully, it is important to establish an integrated process system, starting from the supply and demand analysis process, to briquette commercialization and the opening of new markets. In this analysis, a market study is conducted to determine the population that uses firewood for cooking, as well as the supply of rice husk quantities in the mills. In addition, the sales price is determined, including the profit percentage that the company will earn and estimations of the final proposal budget. Then, it will be necessary to determine the logistics of the proposal's supply chain, beginning with alternatives for rice husk and cassava starch supply, to later produce various production programs based on scenarios of low, medium, and high demand for briquette sales.

Once the production scenarios are determined, a processing plant must be designed, with enough physical capacity to store material for a high demand, considering probable openings to new markets or potential customers, including adequate distribution of machinery, materials, and other physical production resources. The supply chain culminates with the commercialization of briquettes in rural areas where the product will be consumed, considering the necessary resources and transport costs for correct development. For example, the company or mill should include the transport of cassava starch from agricultural areas to the processing plant or the most efficient form of transport for the commercialization of briquettes and rice husks.

Finally, the energy model seeks to be sustainable by ensuring process operability, so the economic, environmental, and social impacts of the briquette production proposal are analyzed. Regarding the economic impact, companies plan to economically value agricultural waste products, which will subsequently generate additional income, entering new briquette markets in both domestic and industrial sectors. Regarding the social impact, quality of life was improved, since inhabitants'

respiratory and lung disease incidence rates decreased, from the reduction of CO_2 produced by burning rice husks and firewood in the domestic sector. **Figure 4** shows the energy model proposed for rice husk briquette production.

Finally, environmental impact was measured by the reduction of CO_2 produced by burning rice husk in paddy fields or around the city and by the minimization of greenhouse gases (GHGs) from substituting wood for briquettes in food preparation.

2.1 Operationalization

As part of process operationalization, a rice husk supply analysis is necessary, which ensures the raw materials meet production demands. For example, San Martín is the region with the highest economic participation in terms of rice industries in Peru, representing 18.49% of annual production in the 2013 agricultural campaign, with a total of 563.99 tonnes of paddy rice. Of the total amount produced, 20% will be converted into husk, meaning large volumes of this agricultural waste product will be burnt, due to limited recycling. **Figure 5** shows the various current uses of rice husk [16], reflecting its potential demand for companies or mills within the regional market. In many agricultural areas of the San Martín region, policies have been established to raise awareness and encourage recycling in other activities, regulated by municipal ordinances prohibiting burning. In addition, from a survey of 100 families in the region, the study concluded that 70% of the population would be willing to substitute firewood for an ecological product, 50% would pay a price equal to that of firewood, and 70% agree that briquettes should be delivered to their homes.

On the other hand, energy model sustainability revolves around the acceptance of demand variability in any successful scenario for briquette sales. For this reason, certain production programs were designed based on briquette machine production capacity. For example, if the market focus is 23% of the firewood-consuming population, mills or companies should produce 69,000 briquettes per month for a total of 92 families, using 13,248 kg of rice husk and 552 kg of cassava starch. Within a supply–demand analysis, the final stock estimate is 36,000 briquettes, which may be distributed monthly to low-income households or be sent to poulterers or bakeries as an alternative source for embers in their ovens.

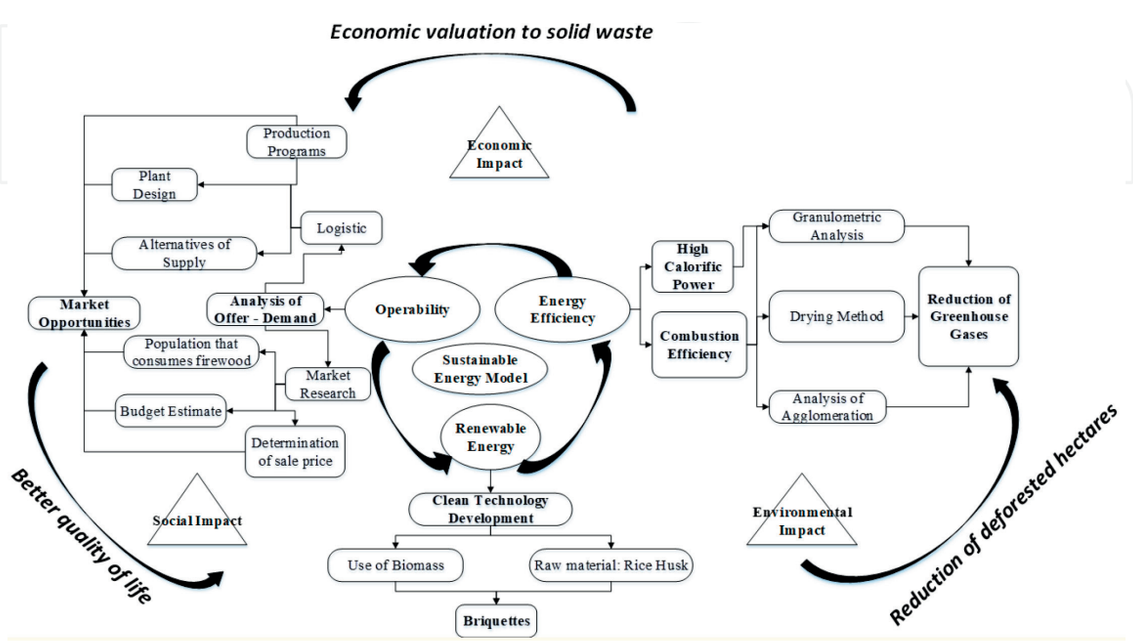


Figure 4.
Sustainable energy model design.

