Preparation of Green Briquettes from Crop Residues to Provide a Sustainable Alternative to Conventional Solid Fuels

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Approval Sheet

Certified that the contents and form of the thesis entitled "**Preparation of Green Briquettes from Crop Residues to Provide a Sustainable Alternative to Conventional Solid Fuels"** submitted by Ms. Maryam Zahid, Ms. Ainah Mughal and Mr. Haseeb Tariq have been found satisfactory for the requirements of the degree of **Bachelor of Environmental Engineering.**

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Abstract

Pakistan is an extremely energy scarce country with a fragile economy and unfortunately the situation does not seem to improve. The dilemma is that not only the people but even the government is still heavily depending on the costly conventional fossil fuels in order to power the industries and boilers. In addition to that, another challenge that Pakistan is facing a serious environmental threat in terms of overall degradation of the air quality due to excessive burning of conventional solid fuels like coal and firewood.

Therefore, it is critically important for Pakistan to shift towards clean and green untapped resources of alternate energy. One such potential lies in using Biomass which is a clean and renewable energy source and perfectly fits the situation of Pakistan. Each year, tonnes of crop residues are produced and openly burnt once the harvesting season is over, and a very small percentage of these resources is brought into constructive use. Hence, our final year project aims to introduce this trajectory of curbing the open burning of crop residues and simultaneously reducing our dependency on heavily polluting foreign fossil reserves by increasing the energy content of the biomass through densification also known as briquetting. Our project falls under the goal 7 of Sustainability Development Goals which aims to substantially increase the share of renewable energy in the global energy mix. This project aims to explore the potential of briquettes made from crop residues of rice straw and wheat straw as an alternative to conventional solid fuels.

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Chapter 1: Introduction

This chapter introduces the motivation behind the project to utilize biomass briquettes as an alternate to conventional solid fuels. It highlights the current global energy trends and also talks about the extensive dependency of the energy sector on fossil fuels. Moreover, in parallel, it also draws attention towards the ritual of open burning of crop residues in Pakistan. Pakistan is an agro-based country with an extensively high amount of crop residue generated each year. It is extremely unfortunate that despite being an abundant renewable resource, most of the biomass residue is largely unaccounted for and consequently burnt each year. The chapter also introduces the objectives and mission statement of the research project.

1.1 Background

The global world is heavily dependent on fossil fuels in order to meet its energy demand. During the course of time, the global energy consumption has increased and so has the dependency on fossil fuels. When fossil fuels are burnt, they release carbon dioxide into the atmosphere which leads to global warming. As the renewable sources of energy are becoming readily available, the world needs to rapidly transition away from fossil fuels and find an alternative as the fossil fuels reserves are not only limited but they also deteriorate the environment. Energy derived from non-fossil fuel sources have lower environmental impact. Biomass utilization for energy production is an efficient and reliable alternative for fossil fuels as it can be replenished.

1.2 Theory

The research project utilizes biomass as the feedstock. Briquettes made from biomass are carbon neutral. The carbon neutrality of biomass is an advantage and minimizes the climate impact of briquettes. It is critically important to understand that briquettes are carbon neutral in nature, and this is why no new carbon dioxide is added into the atmosphere once they are burnt. The carbon dioxide which is released into the atmosphere is the same carbon dioxide that was stored within the biomass during the course of its growth in photosynthesis. Hence, there is no new net addition of carbon dioxide into the atmosphere. On the contrary, the carbon present in the coal is in sequestrated form which is why it is advisable to not use a sequestrated carbon source as a fuel because once it is burnt there is entirely new generation of carbon dioxide and carbon monoxide which was not present in the atmosphere previously.

As the world struggles with global warming and climate change targets, it has become crucial for clean energy sources that do not contribute to new carbon emissions. Biomass renewable energy harvested through briquettes is attractive because of its minimal environmental impacts upon combustion.

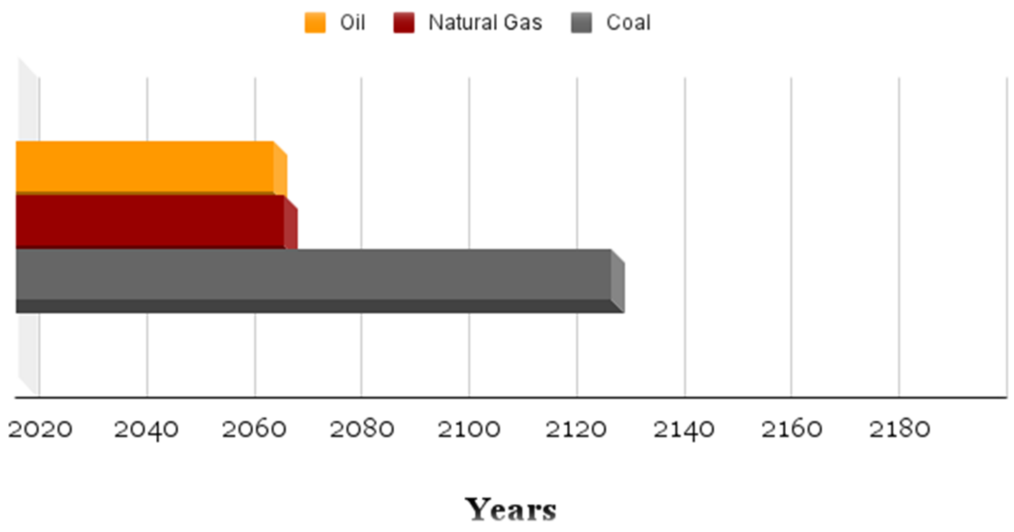


Figure 1- Years of Fossil Fuel Reserves Left (MET Group, 2015)

The bar chart shown above gives a visual representation of the natural reserves of coal, oil and natural gas and the respective years by which we will run out of them. Keeping in mind the fact that these reserves are not only limited but harmful for the environment as well, it is high time that we look for an alternative for fossil fuels.

1.2.1 Oil:

40% of the world's energy today is supplied by oil and it supplies 96% of the transportation energy (MAHB, 2019). The world's oil reserves are depleting faster than they are being discovered. The oil that is being produced is being extracted from discoveries of oil reserves that have been done in the past, but the reserves are not being fully replaced.

1.2.2 Natural Gas:

Out of the total energy demand of the world, gas totaled 23% but grew at a rate of 4.6% in 2018 (MAHB, 2019). Taking into consideration, the demand of natural gas to be used as a fuel, is also increasing which compels us to look for a better and environmentally friendly alternative.

1.2.3 Coal:

Coal demand increased 0.7% in 2018 and the share of coal in the total electricity production globally was 10.116 TWh, 2.6% more as compared to 2017 as it generated 38% of the total generation around the world. (MAHB, 2019). According to the IEA, the global coal consumption increased by 1 percent in 2017, or 50.4 megatons of coal equivalent (MAHB, 2019).

It is extremely unfortunate that despite being finite reserves, not only Pakistan but the global world is still heavily dependent on these finite resources as shown in the figure below.

1.2.4 Global Energy Mix and Pakistan's Energy Mix

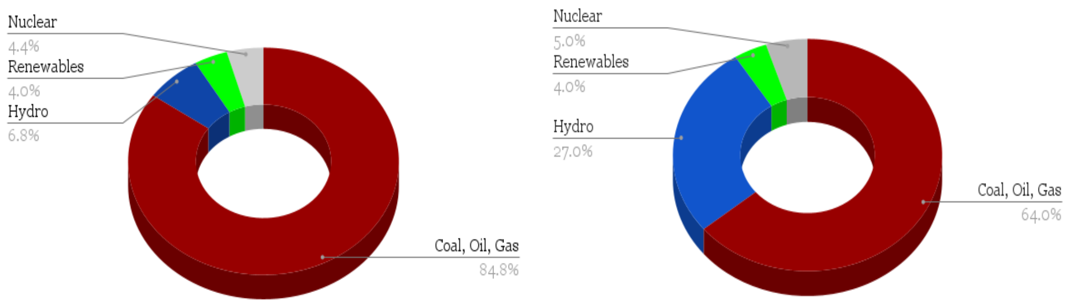


Figure 2- Comparison of Pakistan's and Global Energy Mix

It can be seen in the comparison of energy mix shown above that fossil fuels account for majority of the energy production globally as well as in Pakistan. So, our final year project proposes a solution to get rid of this heavy dependency on fossil fuels by utilizing the renewable resource of biomass residue as an alternative to conventional solid fuels. (What is The Energy Mix, 2020) (Unwin, 2020)

1.3 Problem Statement

Every year, tonnes of crop residues are produced as a result of extensive agricultural activity and are burnt by the farmers during the harvesting season. Crop residue burning contributes to emission of GHGs, air pollutants, particulate matter and smoke which later leads to catastrophes like smog and an overall degradation of the air quality. If we increase our portion of biomass energy in the global energy mix by utilizing biomass, we can reduce our reliance on the fossil fuels for energy and can manage our climate change targets effectively all the while preserving our fossil fuel reserves for our future generations. . If fossil fuels are exploited at the current rate without keeping any precautions in mind, there would be less to no reserves left for coming generations. One of the key strategies to manage climate crisis is to decrease the carbon emissions. This cannot be done unless fossil fuel burning as a primary energy source is reduced.

The burning of crop residue by farmers in Pakistan causes serious environmental problems. Farmers do this in order to prepare the field for the second crop. Many farmers do this when the time between the harvesting of the first crop and the sowing of the subsequent crop is short while many farmers burn the crop residue as they find it inconvenient to use farm machinery burning is a short and more convenient method for them.

The figure below shows the comparison of carbon dioxide emissions from burning of rice straw and wheat straw in Punjab and Sindh province. It can be seen in the figure that the Punjab province produced higher carbon dioxide from agricultural biomass than Sindh province. This crop residue can be used as a sustainable alternative to conventional solid fuels if we make briquettes out of them and this will reduce the greenhouse gas emissions as well.

