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An Economical Assessment of Paddy Residue Supply Chain for Power Generation

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Abstract

Punjab, an agriculturally rich state, generates a substantial amount of biomass in the form of crop residues, particularly paddy straw. Despite its potential as a renewable energy source, much of the residue is burnt, contributing significantly to air pollution. The present study made an economic assessment of paddy residue supply chain along with challenges in utilizing surplus biomass for power generation in Punjab. Primary data were collected 30 farmers and 5 residue collectors in periphery of operational power plant i.e. Universal Biomass Energy Pvt. Ltd., in Sri Muktsar Sahib district during 2023-24. Analysis revealed that for adopters of ex-situ crop residue management (CRM) practices, 19.48 quintals of residue per acre was generated, with surplus largely sold or stored while for non-adopters 15.2 quintals per acre was produced, with most being incorporated, stored, or paid in kind. The baling operation, a key supply chain activity, was economically assessed, revealing costs of Rs 147.37 per quintal and net return of Rs 27.63 per quintal, BC ratio of 2.89 and payback period of 2.12 years. The average baling operation days were 42 i.e. about 458 hours with effective field capacity being 2.56 acres per hour. Among different variable expenses, the largest share was of transportation, accounting for about 27 per cent share in the total cost of baling the paddy straw. The paddy residue collectors faced operational challenges like high initial investment, labor shortages, and rising fuel expenses. Findings highlight the need for targeted interventions to promote sustainable residue utilization through enhanced awareness, CRM infrastructure, and market linkages, fostering environmental and economic benefits.

Keywords: Baling, Benefit, Challenges, Crop residue, Energy, Paddy straw

JEL Classification: D61, D24, O13, Q1, P28

Introduction

Bioenergy is the main source of renewable energy on a worldwide scale, making up around two thirds of the mix of renewable energy sources and 13 to 14 per cent of overall energy consumption (Anonymous 2021). India, with its abundant agricultural biomass resources, has implemented various initiatives to tap its biomass energy potential (Shrimali and Sen, 2020). In India, the biomass power potential, including sugarcane bagasse cogeneration, is estimated at 18 GW. As per MNRE 2024 by 30thJune, 2024 the country had installed approximately 10.95 GW of grid-connected biomass power, which accounts for about 6 per cent of the total installed renewable electricity capacity. This surge in biomass power is crucial for India as it aims to meet 50 per cent of its energy requirements from renewables. In this context, the efficient management of the biomass supply chain, especially the agricultural biomass supply chain becomes imperative not only for energy generation but also for livelihoods and sustainable development. Maintaining the environment and economic growth simultaneously is extremely difficult in emerging nations like India where economies are growing quickly (Mittal et al, 2016). Agricultural biomass supply chain begins with harvesting agricultural residues obtained from crops followed by collection, and transportation. The biomass is stored to prevent spoilage and then utilized for energy through burning, biofuel conversion, or biogas plants. Each stage presents distinct challenges and opportunities, highlighting the supply chain's complexity. To foster a robust biomass ecosystem, the Ministry of Power's Biomass Co-firing Policy mandates thermal power plants to incorporate 5 per cent agro-residue-based biomass with coal, with a planned increase to 7 per cent by 2025–26.

Punjab being an agriculture rich state has huge potential of biomass resource availability in the form of crop residues which has a great use in the niche applications. In spite of huge potential, agricultural residues are mostly burnt out in

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practice due to certain other reasons also like farmers' ease and perception that residue burning is helpful to have clean fields prior to initiating their land preparation for next crop in little time. Proper management of crop residue not only helps in controlling environmental pollution but is also a source of valuable extra income to farmers. Keeping this in mind, the present study was carried out for economic assessment of paddy residue supply chain along with challenges faced for utilizing surplus biomass as a feedstock for the generation of power.

Data Sources and Methodology

For the study, operational power plant located in village Channu of district Sri Muktsar Sahib, Universal Biomass Energy Pvt. Ltd., having annual power generation capacity of about 14.50 Mega-watt (MW) was selected. Further, within the periphery of 15 kms of the selected power plant, villages falling under different blocks were chosen giving due consideration to the distance from the plant. It may be mentioned here that the optimum distance as collection radius of bales should not exceed 15 km as the transport charges become uneconomical beyond 15 km (Kurinji and Kumar, 2021). In this way, blocks namely Malout and Lambi from Sri Muktsar Sahib district were considered for the study and further at the third stage, 30 farmers (15 adopters and 15 non-adopters) were selected randomly from different villages within the periphery of the power plant. Further, five paddy residue collectors involved in mobilizing the crop residue to the selected power generation plant were chosen randomly. Thus, totalsample size included one power plant, 5 paddy residue collectors and 30 farmers.