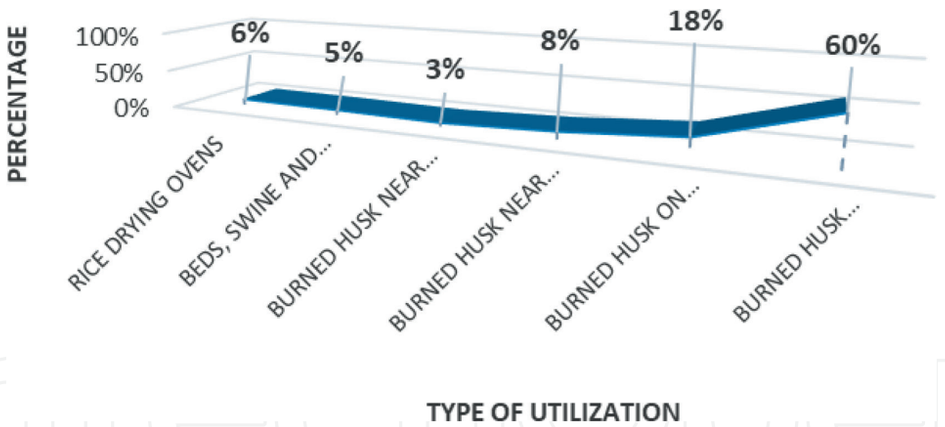


Figure 5.
Utilization of rice husks in agricultural areas of the San Martín region.

However, if at the end of the year a briquette production program is not desired, a second production program can be designed, without the need to change the market focus completely. For example, 20% of the market should initially be addressed between January and July, with a monthly production of 60,000 rice husk briquettes. Subsequently this would increase by 40% from July to December, to supply a total of 112 families with 84,000 briquettes, using the briquette machine's maximum production capacity. Including the final inventories from January to June, this would deplete resources to zero in December. It bears noting that the second production scenario must consider approval and sales success during the first semester.

Note that the proposed briquette machine is of Italian origin—model E60, ECO by Prodeco—which has been used in similar briquette production projects. Its processing capacity is 60 kg of cassava starch and rice husk mix, for a total production of 300 briquettes per hour. Thus, the briquette machine processes a maximum of 2400 briquettes per day. In addition, these machines work 8 hours a day, transforming 1 kg into five briquettes for a market which consumes an average of 5 kg per family. Therefore, a total 25 briquettes per family must be produced for daily consumption, considering the yield equivalence between husk briquettes and firewood.

The briquette production program must consider a processing plant design (see **Figure 6**), with the purpose of strategically distributing the machines and resources corresponding to briquette production. For example, mixing and grinding areas should be separated, because smoke from the grinder must not come into contact with the mixing process of binder and husk.

The production process begins with the selection of raw material, which is comprised of two stages. First, sand, spikes, and residue of different sizes are eliminated using sieves, in the granulometric analysis. The "weighing" process follows, wherein the various resources used during the entire production process are weighed. Next, the "mixing" process, by means of the agglomeration method, combines the rice husk in different quantities. Finally, the mixture is compacted by the briquette machine and passed through the "drying" area, to then be packaged for sale.

2.2 Method

One of the most relevant methods for briquetting is the granulometric method, which is a process of compaction or briquetting by using a piston and a press to reduce mixture structures. However, a briquette machine may also be used,

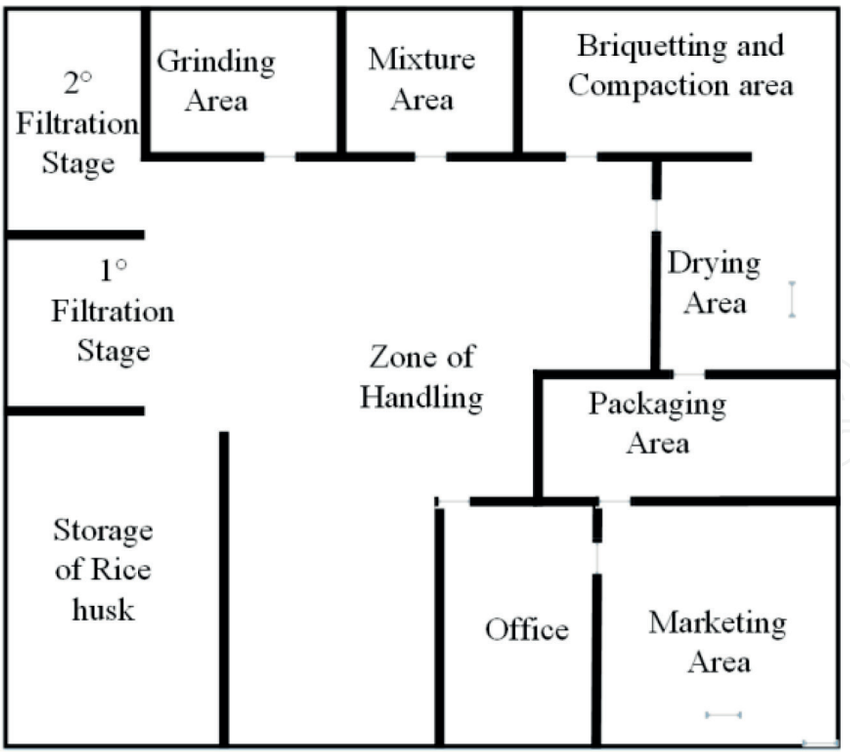


Figure 6.
Design of briquette processing plant.