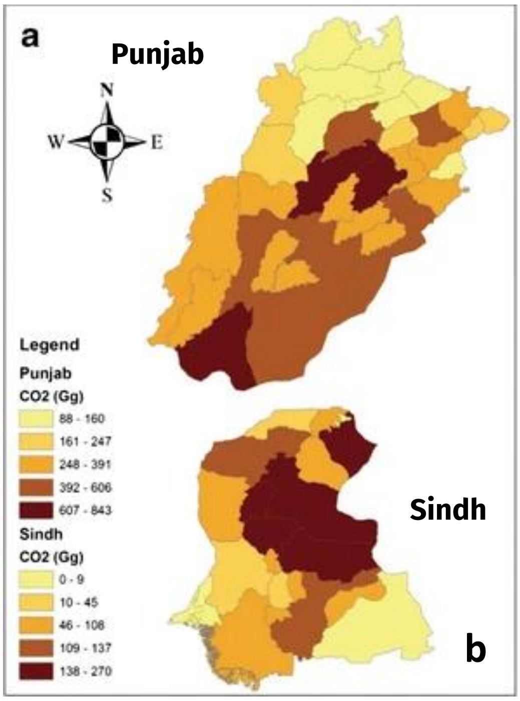


Figure 3-Carbon Dioxide Emission from Crop Residues in Punjab & Sindh

By briquetting, we can produce briquettes of crop residues which would otherwise go to waste. These briquettes can serve as an alternative for fossil fuels thus, causing a decrease in greenhouse gas emissions. The briquettes produced using the crop residues of rice and wheat crops are not only less expensive to produce, but they are also environmentally friendly. Moreover, the calorific value of the prepared briquettes has been found to be nearly equal to that of coal. This makes briquettes a greener and a financially feasible alternative.

1.4 Research Objectives

The objectives of this research project are as follows:

- Lab Scale Development of Green Briquettes.
- Techno Economic and Environmental Performance Evaluation in Comparison with Conventional Solid Fuels.
- Creating an Agricultural Residue Based Energy Map of Pakistan.

1.4.1 Lab Scale Development of Green Briquettes:

The briquettes were prepared using the crop residues of rice and wheat. Three types of binders were used for briquette production: Waste Engine Oil, Glycerol and Glycerol and Glue Solution.

1.4.2 Techno Economic and Environmental Performance Evaluation in Comparison with Conventional Solid Fuels:

A techno-economic comparison has been drawn between the briquettes produced from biomass and coal, indicating the economic feasibility of using briquettes over coal.

1.4.3 Creating an Agricultural Residue Based Energy Map of Pakistan:

An agricultural residue-based energy map has been prepared showing the availability of agricultural residues in different areas and districts of Pakistan. It indicates the areas where briquetting units can be installed keeping in mind the availability of agricultural residues in that region.

1.5 Scope

The scope of this project includes:

1.5.1 Using Crop Residues of Wheat Straw, Rice Straw:

Pakistan is an agrarian country. Rice and wheat crops are produced in large amount so there is plenty of crop residue available for these two crops clearly indicating the reason of selection of these crops for the production of briquettes. The wheat production in Pakistan is expected to be 26.4 MMT in Pakistan for the year 2022-23 (GAIN, 2022) while that of rice is expected to be 9 MMT for the year 2022-23 (GAIN, 2022). So, it can be seen that an ample amount of crop residue is generated by these crops.

1.5.2 Density Test & Drop Resistance Test of Briquette

The density and drop resistance tests were performed to test the durability of the briquettes produced. Their results are mentioned in the results section. The densification of biomass increases the strength of the briquettes and also helps in their transportation. The briquettes with higher density have more durability as compared to those with lesser density. Density test of the briquettes was done by comparing the relaxed and compressed density of the briquettes to find their compression ratio. Moreover, the drop resistance test was also conducted to check the mechanical durability of the produced briquettes to ensure that they do not disintegrate during handling and transportation.

1.5.3 Heating Value Test Using Bomb Calorimeter:

The calorific value of the briquettes prepared was tested using a bomb calorimeter and these calorific values were then compared with that of coal. The calorific values of different types of coal and the prepared briquettes are shown in the results section.

1.5.4 Comparative Analysis of Briquettes with Conventional Fuels:

A techno economic analysis was done to compare the economic feasibility of briquette production compared to that of coal for industries.

1.5.5 Developing an Agricultural Residue Based Energy Resource Map of Pakistan:

An agricultural residue-based energy map of Pakistan has been prepared showing the production of crop residues in different districts of Pakistan. The map helps in estimating applicability of briquetting units in different areas of Pakistan depending upon the production of crop residue production in that area.

1.6 SDG Mapping:

The SDGs were adopted by the United Nations in 2015. They have been developed keeping in mind, the prosperity of the people and to protect the planet. These goals are set as indicators to achieve a sustainable society for all keeping in mind the goals of intersectionality and inclusivity. The goals are indicators for a healthy, progressive society for all. The goals target various aspects like sanitation, education, poverty, sustainable energy, global peace and much more. There are 17 goals in total.

This project is mapped with the SDG no. 7.

1.6.1 SDG No. 7:

The SDG No. 7 is to ensure access to affordable, reliable, sustainable, and modern energy for all. In order to achieve this goal, it is vital that we start looking towards better environmentally friendly alternatives for conventional solid fuels which are economically feasible as well.

1.6.2 Target 7.2:

The target 7.2 is to substantially increase the share of renewable energy in the global energy mix by 2030. This project is mapped with this target as the crop residues are a source of producing renewable energy. The increased use of briquettes as an alternative to conventional solid fuels will help in achieving this target as the crop residues are a renewable source of energy.

Chapter 2: Literature Review

Literature review is an important part of a research to establish a solid ground for future investigation and gathering relevant information to conduct the research in a correct manner with clear direction. Following are few of the articles that were studied for gaining a more thorough insight and to obtain relevant information for this project.

2.1 Importance of Particle Size:

The briquetting of biomass adds valuable functional features to it such as an increase into energy density as well as bulk density. The briquettes require high mechanical durability in order ensure that they do not break or disintegrate during handling and transportation. Out of the briquettes made from three types of particle sizes: 0–2 mm, 2–15 mm, and 15–45 mm, the smallest fraction (0-2 mm) had the highest durability index. It was concluded that the briquettes which were made using larger particle size of biomass were characterized by lower mechanical durability (Dyjakon, 2020). The mechanical durability index was the highest for the smallest fraction (0-2 mm) of particles used to make briquettes. It was also observed that due to lower degradation degree of briquettes made from smaller particles, they could be transported over longer distances as compared to briquettes made from larger particles of biomass (Dyjakon, 2020).

2.2 Technical and Economic Aspects of Biomass Briquetting:

The rapid increase in global population is also leading to rapid increase in energy demand. Moreover, the fossil fuels are diminishing at a very fast rate. The impact of increased utilization of fossil fuels is leading to climate change. In many developing countries, biomass is produced in large quantities, but it is not utilized properly. The biomass which is thrown with the waste can be used to make briquettes out of it. Briquettes can be made from both, by high pressure technique as well as low pressure technique. However, it was observed that the briquettes produced by applying higher pressure to biomass were more durable. It is economically feasible to produce briquettes made from rice straw with or without using cotton stalk as a binder. When briquettes were made by using four types of vegetable market wastes, and the cost of briquettes was compared to that of wood available in the market, it concluded that briquettes are an economically viable option for energy production while being environmentally friendly as well (Kpalo, 2020). So, it was concluded that briquetting of agricultural biomass provides an efficient alternative for fossil fuels and low-cost briquetting machines should be developed in developing countries (Kpalo, 2020).

2.3 Waste Engine Oil as an Additive in Briquette Production:

The addition of an additive can contribute towards increased tensile strength of the briquette as well as provide beneficial functional properties to the briquette. A study was conducted in which briquettes were made from wheat straw with different amounts of waste engine oil added in them as a binder. The influence of waste engine oil as an additive and the additive content, on different properties of the briquettes was studied using experimental data. It was concluded that the use of waste engine oil as a binder increased the higher heating value of the briquettes as well as decreased the ignition temperature (Y.Wang, 2019). It was observed that waste engine oil is a potential additive to reduce energy consumption and improve pellet heating value for the wheat straw pelletizing process (Y.Wang, 2019).

2.4 Glycerol as an Additive in Briquette Production:

Liquid biofuel production from vegetables oil has increased over the past recent years. It is therefore important to find their cheap and efficient utilization. Pellets containing glycerol as an additive have been tested for their applicability in many different experiments. The presence of glycerol in wood pellets in amount of 4.5% and 7% decrease the concentration of NO_x in flue gas (Bala-Litwiniak, 2019). Also, the use of glycerol as a binder for the production of wood pellets is a cost-effective solution. The physicochemical parameters of the pellets made by using glycerol as a binder meet the European standards. The addition of glycerol does not cause harmful flue gas emissions. 7% addition of glycerol lowers pellet consumption while 4.5% of glycerol addition leads to an increase in the pellets spend rate. 4.5% addition of glycerol addition was found to be most appropriate keeping in view the combustion time and pellet density (Bala-Litwiniak, 2019).

2.5 Energy potential of crop residues in Pakistan:

In order to gain sustainability in power generation, we desperately need to transition away from fossil fuels towards sustainable energy resources. In a forecast model developed in MATLAB which incorporated the historical trends in crop yield, crop residue based available biomass resource was studied for five different types of crops which include wheat straw, rice straw, rice husk, cotton stover, cotton straw and bagasse was studied. It was done to estimate the potential of energy generation in Pakistan by using crop residues from 2018 to 2035. The assessment of the model concluded that there was a Capacity of 11000 MW of electricity generation from crop residue in Pakistan in 2018. This capacity is predicted to increase up to 16000 MW by 2035 (M.Kashif, 2020).

Chapter 3: Methodology

The following methodology was followed for the production of the briquettes:

3.1 Material Selection

The crop residues of wheat straw and rice straw were chosen for the production of the briquettes. Wheat and rice are the cereal crops of Pakistan. So, there is an ample amount of crop residues that is available from these two crops. Wheat account for 8.9% value addition and 1.6% of total GDP in Pakistan (The Nation, 2020). 8.9 million Tonnes of rice crop was harvested in Pakistan in the 2021-22 marketing year (Donley, 2022). So sufficient amounts of crop residues are generated from these crops.