The primary data were collected through personal interview method on a well prepared and pre-tested interview schedule prepared separately for the farmers (adopters and non-adopters). From the sampled farmers, data regarding various aspects like socio-personal profile of the farmers, operational holding, farming experience, area allocated to different crops, crop output, residue generated from different crops, different methods followed for crop residue management (CRM), awareness regarding power generation technology from crop residue and different machines/ implements used for ex-situ CRM,were collected through personal interview method on specially designed schedule for the reference year 2023-24.

Similarly, from the selected paddy residue collectors, data relating to investments, returns,residue collection methods from the field, cost related to first-mile transportation to collection center/straw bank were gathered. The cost of machinery used (such as tractor, stubble shaver, rake and baler), labour, and fuel required for cutting and baling of crop residue, loading and unloading, twine used, transportation charges and other additional costs involved in ex-situ CRM and utilization for power generation was also collected by personally interviewing them. Information relating to problems faced by the paddy residue collectors in the operation was also studied.Further the data were analyzed using tabular analysis and following ratios were calculated:

Benefit Cost Ratio (BCR)- In cost-benefit analysis, BCR is a profitability metric that assesses the sustainability of cash flows produced by an asset. The present value of all expenses and benefits derived from an asset are compared using the BCR. The BCR ratio is computed as follows.

$$\text{BCR} = \frac{\Sigma \text{ Present worth of benefits}}{\Sigma \text{ Present worth of cost}}$$

Payback period- The payback period is the length of time it takes to recover the cost of an investment or the length of time an investor needs to reach a breakeven point. The payback period is calculated as mentioned below:

$$\text{Payback period (yr)} = \frac{\text{(Total Intial Investment, Rs/Yr)}}{\text{Net Benefit (Rs/yr)}}$$

Results and Discussion

The baling operation is a mechanical process requiring three tractor-driven machines for cutting, lining, gathering and making bales. First stubble shaver is operated to harvest the stubbles from base level and then lining operation is performed by the rake machine and after that gathering and bale formation is completed by the baler. Once baled, the straw is then transported to a temporary collection (interim storage) before transport to an aggregation centre of the power plant for long term storage and use in the power plants. A small brief regarding the supply chain management (SCM) of paddy has been indicated in Figure 1. The key stages are "Farm to Straw Bank" and "Straw Bank to End-User," with the latter incorporating biomass processing if needed.

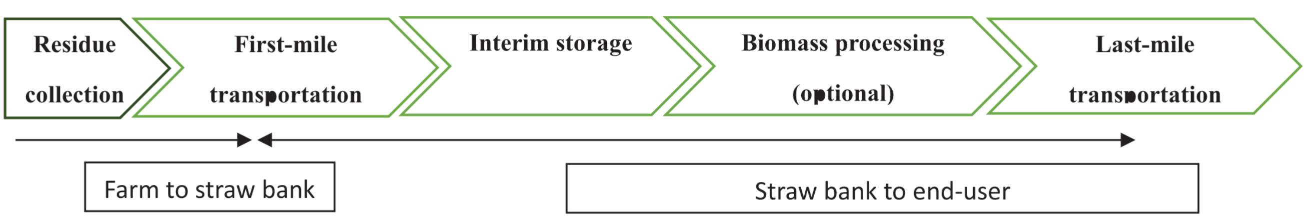

Figure 1: Supply chain of paddy residue for ex-*situ* management

Crop residue generated

The perusal of Table 1 reveals that the type of residue generated varies with the crop. It was observed that on adopter farms 3834.58 quintals (Qtls) of crop residue was generated with 2474.84 Qtls (64.54%) being from kharif crops and 1359.75 Qtls (35.46%) from rabi crops.

