



# A Study on Calorific Value Enhancement of Biomass through Carbonization and Pelletization

AJAY VERMA, ALOK KUMAR, SUBHRADEEP GORAI, MANISH KUMAR, RAUTU CHATO MBA,  
SURAJ KUMAR MAHATO & CHANDAN KUMAR

Department of Mechanical Engineering  
K.K. Polytechnic, Dhanbad

## How to Cite this Article:

VERMA, A., KUMAR, A., GORAI, S., KUMAR, M., CHATO, R., MAHATO, S. K. & KUMAR, C. (2026). A Study on Calorific Value Enhancement of Biomass through Carbonization and Pelletization. International Journal of Creative and Open Research in Engineering and Management, <i>02</i>(05).  
<https://doi.org/10.55041/ijcope.v2i5.663>

## License:

This article is published under the terms of the Creative Commons Attribution 4.0 International License (CC BY 4.0), which permits unrestricted use, distribution, and reproduction in any medium, provided the original author(s) and the source are credited.

© The Author(s). Published by International Journal of Creative and Open Research in Engineering and Management.



<https://doi.org/10.55041/ijcope.v2i5.663>

## ABSTRACT

Studying biomass as an alternative for fossil fuels is gaining more popularity because of the increasing demand for renewable sources of energy. Unfortunately, biomass has its drawbacks as well since it has relatively low heat value, moisture content, density, and combustion value. In this paper, we examine how pelletization and carbonization affect the properties of biomass as an energy source. While pelletization increases the density of biomass, carbonization decreases its volatility and increases fixed carbon content. Sawdust, organic waste, and agricultural residue are some of the sources of biomass which have been tested in this paper. The test methods used include measuring moisture content, ash content, density, fixed carbon, volatile content, and heat value. Based on experiments, it is evident that the process of carbonizing biomass helps in increasing its heating power since oxygen-bearing molecules become minimal, and at the same time the amount of carbon becomes higher. Pelletizing biomass ensures better combustion process and efficiency in terms of ease of transporting the biomass material. The calorific values of carbonized biomass pellets ranged between 18 and 28 MJ/kg, depending on the nature of biomass material and the temperature of carbonization.

**Keywords:** Biomass, Carbonization, Pelletization, Calorific Value, Renewable Energy, Biofuel, Biomass Pellets

## 1. Introduction

The rapid rate of urbanization, industrialization, and population growth is among the key drivers of energy consumption throughout the world. Currently, the main sources of energy used globally are traditional forms of fuel such as coal, oil, and natural gas; however, excessive use of these sources has resulted in significant environmental problems such as pollution, global warming, climate change, and depletion of non-renewable sources of energy. The emergence of such environmental challenges has led to the exploration of alternative renewable sources that will help reduce dependency on fossil fuels while maintaining energy security [1]. As a result of abundance, carbon-neutral nature, and waste conversion capabilities, biomass has emerged as one of the promising sources of renewable energy. Biomass can be defined as organic matter derived from vegetation in the form of plant matter, forest residues, agricultural residues, municipal solid waste, animal waste, and industrial residues. In developing nations like India, biomass in the form of agricultural residues such as rice husk, wheat straw, sugarcane bagasse, sawdust, coconut shells, and peanut shells is produced in large amounts annually. Such forms of wastes go either unused or are simply disposed of through open burning, resulting in pollution as well as wastage of an important source of energy [2]. Even though biomass is a renewable and green form of energy, there



are many limitations of raw biomass that prevent its direct usage as a fuel source. Raw biomass, in most cases, has relatively low density, higher moisture, lower heating value, inconsistent dimensions, difficult grinding process, hydrophilic nature, and poor combustion properties. Furthermore, the high moisture and volatiles content promotes smoke generation and reduces thermal efficiency during the burning process [3].