3.2 Collection of Biomass

The first step was the collection of biomasses. Rice straw was collected from a field in Dinpur village. Wheat straw was collected from IESE lab. The biomass was then solar dried for 3 to 4 days and then it was stored.

Figure 4-Crop Residues of Rice Straw (left) and Wheat Straw (Right)

3.3 Grinding of Biomass

An electric grinder was procured from Air and Noise laboratory at IESE, NUST. The biomass was ground for 7 to 10 seconds in the grinder. After grinding, the biomass is ready for next stage i.e. sieving.

Figure 5 Electric Grinder

3.4 Sieving of Biomass

After grinding, the biomass was sieved into three particle sizes. Both the rice straw and the wheat straw were sieved through sieve no. 07, 10 and 14 for particles ranging between 2.0-2.8mm, 1.4-2.0mm and less than 1.4mm respectively. After sieving 50g of each sieve size was weighed and separated.

3.4.1 Wheat Straw

Sieve 7-10 Sieve 10-14 Sieve 14's passing

Figure 6-Sieving of Wheat Straw

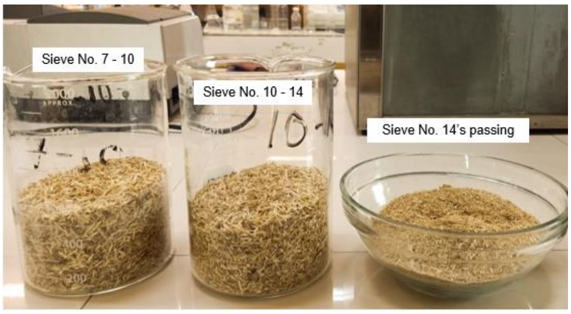


Figure 7-50 gm separated of each Sieve Size

3.4.2 Rice Straw

Sieve 7-10 | Sieve 10-14 | Sieve 14’s passing

Figure 8-Sieving of Rice Straw

Figure 9-50 gm separated of each Sieve Size

3.5 Preparation of Binder

Three types of binders were used with both the wheat straw and rice straw. These included waste engine oil, glycerol, and glycerol + white glue mixture.

3.5.1 Waste Engine Oil

Waste engine oil is a potential additive to reduce energy consumption and improve pellet heating value for the wheat straw pelletizing process (Y.Wang, 2019). Waste engine oil was procured, and its cost was PKR 90 per liter. The cost of waste engine oil for each sample is PKR 2.25.

Figure 10-Waste Engine Oil

The binder was prepared using cotton gauze to filter out and remove any undesirable solids in the oil. Optimization was performed and a quantity of 25mL was selected for addition in the 50g of biomass of each sieve size. The binder was then sprinkled over the biomass for uniform mixing.

(a) (b)

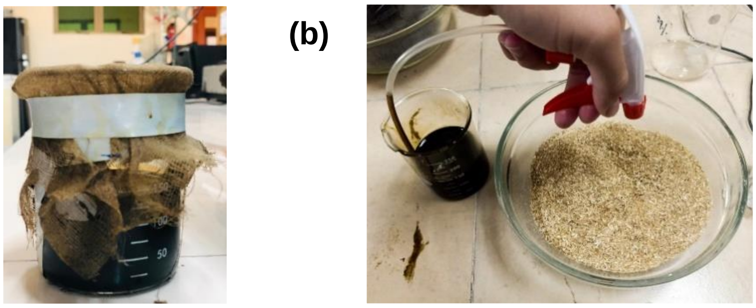


Figure 11-Cotton Gauze Assembly (a) & Waste Engine Oil addition (b)

3.5.2 Glycerol

Glycerol binder was procured from Biotechnology laboratory at IESE. The presence of glycerol in wood pellets in amount of 4.5% and 7% decrease the concentration of NO_x in flue gas (Bala-Litwiniak, 2019). The cost of glycerol was PKR 290 per liter. Optimization was performed and a quantity of 25mLof glycerol was selected for addition in the 50gm of biomass of each sieve size. The binder was then sprinkled over the biomass for uniform mixing.

Figure 12-Glycerol

3.5.3 Glycerol and White Glue

Glycerol was procured from Biotechnology laboratory at IESE. The cost of glycerol was PKR 290 per liter. The cost of white glue was PKR 300 per liter. 30 percent of glue was added to 70 percent of glycerol to obtain a mixture. Optimization was performed and a quantity of 25mL of this mixture was selected for addition in the 50g of biomass of each sieve size. The binder was then sprinkled over the biomass foe uniform mixing.

Figure 13-Glycerol & White Glue Solution

3.6 Preparation of Mold and Piston Press

The mold and the piston press were prepared of stainless steel having a length of 1 foot and a diameter of 7.8cm. The diameter that was selected for the briquettes as per the literature was 8cm and a pipe of the nearest diameter was found i.e. 7.8cm. The total cost for both the mold and the piston was PKR 3500.

Figure 14-Mold & Piston Press

3.7 Compaction

For the densification of the biomass hydraulic press from the SMME, NUST was used. The applied pressure for the compaction was 2000psi in case of waste engine oil for 30 seconds, 1500psi in case of glycerol for 30 seconds and 1500psi in case of glycerol + glue binder for 30 seconds. As a result, the biomass was compacted into briquettes.

Figure 15-Compaction of Biomass

3.8 Testing

There were a wide range of tests carried out in order to gauge the mechanical stability of the briquettes produced.

3.8.1 Density Test

Density is an important parameter as the briquetting process is characterized by density. High density means high energy/volume ratio. So, products with high density are desirable in terms of handling, storage, and transportation. Relaxed and compressed densities of the briquettes were calculated for each sieve size. For the relaxed density the weight of the mixture (biomass and binder) was measured using a digital balance and the volume was calculated by determining the dimensions while the biomass was in the mold before compression.

For the compressed density, weight of the briquettes formed as a result of compression from each sieve size were measured using a digital balance. The dimensions of the briquettes i.e. height and diameter were measured again and again until stable value were obtained to calculate their volume and the compressed density was determined as:

$$\rho = \frac{m}{v}$$

Relaxation ratio of the briquettes was calculated for each sieve size as:

$$Relaxation\ Ratio = \frac{Compressed\ Density}{Relaxed\ Density}$$

3.8.2 Drop Resistance Test

A drop height of 1.2 meters was selected. One sample from each sieve size was dropped three times onto a concrete floor from this height. The weight of the sample before and after the drop was calculated. The shatter resistance of the briquettes was determined. The percentage shatter resistance gives an idea about the ability of the biomass briquettes to withstand against the impact. High percentage shatter resistance means good withstanding ability (Porcol, 2021)

The percentage shatter resistance was calculated as:

$$\%\ SR = 100 - \left(\frac{Initial\ weight - Final\ weight}{Initial\ weight} \times 100\right)$$

3.8.3 Heating Value Test using Bomb Calorimeter

The heating value of the fuel is the total amount of heat rejected upon combustion. Heating value test was performed using a bomb calorimeter. One gram of sample was taken from the briquette made from the smallest particle size i.e. passing of sieve no. 14. The samples were then provided to the CASEN’s Laboratory for heating value test using their bomb calorimeter.

3.9 Lab Scale Development of Green Briquettes

In case of waste engine oil and glycerol + glue binder for both of the biomass, the briquettes made from the largest particle size were weak in nature and their mechanical durability was also low. The briquettes made from the particle size ranging between 1.4 to 2.0mm were stronger than the previously made briquette and their mechanical durability was also higher. The briquettes made from the smallest particle size were strongest of all and they had the highest mechanical durability than the other briquettes made from other particle sizes.

When glycerol was used alone, it came out to be a failed binder. The briquettes made from this binder swelled and they disintegrated upon drying.

3.9.1 Wheat with Waste Engine Oil Binder

50g of each sieve size of wheat straw was taken and 25ml of waste engine oil i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 1-Final Product for Waste Engine Oil-Wheat

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

3.9.2 Rice with Waste Engine Oil Binder

50g of each sieve size of rice straw was taken and 25ml of waste engine oil i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 2-Final Product for Waste Engine Oil-Rice

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

3.9.3 Wheat with Glycerol Binder

50g of each sieve size of wheat straw was taken and 25ml of glycerol i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 3-Final Product for Glycerol-Wheat

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

3.9.4 Rice with Glycerol Binder

50g of each sieve size of rice straw was taken and 25ml of glycerol i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 4-Final Product for Glycerol-Rice

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

3.9.5 Wheat with Glycerol and Glue Binder

50g of each sieve size of wheat straw was taken and 25ml of glycerol + glue i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 5-Final Product for Glycerol and Glue-Wheat

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

3.9.6 Rice with Glycerol and Glue Binder

50g of each sieve size of rice straw was taken and 25ml of glycerol + glue i.e. 50 percent by weight of biomass was added in it as a binder. 2000psi of pressure was applied by a hydraulic press for a dwell time of 30 seconds. As a result, biomass was densified into briquettes.

Table 6-Final Product for Glycerol and Glue-Rice

Sieve No.	7-10	10-14	14's Passing
Sieve (mm)	2.0-2.8	1.4-2.0	Less than 1.4
Image			

Chapter 4: Results

This chapter includes the results of all the objectives of our final year project including test performance, energy map and cost benefit analysis.

4.1 Testing

4.1.1 Density Test

The results of the density test are given below.

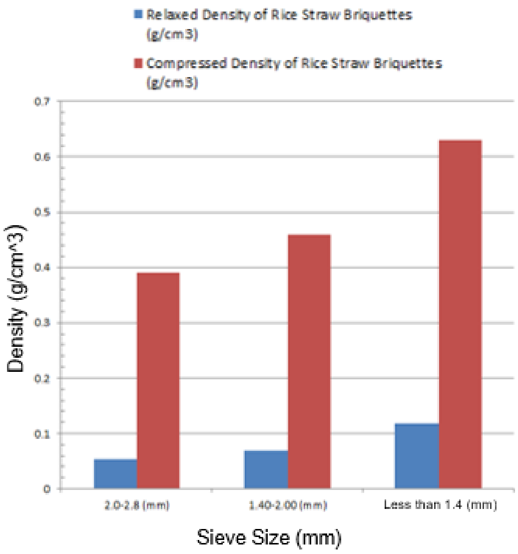
4.1.1.1 Waste Engine Oil-Rice

The values of relaxed and compressed densities calculated are shown in the tables for the rice straw briquettes made by using waste engine oil. Both the relaxed and compressed densities increase as the particle size decreases. The values of relaxation ratio are also given in the table. These values indicate that the relaxation ratio is directly proportion to the particle size. This shows that the briquettes made from the smallest particle size were more stable.