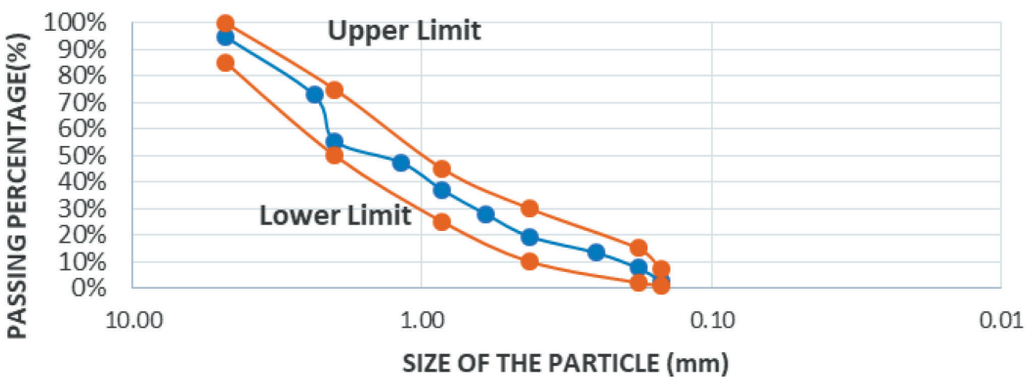


Figure 7.
Granulometry of rice husk particle composition.

optimizing man-hours and increasing production rates. Development methods were performed in the laboratory at the Peruvian University of Applied Sciences (UPC).

The granulometric method is important for proper mixture compaction, since there is a range indicating optimum mixture state; for example, the lower limit indicates a mixture with a larger proportion of finer rice husk, whereas the upper limit indicates a mixture with larger grains. However, if the mixture falls outside the established range, the fine grain mixture will hinder oxygen flow and combustion, whereas if it exceeds the upper limit, the excess oxygen will produce more pollutant gases [17]. **Figure 7** shows the ratio of rice husk particle size necessary for adequate composition. Generally, particle size ranges from 0.10 to 3.00 mm. Composition depends directly on use, for the mixture can be composed of small or large particles, but must fall within this range [13].

The granulometric distribution of the best briquette prototype elaborated in the UPC laboratory is shown in **Figure 8**. This prototype had the greatest energy efficiency, both in terms of correct combustion and heating capacity. This briquette

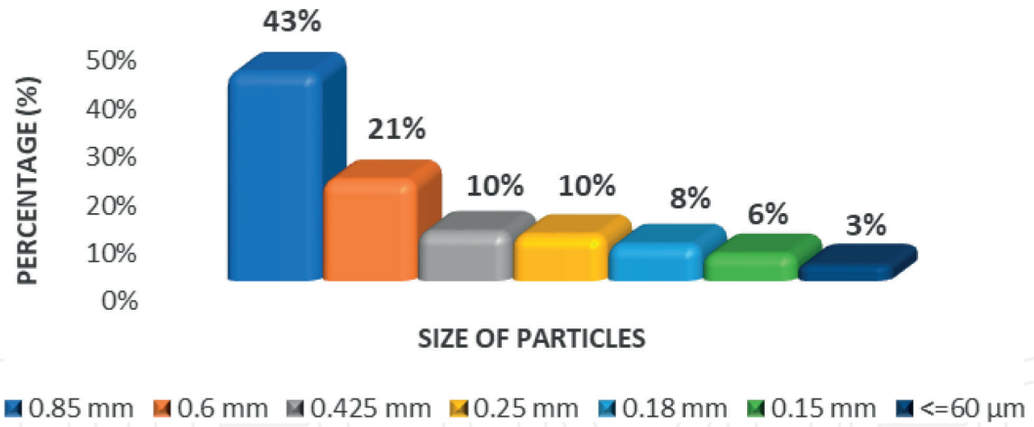


Figure 8.
Granulometric distribution of rice husk particles.

is composed of 0.850 mm particles, as well as smaller particles, making it perfect for briquette compaction using an experimental artisanal method. However, as mentioned above, briquette composition should include particles of different sizes, especially for industrial production, because the briquette machine can compact larger rice husk grains correctly, with an average size of 2.36 mm [18].

Another method within the energy model that will provide sustainability from a technical perspective is agglomeration, which will generate value to briquette production. Agglomeration is the initial mixing stage of cassava starch and water. One liter of water and 200 g of cassava starch were used for this experiment, producing approximately 15 briquettes. The agglomeration process for this type of briquette production was the following, considering the percentage of each input in each stage:

1. Twenty-five percent of cold water is mixed with 200 g of cassava starch and stirred for 2 minutes.

2. Seventy-five percent of the total water is boiled to 100°C.

3. While boiling, the mixture is stirred until adhesive.

4. The adhesive mixture is then added to the rice husk container.

The agglomeration process can be seen in the left section of **Figure 9**, where the entire sequence of general rice husk briquette production processes is also shown, beginning with the "selection" of raw material, comprised of two stages, wherein sand, spikes, and residue of different sizes are eliminated by filtering. The "weighing" sub-process follows, in which the various resources used throughout the production process are weighed. Next, the "mixing" sub-process is performed, by agglomeration of water and cassava starch, which is later combined with rice husk in different quantities. The mixture is then compacted, either by a briquette machine for industrial purposes, or a hydraulic press for experimental artisanal purposes. Finally, the briquettes pass through the "drying" area and are packaged for sale.