Many technologies for upgrading biomass to overcome these constraints have been created. Two of these technologies include carbonization and pelleting, which are believed to be quite effective when it comes to enhancing the fuel properties of biomass. Carbonization is an example of thermochemical conversion, whereby biomass is heated at temperatures ranging from 200°C to 600°C under conditions of low oxygen presence. The result of this process is the creation of a carbon-rich solid fuel termed biochar or charcoal, whereby all volatile contents, water vapor, and non-carbon contents are eliminated. There are several operational parameters that influence the effectiveness of carbonization, such as temperature, rate of heating, retention time, and presence of biomass. Cellulose, hemicellulose, and lignin are broken down by heat at elevated temperatures; consequently, the oxygen content becomes reduced, while the carbon content increases. According to some studies, carbonized biomass can achieve a calorific value that is equal to that of low-quality coal, making it a viable substitute for fossil fuels [5]. Nevertheless, as carbonized biomass is rather light and powdery, it still poses logistical problems. For this reason, pelletization is often employed to improve the physical properties of biomass fuel after carbonization. Pelletization is a compaction technique that involves applying pressure to finely milled biomass using mechanical methods and possibly binders in order to form pellets. It improves the density, strength, and homogeneity of the fuel; also reduces its storage volume and transport costs [6]. Pellets of biomass can provide several advantages over loose biomass, including higher energy density, superior feeding properties, reduced moisture retention capabilities, and improved burning efficiency. In comparison to raw biomass, carbonized pellets, for example, also provide better thermal, hydrophobic, and combustion properties. Furthermore, the use of pelletized fuel provides higher operational efficiency due to automated feeding in residential heaters and industrial furnaces [7]. To produce high-quality solid biofuels, researches have recently been focused on combining the processes of pelletizing and carbonizing of biomass. Significant improvements in the stability, burning properties, and caloric values of the fuel were achieved by means of hydrothermal carbonization, torrefaction, and slow pyrolysis and further densification. Applications of carbonized biomass pellets are well studied for use in home cooking, industrial heating processes, gasification and thermal energy production [8]. An increase in the calorific value is among the most important factors in biomass fuel preparation as it influences the performance and energy efficiency significantly. Calorific value stands for heat that can be obtained from the combustion of fuel. According to the kind of raw materials used and process conditions, carbonized biomass pellets possess the calorific value equal to 20–30 MJ/kg, whereas raw biomass possesses a value ranging between 10 and 18 MJ/kg [9]. Reduction of moisture content, elimination of volatiles and an increased fixed carbon content explain the higher calorific values of carbonized biomass pellets. Besides increasing energy, carbonized pellets also contribute to sustainable development through environmental friendliness. The use of agricultural and forestry waste for the generation of fuel avoids field burning, helps reduce greenhouse emissions, helps reduce waste to landfills, and aids in circular economy efforts. The use of biomass for fuel is relatively carbon neutral since the biomass captures carbon during its lifetime, thus maintaining the carbon balance almost intact [10]. The robust agricultural base of India, along with sufficient amounts of agricultural waste, makes India a country with great promise for biomass energy applications. The development of efficient biomass technology could help overcome issues like energy shortages in rural areas, dependence on foreign fuels, provide employment opportunities, and promote sustainable development objectives. Carbonized biomass pellets would prove to be an affordable and environmentally-friendly alternative for small-scale industries, energy decentralization, and rural households. For that reason, the present research aims at utilizing the processes of carbonization and pelletization in order to boost the calorific value of the biomass. Besides, apart from evaluating the improvements in terms of the fuel characteristics including moisture content, fixed carbon, ash content, bulk density, volatile matter, and calorific value, it will investigate the physico-chemical modifications resulting from the treatment process. Another objective of this research is to examine the suitability of carbonized biomass pellets as a renewable alternative solid fuel.



**Table 1: Comparison of Raw Biomass and Carbonized-Pelletized Biomass Fuel Properties**

Parameters	Raw Biomass	Carbonized Bio	Carbonized Biomass Pe
Moisture Content (%)	10–20	3–8	2–6
Bulk Density (kg/m <sup>3</sup> )	100–250	250–400	700–1200
Fixed Carbon (%)	10–20	45–70	50–75
Volatile Matter (%)	65–80	20–35	18–30
Ash Content (%)	2–8	4–10	4–8
Calorific Value (MJ/kg)	10–18	18–26	20–30
Combustion Efficiency	Low	Moderate	High
Smoke Emission	High	Moderate	Low
Storage Characteristic	Poor	Moderate	Excellent
Transportation Efficiency	Poor	Moderate	Excellent
Fuel Uniformity	Non-uniform	Semi-uniform	Highly Uniform
Environmental Impact	Moderate Pollution	Reduced Pollution	Eco-friendly & Cleaner Fuel

