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Original Article

Comprehensive Assessment of Agricultural Biomass Pellet Production: Market Opportunities in India with a Focus on Uttar Pradesh

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Abstract *- The manufacturing of biomass pellets in India, especially in Uttar Pradesh, offers substantial market prospects. The country's annual biomass production of 667 million tons is a significant contributor to the nation's energy landscape. However, challenges such as low density and seasonal availability hinder its optimal utilization. The National Mission on biomass mandates a 5% blend of biomass pellets in coal-based thermal power stations, creating a significant market. Financial support schemes, benchmarking of pellet prices, and awareness programs further facilitate biomass adoption. The study assesses the potential for biomass in the districts of Uttar Pradesh and finds significant demand and availability for biomass. The study suggests decentralized pellet production, incorporating local businesses and addressing supply chain processes despite obstacles such as feedstock availability and pricing. A scalable, long-term solution requires creative policy approaches and district-specific initiatives. Production of biomass pellets is essential to India's economy, having net-zero carbon emissions by 2070.*

Keywords *- Pellet production, Market opportunities, Decentralized production, Renewable energy.*

1. Introduction

In the global pursuit of sustainable energy solutions, biomass-based energy systems have emerged as a promising avenue, leveraging organic materials like agricultural residues to produce renewable energy, particularly in the form of biomass pellets. India, with its abundant agricultural landscape and growing energy demands, stands at the forefront of this transition, poised to harness the vast potential of biomass resources for sustainable development. India's agricultural sector is a vital pillar of its economy, contributing significantly to GDP and employment. With an annual biomass production of 667 million tons, the country possesses a vast reservoir of organic materials that can be utilized for energy generation [1]. However, challenges such as low biomass density and seasonal availability have hindered the optimal utilization of these resources. Addressing these challenges requires concerted efforts to develop efficient supply chain mechanisms and incentivize biomass adoption across sectors [2]. A key driver of biomass pellet production in India is the National Mission on Biomass, which mandates a 5% blend of biomass pellets in coal-based thermal power stations [3]. This policy initiative not only creates a significant market for biomass pellets but also contributes to India's goal of reducing carbon emissions and transitioning to cleaner energy sources. Furthermore, financial support schemes and price benchmarking initiatives have been introduced to facilitate the seamless implementation of biomass pellet policies. In Uttar Pradesh, a state renowned for its agrarian economy, the assessment reveals substantial biomass availability and demand in the state. However, there are several barriers, like inadequate strategies, limited local engagement, and inefficient supply chain management, which limit the biomass potential in the state.

The study focused on addressing the gaps in exploring the potential of pellet production in a decentralized manner in Uttar Pradesh. As India charts its path towards a net-zero carbon emissions economy by 2070, the role of biomass pellet production becomes increasingly pivotal [4, 5, 6]. This introduction sets the stage for a detailed exploration of market opportunities, technological advancements, and policy interventions aimed at accelerating the transition towards a more sustainable energy landscape in India, with

Uttar Pradesh playing a central role in this transformative journey. Throughout the paper, we will delve into specific market dynamics, technological innovations, and policy frameworks driving biomass pellet production, aiming to provide a comprehensive understanding of the path towards sustainable energy solutions.

2. Market Opportunities for Crop Residue-Based Pellets

There are two distinct market segments for briquettes/pellets in India, namely, a variety of industrial/commercial users and thermal power plants.

- Industries
- Thermal Power Plants

2.1. Industries

In India, there are many large, and MSMEs spread across different geography. Most of these MSMEs rely on fossil fuels like coal, FO and diesel to meet their process heat requirements. Due to the recently increased prices of these fuels and other environmental considerations, industries are looking for alternate options, such as briquettes and pellets, to meet this requirement. The prevailing market price of briquettes is Rs 6000-8000 per ton depending on the type and quality of briquettes, whereas wood pellets prices are Rs 10,000 to 14000 per ton. There is a growing market of biomass briquettes/pellets in India, while sustaining supply and production constraints are critical challenges in meeting this requirement.

2.2. Thermal Power Plants

The Ministry of Power, Government of India (GoI) has initiated a National Mission on the use of biomass in coal based thermal power stations (SAMARTH) through co-firing in pulverized coal-fired boilers and mandated all the coal-based power plants to use 5% blend of biomass pellets along with coal. This has been initiated with the objective of creating a market for biomass pellets and torrefied pellets in India to achieve the national goal of addressing the issue of air pollution due to farm stubble burning and reducing the carbon footprints of thermal power generation. This aims to support the energy transition in the country further and achieve its targets to move towards cleaner energy sources.

The proposed National Mission on biomass will also contribute to the National Clean Air Programme (NCAP). Approximately 2.5 to 3.0 lakh tonnes of biomass pellets are required for 7% blending in a thermal power plant of 1000 MW capacity. The existing India's coal based electricity production capacity is about 214 GW, and annually about 980 million tonnes of coal is used in the power generation application (2022-23). To meet the 5% co-firing target, there is an annual requirement of 50 million tons of biomass pellets in TPPs across States. Over the past few years, there has been a growing trend in the use of pellets by TPPs, as shown in Figure 1. It can be seen that about 1,61,873 MT of pellets are already co-fired in TPPs to date of FY 2023-24 against the total of 50,091 MT of pellets used in FY 22-23 in various TPPs across India. Also, the cumulative capacity of Biomass co-fired is 300335 MT achieved in FY 23-24 till now [7]. As per SAMARTH portal data, out of a total of 269 TPSs in India, about 48 thermal power plants have successfully implemented the co-firing policy and started firing pellets along with coal. The overall potential market size of agro residues based pellets is estimated to be more than 40000 crore industry. To facilitate the seamless implementation of this policy, the Government has initiated various measures. The Ministry of New and Renewable Energy (MNRE) and the Central Pollution Control Board (CPCB) have introduced Finance Assistance Schemes tailored for biomass pellet manufacturing units. The Reserve Bank of India (RBI) has accorded approval, designating 'Biomass pellet manufacturing' as an eligible activity under Priority Sector Lending (PSL).