It is important to note that both methods—granulometry and agglomeration—produce optimum values regarding combustion efficiency and heating capacity, thus both variables will be measured through the "boiling water test" (BWT), which measures the amount of energy transferred from the biofuel to a pot or container with a certain volume of water [19]. Below are some basic characteristics of the BWT:

- Sufficient quantities of water and fuel for the experiment. The fuel must be uniform and completely dry.

- The volume of cold water must be at least 10% of the total water used for the experiment.

- Temperature is measured at boiling point, because at that moment, temperature can no longer vary nor the amount of transferrable energy.

Another BWT characteristic was biofuel moisture content calculation. This observation is related to that mentioned by Michael Lubwama and Vianney Yiga, in the paper "Characteristics of Briquettes Developed from Rice and Coffee Husks for Domestic Cooking Applications in Uganda" in which they state that the moisture content of any type of biomass must oscillate between 10 and 15%, with a compression force of 230 MPa. In addition, humidity values should oscillate between 9 and 10%, to obtain efficient combustion with fewer gas emissions. However, biomass compression is not the only moisture reduction process; a drying process must also be carried out, in which an electric heater is used to reduce humidity before the mixing process. Calculations referring to different means of calculating moisture content will be shown in the following formulae [20]:

$$\text{MOISTURE \% (wet)} = \frac{(\text{Fuel Mass})\text{wet} - (\text{Fuel Mass})\text{dry}}{(\text{Fuel Mass})\text{wet}} \text{ x } 100 \quad (1)$$

$$\text{MOISTURE \% (dry)} = \frac{(\text{Fuel Mass})\text{wet} - (\text{Fuel Mass})\text{dry}}{(\text{Fuel Mass})\text{dry}} \text{ x } 100 \quad (2)$$

$$\text{MOISTURE \% (wet)} = \frac{\text{MOISTURE (dry)}}{\text{MOISTURE (dry)} + 1} \quad (3)$$

Eqs. 1 and 2 are important in analyzing briquette and firewood moisture content in different states, but the equation that was used, which is more frequent in this type of experimental method, corresponds to a dry base humidity calculation, due to better energy efficiency during combustion. Eq. (3) shows the different moisture content calculations.

As mentioned previously, rice husk moisture content is determined using an electric stove, after having passed the grinding process. Subsequently it is weighed and compared with the value obtained in drying. In Eq. 4 it observes the relationship between rice husks mass in different states of humidity:

$$\text{MOISTURE \% (rice husk)} = \frac{\text{Initial Mass}}{\text{Initial Mass} - \text{Final Mass}} \text{ x } 100 \quad (4)$$

As mentioned above, humidity calculations are important for optimal briquette combustion, based on combustion efficiency and heating capacity. In the study "Briquette Production for Use as a Power Source for Combustion, Using Charcoal Thin Waste and Sanitary Sewage Sludge," the authors describe the relationship between heat lost from the fuel and the heat of the water; thus Eqs. 5 and 6 show the calculations for both variables, including some theoretical values [21].

A 150 convective factor ("H" air-water) was considered for heat loss calculations, denominated "Q lost," since it is the most commonly used value with respect to thermal experiments [22]. Regarding water heat, denominated "Q water," the theoretical value for the specific heat of the water, was considered to be 4.18 J/g°C under normal conditions [23]; this value is represented by the "Cp." In addition, the container in which the test was performed had a diameter of 0.12 m and a height of 0.1 m, so the volume container is denominated "A." The equations necessary to estimate briquette heating values are shown below:

$$\text{Q lost (J)} = \text{A} \times \text{H} \times (\text{final temperature} - \text{initial temperature}) \quad (5)$$

$$Q\,\text{water (J)} = Cp\,\text{water} \times (\text{final temperature} - \text{initial temperature}) \times \text{water mass} \quad (6)$$

Table 1 presents values used in the experiment, considering initial temperatures under normal conditions and boiling point as final temperatures.

The difference between these equations allows us to calculate the approximate amount of heat emitted during combustion, which is divided by the charred mass of the briquette. Eq. 7 calculates heating capacity (HC):

$$HC\ (\text{kcal/kg}) = (Q\,\text{water} - Q\,\text{lost})/\text{burned mass} \quad (7)$$

The equation developed by Estela Assureira [24] was used to calculate heating capacity, in which the resultant briquette mass is related to the mass of the inputs used for its production and the ash content representing each component. In Eqs. 8 and 9, the mass of the inputs added to the composition of the briquette is called "M bc." Note that in the experiment, the addition of another binder is necessary. The proportion of this input and its percentage of ash must be included in Eq. 9.

Finally, it bears mentioning that from the equations shown above, it was possible to calculate estimated heating capacity, humidity, and efficiency values, without the need for heating pumps or other laboratory instruments. However, if the focus