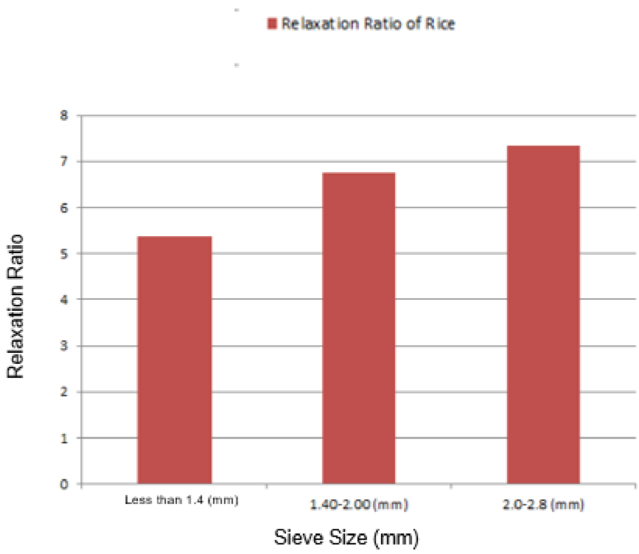
Table 7-Relaxed and Compressed Density, Relaxation Ratio

Sieve No.	Relaxed Density (g/cm^3)	Compressed Density (g/cm^3)	Relaxation Ratio
7-10 Sieve Size: 2.0-2.8 (mm)	0.053	0.39	7.35
10-14 Sieve Size: 1.40-2.00 (mm)	0.068	0.46	6.76
Passing of 14 Sieve Size: Less than 2.00 (mm)	0.117	0.63	5.38

The graph on the left is plotted between the sieve size and the relaxed and compressed density. It shows that as the particle size decreases, both the relaxed and compressed density increase. The graph on the right is plotted between the sieve size and the relaxation ratio. It indicates that the relaxation ratio is directly proportional to the particle size. It shows that the briquettes made from the smallest particle size are most stable.



Plot for Sieve Size vs Densities



Plot for Sieve Size vs Relaxation Ratio

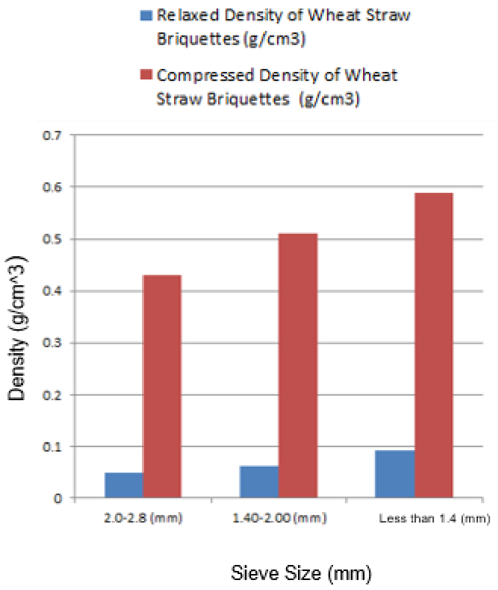
4.1.1.2 Waste Engine Oil-Wheat

The values of relaxed and compressed densities calculated are shown in the tables for the wheat straw briquettes made by using waste engine oil. Both the relaxed and compressed densities increase as the particle size decreases. The values of relaxation ratio are also given in the table. These values indicate that the relaxation ratio is directly proportion to the particle size. This shows that the briquettes made from the smallest particle size were more stable.

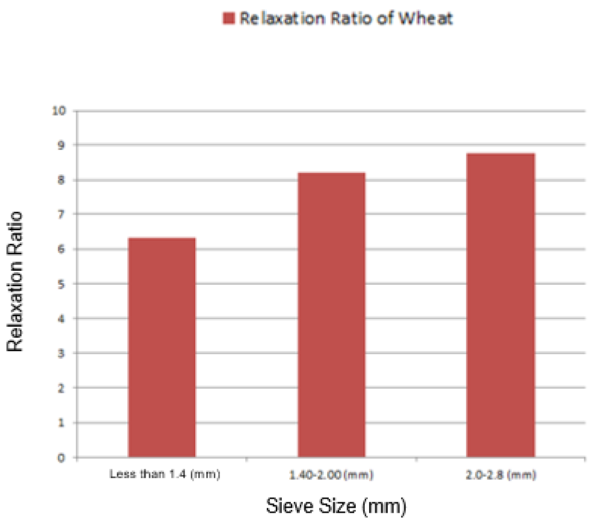
Table 8-Relaxed and Compressed Density, Relaxation Ratio

Sieve No.	Relaxed Density (g/cm^3)	Compressed Density (g/cm^3)	Relaxation Ratio
7-10 Sieve Size: 2.0-2.8 (mm)	0.049	0.43	8.77
10-14 Sieve Size: 1.40-2.00 (mm)	0.062	0.51	8.22
Passing of 14 Sieve Size: Less than 2.00 (mm)	0.093	0.59	6.34

The graph on the left is plotted between the sieve size and the relaxed and compressed density. It shows that as the particle size decreases, both the relaxed and compressed density increase. The graph on the right is plotted between the sieve size and the relaxation ratio. It indicates that the relaxation ratio is directly proportional to the particle size. It shows that the briquettes made from the smallest particle size are most stable.



Plot for Sieve Size vs Densities



Plot for Sieve Size vs Relaxation Ratio

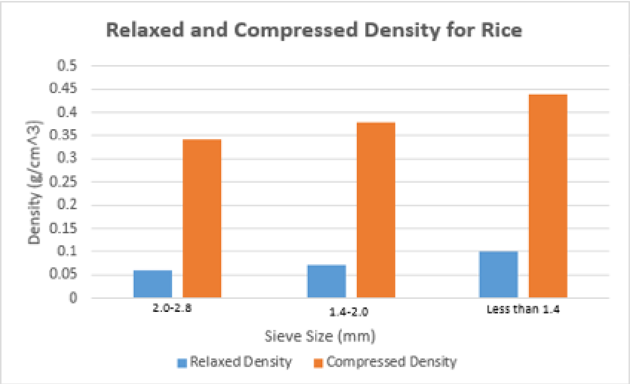
4.1.1.3 Glycerol and Glue-Rice

The values of relaxed and compressed densities calculated are shown in the tables for the rice straw briquettes made by using glycerol and glue. Both the relaxed and compressed densities increase as the particle size decreases. The values of relaxation ratio are also given in the table. These values indicate that the relaxation ratio is directly proportion to the particle size. This shows that the briquettes made from the smallest particle size were more stable.

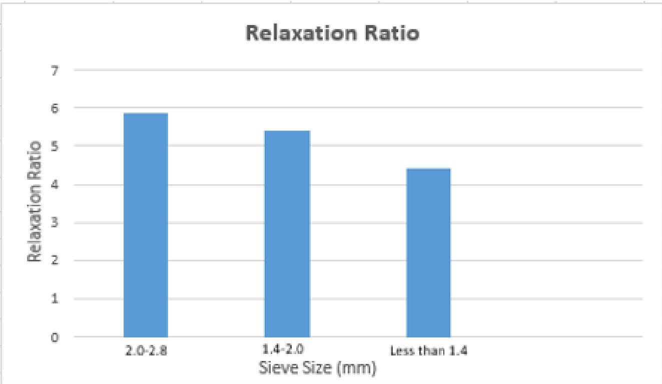
Table 9-Relaxed and Compressed Density, Relaxation Ratio

Sieve No.	Relaxed Density (g/cm^3)	Compressed Density (g/cm^3)	Relaxation Ratio
7-10 Sieve Size: 2.0-2.8 (mm)	0.058	0.34	5.86
10-14 Sieve Size: 1.40-2.00 (mm)	0.07	0.38	5.42
Passing of 14 Sieve Size: Less than 2.00 (mm)	0.10	0.44	4.4

The graph on the left is plotted between the sieve size and the relaxed and compressed density. It shows that as the particle size decreases, both the relaxed and compressed density increase. The graph on the right is plotted between the sieve size and the relaxation ratio. It indicates that the relaxation ratio is directly proportional to the particle size. It shows that the briquettes made from the smallest particle size are most stable.



Plot for Sieve Size vs Densities



Plot for Sieve Size vs Relaxation Ratio

4.1.1.4 Glycerol and Glue-Wheat

The values of relaxed and compressed densities calculated are shown in the tables for the wheat straw briquettes made by using glycerol and glue. Both the relaxed and compressed densities increase as the particle size decreases. The values of relaxation ratio are also given in the table. These values indicate that the relaxation ratio is directly proportion to the particle size. This shows that the briquettes made from the smallest particle size were more stable.

Table 10 -Relaxed and Compressed Density, Relaxation Ratio

Sieve No.	Relaxed Density (g/cm^3)	Compressed Density (g/cm^3)	Relaxation Ratio
7-10 Sieve Size: 2.0-2.8 (mm)	0.06	0.35	5.83
10-14 Sieve Size: 1.40-2.00 (mm)	0.071	0.37	5.21
Passing of 14 Sieve Size: Less than 2.00 (mm)	0.09	0.47	4.89

The graph on the left is plotted between the sieve size and the relaxed and compressed density. It shows that as the particle size decreases, both the relaxed and compressed density increase. The graph on the right is plotted between the sieve size and the relaxation ratio. It indicates that the relaxation ratio is directly proportional to the particle size. It shows that the briquettes made from the smallest particle size are most stable.

