Food and Agriculture Organization of the United Nations

ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT
WORKING PAPER
95
ENERGY

ESTABLISHING RESIDUE SUPPLY CHAINS TO REDUCE OPEN BURNING

THE CASE OF RICE STRAW AND RENEWABLE ENERGY IN PUNJAB, INDIA

CLIMATE & CLEAN AIR COALITION
TO REDUCE SHORT-LIVED CLIMATE POLLUTANTS

ENVIRONMENT AND NATURAL RESOURCES MANAGEMENT

WORKING PAPER

95

ENERGY

ESTABLISHING RESIDUE SUPPLY CHAINS TO REDUCE OPEN BURNING

THE CASE OF RICE STRAW AND RENEWABLE ENERGY IN PUNJAB, INDIA

FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS
Rome, 2022

Required citation:

FAO. 2022. ***Establishing residue supply chains to reduce open burning. The case of rice straw and renewable energy in Punjab, India***. Environment and Natural Resources Management Working Paper No. 95. Rome. https://doi.org/10.4060/cb9570en

ISSN 2226-6062 [Print]
ISSN 2664-6137 [Online]

ISBN 978-92-5-136094-1

CONTENTS

TABLES AND FIGURES

FIGURES

ACKNOWLEDGEMENTS

We would like to warmly thank all stakeholders and actors along the rice chain and in the related policy environment that provided insights and feedback to better understand the fine details of rice production in India and in the state of Punjab and are grateful to the Climate and Clean Air Coalition (CCAC) for contributing to the financing of this report.

The authors of this report are Manas Puri, Luis Rincon and Irini Maltsoglou from the Food and Agriculture Organization (FAO) of the UN and Dr. J.S Samra and Dr. Neetu Gaur from the Centre for Research in Rural and Industrial Development (CRRID), Chandigarh, India. The study benefitted from the overall guidance of Prof Ramesh Chand, Member Agriculture, NITI Aayog, Govt. of India, the inputs received from officers in the Ministry of Agriculture and Farmer Welfare (MoA&FW), Ministry of Environment, Forests and Climate Change (MoEFCC), Ministry of New and Renewable Energy (MNRE), Punjab Energy Development Authority (PEDA) and the Department of Agriculture, Government of Punjab, public sector enterprise like Indian Oil Cooperation Ltd (IOCL), National Thermal Power Cooperation Ltd (NTPC).

Furthermore, we would like to extend our appreciation to CRRID for implementing a survey for current crop residue management practices followed by the farmers in Punjab which provided invaluable data that allowed the authors to undertake the assessment.

We would also like to express our special thanks to the colleagues at FAO Regional Office in Bangkok, Beau Damen and David Dawe and to Zitouni Ould Dada, Deputy Director and Olivier Dubois, Senior Natural Resource Officer of the Office of Climate Change, Biodiversity and Environment of FAO HQ in Rome.

Our colleagues at FAO India, under the leadership of Tomio Shichiri, FAO Representative in India, have been instrumental in supporting the research and for continued engagement with government and other stakeholders.

Finally, a special thanks is extended to Simona Benedetti and Laura Utsey for their support with the editing and preparation of this document, and Giovanna Pesci and Helena Povijac for support with the publication process.

ABBREVIATIONS AND ACRONYMS

GHG	greenhouse gas
NCR	residue to crop ration
NPV	net present value
INR	Indian national Rupee
MNRE	Ministry of New and Renewable Energy
CBG	compressed biogas
CNG	Compressed natural gas
FAO	Food and Agriculture Organization of the United Nations
NCR	National Capital region
MSP	minimum support price
MoAFW	Ministry of Agriculture and Farmer Welfare
MoEFCC	Ministry of Environment, Forest, and Climate Change

EXECUTIVE SUMMARY

Open burning of crop residues is a common practice in many countries. It is estimated that globally around 458 million[1] tonnes of crop residues were burnt in 2019 resulting in 1 238 kilotonnes of CH_4 emissions and 32 kilotonnes of N_2O emissions. Data from FAOSTAT suggests that globally, maize residues are the most frequently burnt crop residues followed by rice, sugarcane, and wheat (FAOSTAT, 2021).

Crop residues can be recycled and made productive in several ways, such as using residues as ground cover, soil amendments like mulch or compost, and animal feeds. Residues can be used in energy generation and in the production of materials such as boards, paper products and bioplastics. However, a major barrier is the lack of an efficient and cost-effective value chain for collection, transportation, and storage. This results in high costs and ultimate waste of the biomass. The problem is often compounded by shortage of rural labour, lack of adequate methods and machinery to treat straw residue, and limited awareness of environmental impacts, security risks and health concerns. (UNESCAP, 2020).

In India, burning of rice straw in the state of Punjab is major challenge. Every year between the rice harvest and sowing of wheat, rice straw is burnt in the fields. On average around 18 million tonnes of rice straw are produced in Punjab, of which an estimated 80 percent is burned causing severe pollution, not only in Punjab and Haryana but also in the neighboring Delhi National Capital (NCR) region. Various factors drive farmers to burn crop residues. These include: (i) the rapid uptake of combined harvesters that harvest the rice grain but leave the straw in the field; (ii) the lack of manual labour; and (iii) the short timeframe between the rice harvest and wheat production cycle. The first policy measure taken to reduce burning focused on ***in situ*** management of the residues through the Happy Seeder programme and subsidies. However, given the very large volume of rice straw generated — around 18 million tonnes in Punjab alone — both ***in situ*** as well as ***ex situ*** applications need developing.

This report presents the specific case of rice straw in Punjab in a series of steps. At first the context and setting of rice production in Punjab is assessed. This is followed by analysis of the actual amount of rice straw that could be used for other purposes, considering current needs and the amounts to be set aside for soil amendments. The third part of the analysis outlines the requirements of the block of the straw residue value and the costs entailed. This includes identifying the main equipment, labour requirement and investments to mobilize rice straw within the 20 day period available between rice harvest and wheat sowing. The assessment concludes with the technoeconomic assessment of the relevant bioenergy options that the country is currently considering to meet their energy needs and renewable energy targets. The energy technologies analysed are 2G ethanol, compressed biogas (CBG) and biomass pellets. The selection of these technologies was based on the Government of India's dedicated policies and targets for biomass as feedstock for the three technologies.

The result suggests that to mobilize 30 percent of the rice straw produced in Punjab an investment of around Indian national Rupee (INR) 2,201 crore (USD 309 million) would be needed to collect, transport and store it within a 20 day period. This would reduce greenhouse gas (GHG) emissions by about 9.7 million tonnes of CO_2 equivalent[2] and around 66 000 tonnes of PM2.5. Furthermore, depending on market

[1] Aggregate of residues from maize, rice (paddy), sugarcane and wheat production.
[2] Including CO_2, CO, CH_4 and N_2O emissions.

conditions, farmers can expect to earn between INR 550 and 1 500 per ton of rice straw sold.

The technoeconomic assessment of energy technologies suggests that in the current context, rice straw can be cost effective for production of CBG and pellets. Efficiently producing 2G ethanol would require interventions to reduce capital cost. Establishing a dedicated pricing strategy for 2G ethanol separate from 1G ethanol would also be useful. Pellet production in Punjab is profitable in most districts and needs less capital investment. Although CBG has great potential to produce higher profits in the long term, it needs more investment. The districts of Sangrur, Ludhiana, Patiala, Moga and Barnala appear to be the most promising for both CBG and pellets. However, since pellets need less capital investment and are profitable in most districts, it is advisable to establish CBG plants in Sangrur, Ludhiana, Patiala and to spread pellet production across other districts.