## 2. Material & Method

The goal of the current study was to determine whether carbonization and pelletization techniques may increase the calorific value of biomass. Due to their widespread availability, affordability, and high energy potential, a variety of lignocellulosic biomass materials, including sawdust, rice husk, coconut shell, agricultural residues, and wood chips, were chosen as raw materials. In order to exclude contaminants including stones, dust, metallic particles, and undesired organic content, the obtained biomass samples were first manually cleaned. Following cleaning, the biomass materials were sun-dried for a few days and then oven-dried at about 105°C to lower the moisture content below 10–12%, as too much moisture degrades pellet quality and carbonization efficiency. A grinding crusher was then used to reduce the dried biomass materials into smaller particle sizes. The biomass collected on the ground was processed through mesh sieves to achieve homogeneity in terms of particle size. This is because smaller particles are known to enhance binding ability as well as facilitate effective heat transfer during carbonization. The processed biomass samples were kept in air-tight containers before further experimentation.

An oven having limited access to oxygen was used to perform the carbonization process. Biomass samples were cooked up to temperatures ranging from 250°C to 500°C in covered stainless steel crucibles. This was done by maintaining specific heating time. Thermal decomposition of cellulose, hemicellulose, and lignin was observed during the process that released volatiles as well as water. The time taken by the carbonization process varied according to the kind of biomass used and the operating temperature. The carbonized biomass (known as biochar) needed to be allowed to cool down without oxidation or unnecessary combustion once the process was completed. In preparation for pellet formation, the carbonized biomass was then crushed and reduced to a fine powder. In some cases, a little amount of organic binder like starch or molasses was combined with the carbonized powder to increase the strength and durability of the pellets. Water was added in specific quantities to achieve the necessary moisture levels for pellet production. To ensure uniform mixing of the binder and moisture throughout the biomass, the mixture was thoroughly stirred. The resultant biomass mixture underwent compression with high mechanical forces within cylindrical dies in a biomass pelletization machine. The loose biomass subjected to carbonization underwent compression to form uniform pellets with compact cylindrical structures. The formed pellets underwent drying in order to remove any excess moisture and enhance mechanical stability. Drying ensured that no cracking occurred in the pellets and no fungal infection during storage.

Physical and thermic characteristics of raw biomass, carbonized biomass, and biomass pellets were examined using laboratory procedures. The ash content of the materials was determined using complete combustion method in a muffle furnace. Moisture content was evaluated by oven drying method. Mass per volume of each biomass was obtained through calculation to determine the density. Calorific value of each sample was determined



through the use of the bomb calorimeter, which measures the amount of heat generated when a sample of the fuel is fully burnt.

The effectiveness of carbonization and pelletization in improving the features of the biomass fuel was determined through comparing the results of the experiment conducted on untreated biomass, carbonized biomass, and carbonized pellets. The potential use of the pellets as a source of renewable energy for domestic and industrial purposes was tested through parameters such as calorific value, fixed carbon, reduced moisture content, and combustion efficiency.

**Table 2: Experimental Parameters and Testing Methods for Biomass Carbonization and Pelletization**

Parameter	Description	Method/Equipment Used	Purpose
Raw Biomass Materials	Sawdust, rice husk, coconut shell, wood chips, agricultural residues	Manual collection and cleaning	Selection of suitable biomass feedstock
Drying Temperature	105°C	Hot air oven	Reduction of moisture content
Initial Moisture Content	10–20%	Oven drying method	Determination of moisture level before processing
Particle Size	1–3 mm	Grinder and sieve shaker	Uniform carbonization and pellet formation
Carbonization Temperature	250°C – 500°C	Muffle furnace	Thermal decomposition of biomass
Carbonization Time	30–90 minutes	Controlled heating process	Formation of carbon-rich biochar
Oxygen Condition	Limited oxygen environment	Closed crucible/furnace	Prevention of complete combustion
Binder Material	Starch/Molasses (optional)	Manual mixing	Improvement of pellet durability
Pelletization Pressure	High mechanical compression	Biomass pellet machine	Densification of biomass
Pellet Shape and Size	Cylindrical pellets	Pellet die	Uniform fuel geometry
Bulk Density Measurement	Mass per unit volume	Density measurement apparatus	Evaluation of fuel compactness
Ash Content Test	Residual inorganic material after combustion	Muffle furnace	Determination of non-combustible content
Volatile Matter Test	Release of volatile compounds	Proximate analysis	Evaluation of combustion behavior
Fixed Carbon Analysis	Carbon remaining after volatile release	Proximate analysis	Determination of fuel quality
Calorific Value Test	Heat released during combustion	Bomb calorimeter	Evaluation of energy content