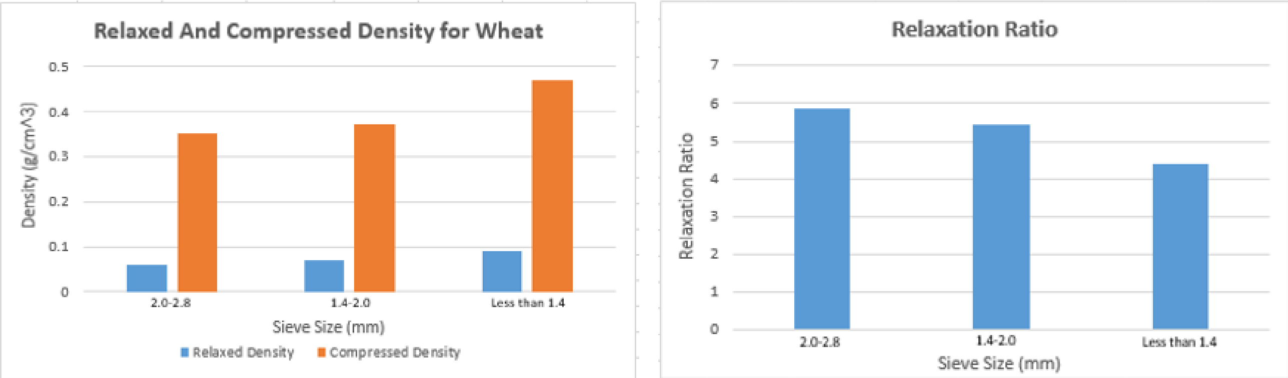


Figure 16 Relaxed and Compressed Density

4.1.2 Drop Resistance Test

4.1.2.1 Waste Engine Oil

The values for the weight before and after the drop of the briquettes are given in the table 11. The briquettes made from the largest particle size disintegrated upon a fall from the height of 1.2m in case of both weight and rice straw. For particles ranging between 1.4 to 2.0mm, the rice straw briquette had a moderate disintegration while the wheat straw briquette disintegrated completely. The briquettes made from the smallest particle size were most durable and they had a very low disintegration for both rice and wheat. It indicates that the smallest particle size yielded more durable briquettes.

Table 10-Weights of Briquettes before and after drop

Sieve No.	Rice Straw Briquettes Drop Height (1.2m)	Wheat Straw Briquettes Drop Height (1.2m)
7-10 Sieve Size: 2.0-2.8 (mm)	Weight before drop = 65.40g Disintegrated.	Weight before drop = 64.39g Disintegrated.
10-14 Sieve Size: 1.40-2.00 (mm)	Weight before drop = 64.80g Weight after drop = 45.30g Moderate Disintegration.	Weight before drop = 62.60g Disintegrated.
Passing of 14 Sieve Size: Less than 2.00 (mm)	Weight before drop = 64.31g Weight after drop = 57.59g Relatively Highest Durability. Very Low Disintegration	Weight before drop = 58.51g Weight after drop = 46.21g Relatively Highest Durability. Very Low Disintegration

4.1.2.2 Glycerol and Glue

The values for the weight before and after the drop of the briquettes are given in the table 12. The briquettes made from the largest particle size had a moderate disintegration in case of rice while high disintegration in case of wheat straw upon a fall from the height of 1.2m. The briquettes made from the particle size ranging from 1.4 to 2.0mm and the less than 1.4mm showed a very low disintegration for both the rice and wheat. It indicates that the smallest particle size yielded more durable briquettes.

Table 11-Weights of Briquettes before and after drop

Sieve No.	Rice Straw Briquettes Drop Height (1.2m)	Wheat Straw Briquettes Drop Height (1.2m)
7-10 Sieve Size: 2.0-2.8 (mm)	Weight before drop = 60.8g Weight after drop = 32.19g Moderate Disintegration.	Weight before drop = 88.17g Weight after drop = 34.9g High Disintegration.
10-14 Sieve Size: 1.40-2.00 (mm)	Weight before drop = 54.3g Weight after drop = 52.84g Very Low Disintegration	Weight before drop = 74.8 g Weight after drop = 69.7g Low Disintegration
Passing of 14 Sieve Size: Less than 2.00 (mm)	Weight before drop = 69.5g Weight after drop = 67.6g Relatively Highest Durability. Very Low Disintegration	Weight before drop = 52.1g Weight after drop = 50.3g Relatively Highest Durability. Very Low Disintegration

4.1.2.3 Shatter Resistance

The table 13 shows the percentage shatter resistance values for both of the binders for respective biomass. The calculated values show that as the particle size decreases, the % SR increases. Higher the % SR means the briquette has more withstanding ability towards shattering. So, the briquettes made from the smallest particle size were more stable in terms of percentage shatter resistance.

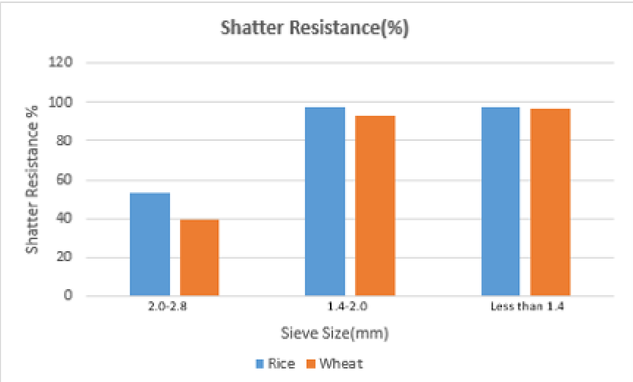
In terms of binder, briquettes made from the glycerol and glue showed more % SR while the briquettes made from the three of the particle size disintegrated completely in case of waste engine oil. In terms of crops, rice straw briquettes showed more % SR than the wheat straw briquettes and were more durable.

Table 12-Percentage Shatter Resistance

	Waste Engine Oil		**Glycerol + Glue**	
Sieve No.	Shatter Resistance (%) Rice	Shatter Resistance (%) Wheat	Shatter Resistance (%) Rice	Shatter Resistance (%) Wheat
7-10 Sieve Size: 2.0-2.8 (mm)	Disintegrated	Disintegrated	52.94	39.58
10-14 Sieve Size: 1.40-2.00 (mm)	69.9	Disintegrated	97.31	93.18
Passing of 14 Sieve Size: Less than 2.00 (mm)	97.79	94.35	97.2	96.54

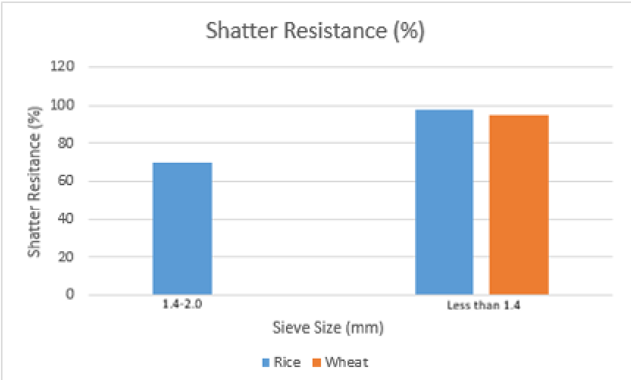
The graph on the left is plotted between the sieve size and percentage shatter resistance for the briquettes of wheat and rice straw made by the glycerol and glue binder. It shows that the briquettes made from the particle size ranging between 1.4-2.0mm and less than 1.4mm showed the highest %SR.

The graph on the right is plotted between the sieve size and percentage shatter resistance for the briquettes of wheat and rice straw made by the waste engine oil binder. It shows that the briquettes made from three of the particle sizes disintegrated. The briquettes made from the smallest particle size showed the highest %SR.



Plot for % SR vs. Particle Size for Glycerol and Glue Binder

Plots for Sieve Size vs Shatter Resistance



Plot for % SR vs. Particle Size for Waste Engine Oil Binder

Plots for Sieve Size vs Shatter Resistance

4.1.3 Heating Value Test using Bomb Calorimeter

The table 14 shows the calorific values of the briquettes made from the smallest particle size i.e. passing of sieve no. 14 for both of the binders. The briquettes made from the wheat straw had more calorific values than the rice straw briquettes. In terms of binder, briquettes made by using waste engine oil showed higher calorific values.

Table 13-Calorific Values of Briquettes

Biomass	Binder	Calorific Value (MJ/Kg)
Wheat	0.5ml of Waste Engine Oil / 1g of Biomass	29.138706
Rice	Rice 0.5ml of Waste Engine Oil / 1g of Biomass	27.181379
Wheat	70% of glycerol and 30% of white glue / 50g of Biomass	18.695255
Rice	70% of glycerol and 30% of white glue / 50g of Biomass	16.618976

4.2 Creating an Agricultural Residue Based Energy Map of Pakistan

Pakistan is an agro-based country with an extensively high amount of crop residue generated each year. It is extremely unfortunate that despite being an abundant renewable resource, most of it is largely unaccounted for and no one tries to monitor the amount of residues produced and consequently burnt each year. Our objective with the development of an agricultural residue-based energy map of Pakistan was to gauge this amount and accordingly draw the attention of the masses towards this untapped resource.

Pakistan's two pivotal cereal crops are Rice and Wheat which is exactly why we have focused our entire final year project towards these two staple crops of the country.

4.2.1 Data Collection

In order to develop the Agricultural Residue Based Energy Map of Pakistan, we collected the district wise data of crop production from 125 cities of Pakistan. The latest district wise data was available from the years 2013-2014 and the development of the production maps was the very first step was to develop the Agricultural Residue Based Energy Map of Pakistan for both Rice and Wheat Crop. The following graphs is the visual representation of the crop production data that we collected from all the 125 districts.