2G ethanol requires substantial investments ranging from over INR 250 Crore for a 5 million litres per year plant, to over INR 1 000 Crore for a 100 million litres plant. At the current price of INR 63, the production of 2G ethanol is profitable only in certain districts of Punjab. The major factor keeping 2G production unviable is the high capital cost of setting up the plant. Production could be made viable by either:

- having a higher price for 2G ethanol; or
- providing financial support to entrepreneurs to reduce capital costs.

Using 30 percent of the rice straw can contribute to 5 percent of the CBG production target set by the SATAT scheme. Moreover, producing CBG can be beneficial for the state of Punjab by satisfying 100 percent of its current demand. It could also increase local entrepreneurship, increase farmers' income and reduce open burning of rice straw. However, only production facilities with a production capacity of more than 12 000 m^3/day will be economically viable. Using biomass pellets from rice straw has the potential to reduce coal use in thermal power plants across India. For example, 3.5 million tonnes of pellets could be produced from 15 percent of the straw, thus satisfying 72 percent of the target. If 30 percent of the straw were to be used, 7.1 million tonnes of pellets could be produced, equivalent to 143 percent of the target. At a purchase price of INR 7/kg, production facilities with a capacity larger than 130 kg/hour seem to be profitable. The districts of Sangrur, Ludhiana and Barnala promise to be the most profitable districts for pellet production.

However, in order for these energy carriers to be successfully upscaled, a constant supply of rice straw at an affordable price must be ensured. To achieve this, a formal and effective value chain that can collect, transport and store rice straw within 20 days is imperative. It is equally important to encourage participation of the private sector in collecting and storing rice straw and transforming it into various products. Policies and finance should be made available that would encourage using rice straw for productive purposes.

CHAPTER

1

INTRODUCTION

Open burning of crop residues is the customary practice used across several countries globally. Crop residues from rice, maize, sugarcane, and cotton are often routinely burnt to quickly prepare the field for the next cropping season. It is estimated that globally around 458 million[3] tonnes of crop residues were burnt in 2019 (FAOSTAT, 2021), resulting in 1 238 kg tonnes of CH_4 emissions and 32 kg tonnes of N_2O emissions. Data from FAOSTAT suggests that maize residues are the most frequently burnt crop residues globally followed by rice, sugarcane, and wheat residues.

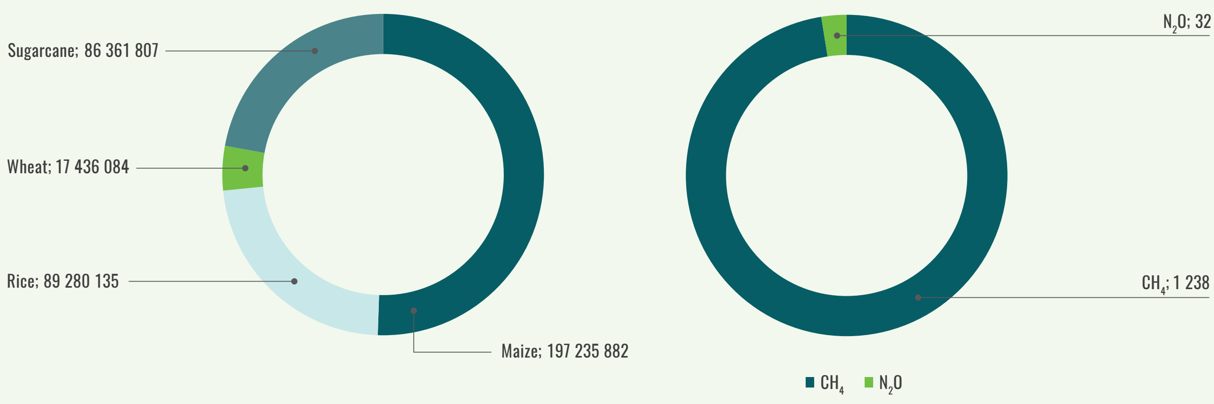
In addition to emitting greenhouse gasses, open burning of crop residues is a major source of a range of air pollutants harmful to human health. Furthermore, the burning of crop residues results in severe consequences food security in the long term as it causes soil deterioration. Soil nutrients, pH level, moisture, available phosphorus, soil organic matter and microbial population are all adversely influenced by burning. Estimations suggest that burning 1 tonne of rice straw emits 5.5 kg of nitrogen, 2.3 kg of phosphorous, 25 kg of potassium and about 1.2 kg of sulphur, which are all lost as a result of burning (UNESCAP, 2020). Essentially, by burning crop residues farmers invariably deplete the soil of its essential nutrients, which as a result decreases the long term fertility of the soil.

From a human health perspective, emissions of particulate matter, both PM 2.5 and PM 10 are of specific concern. Furthermore, the open burning of crop residues also emits other local pollutants such as carbon monoxide (CO), volatile organic compounds (VOCs), nitrogen oxides (NO_x), ammonia (NH_3), Sulphur dioxide (SO_2), carcinogens such as polycyclic aromatic hydrocarbons (PAHs), and multiple other toxic compounds (World Bank, 2018). In aggregate terms, China, India, and the United States burn the most crop residues, followed by Brazil, the Russian Federation and Indonesia.

[3] Aggregate of residues from maize, rice (paddy), sugarcane and wheat production.

FIGURE 1.

CROP RESIDUES BURNT GLOBALLY (TONNES) AND GHG EMISSION (KG TONNES) IN 2019



Source: FAOSTAT, 2021.

The factors driving farmers to burn crop residues vary greatly across countries, ranging from the lack of local labour, the convenience of burning, traditional practices, lack of markets for biomass residues (World Bank, 2018). In regions where farmers plant several crops during the year, burning crop residues offer a quick, inexpensive, and easy way to prepare the field for sowing the next crop. In some cases, farmers lack the economic means to pay for the clearing of the fields, or have no access to equipment and labour, therefore they are unable to use the crop resides for compost or for producing energy. Additionally, the lack of markets where crop residues can be sold leads farmers to believe that crop residues are a waste and not a productive resource (World Bank, 2018). This perception severely limits the use of crop residues for other productive purposes, and farmers resort to open burning, which not only causes air pollution but also prevents farmers from diversifying their incomes.

Crop residues can be recycled and made productive in several ways, such as using residues as ground cover, soil amendments like mulch or compost, animal feed, or for energy production construction materials like boards, paper products, bioplastics. However, a major barrier limiting the use of crop residues for productive use is the lack of an efficient value chain of crop residues that can allow for collecting, mobilizing, and storing crop residues in an efficient and cost-effective way. The lack of a structured residue value chain results in high costs for collection, transportation, and storage of the biomass. This problem is often compounded by the shortage of rural labour, lack of adequate methods and machinery to treat straw residue, as well as a weak awareness of the impacts on the environment, security risks and health concerns (UNESCAP, 2020).

To enable the sustainable use of crop residues it is imperative to first assess the technical feasibility and economic attractiveness of the alternatives to burning. Additionally, it would require that the full range of drivers and barriers be addressed, including the hidden costs of switching practices, farmer perceptions of crop residues and their different possible uses (World Bank, 2018).

CHAPTER

2

AIM AND SCOPE

India is the second largest producer of rice in the world and generated around 178 million tonnes of rice in 2019. The state of Punjab in the north of India is a major agrarian state producing large quantities of rice and wheat as well as per crops such as cotton, sugar cane and vegetables.