2.3. Financial Subsidies and Schemes

2.3.1. Financial Support

For Non-torrefied plant setups, financial support under Environment Protection Charge (EPC) funds entails a one-time assistance of Rs. 14 Lac per ton of production capacity per hour, capped at Rs. 70 Lakhs. For Torrefied plant setups, a one-time capital support of Rs. 28 Lac per ton of production capacity per hour is provided, with a ceiling of Rs. 1.40 Crores. A designated corpus of Rs. 50 crores have been earmarked for utilization following the stipulated guidelines [8].

MNRE Bio Energy Schemes

Under the MNRE Bio Energy Schemes, pellet manufacturing plants stand to receive Rs. 9 Lakh per Metric Ton Per Hour (MTPH) or Rs. 45 Lakhs per plant as Central Financial Assistance. To bolster the procurement and availability of biomass pellets, the Ministry of Power has undertaken multifaceted initiatives. The Ministry has also rolled out awareness programs and advertisement campaigns to promote the use of biomass pellets in Thermal Power Plants. Due to the fact that agro-residue based pellets are in the nascent stage and are evolving market conditions for different stakeholders, including thermal power plants, pellet manufacturers, farmers, bankers, etc. The Ministry of Power (MoP) has decided to benchmark the prices of biomass pellets used for co-firing in Thermal Power Plants (TPPs). The benchmark price focuses on the electricity tariff rate, viability of business and pellet production purchase by power utilities. The price benchmarking of pellets also aims to enable the TPPs, as well as pellet producers, to establish a sustainable supply mechanism for the co-firing of pellets. As per the directives issued by the Ministry of Power, Govt. of India pellet price of Rs 2.32/1000 Kcal is being set for NCR and adjoining area within a 300 km radius of Delhi [9].

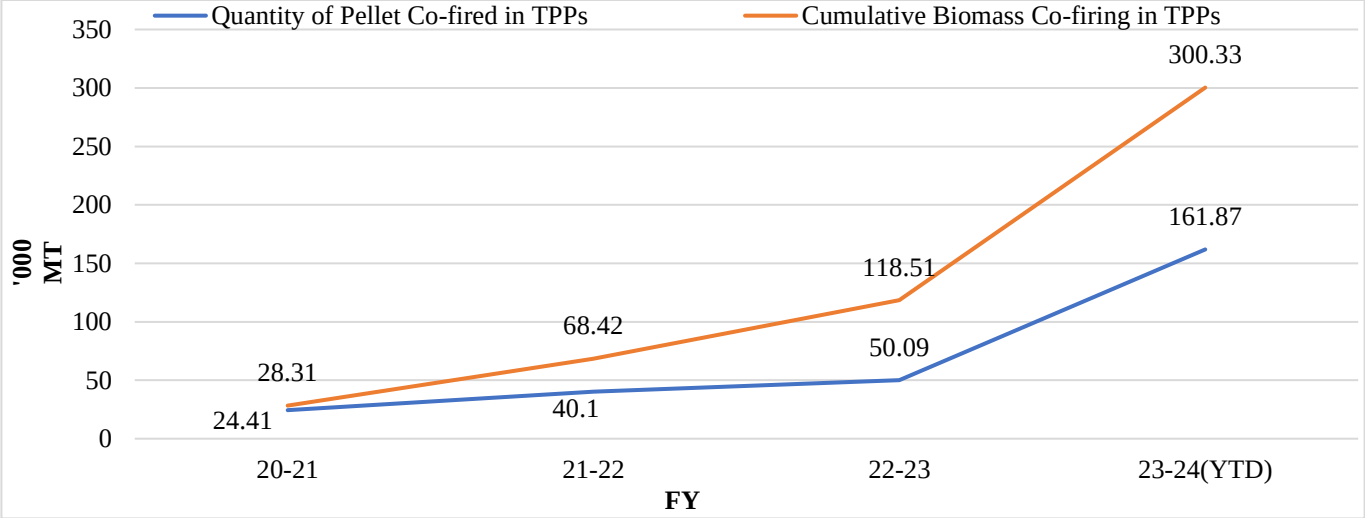

Fig. 1 Year quantity of pellet co-fired in TPSs

The price of Rs 2.27/1000 Kcal is set for the Northern region of India covering states like Uttar Pradesh, Rajasthan, Uttarakhand, Haryana, Punjab, Himachal Pradesh, J&K and Ladakh and price of Rs 2.24/1000 Kcal is set for western states of India covering states like Madhya Pradesh, Gujrat, Maharashtra, Chhattisgarh [10,11]. This results in a pellet base price of Rs 6272 to 9280 depending on pellet quality and GCV, with the price excluding GST and transportation costs at the pellet manufacturing plant site.