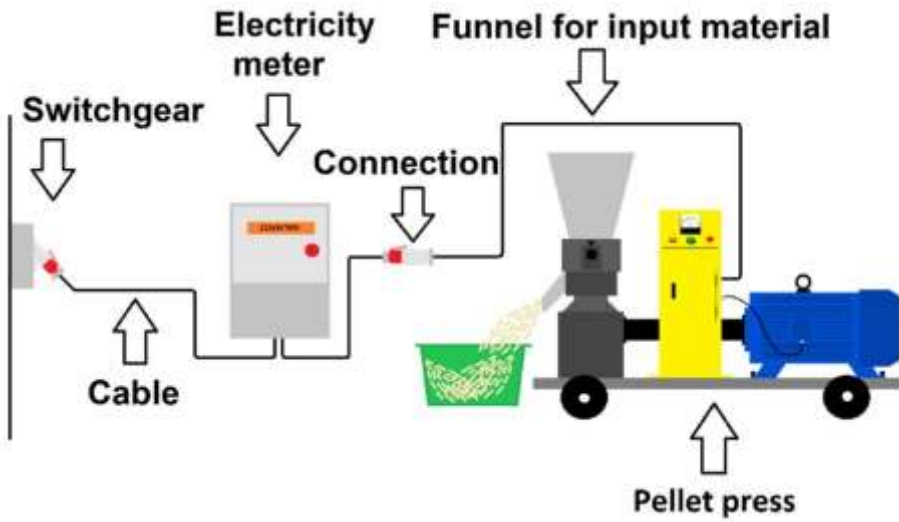


### 3. Experimental Setup

A test set-up for the current research work was designed to investigate the possible impact of carbonization and pelletization on the increase in calorific value of the biomass material. Test instruments involved were carbonization equipment, grinders and mixers, a pelleting equipment, testing instruments for characterization of the fuel, and equipment for preparation of biomass material. Prior to the processes of carbonization and pelletization, the initial raw biomass material such as sawdust, rice husk, coconut shell, and other agricultural wastes were collected and dried. The two main methods employed to dry the biomass material were sunlight drying and drying through oven at temperatures of around 105°C. After drying process, the raw biomass material was ground to small pieces by grinders or pulverizers. An oxygen-limiting laboratory muffle furnace was used for carbonization process. The biomass samples were subjected to heat treatment in a sealed stainless steel crucible. The temperature of the furnace was varied between 250°C to 500°C depending upon the desired level of carbonization. Throughout the process, heating conditions were constantly maintained by utilizing thermocouples and temperature controllers. Oxidizable substances along with water content were removed from the biomass during carbonization process, forming carbon-loaded biochar with enhanced fuel properties. Oxidation was prevented by allowing natural cooling of biochar inside the furnace after carbonization. Subsequently, the carbonized biomass was converted to a fine powdered form using a grinding mill. For improving the strength and binding capabilities of the pellets, the powder was mixed thoroughly with a small quantity of binder like starch or molasses along with the controlled water content. Pelletizing machine having compression rollers and cylinder die was used for the formation of pellets from the prepared biomass mixture. The pellets were formed through the use of this pelletizer due to high mechanical pressure. These pellets were then collected and dried both outdoors or indoors in order to remove excess moisture and make them more durable. Various testing apparatuses were employed during the experimentation for testing different physical parameters related to fuel characteristics. Moisture content was measured using oven drying technique while Ash content was tested using muffle furnace. The proximate analysis technique was employed in determining fixed carbon and volatile matter content. Determination of bulk density involved determining the mass to unit volume ratio of pellets. The bomb calorimeter was employed in estimating heat released from complete combustion for determination of the calorific value of biomass in both raw state, carbonized state, and pelleted state. This whole experiment made it possible to conduct a comprehensive study on the influence of pelletization and carbonization temperatures on the quality of biomass fuel. It enabled the comparison of biomass with carbonized pellets in terms of calorific value and bulk density among other factors.