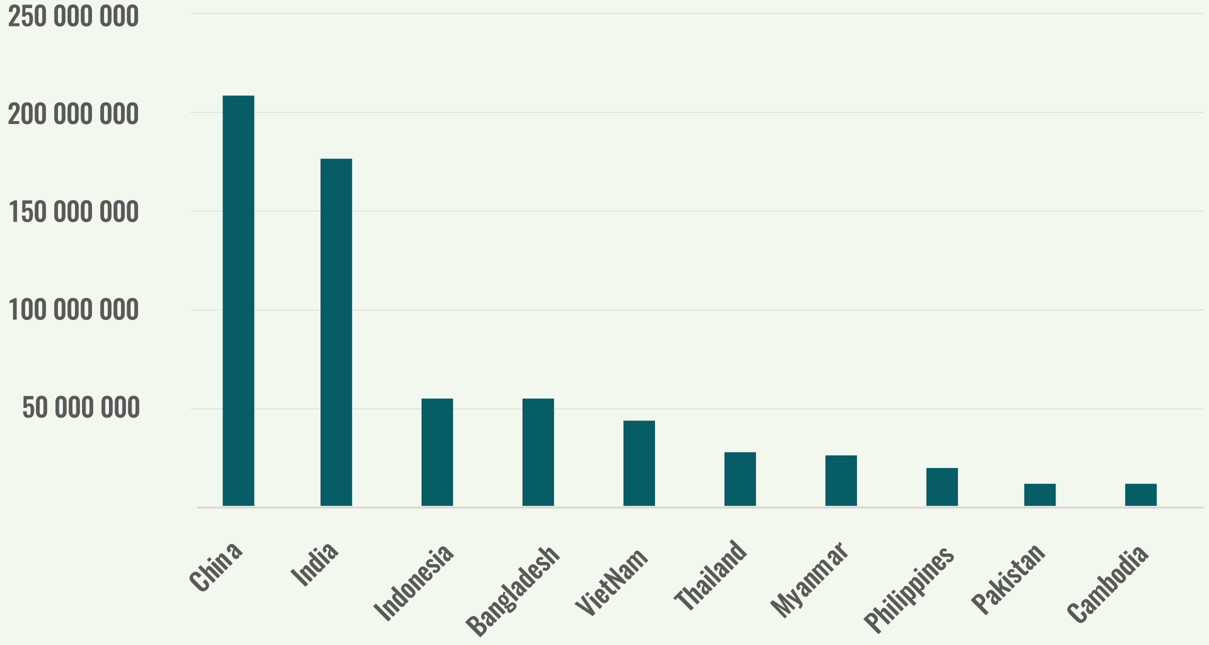
The state of Punjab is an agrarian economy that contributes significantly to both the food security of India and the income of its farmers. About 83.4 percent of the total geographical area of 5.036 million hectares of Punjab are cultivated. Wheat is the traditional crop of the state of Punjab and is grown from November to April. However, due to the improvements in rice cultivation and the growing demand for rice, the traditional (kharif) summer crops, mainly coarse cereals, pulses and oilseeds have been replaced by rice. This diversification was created by the better technologies of rice varieties, guaranteed irrigation with good quality canal and groundwater, rural electrification, marketing infrastructure and enabling policy for sustaining food security system in India. Punjab consists of 22 districts all of which produce rice to a varying degree.

Every year between the rice harvest and sowing of wheat, large quantities of rice straw is burnt in the fields in Punjab causing severe air pollution. On average around 18 million tonnes of rice straw are produced in Punjab, of which an estimated 80 percent is burnt annually causing severe spikes in pollution levels, not only in Punjab and Haryana but also in the Delhi National Capital region (NCR) region.

Various factors drive farmers to burn crop residues after the rice harvest. These factors include: (i) the rapid uptake of combined harvesters that harvest the rice grain but leave the straw in the field; (ii) the lack of manual labour; and (iii) the short timeframe between the rice harvest and wheat production cycle. The first policy measure taken to reduce burning has focused the attention on ***in situ*** management of the residues through the Happy Seeder programme and subsidies. However, given the very large volume of rice straw generated — around 18 million tonnes in Punjab alone — both in *situ as* well as *ex situ* applications need developing.

FIGURE 2.

TOP 10 PRODUCERS OF RICE GLOBALLY



Source: FAOSTAT, 2021.

Whilst the Ministry of Agriculture and Farmer Welfare has provided support for the *in situ* management of rice straw in the form of the Happy Seeder programme, the Ministry of Petroleum and Natural Gas has announced support for specific *ex situ* application that supports the use of crop residues to produce 2G ethanol and compressed biogas as transport fuels. Furthermore, the National Thermal Power Corporation (NTPC) has also announced plans to use pellets made from crop residue to co-fire thermal power plants. Nevertheless, a key requirement for the *ex situ* options to become viable is to develop a crop residue supply chain that enables the further use of residues in an economically and financially viable way. The supply chain needs to facilitate the use of the residues by the private sector while ensuring the inclusion and revenues on the farmer side too.

In light of this, the aim of the report is to:

1. assess the total quantity of rice straw produced and its distribution across the districts in Punjab;
2. design a model rice straw value chain to mobilize rice straw in Punjab and estimate the investment required;
3. assess the techno-economic viability of using rice straw to produce 2G ethanol, biomass pellets and compressed biogas.

The results of the assessment will outline the requirements for developing a rice straw value chain in the specific context of Punjab. Furthermore, it will identify the best suited energy technology that can use rice straw to produce sustainable energy and support India in reaching its energy related targets.

CHAPTER

3

RICE-WHEAT LANDSCAPE IN PUNJAB

Rice and wheat are the major cereals produced in Punjab. Over the last two decades, areas under rice cultivation in Punjab have gradually increased. The rice-wheat cropping pattern has encroached on the areas where low-input traditional crops like maize, bajra and pulses have been cultivated over the years. **Table 1** provides the area and production of rice and wheat in Punjab since 1980-81, respectively. Wheat has been a traditional crop of the states of Punjab and Haryana for centuries and is grown from November to April. However, the improved technology of rice cultivation during June to October has replaced the Kharif (summer) crops of coarse cereals, pulses and oil seeds since 1966. This diversification was created by better technologies of rice varieties and guaranteed irrigation with good quality canal and ground water, rural electrification, marketing infrastructure. Furthermore, it has made policies for sustaining the food security system in India possible. Rice is a staple food in most of India except in the North-West region consisting of Punjab, Haryana, Rajasthan and parts of Gujarat. Therefore, rice cultivation in Punjab and Haryana is mainly a result of market driven commercial considerations. The improved crop technology also raised the productivity of the wheat component of the cropping system. Therefore, the rice-wheat cropping system is of great importance for the country and farmers, in spite of the over-exploitation of ground water and excessive utilization of resources. The rice-wheat system has been adopted on 13.5 million hectares of the Indo-Gangetic plains, which are very fertile and alluvial soils in India. Productivity of the rice wheat system is about 12 tonnes per hectare per annum. However, this system is highly concentrated in the state of Punjab and Haryana (**Table 1**). In 2018-19 wheat was sown on 3.50 million hectares in Punjab.

TABLE 1.