Out of the total 1.58 million tonnes of annual biomass generated, about 0.772 million tonnes of biomass is estimated to be surplus, mostly available at agricultural fields and which could be potentially procured for pellet production. To address the challenge of crop residue management, district/block-level-specific plans must be developed with an emphasis on crop residue production and surplus quantity, demand of energy (fuels, electricity, and drying/ cooling applications) in agricultural industries and HH sectors, besides the use of crop residues for soil incorporation purpose.

A more innovative and integrated policy approach by combining in situ and ex situ approaches is needed for a scalable and long-term solution to this problem. This can play an important role in achieving a net-zero carbon emissions economy by 2070. Also, achieving the national goal of reducing GHG emissions and decarbonizing the power sector in India. The complexity of agro residues includes biomass collection, processing, storage and eventually its transportation to the point of ultimate utilization due to the dispersed and voluminous nature of this resource, lack of a robust institutional and market mechanism for efficient procurement of the required quantity of agro residues in a short span of time add additional challenge in the management of this resource. Similarly, with the lower energy density characteristics and life cycle emission perspective, it is inevitable to use these resources at a decentralized scale rather than transporting them over long distances. One of the critical challenges to scaling up these efforts on the ground is that project developers perceived risk primarily due to feedstock challenges in terms of availability and pricing. The lack of policies and incentives in crop residue collection and aggregation business, coupled with access to efficient farm machinery to handle these residues during harvesting seasons, are critical missing links in value chain creation.

To address these challenges, it is important to develop a decentralized model involving Farmer Producer Organizations (FPOs), farmers cooperatives, etc., in the production of crop residue pellets or torrefied pellets at the village level to utilize crop residues to meet the growing demand of fuel in power generation. A 2 TPH capacity biomass pellet plant can utilize about 7500 tonnes of crop residues annually. It can support 70 direct and indirect sustainable jobs in rural areas through this project, in addition to income from supplemental activities.

The socio-economic benefits of something like this could range from reduction of air pollution to increased farmer income. This has the potential to make the farmers not only self-reliant but also provide opportunities to become agro entrepreneurs. It could also promote local entrepreneurship development and employment opportunities in rural areas. To address the challenge of crop residue management, district/block level, specific plans must be developed with an emphasis on crop residue production and surplus quantity, demand of energy (fuels, electricity and drying/cooling applications) in agriculture, industries and HH sectors, besides the use of crop residues for soil incorporation purpose. More innovative and integrated policy approaches by combining in-situ and ex-situ approaches are needed for scalable and long term solutions to this problem.

This can play an important role in achieving a net-zero carbon emissions economy by 2070 and in achieving the national goal to reduce GHG emissions and decarbonize the power sector in India.

3. Assessment of Agricultural Biomass in Uttar Pradesh

A comprehensive framework based on the latest secondary data available and to undertake a comparative analysis for the districts of Uttar Pradesh for setting up decentralized pellet production plants and to recommend the districts where this can be piloted. Evaluate biomass availability in two districts, Basti and Jaunpur. The work involved visits to 114 units across both districts for conducting primary research work to study the supply chain of agricultural residues. During primary research work, the status of biomass from the demand and supply side was studied thoroughly by interviewing the industrial sector, farmers and biomass traders. Data was collected from sample MSME units, such as brick kilns, jaggery units, paper mills, and institutions like midday meals, anganwadi, and hostel mess, besides hotels/dhabas about their present energy consumptions, type of fuel used, daily/ annual quantity of fuels used and its cost. The survey was also conducted to assess the willingness to shift towards cleaner forms of biomass fuels. The prices of different fuels used in the district were also collected during the survey.In Basti district, it is calculated that 1.58 million tonnes of agricultural biomass is generated annually in Kharif, Rabi and Zaid crops from all the developmental blocks.

In Kharif, crops like paddy produce 42810 tonnes of rice husk at the milling stage, while 321075 tonnes of rice stalk and an equal quantity of rice straw are produced at the farmer's field. Power plants and other industrial units consume most of the rice husk produced in the district. Sugarcane produces 766750 tonnes of bagasse in sugar mills and is almost fully consumed in the mill itself for co-generation application.

During sugarcane harvesting, about 116174 tonnes of top leaves are produced, which are available in the field. Arhar is another kharif crop, producing 876 tonnes of husk and 7301 tonnes of stalk which is also available at the farmer's field. Rabi crop, Rai/ Sarson, is an important crop grown in this district and is estimated to generate 14.77 tonnes of husk and 61.92 tonnes of stalk annually. In the Zaid crop, the mung crop produces 0.15 tonnes of husk and 1.1 tonnes of stalks annually, as shown in Figure 2.

Out of the total 1.58 million tonnes of annual biomass generated, about 0.772 million tonnes of biomass is estimated to be surplus, mostly available at agricultural fields and which could be potentially procured for pellet production [12, 15].In the Jaunpur district, the primary research work was conducted at the village level to analyse the average landholding, crops grown in different seasons, their productivity and biomass generated and their use in domestic and other sectors. The farmers were surveyed for the collection of primary data related to crops cultivated and biomass generated, and the analysed scenario of agricultural biomass is given in Figure 3 below [13, 14].