On an average, 19.48 Qtls of crop residue generated from each acre cultivated on the adopter farms with average figures per acre for paddy, basmati, wheat and mustard being 26.2, 22.42, 13.71 and 15.7 Qtls respectively. During kharif season, paddy generated most of the crop residue, accounting for about 76.22 per cent (1886.4 Qtls) of the total residue produced. While among rabi crops, wheat contributed the most with 96.82 per cent share i.e. 1316.57 Qtls followed by mustard with mere share of 3.18 percent (43.18 Qtls) in the total residue generated on adopter farms.

In case of non-adopter farms it was observed that 4667.25 quintals (Qtls) of crop residue was generated with 2427Qtls (52%) being from kharif crops and 2240.25 Qtls (48%) from rabi crops. On an average, 15.2 Qtls of crop residue was generated from each acre cultivated in Punjab. The average residue produced per acre for paddy, basmati, wheat and mustard was17.74, 11.64, 14.57 and 16.5 Qtls respectively. During kharif season, paddy generated most of the crop residue, accounting for about 76.74 per cent (1862.5 Qtls) of the total residue produced. Among rabi crops, wheat contributed the most with 98.53 per cent share i.e. 2207.25 Qtls followed by mustard with mere share of 1.47 percent (33 Qtls) in the total residue generated.

Table 1: Crop residue generated on respondent farms in Punjab, 2023-24

S.no.	Crop	Residue type	Area (acres)	Residue generated	
				Total (Qtls)	Average (Qtls)
Adopters					
1	Paddy	Straw	72	1886.4 (76.22)	26.2
2	Basmati	Straw	26.25	588.44 (23.78)	22.42
Sub-total A			98.25	2474.84 (64.54)	25.19
1	Wheat	Straw	96	1316.57 (96.82)	13.71
2	Mustard	Stalk	2.75	43.18 (3.18)	15.7
Sub-total B			98.75	1359.75 (35.46)	13.77
Grand total (A+B)			**197**	**3834.58 (100.0)**	**19.48**
Non-adopters					
1	Paddy	Straw	105	1862.5 (76.74)	17.74
2	Basmati	Straw	48.5	564.5 (23.26)	11.64
Sub-total A			153.5	2427 (52.0)	15.81
1	Wheat	Straw	151.5	2207.25 (98.53)	14.57
2	Mustard	Stalk	2	33 (1.47)	16.5
Sub-total B			153.5	2240.25 (48.0)	14.59
Grand total (A+B)			**307**	**4667.25 (100.0)**	**15.2**

Crop residue utilization pattern

The data collected on the crop residue utilization patterns in Punjab revealed a diverse approach to manage crop residues from different crops. Analysis of the data indicated that consumption of the residue constituted fodder, fuel and littering material needs while the surplus included the quantity removed as waste, paid in kind, removal, use in factories, storage and as gift to others.

Of the total crop residue generated on adopter farms, about 292.25 Qtls was consumed, while 3542.33 Qtls remained surplus. In case of adopters, no use of paddy residue as fodder or fuel was observed.From the surplus crop residue, about 0.54 petr cent each was either paid in kind or gifted free to others and about 1.45 per cent each was either stored or sold. In case of wheat about 1040.57 Qtls of the residue generated remained surplus with only about 276 Qtls being used for fodder. The surplus wheat residue was mainly sold or stored for future use(Figure 2a and 2b).

In case of non-adopters, of the total crop residue generated, 268.63 Qtls was consumed, while 4391.57 Qtls remained as surplus. About 0.34 per cent of the surplus was incorporated and whole of the paddy residue was incorporated into the soil while 0.47 per cent was gifted free and 1.37 per cent was removed as waste. About 14 per cent was sold up, about 27 per cent was paid in kind and about 55 per cent was stored for future use.

Awareness among respondents

Data were also collected regarding awareness to the selected farmers about different machines/implements used for effective crop residue management (CRM).It was found that majority of the selected farmers were aware about different CRM machines like Super seeder, Happy seeder, Baler, Zero till seed drill, Mulcher, Rotavator, Rotavator with seed drill, Reaper and Straw reaper.Notably, all adopter respondents across the three districts were fully aware of the CRM machines. However, awareness levels varied slightly with the rotavator with seed drill. Specifically, 13.33 per cent of the respondents lacked awareness about the rotavator with seed drill.Similarly, there was widespread awareness of CRM machinery among the non-adopters, with some minor gaps in knowledge about specific machines like the Super SMS and Rotavator with Seed Drill.