AREA AND PRODUCTION OF RICE AND WHEAT IN PUNJAB

YEAR	AREA IN MILLION HECTARES		PRODUCTION IN MILLION TONS	
	RICE	WHEAT	RICE	WHEAT
1980-81	1 183	2 812	3 233	7 677
1990-91	2 015	3 273	6 506	12 159
2000-01	2 612	3 408	9 157	15 551
2010-11	2 826	3 510	10 819	16 472
2012-13	2 849	3 517	11 390	16 614
2013-14	2.849	3 510	11 259	17 610
2014-15	2 895	3 505	11 111	15 086
2015-16	2 970	3 506	11 111	16 068
2016-17	3 046	3 495	12 638	17 636
2017-18(P)	3 065	3 512	13 382	17 830

Source: Compiled by CRRID based on data from MoAFW

Wheat has been a traditional crop of the states of Punjab and Haryana for centuries and is grown from November to April. However, the improved technology of rice cultivation during June to October has replaced the Kharif (summer) crops of coarse cereals, pulses and oil seeds since 1966. This diversification was created by better technologies of rice varieties and guaranteed irrigation with good quality canal and ground water, rural electrification, marketing infrastructure. Furthermore, it has made policies for sustaining the food security system in India possible. Rice is a staple food in most of India except in the North-West region consisting of Punjab, Haryana, Rajasthan and parts of Gujarat. Therefore, rice cultivation in Punjab and Haryana is mainly a result of market driven commercial considerations. The improved crop technology also raised the productivity of the wheat component of the cropping system. Therefore, the rice-wheat cropping system is of great importance for the country and farmers, in spite of the over-exploitation of ground water and excessive utilization of resources. The rice-wheat system has been adopted on 13.5 million hectares of the Indo-Gangetic plains, which are very fertile and alluvial soils in India. Productivity of the rice wheat system is about 12 tonnes per hectare per annum. However, this system is highly concentrated in the state of Punjab and Haryana (**Table 1**). In 2018-19 wheat was sown on 3.50 million hectares in Punjab.

Wheat straw is very good fodder and about 90 percent is being utilised for stall feeding and paper mills. In 2019 only 11 000 burning events were recorded after the wheat harvest as compared to 52 525 after the harvest of paddy in Punjab alone. Very limited wheat straw is burnt for a short duration (70 days) to cultivate leguminous crops such as moong bean (Vigna phaseolus) before sowing the next main crop, rice. Mechanization and subsidised electricity also led to more than 200 percent of cropping intensity. This leaves only a 25-30 day period for the timely sowing of the next wheat crop after rice harvesting. Due to these constraints, rice farmers resort to burning rice straw after

the rice harvest to prepare the field for wheat sowing, causing significant levels of pollution and greenhouse gas (GHG) emissions. **Table 3** provides the emission potential of various GHG and pollutants from burning rice straw.

TABLE 2.

PERCENT AREA UNDER RICE AND WHEAT CROPPING SYSTEM, RICE RESIDUE PRODUCTION AND BURNING IN PUNJAB AND HARYANA OF INDIA

STATE	(%) AREA UNDER RICE – WHEAT CROPPING SYSTEM	RICE RESIDUE PRODUCTION (MILLION TONNES)	RICE RESIDUE BURNT (MILLION TONNES)
PUNJAB	90	22.0	18.7
HARYANA	77	7.5	3.0

Source: NAAS, 2018.

TABLE 3.

POLLUTION POTENTIAL OF BURNING ONE TON OF RICE RESIDUES

GASES	EMISSION POTENTIAL	
	(kg t^{-1})	CO_{2eq} (kg t^{-1})
CO_2 (CARBON DIOXIDE)	1 515.0	1 515.0
CO (CARBON MONOXIDE)	92.0	184.0
NO_x (NITROUS OXIDES)	3.8	1 007.0
SO_2 (SULPHUR)	0.4	
CH_4 (METHANE)	2.7	784.0
ASH	199.0	
NON-METHANE VOLATILES	15.7	
TOTAL (CO_{2EQ})		3 490.0

Source: CRRID, 2019.

The large rice production in Punjab also results in the production of a large amount of rice straw in the state. To estimate the rice straw production per tonne of rice produced, the straw to grain ratio, which is also called the harvest index, is used. A harvest index is the ratio of grain to the total shoot dry matter. The harvest index varies between grains, and even within the same grain family it changes with different varieties of grains. Several different varieties of rice are grown in Punjab, each with a different harvest index. Available information about the grain-straw ratio of important varieties of rice is given in **Table 4**. The Parmal variety is the type of rice most commonly grown in Punjab.

TABLE 4.

HARVEST INDEX (GRAIN – STRAW RATIO) OF DIFFERENT RICE VARIETIES OF SHORT DURATION (PARMAL) AND LONG DURATION (SCENTED BASMATI VARIETIES) OF PUNJAB AND HARYANA

VARIETIES	HARVEST INDEX (%)
PARMAL VARIETIES	
PR 126	45.3
PR 124	44.5
PR 122	45.0
PR 121	45.2
PUSA 44	44.0
OVERALL AVERAGE	44.8
LONG DURATION BASMATI VARIETIES	
PUSA BASMATI 1	39.1
TARORI BASMATI	29.9
PUSA 1121	39.6
PUNJAB BASMATI 3	38.3
PUNJABI BASMATI 4	42.1
PUNJAB BASMATI 5	35.8
OVERALL AVERAGE	37.4

Source: Collected by CRRID during field work

3.1. AN OVERVIEW OF PREVALENT AGRONOMIC PRACTICES OF RICE AND WHEAT PRODUCTION.

Punjab is an advanced agriculture state in India with a high level of irrigation infrastructures as well as farm mechanization. About 98 percent of the cultivated area of Punjab is irrigated. The remaining area also receives one or two irrigations with locally harvested rainwater, while rainfed or un-irrigated production may receive little to no treatment. Wheat crops are cultivated from November to April after mechanized harvesting of the rice crops, leaving behind loose biomass as well as anchored stubbles that are about 30-37 cm tall. This residue is a major challenge for the cultivation and sowing of the next wheat crop. This biomass gets wedged into the tines of farm implements and the seeding therefore is not uniform, which lowers the yields (productivity) and profitability of the wheat crop. The period of time required for the incorporation and ***in situ*** decomposition is insufficient. According to one small sample survey, 13-18 days are available for seeding wheat and 46-48 days for transplanting rice seedings (**Table 6**).

TABLE 5.

AVERAGE # OF DAYS AVAILABLE FOR THE NEXT CROP WHEN CROP RESIDUE IS REMOVED BY DIFFERENT PRACTICES

VILLAGE	AVERAGE NUMBER OF DAYS AVAILABLE FOR PLANTING WHEAT AFTER HARVESTING RICE		
	BURNT IN THE CASE OF PADDY	INCORPORATED IN SOILS USING ROTAVATOR OR ZERO DRILL	REMOVED FROM THE FIELD
AJNAUDA KALAN	13	18	21
DHANORI.	13	10	-
SIMRO	13	14	16
AVERAGE.	13	15	18

Source: Collected by CRRID during field work

Heavy duty seeders have been designed to overcome the problem of the narrow window of availability for sowing the next crop. In fact, a subsidy of 50 percent to individual farmers and 80 percent to a group or society of farmers is being provided in Punjab to avoid burning. However, farmers have expressed their concerns about its actual use, given the heavy cost of the machinery as well as manual collection. This was evaluated by the willingness to pay (WTP) or willingness to accept (WTA) choices analysis of the consumer choice in **Table 6**.

TABLE 6.