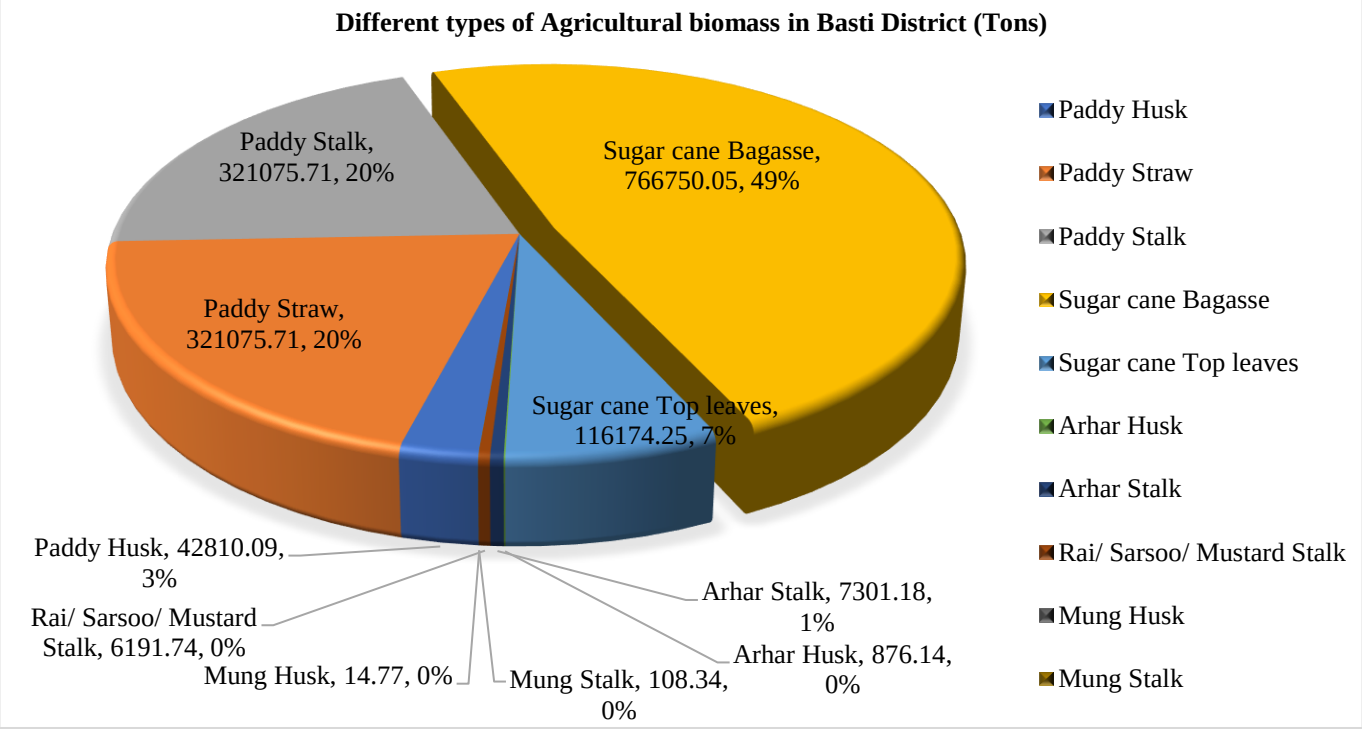

Fig. 2 Share of different types of biomass and its quantity in Basti district of Uttar Pradesh