Paddy area covered and straw handled by the paddy residue collectors

As paddy harvesting in the state starts from end-September and extends up to mid-November, the baling operation is carried out for about 40 to 45 days. In the present study, the average baling operation days was 42 i.e. about 458 hours with effective field capacity being 2.56 acres per hour (Table 2).

Table 2: Details regarding paddy area covered and straw handled by the paddy residue collectors in Punjab, 2023-24

S.No	Particulars	Value
1	Paddy area covered (Acres)	1173.75
2	Paddy straw recovery (Qtls)	28944.68
3	Average weight of bale (Qtls)	0.23
4	Number of bales (per acre)	107.22
5	Baling operation (Hours)	458.42
6	Baling operation (Days)	41.75
7	Effective field capacity (Acres per hour)	2.56

Analysis of data further revealed that about 107.22rectangular bales were generated on an acre with average weight of 23 Kilogram. On an average, 28944.68Qtls of paddy straw was handled covering an area of 1173.75 acres by the selected paddy residue collectors during the season. similar results were obtained in earlier studies (Singh and Ranguwal, 2022; Singh et al, 2022)

Economics of collection and utilization of crop residues for ex-situ crop residue management

The cost involved in mechanized paddy straw collection was calculated based on two cost components i.e. Fixed

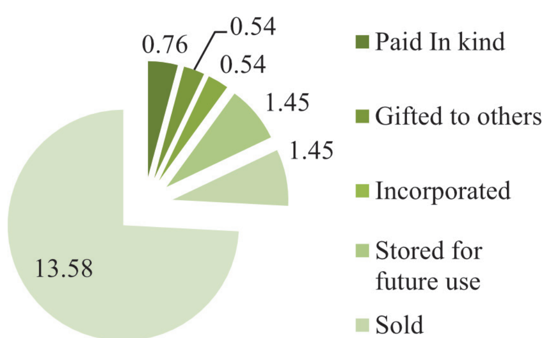

Figure 2a: Adopters

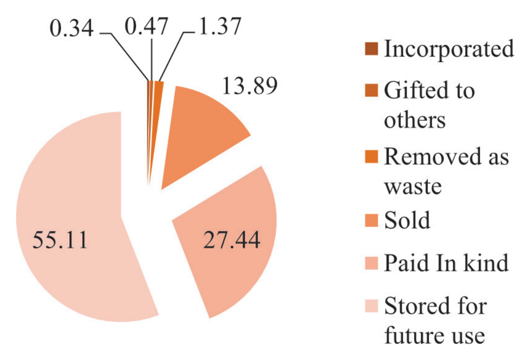

Figure 2b: Non adopters

Figure 2: Utilization pattern of surplus crop residues (% share in surplus)

Table 3: Economics of baling paddy straw in Punjab, 2023-24

Particulars	Cost and returns	
	(Rs/Qtl)	Rs/bale
Total fixed cost (A)	13.15	3.03
Total variable cost (B)	134.22	30.87
Total cost (A+B)	147.37	33.90
Total returns	175.00	40.25
Net returns	27.63	6.35
BC ratio	2.89	2.89
Payback period	2.12	2.12

ones including the depreciation of the machine, interest, taxes, insurance and shelter and the variable costs i.e. fuel consumption, manpower, twine, transportation and other miscellaneous expenses like minor repair, kind payments involved. The following section covers the cost and returns from collection and utilization of paddy residue by using ex-situ CRM for power generation. The fixed cost for each baled quintal of paddy straw was Rs 13.15 i.e. Rs 3.03 per bale (Table 3). The total variable cost covering all operational expenses required for straw collection and management summed to Rs 134.22 per quintal.

The total cost incurred in bailing each quintal of paddy straw was Rs147.37 i.e. Rs 33.9 per bale of paddy straw. The cost of producing one twine tied bale was Rs.30.87 and cost for twine used per bale was Rs. 4.97. Total returns were estimated at Rs 175 per quintal i.e. Rs 40 per bale.

Further, the share of different variable cost components has been shown in Figure 3.Among different variable expenses, the largest share was of transportation, accounting for about 27 per cent share in the total cost of baling the paddy straw. Fuel followed with a share of 23 per cent while loading charges represented 18 per cent of the costs and the twine used to bind paddy straw into compact bales comprised about 16 per cent of the TVC followed by moisture cut (6.47%).For all other inputs, the per cent share remained below five per cent.