THE EASIEST AND QUICKEST WAY TO GET RID OF THE CROP STUBBLE (PERCENT OF HOUSEHOLD CHOICE OF FARMERS)

NAME OF THE VILLAGE	BURNING	INCORPORATION USING OTHER METHODS	MANUAL WAY OF HARVESTING AND COLLECTION	REMOVAL FROM THE FIELD BY OTHER MEANS
DHANORI	89.89	8.99	1.12	0.00
AJNAUDA KALAN	79.55	14.77	3.14	2.27
SIMRO	78.82	17.65	3.53	0.00
TOTAL	**82.82**	**13.74**	**2.67**	**0.76**

Source: Collected by CRRID during field work

Other important points of this overview are given below:

- pesticide consumption in Punjab is 0.74 kg/ha, Haryana 0.62 kg/ha, all India average 0.29 kg/ha as compared to 5-7 kg/ha in the UK. Maximum consumption of pesticides and fungicides is in paddy (29 percent) followed by cotton (16 percent);
- per hectare fertiliser consumption in Punjab is 224.9 kg, all India average 133 kg;
- about 90 percent harvesting of wheat and 80 percent of paddy by combine harvesters is mostly done by the custom hiring services, while the rest is done manually in both states. Custom hiring of costly farm machinery of happy seeders, rotavators, mould bold plough, laser levels, and balers is also available in all districts of Punjab;
- rice and wheat crops are generally procured or purchased by the state agencies at the assured rates announced at the time of sowing, and food grains are passed on to the central government for public distribution schemes. Only a very small fraction of the wheat production is used in the biscuit industry. Milled rice is also purchased by government agencies and dispatched to the

centre government for public distribution. Scented, long grain fine rice is purchased by the private sector and exported. Overall storage of food grains is the responsibility of the government of Punjab on behalf of central government of India;

- there are more than one 30 000 rice mills in India and more than 4 000 each in Punjab. Rice was also exported to more than 90 countries at a value of USD 4 712 in 2018-19 and USD 3 398 during April-January in 2019-20;
- there are very few possibilities of other post-harvest value chains since both commodities are procured under the minimum support price (MSP) announced before sowing/ transplanting for the public distribution system under the food security act.

3.2. AN OVERVIEW OF POST-HARVEST RESIDUE MANAGEMENT PRACTICES

The use of rice straw as animal fodder and for composting has been a traditional practice across the world. In India rice and wheat straw have also traditionally been used as fodder, thatching and bedding material for animals, composting of manure, mushroom cultivation, packing material/paper, the manufacture of cardboard and panel. Most of the surplus rice and small amounts of wheat straw are being burnt. Over the years the use of rice straw has changed in Punjab. Data available from 1997 showed that rice straw was either sold or used for household consumption in most states in India. As shown in **Table 7**, only a limited amount was disposed of.

However, this pattern changed over time, and by 2007 open burning in Punjab had risen to 81 percent for rice and 48 percent for wheat straw (**Table 7**).

TABLE 7.

STATE WISE UTILISATION PATTERN OF PADDY AND WHEAT STRAW IN DIFFERENT STATES OF INDIA IN 1997

#	STATES	PERCENTAGE UTILISATION					
		SOLD		HOUSEHOLD CONSUMPTION		DISPOSED OFF	
		PADDY STRAW	WHEAT STRAW	PADDY STRAW	WHEAT STRAW	PADDY STRAW	WHEAT STRAW
1	ANDHRA PRADESH	19.6	-	79.3	-	1.1	-
2	BIHAR	22.9	25.4	77.1	74.6	-	-
3	GUJARAT	27.5	6.3	72.5	9.7	-	-
4	HARYANA	9.1	6.0	77.0	94.0	13.9	-
5	HIMACHAL PRADESH	53.2	27.4	42.6	71.2	4.2	NEG
6	KARNATAKA	11.5	-	86.2	100.0	2.3	-
7	KERALA	49.4	-	50.6	-	-	-
8	MADHYA PRADESH	6.5	10.6	93.5	89.4	-	-

#	STATES	PERCENTAGE UTILISATION					
9	MAHARASHTRA	19.10	21.3	81.10	78.7	-	-
10	ORISSA	18.4	79.2	84.6	10.8	-	-
11	PUNJAB	39.0	31.2	36.2	68.8	24.5	-
12	RAJASTHAN	-	24.9	100.0	75.1	-	-
13	TAMIL NADU	35.9	-	63.9	-	0.2	-
14	UTTAR PRADESH	41.3	21.4	58.7	-	-	-
15	WEST BENGAL	25.8	9.2	74.2	90.8	-	-
16	ALL INDIA	259	22.3	71.5	77.7	2.6	NEG

Source: National Productivity Council of India.

TABLE 8.

END USE OF STUBBLE BY THE FARMERS IN PUNJAB IN 2007

END USE	RICE (% OF TOTAL STUBBLE PRODUCTION)	WHEAT (% OF TOTAL STUBBLE PRODUCTION)
FODDER	7	45
SOIL INCORPORATION	1	<1
BURNT	81	48
ROPE MAKING	4	0
MISCELLANEOUS	7	7

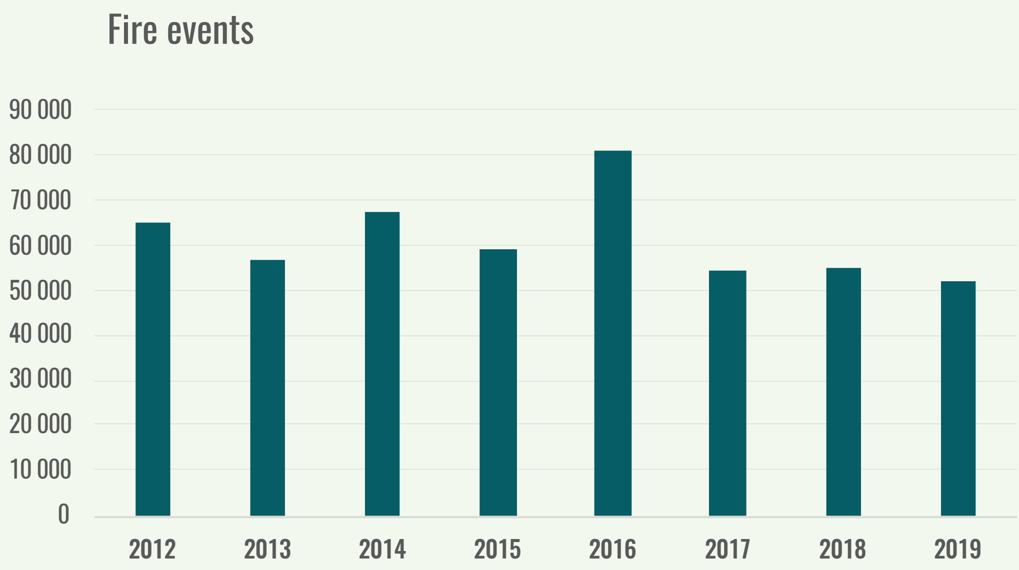
Source: Government of Punjab (2007).

The increase in burning crop residues over the last decade has been caused by several factors, for example, the increased use of combine harvesters that, while harvesting rice, leave the straw in the field. Additionally, human migration from rural areas to urban areas in Punjab has reduced the availability of labour. In Punjab, rice is grown during the warm season between June and October while wheat is grown between November and March. This leaves farmers a brief period of around 20-25 days, between rice harvesting and the planting of wheat. Manual harvesting, the traditional practice, is no longer an economical option for farmers — labour wages have increased and there is a labour shortage. The size of the workforce in agriculture declined by around 30.57 million between 2004-05 and 2011-12 despite an increase in the total workforce (CRRID, 2019). Over the last decade, the number of stubble-burning events recorded by the Residue Burning (CRB) Information and Management System of Punjab have varied. The burning events of rice straw in Punjab intensified according to the latest data available of 2020. Several other latest reports reveal that now a major part of the residue especially of non-basmati (non-scented) varieties is burnt. Burning events very clearly decreased after 2014, re-peaked in 2016, and subsequently came down slightly to almost stabilize. This calls upon alternative practices of management.