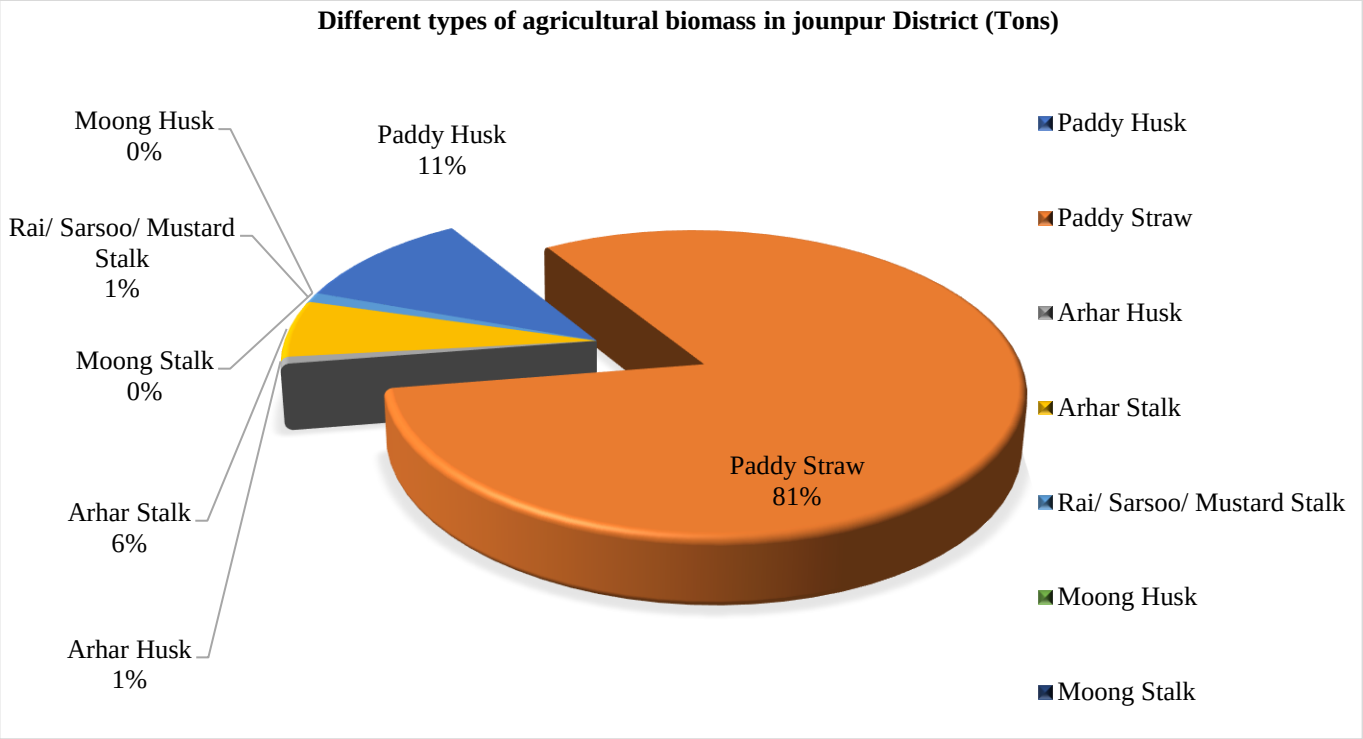

Fig. 3 Share of different types of biomass and its quantity in Jaunpur district of Uttar Pradesh

3.1. Biomass from Industry

In Basti district, two out of four sugar mills were functional. These sugar mills normally remain functional for 45–50 days during January to March, 85-90 days during October to December and overall about 130-140 days annually. On average, 131947 tonnes of sugarcane is crushed from January to March 360180 tonnes from October to December, that is, a total of 492127 tonnes annually. The crushing of bagasse generates 40903 tonnes of sugar from January to March, and 40903 tonnes of bagasse is generated from October to December; that is, a total of 152559 tonnes of bagasse annually. However, most of the bagasse generated is consumed in the sugar mills for co-generation. In Jaunpur, sugar mills are non-functional due to price issues of raw materials.

In Basti district, there are also 4 rice mills, which are generally operational during the first (January to March) and last (October to December) quarter of the year. During these seasons, rice mills operate for 12 hours a day, nearly 80 hours a week, 960 hours in a quarter and 1920 hours annually, leaving 3–4 hours weekly for maintenance, and these rice mills remain closed from April to September of the year. During operation, these mills process 45–47 quintals of rice per day and 7520 quintals annually. On average rice mill operates 160 days annually, which results in the generation of 1654 quintals (22%) husk and 600 quintals (8%) bran. These rice residues are generally sold at the rate of Rs. 200/- per quintal and Rs. 1500/- per quintal, respectively, at the site excluding freight. Most of the husk is purchased by biomass traders, supplying biomass to biomass based power plants. There are 5–6 such mills in the district. Along with it, there are more than 1000–1200 decentralized rice mills located at the village level. Out of which 300 are operational during the season [9]. Whereas in Jaunpur district, there are 444 medium-scale rice mills, around 950 small-scale rice mills in addition to 4 large-scale rice mills functional in the district.

On average, medium-scale mills process about 65–70 kg/h of paddy, while small capacity mills process 15kg/h of paddy. These rice mills are operational for six months, spread from January to March and October to December. During the milling of paddy, around one-third of the husk by weight is generated as residue, which is generally sold at the rate of Rs. 200–250/quintal. Major buyers of rice husk in the district are biomass traders, murmura-making industries, and farmers rearing livestock, and chick birds. The total annual rice husk produced from small- and medium-sized rice mills in the district is 62680 quintals (Source: Primary Research).

The quantity of husk generated by the rice mills in the Basti and Jaunpur districts is shown in Figure 3 below. In Basti district, the sawmills were visited and interviewed to know the status of biomass generation in the form of saw dust, woodchips and end cuts. The data collected from the average wood sawmill plant indicates that the sawmill is operated on an average for 3–4 hours a day, and 20–23 quintals of wood is chopped. Each sawmill, on average, processes 6500 quintals of wood annually, which generates 564 quintals of sawdust and 276 quintals of end cuts. Raw

wood species such as Babool, Jamun, Mango, Mahuwa, Sheesham, and ply boards are the main wood species processed. During July, most of the sawmills remain closed for a month. The sawdust and end cuts are sold locally at an average price of Rs. 300–350/ quintal and Rs. 450–530/ quintal, respectively, excluding transportation costs.

In Basti district, there are nearly 50 sawmills and therefore, the estimated saw dust available in the district is about 25380 quintal and 12440 quintal end cuts annually. As per the District Industrial Officer, Jaunpur, there are around 208 sawmills situated in different villages/ blocks. These sawmills operate for 7–8 months a year and see the wood of trees, such as Babool, Jamun, Mango, Mahuwa, Sheesham, ply boards, etc.

To estimate the average sawdust generated in the sawmills, primary data/ information was collected from 6 sawmills of different capacities in the district to estimate the sawdust residue quantity generated by these mills and its average selling price.

The data collected from the sawmill plant indicates that the sawmill is operated for an average of 8 hours a day and processes 25-30 quintals of wood. Each sawmill, on average, processes 5156 quintals of wood annually, which generates 902 quintals of sawdust. The comparative assessment of sawdust and end cuts generated for the Basti and Jaunpur districts is shown in Figure 4 [11, 12].

3.2. Demand for Biomass Fuels

As shown in Figure 6, the average demand of biomass in Basti is assessed for 2526 Nos. of Mid-Day Meal (MDM) serving institutions, 2655 Nos. of Aaganwadies, 399 Nos. of Brick kiln units, 1250 Nos. of Hotels and 400 – 450 Nos. of Small and Medium hotels. In the Jaunpur district, a similar assessment was made for 3573 Nos. of MDM serving institutions, 250 Nos. of brick kiln units, 250 Nos. of Murmura making units, 50 Nos. of Namkeen making units, 5000 Nos. of Tea stalls, 220 Nos. of Dhabas (medium) and 100 Nos. of hotels (small) (see Figure 7).