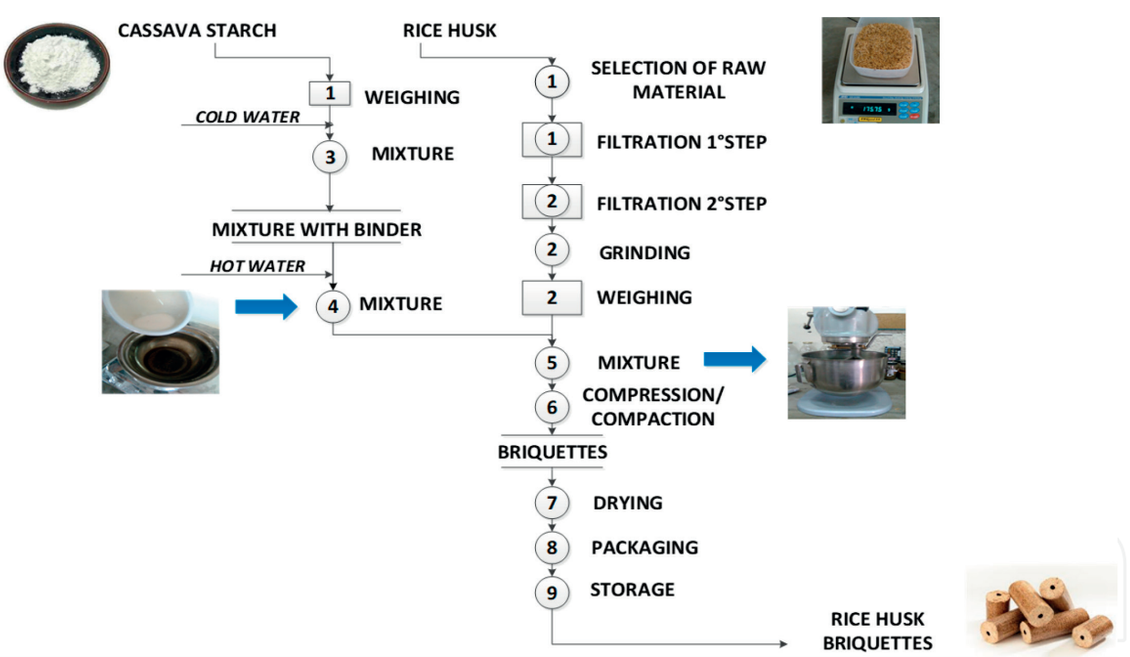


Figure 9.
Rice husk briquette production process.

Characteristic	Value
Final temperature (°C)	100
Initial temperature (°C)	22
Cp water (J/g.°C)	4.18
Container volume (m^3)	0.012
H air–water ($W/m^2.K$)	(20–300)

Table 1.
Experiment characteristics.

of the briquette production proposal was industrial and with a business vision, it would be necessary to use a briquette machine and sophisticated measuring instruments.

$$\text{combustion efficiency (\%)} = (\text{initial mass} - \text{final mass})/\text{mass bc} \quad (8)$$

$$\text{mass bc (kg)} = [\text{mass husk} \times (1 - \%\text{ash})] + [\text{mass binder} \times (1 - \%\text{ash})] \quad (9)$$

3. Results

Experiment results will be analyzed in two ways. The first will be based on the energy analysis of the briquette prototypes and the comparison of their physical–chemical properties with firewood through agglomeration and granulometry methods. The second analysis corresponds to the environmental impact in low-income agricultural areas in Peru, where firewood is used, from the production of rice husk briquettes.

3.1 Energy analysis

The experiment was based on the preparation of various briquette prototypes, considering size, shape, and composition as relevant characteristics for each type, to obtain the greatest energy efficiency—that is to say, a similarity in heating capacity and combustion efficiency.

Table 2 shows that the best briquette prototype is 1, which is referred to as "BR 1," with a heating capacity of 4040 kcal/kg and a combustion efficiency of 80.39%. This briquette is composed of 80% rice husk and 20% cassava starch. Other ingredients are not suitable for making briquettes, such as rubber which increases humidity or bentonite which results in low compaction levels. **Table 2** also shows the physical-chemical characteristics of each briquette prototype, represented by the nomenclature "BR."

Within the results presented in **Table 2**, density is the physical-chemical characteristic relevant to briquette production methods, due to the type of machine used for compaction. For this experimental process, in which a hydraulic press was used, density was greater than that of a briquette machine, due to the greater compression force that machines have (an average theoretical value of 350 kg/m^3, based on statistical data regarding the impact between compression capacity and this type of material) [25]. The results obtained in Ref. [26] showed a very low value of the density. Adding a binder increases moisture content, reducing combustion efficiency, since it is proportional to the increase in density. In addition, they mention an important aspect regarding rice husk transport costs, stating that this cost will be higher due to reduced availability [26].

Agglutinants should be added to artisanal briquettes to better compact the husk and cassava starch mixture. In addition, the cost of transporting the briquettes is always nominal. For the present case, briquette density was 678.7 kg/m^3.

As well as comparing heating capacity between different briquette prototypes, it will be necessary to compare the physical-chemical properties with those of firewood, to determine the advantages of using briquettes. In **Table 3**, a greater heating capacity is observed compared to firewood, since firewood loses a large part of heat energy due to certain properties. Briquettes, however, burn their initial

Characteristic	Components	BR 1	BR 2	BR 3	BR 4	BR 5	BR6
Composition	Rice husk	80	90	75	90	80	80
	Yucca starch	20	0	15	10	10	0
	Bentonite	0	10	5	0	10	0
	Rubber	0	0	5	0	0	20
Shape		Cylindrical					
Diameter (mm)		73	73	53	53	53	73
Height (mm)		22	28	35	30	30	37
Humidity (%)		9.63	10.97	8.23	8.23	9.46	10.86
Bulk density (kg/m^3)		678.7	654.7	604.3	409.5	906.5	963.7
Time of ignition (min)		8	12	10	11	12	10
Heating power (kcal/kg)		4040	4010	3745	4020	4010	3500
Combustion efficiency (%)		80.39	78.13	79.17	76.29	77.14	71.29

Table 2.
Briquette prototype analysis.