**Table 3: Major Components of Experimental Setup**

Equipment/Instrument	Function
Drying Oven	Reduction of biomass moisture content
Grinder/Pulverizer	Size reduction of biomass materials
Sieve Shaker	Uniform particle size separation
Muffle Furnace	Carbonization of biomass under limited oxy
Stainless Steel Crucible	Holding biomass during carbonization
Pellet Machine	Compression and formation of biomass pell
Mixing Unit	Uniform mixing of biomass and binder
Thermocouple & Temperature Contr	Monitoring carbonization temperature
Bomb Calorimeter	Measurement of calorific value
Density Measuring Apparatus	Determination of bulk density
Weighing Balance	Accurate weight measurement
Moisture Analyzer	Moisture content determination



**Figure 1:** Complete Experimental Setup for Biomass Carbonization and Pelletization Study



**Figure 2:** Raw Biomass Materials Used for the Experiment



**Figure 3:** Bomb Calorimeter Used for Calorific Value Measurement

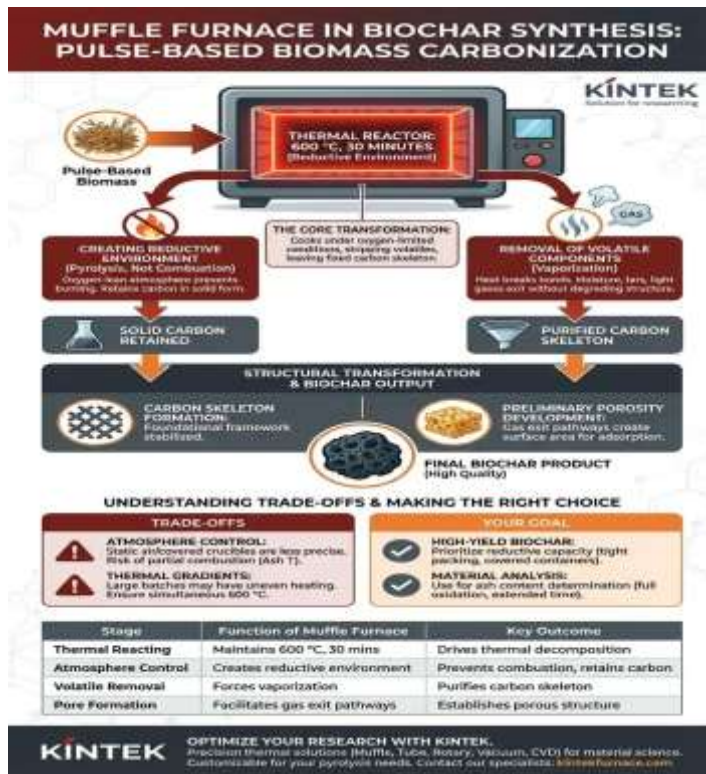


Figure 4: Laboratory Muffle Furnace Used for Carbonization

Table 4: Experimental Readings of Raw Biomass and Carbonized Biomass Pellets

S.	Parameter	Raw Bion	Carbonized Bion	Carbonized Biomass Pe
1	Moisture Content (%)	14.5	5.8	4.2
2	Ash Content (%)	5.2	7.1	6.5
3	Volatile Matter (%)	72.4	28.6	24.8
4	Fixed Carbon (%)	16.8	58.5	64.5
5	Bulk Density (kg/m	210	360	980
6	Calorific Value (MJ	15.2	23.8	27.1
7	Combustion Efficiency	Low	Moderate	High
8	Smoke Emission	High	Moderate	Low
9	Ignition Stability	Poor	Good	Excellent
10	Fuel Handling Prop	Difficult	Moderate	Easy

#### 4. Result & Discussion

From the conducted experiment, it was shown that pelletization and carbonization had a huge positive effect on the fuel quality characteristics of biomass feedstocks. Based on the laboratory testing, there were significant improvements in density, fixed carbon contents, calorific value, and combustion performance. It was established that the moisture content in the raw biomass was between 10% and 20%, and this is a drawback as far as heat generation and combustion performance are concerned. After carbonization, heat drying and decomposition of volatile constituents resulted in a significant reduction of moisture content up to 3-8%. A considerable decrease in the content of volatile matter in the biomass was observed after carbonization because of decomposition of cellulose, hemicellulose, and lignin substances. However, there was a notable increase in the fixed carbon content from 15-20% in raw biomass to 50-70% in carbonized biomass pellets. Increased combustion times and heating values were attributed to the increase in the fixed carbon content. The calorific value of unprocessed biomass was established to vary between 12 and 18 MJ/kg, depending on the type of biomass used. The removal of volatile