4. Key Challenges, Findings and Conclusion

Managing agro residues presents challenging issues as the demand for biomass to replace fossil fuels rises. Because the resource is scattered, this covers gathering, processing, storing, and shipping. Acquiring agricultural leftovers efficiently is made more difficult by the absence of strong market and institutional processes. Value chain creation is further impeded by inadequate rules and investments in crop residue collection, and project developers perceive risks associated with feedstock supply and pricing. These difficulties are made worse by limited access to effective farm equipment.

Table 1 presents a summary of the main conclusions about the availability of biomass, demand analysis, fuel wood consumption, interest in biomass pellets, obstacles, potential, price swings, supply chain problems, and more.

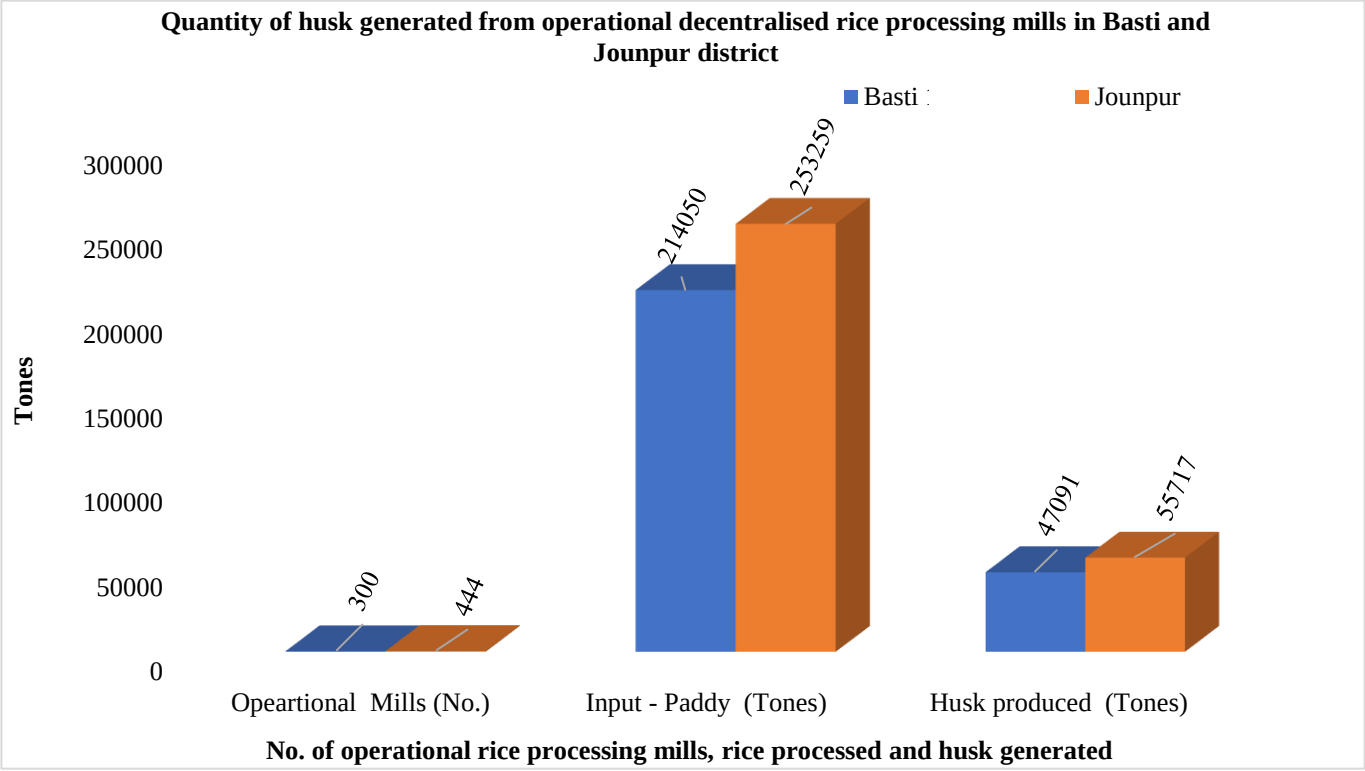

Fig. 4 Share of different types of biomass and its quantity in Basti district of Uttar Pradesh