Characteristic	Unity	Rice husk briquettes	Firewood
Heating power	kcal/kg	4040	4010
Bulk density	kg/m^3	860	820
Ash	%	1.50	0.92
Humidity	%	9.0	17.4
Fixed carbon	%	15.6	16.8
Volatile matter	%	86.5	82.2
Combustion efficiency	%	80.39	70.40

Table 3.
Comparison of energy characteristics for both fuels.

properties until completely consumed. The briquette has a combustion efficiency value of 80.39%, approximately 10% more than firewood, meaning less fuel would be needed for food preparation.

Figure 10 shows the briquette prototype 1, denominated "BR 1," which obtained a heating capacity value of 4040 kcal/kg and a combustion efficiency of 80.39%.

3.2 Environmental impact analysis

Within the energy model, environmental impact will be measured based on the CO_2 reduction from the use of rice husks in briquette production, as well as gases emitted by firewood for food preparation and the amount of CO_2 produced by cutting down trees.

The first source of CO_2 emissions is the number of hectares deforested due to firewood production; thus, substituting firewood with briquettes will reduce greenhouse gas emissions. The amount of firewood obtained per tree cut was calculated



Figure 10.
"BR 1" rice husk briquette prototype 1.

in a study by the National University San Martín (UNSM) in Tarapoto [27]. Eq. 10 shows the volume of an average tree in the San Martín region, which is 0.32 m^3. Note that the height of the tree is denominated as "commercial H," the coefficient value for San Martín is denominated "Cf," and "AB" was calculated in Eq. 10:

$$\begin{aligned} \text{Volume } (m^3) &= D^2 \times 0.7854 \times \text{commercial H} \times Cf \\ \text{Volume } (m^3) &= 0.302 \times 0.7854 \times 7 \times 0.65 \\ \text{Volume } (m^3) &= 0.3216 \end{aligned} \tag{10}$$

On the other hand, based on the estimated volume of firewood obtained from a tree, which is 0.32 m^3, it was possible to calculate the estimated number of trees that would be deforested. Information was taken from a study by "Tienda Biomasa" of the Spanish company Leñas Oliver SL, which for the sale of its ecological products such as briquettes, pellets, and other biofuels calculated that 1000 kg of firewood is equivalent to 2m^3 [28]. Therefore, if a specific briquette production proposal focuses on 23% of the market, in a population that consumes 27,600 kg of firewood monthly, the volume of firewood obtained would be 55.20 m^3. From the value obtained in Eq. 10, it was estimated that 173 trees would be saved monthly.

In the analysis of trees saved from the use of briquettes, it is important to consider the number of forest hectares that will be protected. In this case, the trees of the San Martín region belong to 50-year secondary forests, according to data extracted by the Moyobamba Forestry Office [29]. Thus, 6 fewer hectares will be deforested per year, according to characteristics in **Table 4**.

Figure 11 shows the exponential relationship between the number of trees saved and the amount of CO_2 emissions that each of them represents. From a study on the environmental impact of firewood, by Peruvian researchers Torres, H. and Polo, C., with the collaboration of scientists Seifert, D. and Neuoetting, D., it has been found that 1 kg of firewood emits 1.83 kg CO_2, since half the wood's mass is carbon (C) and its relation with the molecular weight of CO_2 is 44/12, thus 1 kg of firewood produces 0.5 (44/12 kg of CO_2) = 1.83 kg of CO_2 [30].

As mentioned above, the number of deforested hectares and CO_2 emissions will depend directly on the type of market on which briquette production will focus. In this case, the monthly consumption of 23% of the population of San Hilarión is 27,600 kg of firewood, which represents monthly CO_2 emissions of 50,508 kg. Therefore, 33,120 trees are estimated for a 5-year period; that is to say, the use of rice husk briquettes would reduce CO_2 emissions by almost 10,000 kg.

Finally, in addition to reducing CO_2 emissions by protecting trees, CO_2 emissions will further be reduced with respect to burning rice husks in cultivation areas

or around the city, due to the fact that a considerable amount of this agricultural waste product will be recycled in briquette preparation. From a physical-chemical rice husk analysis by the research group *Gestión Ambiental Sostenible* (Sustainable Environmental Management), formed by environmental engineers Aberlardo Prada and Carol Cortés of the University of Llanos, 1 kg of carbonized rice husk is equivalent to 1.43 kg of CO_2 [31]. Thus, from the number of briquettes produced, the CO_2 reduction from recycling rice husks can be calculated. **Figure 12** shows the relationship between the amount of husk used to make briquettes and the reduction in CO_2 emissions.

Type of forest	Diameter type	Trees/ha
Secondary forest (50 years)	20–30 cm	340
	Over 30 cm	100

Table 4.
Characteristics of forest resources in San Martín.

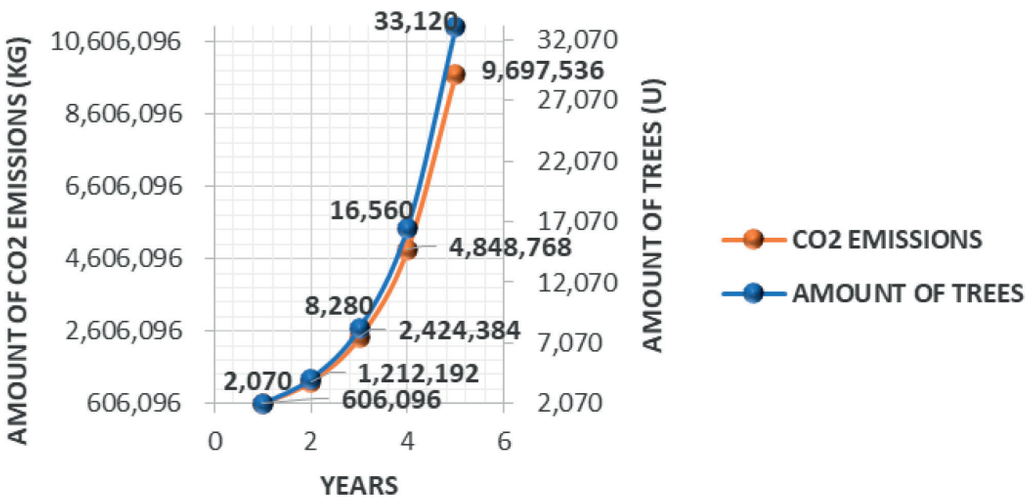


Figure 11.
Amount of CO_2 emissions avoided by not cutting trees.