4.2.2 Wheat Crop Production

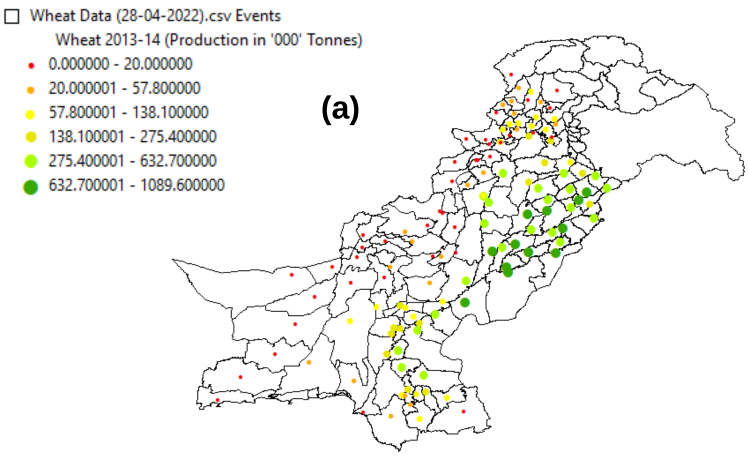


Figure 17 Wheat Crop Production (a)

4.2.3 Rice Crop Production

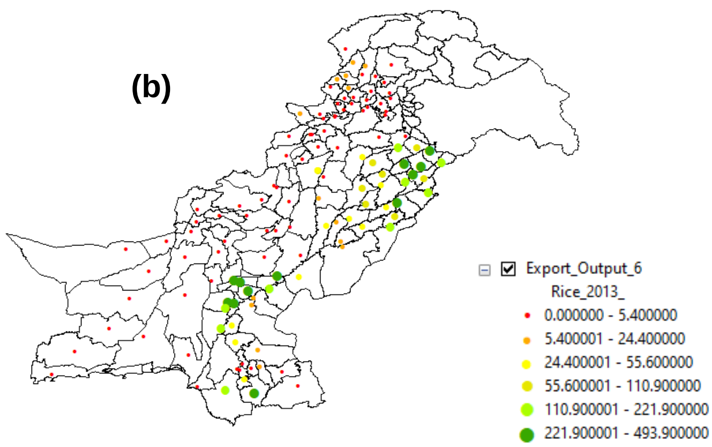


Figure 18 Rice Crop Production (b)

4.2.4 Residue to Crop Production Ratio (RPR)

The residue-to-crop production ratio (RPR) is a method adopted to calculate the amount of unused crop residue which might be left after a harvesting season is over. RPR's can extensively be used to model and estimate the amount of biomass that can be utilized in bioenergy products.

The factor of Residue to Crop Production Ratio used for Wheat and Rice was 1.75 and 1.76 respectively, according to the literature. (Nicolae Scarlat, 2010)

4.2.5 Crop Residue Generation Map for Wheat in Pakistan

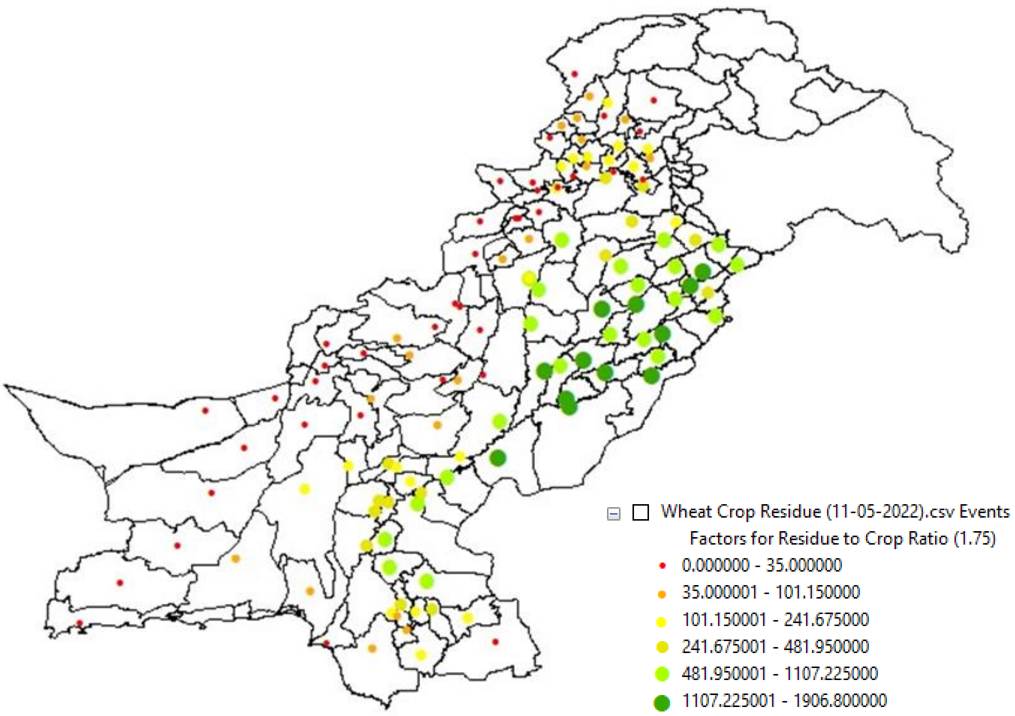


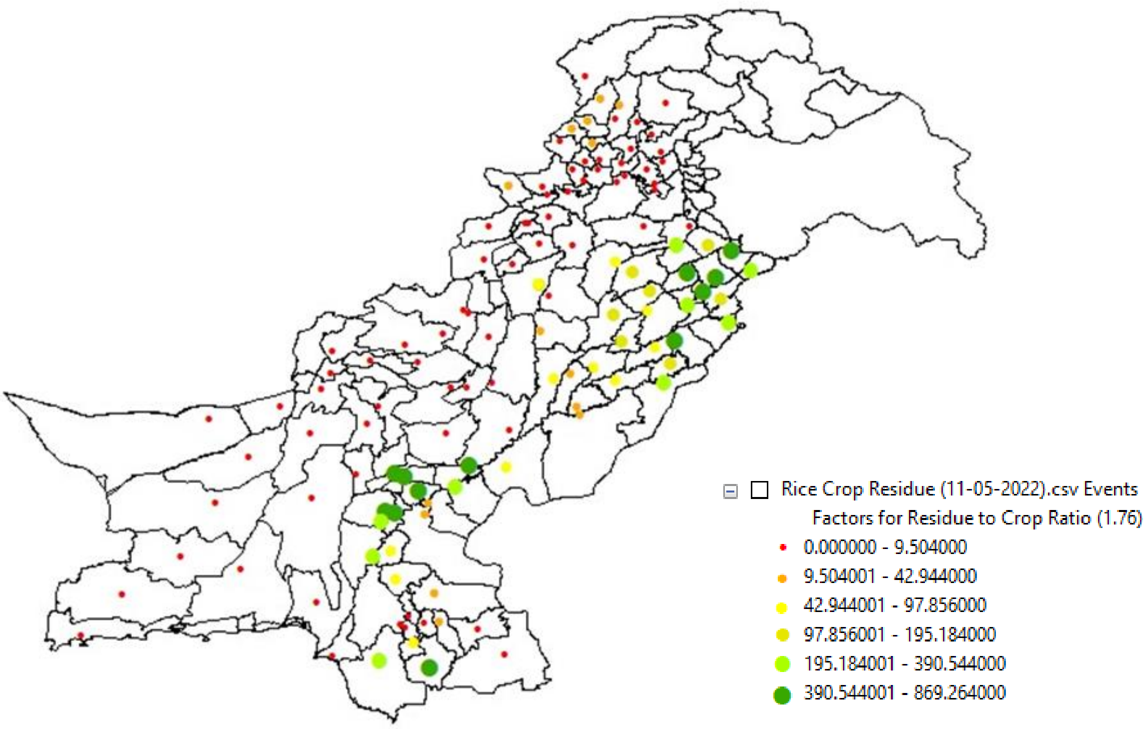
Figure 19

The figure attached above is the Crop Residue Generation Map of Wheat left once the harvesting season is over. With the help of the map, we can see that around 1107-1907 tonnes of Wheat residues are left most of which are exposed to open burning in order to get rid of. Cities which have the highest generation of Wheat residues are mainly located in the Punjab province which namely include Faisalabad, Sheikhupura, Rahim Yar Khan and Okara.

Consequently, this map gives an idea of all the viable locations where the Briquetting mills can be installed to harness the renewable resource of Biomass from Wheat Residue.

4.2.6 Crop Residue Generation Map for Rice in Pakistan

Figure 20 Crop Residue Generation Map of Rice in Pakistan

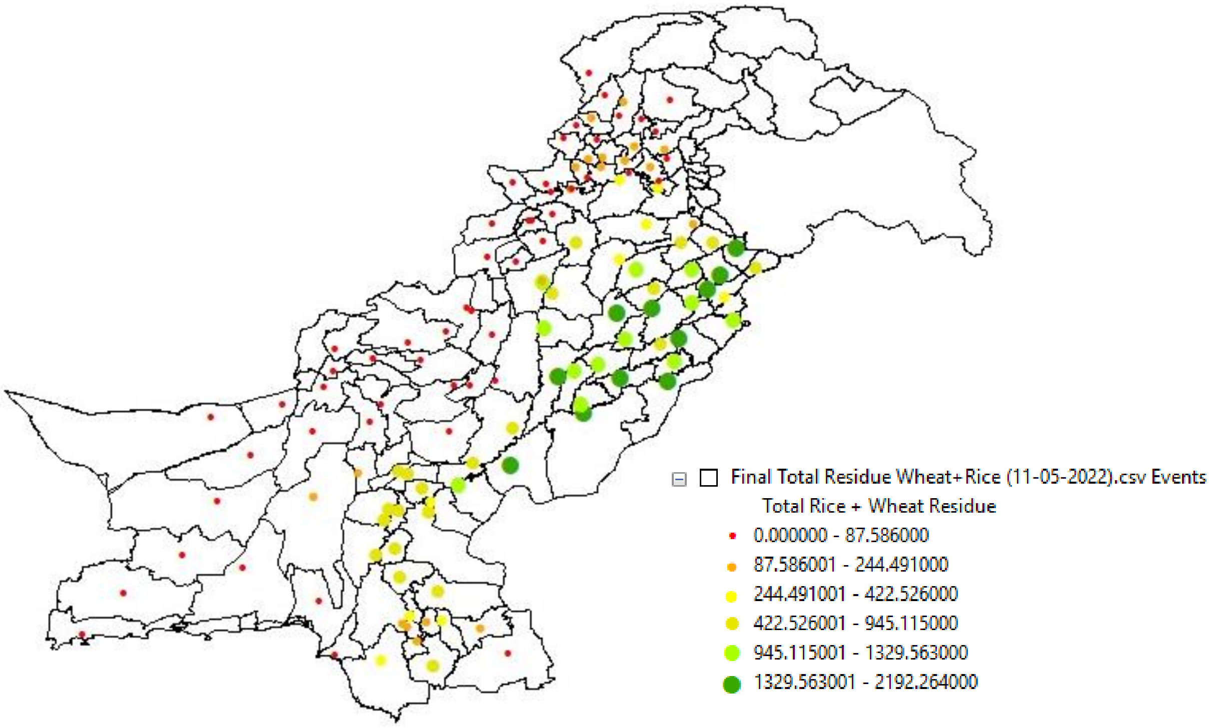


The figure attached above is the Crop Residue Generation Map of Rice left once the harvesting season is over. With the help of the map, we can see that nearly 391-869 tonnes of Rice residues are left most of which are exposed to open burning in order to get rid of. Cities which have the highest generation of Wheat residues are spread across Punjab and Sindh province which namely include Sialkot, Sheikhupura, Larkana and Badin

Consequently, this map gives an idea of all the viable locations where the Briquetting mills can be installed to harness the renewable resource of Biomass from Rice Residue.