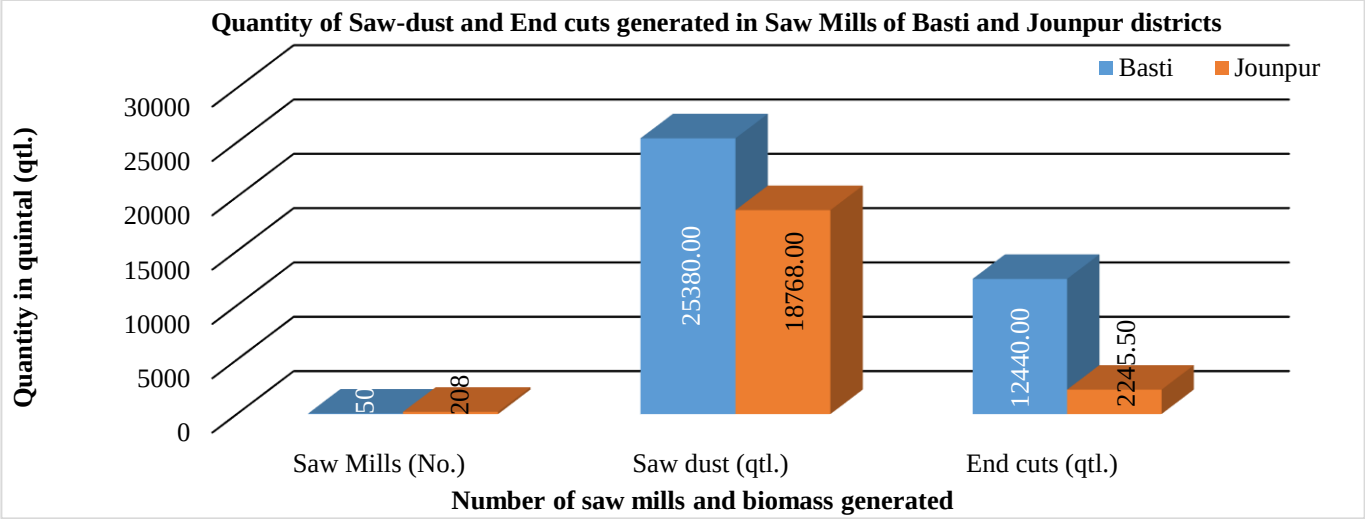

Fig. 5 Share of different types of biomass and its quantity in Basti district of Uttar Pradesh

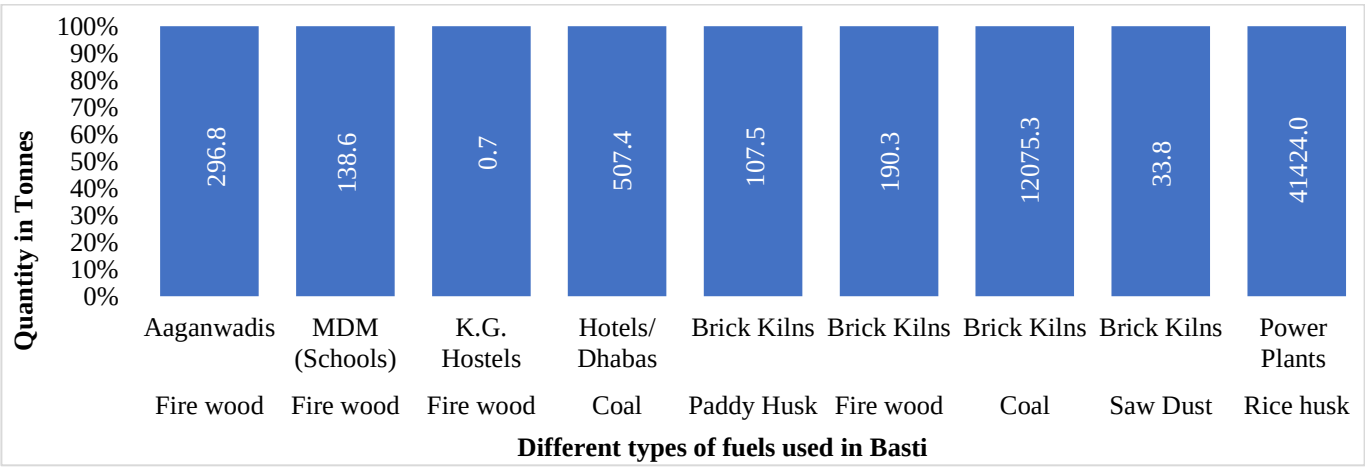

Fig. 6 Annual demand for biomass fuels for heating by industrial units in Basti district

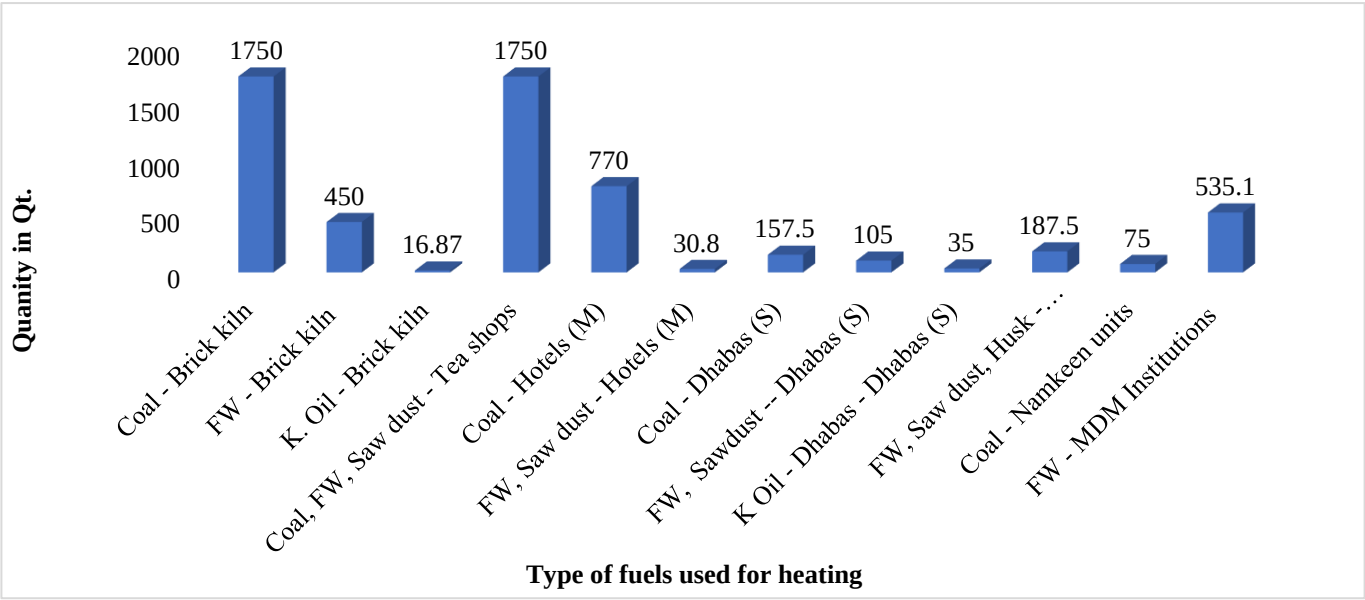

Fig. 7 Demand for biomass fuel use for heating by industrial units in Jaunpur district