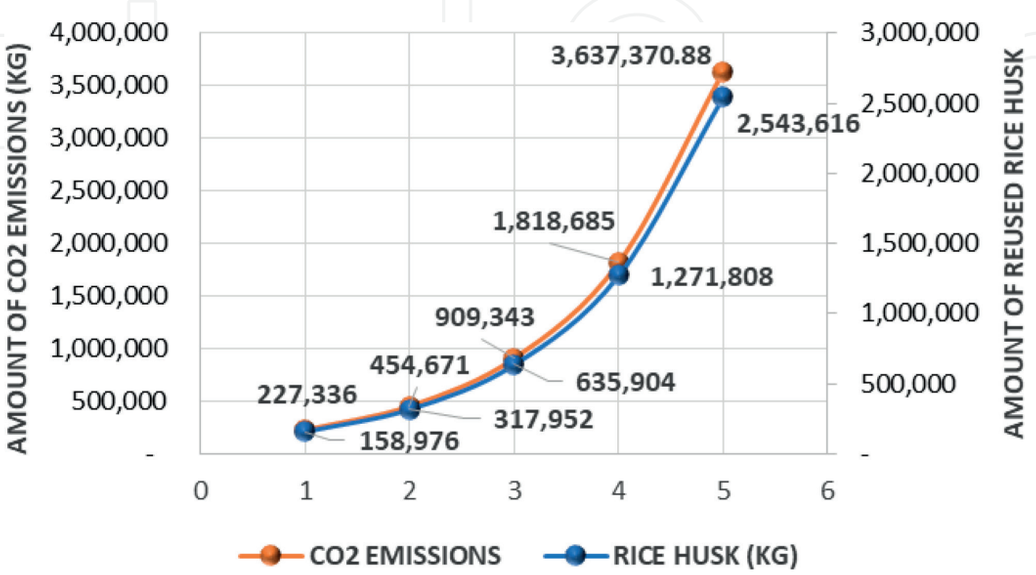


Figure 12.
Amount of CO_2 emissions avoided by recycling rice husks.

In this way, social costs on the population will be minimized, since there will be fewer respiratory and pulmonary diseases due to the reduction of CO_2 emissions from felling trees and burning rice husk. It was estimated that in 1 year, CO_2 emissions could be reduced by 833,000 kg.

4. Conclusions

The energy model design will provide sustainability to a specific proposal for the production of rice husk briquettes, from both an energetic and an environmental perspective, in which a quality product based on renewable energy is proposed. Additionally, from an economic and efficient perspective, the supply chain of all the resources corresponding to the production process is optimized and managed efficiently.

Furthermore, briquette production will generate the opportunity to recycle agricultural waste products from the rice industry, which is currently obliged to make use of them without burning in the vicinity of the city or agricultural areas, due to economic sanctions established by the municipal ordinances in the San Martín region. In addition, rice husk will be economically valued within the paddy rice value chain, as new markets will be opened, positioning briquettes as a viable alternative to firewood. Advantages such as heating capacity and reduced greenhouse gases are key, minimizing the rate of pulmonary and respiratory diseases in the population.

From an experimental analysis of different types of rice husk briquette, performed in the laboratory at the Peruvian University of Applied Sciences (UPC), an ideal briquette prototype was obtained with a combustion efficiency of 80.39%, reducing the amount of kg used for food preparation by 30%. As for heating capacity, the briquette obtained a value of 4040 kcal/kg, which is greater than firewood. The briquettes made the water reach boiling point before firewood, which registered a temperature of 70° C when the briquette had already reached 100° C.

Finally, rice husk recycling will generate a circular economy within the paddy rice value chain, promoting an improved environmental culture in society through the development of clean technology, which focuses on the reduction of greenhouse gases, amounting to approximately 833,000 kg of CO_2 per year, considering the protection of forest hectares and rice husk briquette production.

DOI: http://dx.doi.org/10.5772/intechopen.81817

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References

[1] García H. Barreras para el Desarrollo de la Bioenergía. Matriz Energética en el Perú y Energías Renovables. Lima: Fundación Friedrich Ebert (FES) en colaboración con Derecho, Ambiente y Recursos Naturales (DAR); 2013

[2] Orrego Moya R. Estado del arte y novedades de la Bioenergía en el Perú. La Bioenergía en América Latina y el Caribe. Santiago: Organización de las Naciones Unidas para la Alimentación y Agricultura (FAO); 2013. pp. 341-375

[3] Programa Nacional de Conservación de Bosques para la Mitigación del Cambio Climático. En Análisis de la Realidad Propia. Lima: Editorial of the Environment Ministry; 2013. pp. 18-45

[4] Assureira E. Rice husk, an alternative fuel in Peru [Abstract]. Biomass and Coal Research Programme. Lima: E-Publishing of the Pontifical Catholic University of Peru; 2002