However, there is great deal of variation found among the districts of Punjab in terms of stubble burning. **Table 4** provides the details of areas under rice production and the percentage of areas under rice production across the district in Punjab in 2018. There is clearly a noticeable disparity as regards the extent of stubble burning in Punjab. Fazilka, Mansa, Shri Muktsar Sahib, Ferozepur, Bathinda are the districts found to have the largest incidents of rice burning in Punjab.

FIGURE 3.

NUMBER OF RICE STRAW FIRE COUNTS IN PUNJAB BETWEEN 2012–2019



Source: CRRID 2020 based on NASA VIIRS 375 m accessed via NASA FIRMS.

TABLE 9.

PERCENT AREA OF RICE UNDER BURNING ACROSS DISTRICTS OF PUNJAB (2018)

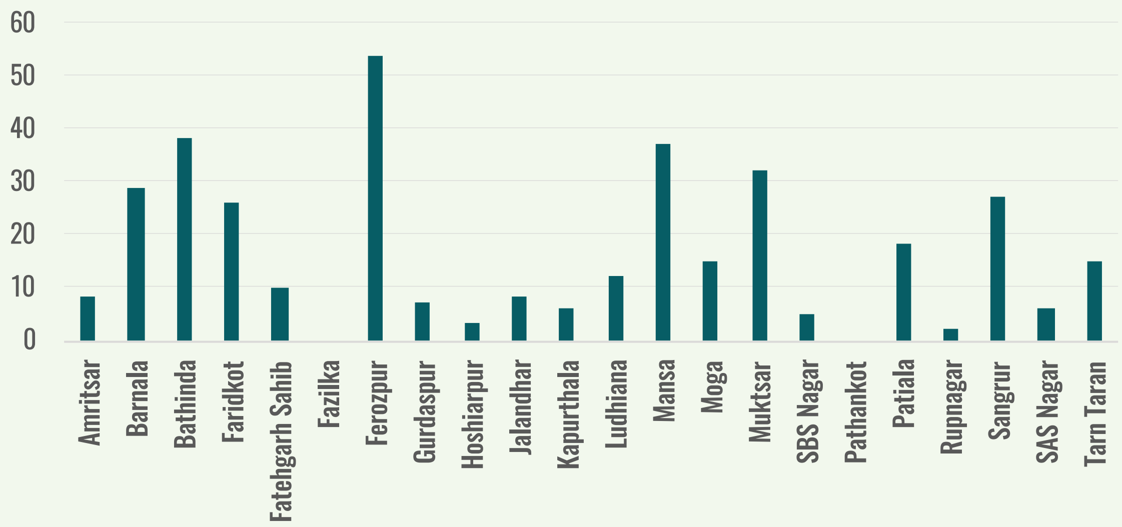
DISTRICT	PERCENT AREA OF RICE UNDER BURNING	PERCENT AREA UNDER RICE
HOSHIARPUR	0.0	98
PATHANKOT	0.0	2168
SAS NAGAR	6.54	81.58
RUPNAGAR	17.92	59.42
AMRITSAR	18.06	89.55
NAWANSHAHR	18.59	61.86
GURDASPUR	19.81	81.13
LUDHIANA	39.70	87.21
PATIALA	40.03	92.13
FATEHGARH SAHIB	44.19	89.58
JALANDHAR	45.55	77.23
SANGRUR	49.30	91.99
KAPURTHALA	52.61	80.27
TARAN TARN	53.51	94.42
MOGA	54.17	95.26
BARNALA	56.58	91.94
FARIDKOT	72.63	91.34
FAZILKA	75.57	82.01
MANSA	75.85	65.91
SHRI MUKTSAR SAHIB	76.19	79.56

DISTRICT	PERCENT AREA OF RICE UNDER BURNING	PERCENT AREA UNDER RICE
FEROZEPUR	77.99	97.89
BATHINDA	78.22	60.51

Source: Ministry of agriculture and farmer welfare Government of India

FIGURE 4.

FIRE EVENTS PER 1 000 HECTARES ACROSS DISTRICTS OF PUNJAB



Source: CRRID, 2020

3.2.1. Post-harvest *in situ* residue management

Managing crop residues sustainably can be carried out in two major ways. The residue produced after harvest can either be incorporated back into the soil (***in situ***) or collected and transported from the field to be used as feedstock or for other processes such fuel in industries, power plants and in packaging materials (***ex situ***). In India, both the central and state governments developed policies to encourage ***in situ*** uses of rice straw. In 2018, the central government launched its ***in situ*** management scheme in the States of Punjab, Haryana, Uttar Pradesh and NCT of Delhi, which subsidised the cost of machines such as the Happy Seeder. Under the scheme, Punjab was allotted INR 810 crore between 2018 and 2020 and an additional Indian national Rupee (INR) 235 crore in 2021–22 (CRRID, 2021). The machinery provided a subsidy of 50 percent to private individual farmers and 80 percent to their groups or organizations. Happy seeders, mould bold ploughs, rotavators, laser land levellers were promoted for the ***in situ*** management.

So far, the subsidy programme has produced mixed results. CEEW (2021) analysed the use of machinery for ***in situ*** management of rice straw. The results suggested that while the existing stock of seeders in Punjab can be used to manage nearly 66 percent of the non- basmati farmland, in reality, most machines remain underutilised (CEEW, 2021). The analysis further suggests that in 2020, 125 out of 22 districts that burnt crop residue on more than 50 percent of their land had a stock of CRM machines that could be used to manage more than 40–50 per cent of the non-basmati farms. In addition to the subsidy programme, in November 2019 the Supreme Court of India ordered the collection and sale of the residue in order to prevent burning. In non-compliance with orders from the Supreme Court of India, the Government of Punjab demanded compensation for the small and marginal farmers for ***in situ*** management (vide order no. PA/SA/2019/6257-L dated 08-11-2019) and furthermore, extended this to ***ex situ*** management (vide no. PA/SA/2019/6258-L dated 11-11-2019).

3.2.2. Post-harvest *ex situ* residue management

Ex situ management is now being promoted under the new bio-fuel policy of 2018 for converting surplus biomass into renewable energy, bio manure, employment, wealth and healthy environment. In this case, the clearing of the fields is carried out by picking up straw, baling and mechanical densification to reduce transport costs and storage space. Some of the emerging utilities of this raw material are:

PULPING

Indian Agro Paper Mills Association studied the potential of collection by baling in 1997 and argued for baling machines. In the state of Punjab, Trident is currently a manufacturer and supplier of high-quality wheat-straw based paper. Shreyans Industry Limited has two paper manufacturing units located at Ahmedgarh (Distt. Sangrur) and at Banah (Distt. Nawanshaher). Further prospects for paddy straw pulping with extractants developed for the extraction of silicon and lignin by IIT, New Delhi are in the pipeline (Kaur et.al 2017).

ELECTRICITY GENERATION

In Punjab the existing seven biomass power projects of 62.5 MW capacities are consuming over 0.55 million tonnes per annum and another three plants of 46 MW capacity are under consideration that may consume an additional 0.5 million tonnes of straw. The Punjab State Regulatory Commission decided on a fixed tariff of Rs. 3.8, a variable tariff of Rs. 4.88 and a net tariff of Rs. 7.97 per Kwh, assuming a fuel price of Rs. 3 342.6 per metric ton of paddy straw (vide Petition No 53 of 2016 and Order dated 6 December 2016). This tariff was much higher than the solar, wind and open auction rate of Rs. 4.31 per Kwh of the national grid, and PSPCL (Punjab State Power Corporation Ltd) is reluctant to provide a subsidy. In Haryana some plants are under consideration.