Table 1. Biomass availability, demand, and potential

Aspect	Findings
Biomass Availability	• Significant availability from agricultural residues and agro-processing industries. • Surplus rice straw production: 7.72 lakh quintals in Basti, 1.09 lakh quintals in Jaunpur annually. • Sawdust and end cuts generated by sawmills. - Rice husk and sugarcane bagasse used for co-generation.
Demand Analysis	• Brick kiln industry is the largest biomass fuel and coal consumer in Jaunpur. • Murmura/Namkeen units also use large amounts of fuel, wood and coal. • Annual demand: 24,625 tonnes in Jaunpur, 53,830 tonnes in Basti. • Institutions like Aanganwadis and MDMs are major consumers.
Fuel Wood Consumption	• Seasonal variation, higher demand during winter months. • Price range: Rs 5–7 per kg for fuel wood, Rs 9–11 per kg for coal.
Interest in Biomass Pellets	• Industries and institutions show interest in biomass-based pellets as clean fuels. • Interest subject to hassle-free combustion, calorific values, and affordable pricing.
Challenges and Potential	• Lack of awareness among farmers and stakeholders about pelletizing technology. • Biomass pellet production offers significant potential for clean energy in institutions and industrial sectors. • Setting up biomass supply chains is crucial for successful palletization.
Price Fluctuations and Supply Chain Issues	• Fluctuation in biomass material depending on the seasonal availability. • Need for biomass supply chain mechanisms involving entrepreneurs. • High demand for solid fuels despite high prices.
Potential of Biomass Pellets	• Biomass pellets have huge potential in institutional, commercial, and industrial applications.

The local farmers and stakeholders currently lack awareness of the potential of utilizing agro residues through pelletizing technology despite the significant opportunity it presents. Biomass-based pellet production holds substantial promise in meeting the clean energy needs of institutions and industrial sectors. However, the key to realizing this potential lies in establishing a robust biomass supply chain mechanism. Presently, agricultural residues are either locally used for household purposes or disposed of at minimal prices, while there exists a notable demand for solid fuels like coal, fuel wood, and sawdust despite their high costs, partly due to transportation expenses. The seasonal availability and other factors that were responsible for biomass material prices further underscore the importance of creating a reliable supply chain involving entrepreneurs and setting up pellet production facilities. Biomass pellets emerge as cost-effective alternatives to competing fuels such as firewood and coal, offering extensive applicability across institutional, commercial, and industrial sectors.

Based on these conclusions, the following set of recommendations has been made:

- Implementing a decentralized model involving Farmer Producer Organizations (FPOs), farmers cooperatives, etc., for crop residue pellet production at the village level can effectively meet the increasing fuel demand.
- A 2 TPH biomass pellet plant can utilize 7500 tonnes of crop residues annually, creating 70 sustainable jobs. This initiative promotes local entrepreneurship and rural employment. These initiatives offer various socio-economic benefits, including reduced air pollution and increased farmer income. By empowering farmers as agro-entrepreneurs, they contribute to rural development. District-level plans are needed to manage crop residues effectively, considering production quantity, surplus, and energy demand. An integrated policy approach is vital for scalable and long-term solutions, aligning with India's goal of achieving a net-zero carbon economy by 2070.
- The study recommends setting up a biomass based decentralized pellet production facility with capacities ranging from 500 to 1000 kg/h in both districts to meet the demand in the identified local institutions and MSMEs units.
- To carry out a techno-economic study to set up the decentralized pellet production plant in both districts.
- Based on the techno-commercial report, involve local entrepreneurs to invest in decentralized pellet production plants and to develop new business models/ opportunities.
- Create awareness and sensitize State and District level agencies about the potential of biomass for pellet

production and its applications as a source of clean fuel in these Districts and the State at large. There must be an involvement of local institutions and entrepreneurs in processing the biomass materials and further connecting with MNREGA and PMEGP- Prime Minister's Employment Generation Program.

- Awareness generation of rural people and institutions about the harmful effects of emissions due to inefficient burning of conventional fuels (like wood logs, coal, etc.) and sensitize them to shift to clean forms of biomass using efficient stoves.
- Provision for financial incentives and other schemes for promoting is sector is essential to encourage investment in this sector. Credit institutions, such as agricultural development banks, which are not familiar with biomass pellet technology and related opportunities, could be made aware through awareness and capacity building programs.
- The biomass pellets based on agricultural residues have a higher amount of volatile matter and a low ash melting point as compared to fuel wood or coal. It is thus apparent to develop a proper design of suitable retrofitting/ combustion devices to promote biomass pellet fuels.

  Therefore, the combustion characteristics of various biomass pellets have to be studied vigorously in order to design suitable combustion equipment for pellets.

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