4.2.7 Total Crop Residue Generation Map of Pakistan (Rice and Wheat)

Figure 21 Total Crop Residue Generation Map



The figure attached above is the Total Crop Residue Generation Map of Wheat and Rice left once the harvesting season is over altogether. With the help of the map, we can see that nearly 1330-2192 tonnes of Wheat and Rice residues are left most of which are exposed to open burning in order to get rid of. This open burning of the crop residues generates a significantly high amount of air pollutants which serve as a precursor to many environmental problems like smog and acid rain.

Overall, Punjab has a relatively higher amount of Crop Residue generation throughout the year as compared to other parts of the country which is why it more viable to install Briquetting Units in this part of the country. Namely, cities like Sialkot, Vehari, Rahim Yar Khan and Sheikhupura have the highest consolidated generation of Wheat and Rice residues.

Henceforth, this map gives an idea of all the viable locations where the Briquetting mills can be installed to harness the renewable resource of Biomass.

4.3 Techno-economic and Environmental Performance Evaluation in Comparison with Conventional Fuels.

Techno-economic analysis is critically important in order to understand the economic feasibility of a project. Here we have performed a Techno-economic Analysis to articulate the Capital Costs involved in setting up a Commercial Briquetting Unit followed by computing the Installation Costs incurred and ultimately gauging the Potential Revenues that can be generated out of it.

4.3.1 Capital Cost

The capital cost largely includes the costs incurred to purchase the Pre-processing equipment and the cost experienced in buying a suitable land area for installing the briquetting unit. The Pre-processing equipment costs mainly comprises of the cost of the Electric Grinder and a Briquetting Press. Moreover, both are needed to prepare the crop residues for the process of densification via Briquetting.

4.3.1.1 Electric Grinder

The Electric Grinder was sourced from an online retailer Alibaba. In Pakistan, the availability of commercial scale electric grinders and hoppers exclusively for biomass is a rarity which is why it is desirable to import one from an online retailer because it is most like going to fulfill most of the unit requirements as opposed to a locally manufactured generic grinder. The Electric Grinder that we chose has a daily output capacity of 800-1000kg/h which is compatible with the system that we have designed.

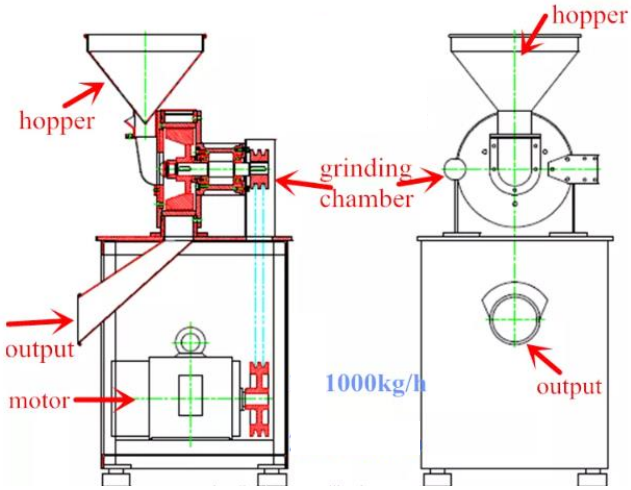


Figure 22 Electric Grinder

4.3.1.2 Briquetting Press

The Briquetting Press was sourced from Al Noor Machinery which is a local retailer located in Lahore and the Briquetting Press has a capacity of Briquetting 20 tonnes of Biomass in a day.

4.3.1.3 Land

Land is an extremely variable cost, and it varies depending upon the size and the location of the briquetting plant site. We have designed our facility with a land area requirement of 1500 sq. ft. as quoted in the literature for a briquetting plant having a capacity of 10 tonnes of briquette production each day.

4.3.1.4 Miscellaneous Costs

Additionally, a few other miscellaneous costs which are incurred during the residue handling and transport are also added in the overall Capital Cost.

Table 14 Capital Cost

Capital Cost		
Preprocessing Equipment	Electric Grinder Output (kg/h): 800-1000 kg/h	$1799 PKR 347 400
	Briquetting Press of 20 tonne/day	PKR 115 000 – 145 000
Land	30ft * 50ft = 1500 sq ft	PKR 100 0000 -120 0000
Miscellaneous Cost	Raw Material Handling	PKR 367600
Total Capital Cost		**PKR 20 60 000**

4.3.2 Installation Cost

There are costs incurred in erecting a briquetting unit on the site. This cost is mostly charged by the local equipment suppliers in case of sourcing the equipment from a local retailer. But if we are procuring our machines from an international source, we need to have some local technicians, electricians, and laborers on board.

Table 15 Installation Cost

Installation Cost				
		Number of Laborers Required	**Days of Activity**	**Cost PKR**
Installation of Briquetting Unit	Installation of Grinder	2	1	1600
	Installation of Briquetting Press	3	2	4800
Land	Demarcation	2	1.5	4800
	Cleaning of Debris	29	1.5	4800
Total Cost				**16 000**

Consolidated Cost of Capital and Installation (PKR) = 206 0000 + 16 000

= PKR 207 60000

4.3.3 Daily Operating Cost

The daily operating costs include several expenditures incurred in running the briquetting unit each day. These costs include the cost incurred in collecting, preprocessing, and transporting the crop residues from field area to site area which means that the fuel costs for running the trucks and the manpower involved is what mainly forms this chunk. Moreover, it also includes the daily electricity consumption to drive the briquetting unit. Additionally, oil lubricant electricity as well as manpower required to operate unit is also added to the daily operating costs.

Table 16 Daily Operating Cost

Daily Operating Cost		
Cost of Crop Residue Transportation per day to Briquetting Unit		
Truck Capacity of 16 000 Kg and Fuel Diesel Consumption = 4km/l		
Procuring Raw Materials from Location X in Sheikhupura, considering procurement within 100km radius, Fuel Consumed = 25l		
Cost of Diesel (PKR/L) as of May 2022.		PKR 144.5
Raw Material Procurement Cost		PKR 3612.5
Electricity Consumption = 500KWh per day Cost of 1KWh = PKR 16.4559 as of April 2022		PKR 8227.95
Miscellaneous Costs	Manpower Cost per day (4 men working in 2 shifts)	PKR 3600
	Lubricant Cost per day	PKR 500
	Repair and Maintenance Cost of Briquetting Press per day	PKR 800
Total Daily Operating Cost		**PKR 16740.45**

4.3.3 Unit Cost of Briquette Production

The determination of unit cost of briquette production is critically important to perform a cost benefit analysis in comparison to other conventional fuels. We have designed a briquetting unit having a production capacity of 10 tonnes of briquettes per day. Moreover, the investment plan of our unit lays over a period of 15 years. Accordingly, we have performed the following computations to draw up the cost incurred to produce 1 ton of Briquettes.

Table 17 Unit Cost of Briquette Production

Unit Cost of Briquette Production	
Total Working Hours per day = 8hrs	
Total Briquettes produced per day = 10 tonnes	
So, production of 1 tonne of Briquettes requires = 10/8 = 1.25 hrs.	
Considering a service life of 15 years, therefore 7% of initial investment's portion is added for cost calculation for first years.	
So initial investment cost = PKR 207 60000 per year and 16.6346 per hour	
Computation	**Cost PKR**
For 1.25 hour, the initial investment cost = 16.6346 * 1.25	20.7933
Operating Cost for 1 hour = 16740.45 / 24	697.52
Therefore, for 1.25 hours	871.89
Repair and Maintaining Cost per hour	33.33
For 1.25 hours, Repair and Maintaining Cost	41.67
Total Cost for 1 tonne Briquette Production per hour	934.36
Total Cost for 1 tonne Briquette Production per day	22424.619
Total Cost for 1 tonne Briquette Production per day	**22424.619**

4.3.4 Cost Benefit Analysis of Briquettes over Coal

In order to gauge the cost effectiveness of the briquettes produced, we ran a cost benefit analysis and compared them with the commercially used conventional solid fuel i.e. coal. Our final year project is an approach to provide an alternative fuel source to industrial boilers over coal. For briquettes to become a complete substitute of coal, we need to ensure that they are cheaper than coal. To perform the Cost Benefit Analysis, we used a ZBG Boiler which is one of the most commonly used industrial boilers in industries. According to the manufactures of ZBG Boilers, it has a daily fuel requirement of nearly 2 tonnes. Consequently, we computed its daily fuel requirements, and the results are presented in the table below.

Table 18 Cost Benefit Analysis of using Briquettes over Coal

Cost Benefit Analysis of using Briquettes over Coal	
ZBG Steam Boilers uses 2 tonnes of Coal per day	
Computation	**Cost (PKR)**
Cost of 1 tonne of Coal	42537
Cost of 2 tonnes of Coal	85074
Cost of 1 tonne of Biomass Briquette	22424.62
Cost of 2 tonnes of Biomass Briquettes	44849.24
Savings by using Biomass Briquettes over coal per day	**40 224.76**

Discussion:

After performing a cost benefit analysis of Biomass Briquettes over Coal, we can safely say that by using Briquettes we will be running our industrial boilers in nearly half the cost as that incurred to buy coal. This is exactly why our Briquettes have a significantly high potential to replace coal as the mostly used industrial fuel for boilers because this would overall decrease the production cost of all the goods.