[5] Muro J. El Arroz: Principales aspectos de la cadena agroproductiva. Lima: E-Publishing of the Direction General of Agricultural Competitiveness; 2015

[6] Marcos MF. Pélets y Briquetas. 1994. pp. 54-62. Extracted on: http://www.informadera.net/uploads/articulos/archivo_2293_9990.pdf

[7] CORINAY. Briquetas Corinay. 2008. Extracted on: www.corinay.com/

[8] Garcia M. Diseño de Proceso y Planta Piloto para Fabricación de Briquetas de Aserrín. In: Apéndice E, Ficha Técnica de Briquetadora. Piura: Institucional repository PIRHUA; 2014

[9] Orrego Moya R. En Estado del arte y novedades de la Bioenergía en el Perú. La Bioenergía en América Latina y el Caribe. Santiago: Organización de las Naciones Unidas para la Alimentación y Agricultura (FAO); 2013

[10] Espinoza C, Bernabel F. Emisiones al ambiente generadas por la transformación de energía, consumo propio y consumo final de energía comercial. Balance Nacional de Energía (BNE). Lima: Ministerio de Energía y Minas del Perú (MEM); 2014

[11] Velásquez J. Evaluación del Potencial de Generación Energética con cáscara de arroz en la zona del Huallaga Central del Departamento de San Martín. Lima: E-Publishing of the Regional Direction of Energy and Mines; 2013

[12] Briquetas Combustibles para uso doméstico. In: Norma Técnica Colombiana; 2013

[13] Fonseca E, Tierra L. Desarrollo de un Proceso Tecnológico para la obtención de Briquetas de aserrín de madera y cascarilla de arroz, y pruebas de producción de gas pobre. Riobamba: Escuela Superior Politécnica de Chimborazo (ESPOCH); 2011

[14] Tolosana E, Ambrosio Y, Laina R, Martínez R, Pinillos F. Rendimientos y Costes de diferentes aprovechamientos de la biomasa forestal. Madrid: Institute for the Diversification and Saving of the Energy and Mines; 2007

[15] Botta NA. Salud e Higiene laboral. In: Poder Calorífico. Buenos Aires: Red Proteger; 2012

[16] Velásquez Piñas J. Evaluación del potencial de generación energética con cáscara de arroz en la zona del Huallaga Central del departamento de San Martín. Moyobamba: Editorial of the Regional Direction of Energy and Mines San Martín; 2014

[17] Orts B, Campos B. Métodos de análisis granulométrico. Aplicación al control de la granulometría de materias primas. Castellón: E-Publishing of the Association of Research of the Ceramic

Industries, Instituto de Tecnología Certimica Universitat Jaume 1; 2008

[18] Faborode M, O'Callaghan J. Optimizing the compression briquetting of fibrous agricultural materials. Journal of Agricultural Engineering Research. 1987:245-262

[19] Bailis R, Ogle D, MacCarty N, Still D. The Water Boiling Test (WBT). Household Energy and Health Programme; 2007

[20] Lubwama M, Yiga V. Characteristics of briquettes developed from rice and coffee husks for domestic cooking applications in Uganda. Renewable Energy. 2017. DOI: 10.1016/j.renene.2017.11.003

[21] De Olivera R, Palacio S, Da Silva E, Mariani F, Reinehr T. Briquettes production for use as power source for combustion using charcoal thin waste and sanitary sewage sludg. Environmental Science and Pollution Research. 2017. DOI: 10.1007/s11356-017-8695-0

[22] Sarangi M, Bhattacharyya S, Behera RC. Rice Effect of Temperature on Morphology and Phase Transformations of Nanocrystalline Silica Obtained from Rice Husk2012. pp. 377-386

[23] Giwa A, Alabi A, Yusuf A, Olukan T. A comprehensive review on biomass and solar energy for sustainable energy generation in Nigeria. Renewable and Sustainable Energy Reviews. 2017;**69**:620-641

[24] Assureira E. Rice husk, an alternative fuel in Peru [Abstract]. In: Biomass and Coal Research Programme. Lima: E-Publishing of the Pontifical Catholic University of Peru; 2002

[25] Obi OF, Ezema JC, Okonkwo WI. Energy Performance of biomass cookstoves using fuel briquettes. In: AIP Conference Proceeding. 2017. DOI: 10.1063/1.5021237

[26] Brand M, Jacinto R, Antunes R, Bayestorff A. Production of briquettes as a tool to optimize the use of waste from rice cultivation and industrial processing. Renewable Energy. 2017. DOI: 10.1016/j.renene.2017.03.084

[27] Lozada Cubas J. Evaluación de la reducción de uso de leña, para la producción de ladrillo arcilla. Tarapoto: E-Publishing of National University of San Martin; 2012

[28] La Tienda Biomasa. Revista Leñas Oliver. 2015. Extracted on: http://tiendabiomasa.com/medir-lena

[29] Estudio Técnico de la Leña de la Sede Forestal Moyobamba. Moyobamba: Editorial of Regional Government San Martín; 2009

[30] Torres H, Agreda J, Polo C. Evaluación de impacto ambiental producido por el uso de cocinas tradicionales en el área de conservación regional Vilacota-Maure, Tacna, Perú. 2012. DOI: 10.23850/22565035.25

[31] Prada A, Cortés C. La descomposición térmica de la cascarilla de arroz: Una alternativa de aprovechamiento Integral. Revista Orinoquia. 2010;**14**:155-156