Constraints faced by paddy residue collectors

Further, different challenges faced by the paddy residue collectors were also studied. Figure 4 highlights the key constraints faced by paddy residue collectors, ranked based on their severity.

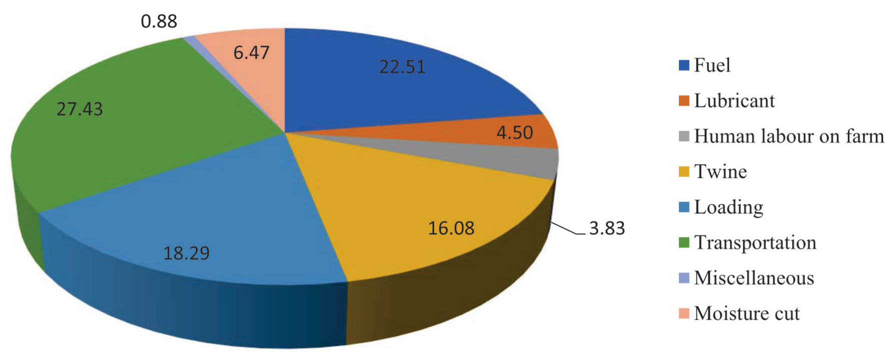

Figure 3: Cost for bailing paddy straw (% share in TVC)

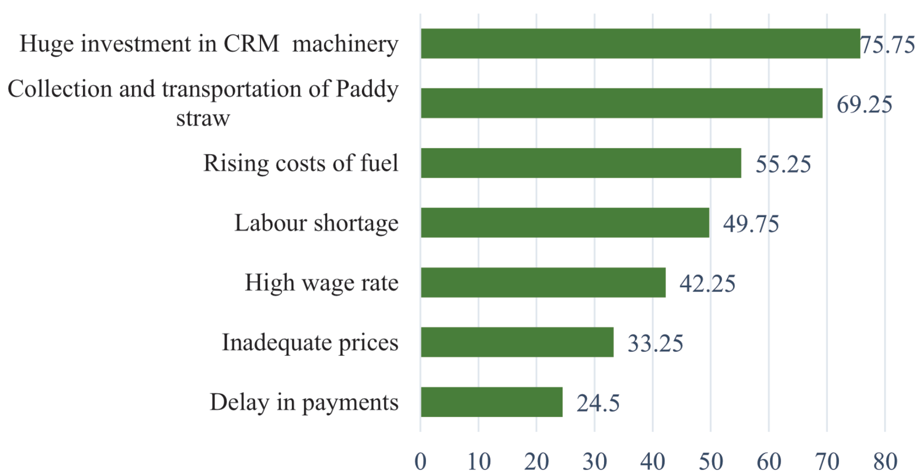

Figure 4: Constraints faced by paddy residue collectors (Mean scores)

The most considerable challenge faced by the paddy residue collectors was the huge initial investment required for CRM machinery (mean score 75.75). Another major constraint was the difficulty faced in collecting and transporting paddy straw (mean score 69.25). Rising fuel costs (mean score 55.25) and labor shortages (mean score 49.75) were also major concerns, as they increase the operational costs. High wage rates (mean score 42.25) further strained the financial resources, while inadequate prices for paddy straw (mean score 33.25) was also mentioned as a constraint in limiting profitability of the paddy residue collection business. Finally, delayed payments (mean score 24.5) add to the financial stress of collectors, hindering the overall efficiency and sustainability of ex-situ paddy residue management.

Conclusion and Policy Implications

The increasing reliance on agricultural biomass as a renewable energy source underscores its potential to contribute significantly to energy mix and sustainable development goals. However, the complexities of managing the agricultural biomass supply chain, including issues of collection, storage, transportation, and highlight the need for strategic interventions. The findings emphasize the need for targeted interventions to promote the sustainable use of surplus residues, particularly paddy, through enhanced awareness, infrastructure, and market linkages. By improving information dissemination and access to a broader range of CRM tools, stakeholders can enhance the adoption of sustainable residue management practices, contributing to reduced environmental impacts and increased agricultural productivity.

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