Chapter 5: Conclusion and Recommendations

Pakistan is an extremely energy scarce country with a fragile economy and unfortunately the situation does not seem to improve. The dilemma is that not only the people but even the government is still heavily depending on the costly conventional fossil fuels in order to power their industries and boilers. Moreover, another challenge that Pakistan is facing a serious environmental threat which is why it is critically important to utilize the clean and green untapped resources of alternate energy. One such potential lies in using Biomass which is a clean and renewable energy source and perfectly fits the situation of Pakistan.

5.1 Calorific Values for Coal, Wood, and Biomass Briquettes

Table 19 Calorific Value

Fuel	Calorific Value (MJ/Kg)
Anthracite	30
Bituminous	29.3
Sub Bituminous	25
Lignite	14.3
Wood	18.5
Wheat and Waste Engine Oil	29.13
Rice and Waste Engine Oil	27.18
Wheat and Glycerol + Glue	18.69
Rice and Glycerol + Glue	16.61

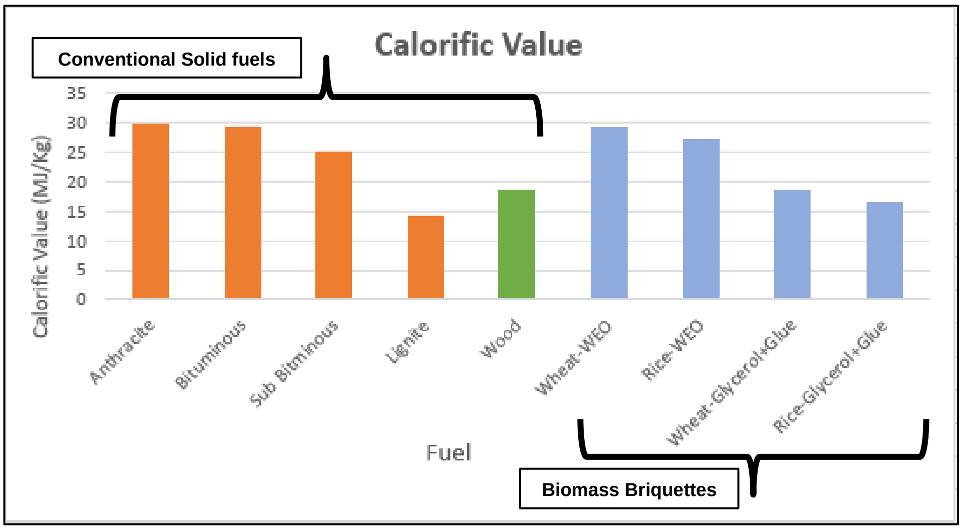


Figure 23 Calorific Values of Conventional Solid Fuels

Discussion:

Table 20 is a tabular representation of the calorific values of all the fuels. It includes the 4 types of most commonly used coal in Pakistan which are Anthracite, Bituminous, Sub Bituminous and Lignite along with firewood which collectively forms the chunk of conventional solid fuels used in this country. Table 20 also represents the calorific values of our lab scale developed briquettes. Additionally, Figure 22 is a graphical representation of all the calorific values of all the solid fuels and we safely say that the calorific values of our lab scale developed biomass briquettes is very similar to that of heating values yielded from conventional solid fuels. In fact, the calorific value of the briquette of wheat with waste engine oil as the binder had a heating value similar to that of Anthracite Coal which has the highest calorific value among all.

5.2 Cost Effectiveness of Green Briquettes

Table 20 Cost Effectiveness of Briquettes

Cost Benefit Analysis of using Briquettes over Coal	
ZBG Steam Boilers uses 2 tonnes of Coal per day	
Computation	**Cost (PKR)**
Cost of 1 tonne of Coal	42537
Cost of 2 tonnes of Coal	85074
Cost of 1 tonne of Biomass Briquette	22424.62
Cost of 2 tonnes of Biomass Briquettes	44849.24
Savings by using Biomass Briquettes over coal per day	**40 224.76**

Discussion:

After performing a cost benefit analysis of Biomass Briquettes over Coal, we can safely say that by using Briquettes we will be running our industrial boilers in nearly half the cost as that incurred to buy coal. This is exactly why our Briquettes have a significantly high potential to replace coal as the mostly used industrial fuel for boilers because this would overall decrease the production cost of all the goods.

5.3 Comparison in terms of Binders

Table 21 Comparison in terms of Binders

Binders	Waste Engine Oil	Glycerol	Glycerol + Glue
Comparison in terms of Calorific Values	Briquettes made of waste engine oil had a higher calorific value as compared to Glycerol + Glue.	This was a failed binder and the briquettes made from it swelled and disintegrated upon drying.	Briquettes made of glycerol and glue had slightly higher mechanical durability and strength as compared to Waste Engine Oil.

Discussion:

The highest calorific values were attained when we used waste engine oil as the binder and that shows that waste engine oil has the potential to produce briquettes with significantly higher heating values as compared to the other two binders of glycerol and glycerol with white glue.

Moreover, Pakistan extensively imports and uses Bituminous coal as a solid fuel which has a calorific value of 29.0-30.2 MJ/Kg whereas the Biomass Briquettes of Wheat + Waste Engine Oil had a calorific value of 29. 1 MJ/Kg which is very close to that of coal. Hence it has to potential to significantly replace imported and heavily polluting coal with relatively cheaper locally produced Briquettes.

In addition to this, another widely used conventional solid fuel is firewood that has a calorific value of 15.4-18.5 MJ/Kg which is still lesser than to our briquette with the least calorific value i.e. of Rice and Glycerol with White Glue. Consequently, this means that Pakistan can implement the use of Briquettes as an alternate to conventional solid fuels on a large scale because of biomass being a cheap, clean, and readily available renewable resource as opposed to the depleting and heavily polluting fossil fuel reserves.

5.4 Final Comparison of Crops

Table 22 Final comparison of crops

Crops	Wheat	Rice
Calorific Value	Briquettes made from wheat had a higher calorific value as compared to rice	Briquettes made from rice had slightly lower calorific values as compared to wheat
Mechanical Durability	Briquettes made from wheat mechanical stability was lower.	Briquettes made from rice had significantly higher mechanical durability compared to wheat.
Best Sieve Size	Briquettes made from Wheat passing from Sieve No.14's passing yielded the best results.	Briquettes made from Rice passing from Sieve No.14's passing yielded the best results.

Discussion:

We observed that the Briquettes made from Wheat Straw yielded relatively higher calorific values because of a greater lignin content being present which is around 16-25% by composition. Whereas the Lignin content present in Rice Straw was just about 2-25% of the entire composition. This is exactly the why Briquettes made from wheat straw yielded higher calorific values for the same amount of binder being added to both the crops.

While we achieved a higher calorific value in case of wheat there was a slight overall decrease in the mechanical durability of the briquettes made from wheat straw. On the contrary, an opposite trend was observed in the briquettes made from rice straw. Though there was a relative compromise in the heating values, but the mechanical durability of rice straw briquettes was far greater than of wheat straw briquettes.

5.5 Environmental Impacts

Moreover, another aspect that needs to be discussed is the environmental parameter that most of us forsake. It is critically important to understand that briquettes are carbon neutral in nature, and therefore no new cardon dioxide is added into the atmosphere once they are burnt. The carbon dioxide which is released into the atmosphere is the same carbon dioxide that was stored within the biomass during its growth in photosynthesis. Hence, there is no new net addition of carbon dioxide into the atmosphere. On the contrary, the carbon present in the coal is in sequestrated form which is why it is advisable to not use a sequestrated carbon source as a fuel because once it is burnt there is entirely new generation of carbon dioxide and carbon monoxide which was not present in the atmosphere previously.

5.6 Conclusion

Pakistan is an extremely energy scarce country with a fragile economy and unfortunately the situation does not seem to improve. The dilemma is that not only the people but even the government is still heavily depending on the conventional solid fuels like coal and firewood in order to power their industries and boilers. In addition to that, Pakistan is facing a serious environmental threat which is why it is critically important to dive into and utilize clean and green untapped resources of alternate energy. One such potential lies in using Biomass which is a clean and renewable energy source and perfectly fits the situation of Pakistan. Each year, tonnes of crop residues are produced and openly burnt once the harvesting season is over, with a very small percentage of these resources being brought into constructive use.

Our final year project introduces this trajectory of curbing the open burning of crop residues and simultaneously reducing our dependency on heavily polluting fossil reserves coal in order to meet our energy demands. Our study includes the comparison of the Calorific Values of 4 most commonly used coal types in Pakistan which are Anthracite, Bituminous, Sub Bituminous and Lignite along with firewood with the lab scale Briquettes. The calorific values of our lab scale developed biomass briquettes is very similar to that of heating values yielded from conventional solid fuels. In fact, the calorific value of the wheat briquette with waste engine oil as the binder had a heating value similar to that of Anthracite Coal which has the highest calorific value among all coal types. Anthracite and Bituminous Coal has a calorific value of 29.0-30.2 MJ/Kg whereas the Biomass Briquettes of Wheat + Waste Engine Oil had a calorific value of 29. 1 MJ/Kg which is very close to that of coal. Hence, it has to potential to significantly replace imported and heavily polluting coal with relatively cheaper locally produced Briquettes. In addition to this, another widely used conventional solid fuel is firewood that has a calorific value of 15.4-18.5 MJ/Kg which is still lesser than to our briquette with the least calorific value i.e. of Rice and Glycerol with White Glue.

After performing a cost benefit analysis of Biomass Briquettes over Coal, we can safely say that by using Briquettes we will be running our industrial boilers in nearly half the cost as that incurred to buy coal. This is exactly why our Briquettes have a significantly high potential to replace coal as the mostly used industrial fuel for boilers because this would overall decrease the production cost of all the goods.

Consequently, this means that Pakistan can implement the use of Briquettes as an alternate to conventional solid fuels on a large scale because of biomass being a cheap, clean, and readily available renewable resource as opposed to the depleting and heavily polluting fossil fuel reserves.

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