PELLETING AND BRIQUETTING

This technique increases the density of loose biomass, calorific value and improves the logistics of the feedstock value chain (Sharma ***et al.*** 2015; Purohit and Chaturvedi 2016 and 2018). India Mart is advertising the sale rate at INR 11 per Kg of pellets. It has been reported that in Japan pelleting cost depends on the scale (Ishii, K. ***et al.***, 2016). This adds to the overall cost of raw material and furthermore, the levelized electricity tariff of INR 8.35/Kwh is higher as compared to INR 6.92/Kwh of imported coal (Purohit and Chaturvedi, 2015).

TORREFACTION AND BIO CHAR

These are emerging technologies that convert loose biomass into compact and densified material for commercial applications of the feedstock (Dhakate ***et al.***, 2019). However, it is a very nascent technology and there are still some issues to be resolved.

BIO REFINERIES

Fast pyrolysis at high temperatures is being discussed to produce multiple fuels and chemicals analogous to crude oil refineries (Jin ***et al.***, 2014; Zhu ***et al.***, 2015; Abraham ***et al.***, 2016; SAE, 2016). The setting up of a plant in Bathinda (Punjab) is under serious consideration.

BIO-ETHANOL PRODUCTION

Major efforts are being made to perfect technologies for ethanol production from surplus lingo-cellulosic biomass of agriculture sector that is being burnt (Singh ***et al.***, 2016, Kraussler ***et al.***, 2018). The setting of one plant at Panipat (Haryana) is under consideration.

BIOENERGY AND BIO-MANURE

The production of bio compressed natural gas (CNG) (methane) from crop biomass is quite sustainable and environmentally benign (Chandra ***et al*** 2015). In 2020, a compressed biogas (CBG) plant was commissioned that is expected to utilize 300 tonnes of biomass to produce around 33 tonnes of bio CNG per day. The plant is currently being constructed in Sangrur in Punjab at a cost of INR 1.6 billion. Collecting, baling, aggregating and storage of biomass to produce the reviewed economic goods and services are a critical factor. The raw material supply chain contributes about 35-50 percent of the product costs. Since paddy is produced only during one season in northern India and its inventory has to be maintained for about 6-10 months, this further contributes to the cost of feedstock. This biomass is bulky and therefore the collection of up to about 30 km is advisable. There are about 600 balers in Punjab and 300 in Haryana, mostly in the private sector to aggregate rice, wheat and other straw.

While there are several *ex situ* uses, it is imperative that farmers be aware of this in addition to the benefits and challenges that they may have to face. A recent small sample survey of the awareness of the farmers by Roy and Kaur (2016) analysed further expansion in the commercial alternatives of *ex situ* straw management (**Table 10**).

TABLE 10.

AWARENESS AMONG FARMERS (PERCENT) REGARDING VARIOUS ALTERNATIVES OF PADDY STRAW MANAGEMENT IN PUNJAB (BASED ON 60 FARMERS) IN 2016

ALTERNATIVES OF MANAGEMENT	PUNJAB (%)
1. PRODUCTION OF ENERGY	63.3
2. CHARCOAL PRODUCTION	0
3. METHANE	0
4. BIOGAS PRODUCTION	20.0
5. ANIMAL FEED	93.3
6. MULCHING MATERIAL	11.6
7. MUSHROOM PRODUCTION	50.0
8. THATCHING	50.0
9. PAPER MILL FEED STOCK	16.6
10. COMPOST MAKING	36.6
11. FUEL PURPOSE	93.3
12. PACKING MATERIAL	16.6
13. BIO CHAR	0
14. INCORPORATION	70.0
15. HAPPY SEEDER/ZERO TILLAGE	16.6

Source: Roy and Kaur (2016)

To effectively scale up the use of crop residues for *ex situ* purposes, there is the need to develop a value chain of residues that can enable the collection, mobilization, and storage of these residues in an economically viable way. The following section of this report proposes a model value chain and estimates the various requirements for developing a value chain in Punjab.

CHAPTER

4

MODEL VALUE CHAIN OF RICE STRAW

A crop residue supply chain consists of the sequence of processes involved in the harvesting, baling transport and storage of crop residues. Developing such a supply chain requires deploying specific equipment that allows for the baling of straw, its transport and finally storage until the next harvest season. As the collection of rice straw is available for only a few days during the year, the proper infrastructure is key to storing the straw throughout the entire year until the next harvest season. The lack of a well-functioning residue supply chain hinders the timely and consistent supply of crop residues for *ex situ* usage, thereby increasing the business risks for entrepreneurs engaged in the *ex situ* utilisation of crop residues.

The structure of a crop residue supply chain is depicted in **Figure 5**. The supply chain consists of three major steps:

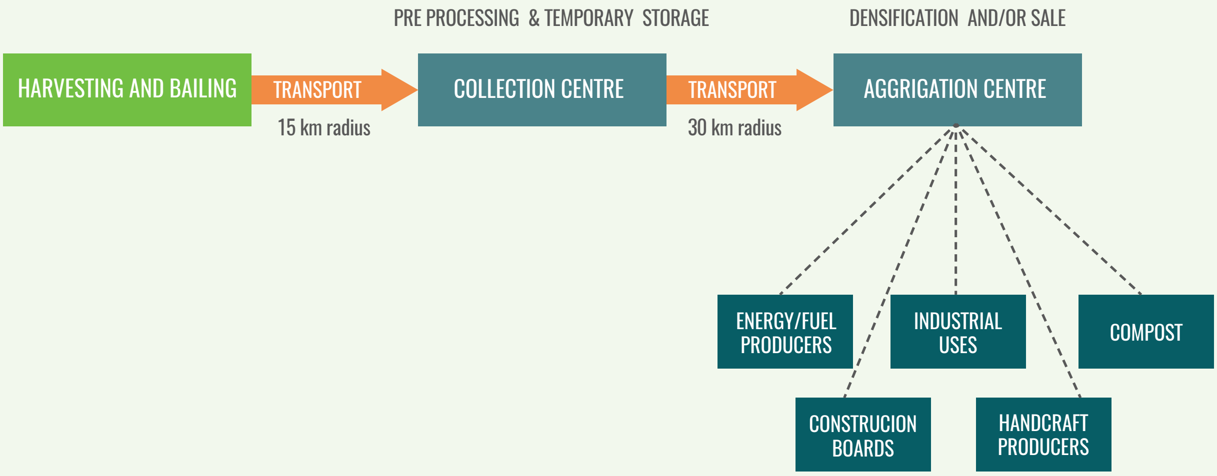
(i) harvesting and baling straw

(ii) transport to temporary collection centres

(iii) transport to and storage at the aggregation centres.

FIGURE 5.

STRUCTURE OF CROP RESIDUE SUPPLY CHAIN



Source: Authors.

Balers and rakes can be used simultaneously on the field after the rice has been harvested by a combine harvester. Once baled, the straw is then transported to a temporary collection centre, which can be an open field near a major road where bales with a radius of 15 km can be temporarily stored before transport to an aggregation centre. This reduces the number of trips that would otherwise be required for the transport of the collected straw directly to the aggregation centre. The aggregation centres are a modern warehouse where bales can be stored throughout the year. The aggregation centre also acts as the wholesale point for straw that can be purchased for various ***ex situ*** uses, e.g. CBG production, pellets production, production of construction boards, composting.

This analysis estimates the type and amount of equipment required for baling and transporting straw, as well as the location and costs involved in building the aggregation centres required to store rice straw. Furthermore, estimates are also provided on the potential additional earnings that farmers can expect from selling their straw. Specific operations and machinery are identified that would be required at each step of the supply chain. These are depicted in **Figure 6**.