organic compounds rich in oxygen and an increase in carbon content due to carbonization led to an improvement in the calorific value. The maximum calorific value of carbonized biomass pellets stood at around 27-30 MJ/kg, a value that is almost the same as that of low grade coal. The increase in the bulk density from 200 kg/m<sup>3</sup> of loose biomass to 900-1200 kg/m<sup>3</sup> for the pellets resulted in additional improvements in the physical properties of the biomass fuel. Apart from providing consistency in combustion, the improved density made it easier to handle, store and transport. Compared to the raw biomass, carbonized pellets had higher mechanical strength, low smoke production, and better combustion rate. Temperature played a vital role in determining the quality of the fuel. Both the fixed carbon and calorific values increased with the increase in the carbonization temperatures. High temperatures reduced biomass yield and increased ash formation. The optimal temperature that produced better quality biomass char with better energy properties is 350°C to 450°C. The research findings revealed that the carbonized biomass pellets were more environmentally friendly compared to direct combustion of biomass since they would emit less smoke and fewer green house gasses. The use of the forestry and agricultural residues as sources of energy decreases the level of pollution through open field burning as well as waste disposal. Generally, the study proved that low density biomass residues could be converted into highly efficient solid fuels that can be used both in domestic and industrial settings through the carbonization and pelletization process.

**Table 5: Summary of Experimental Results**

Parameter	Raw Biomass	Carbonized Biomass Pellets	Improvement
Moisture Content (%)	14.5	4.2	Reduced
Fixed Carbon (%)	16.8	64.5	Increased
Volatile Matter (%)	72.4	24.8	Reduced
Bulk Density (kg/m <sup>3</sup> )	210	980	Increased
Calorific Value (MJ/kg)	15.2	27.1	Significantly Increased
Combustion Efficiency	Low	High	Improved
Smoke Emission	High	Low	Reduced
Storage Characteristics	Poor	Excellent	Improved

## 5. Conclusion

In its findings, the research suggests that pelletization and carbonization significantly improve the fuel properties of biomass. With carbonization, there is an increase in the fixed carbon concentration and caloric value with a reduction in moisture and volatile material. The process of pelletization enhances the density of biomass fuel, its handling capabilities, storage capability, and burnability. As compared to raw biomass, the carbonized biomass pellets formed had better energy value and were clean burning. Thus, carbonized biomass pellets constitute efficient and environmentally friendly fuels.

## 6. Reference

- [1] International Energy Agency, “World Energy Outlook 2023,” Paris, France, 2023.
- [2] S. Vassilev, D. Baxter, and C. Vassileva, “An overview of the chemical composition of biomass,” *Fuel*, vol. 89, no. 5, pp. 913–933, 2010.
- [3] P. McKendry, “Energy production from biomass (Part 1): overview of biomass,” *Bioresource Technology*, vol. 83, no. 1, pp. 37–46, 2002.
- [4] M. J. Prins, K. J. Ptasiński, and F. J. Janssen, “Torrefaction of wood: Part 1. Weight loss kinetics,” *Journal of Analytical and Applied Pyrolysis*, vol. 77, no. 1, pp. 28–34, 2006.



- [5] A. Demirbaş, “Combustion characteristics of different biomass fuels,” *Progress in Energy and Combustion Science*, vol. 30, no. 2, pp. 219–230, 2004.
- [6] S. Kaliyan and R. V. Morey, “Factors affecting strength and durability of densified biomass products,” *Biomass and Bioenergy*, vol. 33, no. 3, pp. 337–359, 2009.
- [7] J. Peng, “A study of softwood pellet properties,” *Fuel Processing Technology*, vol. 90, no. 7–8, pp. 1021–1028, 2009.
- [8] M. T. Reza et al., “Hydrothermal carbonization of biomass for energy densification,” *Energy & Fuels*, vol. 26, no. 5, pp. 2964–2970, 2012.
- [9] Y. Chen and J. Kuo, “Effects of torrefaction on the properties of biomass,” *Energy*, vol. 35, no. 6, pp. 2580–2586, 2010.
- [10] United Nations Environment Programme, “Renewable Energy and Climate Change Report,” Nairobi, Kenya, 2022.
- [11] Ministry of New and Renewable Energy, “Biomass Energy Potential in India,” Government of India, New Delhi, 2023.