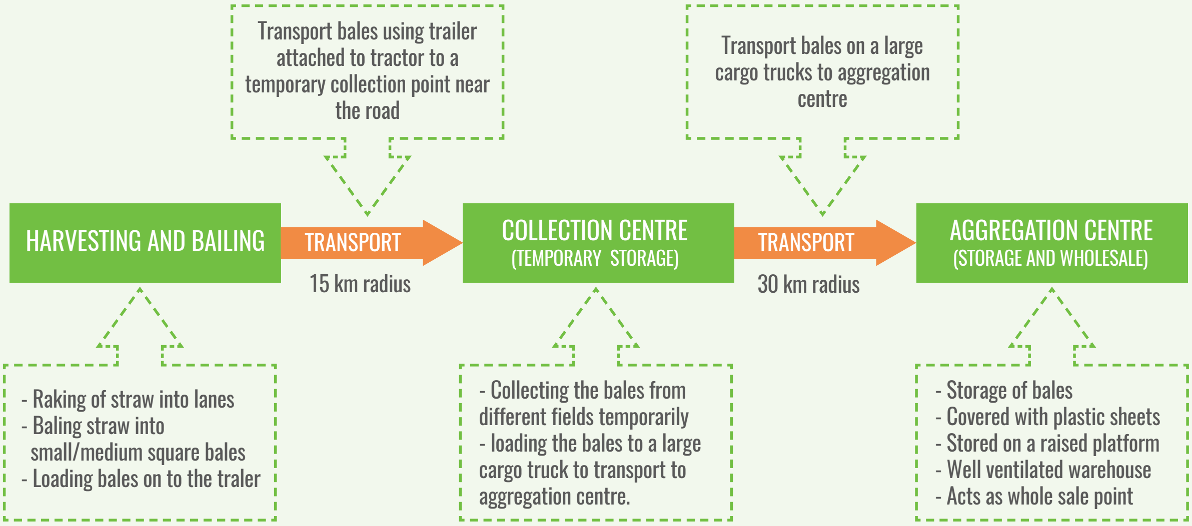
The analysis considers several factors including crop production, area harvested, crop density[4], and the district area. The analysis employs a 2-step approach (see **Figure 7**. Two main steps in the assessment); the first step is the biomass assessment component. The biomass assessment defines the amount of crop residues produced, their spatial distribution, accessibility and current and competing uses. This analysis is carried out at district and state level. The second step of the analysis is the logistic and economic analysis. This component defines how to bale the residues, transport and store them, and the related collection costs.

Given that not all of the residues generated should be taken off the field since this would have a negative impact on soil health and quality, at this level of analysis it is assumed that a maximum of 30 percent of the residues should be removed from the field for further uses (*ex situ*). The analysis considers the identified 20-day window of time available for collection between the two cropping seasons. Moreover, given that rice yields vary by district (and therefore the amount of straw produced), the analysis uses district-specific rice straw yields to estimate the total volume of straw that requires baling, transportation, and storage.

[4] Ratio of area under rice cultivation and total area of district.

FIGURE 6.

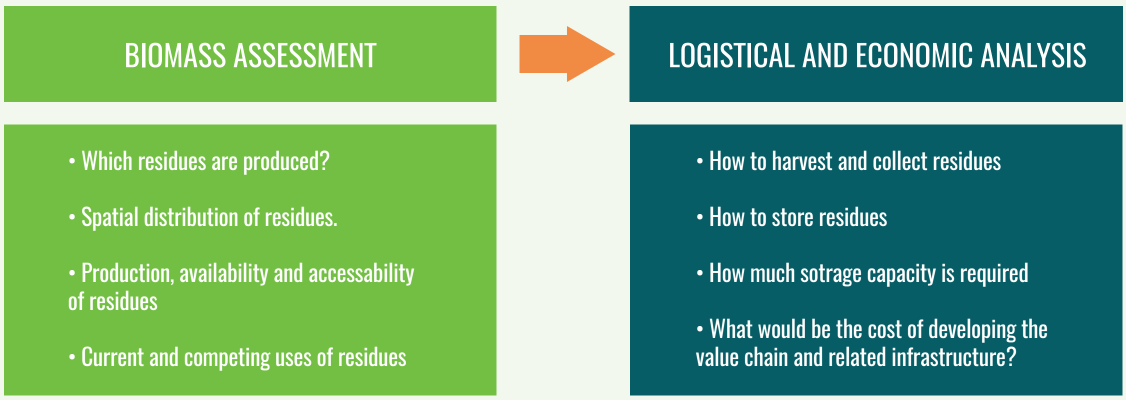
THE COMPONENTS OF THE SUPPLY CHAIN WITH THE REQUIRED PROCESSES AT EACH STEP



Source: Authors' calculations

FIGURE 7.

TWO MAIN STEPS IN THE ASSESSMENT



Source: Authors' calculations.

Combining the target quantity of straw that needs to be mobilised and the average baling and raking capacity of rake and baler (tonnes/hour), the number of all equipment (tractors, balers, rakers) are estimated together with their associated costs. As explained, the storage of baled straw is of critical importance since the straw collected needs to be stored in a weatherproof infrastructure until the next harvest season. The analysis uses the size, volume and density of baled straw to estimate the total storage infrastructure that would be required to store the bales, in addition to the corresponding cost of construction of the aggregation centres. The cost of building storage infrastructure is also estimated and included in the final cost of straw (INR/tonne).

The collection distances and number of aggregation centres were estimated using a constrained Non-linear Programming (NLP) model. This model was designed to minimize and the storage and transport costs are subject to the constraints of a maximum storage area (100 000 sq.ft) and maximum collection distance (30 km).

4.1. BIOMASS ASSESSMENT

The state of Punjab is an agrarian economy that contributes significantly to the food security of India as well as the income of the farmers. About 83.4 percent of the total geographical area of 5.036 million hectares of Punjab are cultivated. Wheat is grown from November to April and is the traditional crop of the state of Punjab. However, due to the improvements in rice cultivation and the growing demand for rice, the traditional (kharief) summer crops, mainly coarse cereals, pulses and oilseeds have been replaced by rice. This diversification is the result of better technologies available for rice varieties that ensure irrigation with good quality canals and groundwater, rural electrification, and marketing infrastructure. Furthermore, these technologies provide a policy for sustaining food security system in India. Punjab consists of 22 districts, all of which produce rice to a varying degree.

4.1.1. Estimation of rice straw production

The harvest index and residue to crop ratio (RCR) of the main varieties of rice cultivated in Punjab were used (see **Table 10**) to estimate the production of rice straw. The harvest index is defined as the total quantity of crop (in this case rice) produced, divided by the total quantity of above-ground biomass (in this case, straw plus rice grain).

TABLE 11.

HARVEST INDEX AND RCR OF RICE VARIETIES GROWN IN PUNJAB

VARIETIES	HARVEST INDEX (%)	RCR
PARMAL VARIETIES		
PR 126	45.30%	1.21
PR 124	44.50%	1.25
PR 122	45.00%	1.22
PR 121	45.20%	1.21
PUSA 44	44.00%	1.27
OVERALL AVERAGE	**44.80%**	**1.23**

Source: Collected by CRRID during fieldwork in 2020.

Based on the total quantity of rice produced in each district and the average RCR derived from the data in **Table 10**, the following equation was used to estimate the total rice straw produced in each district of Punjab (see **Table 11**).

TOTAL RICE STRAW PRODUCED =RCR× QUANTITY OF RICE PRODUCED

TABLE 12.

RICE PRODUCTION IN PUNJAB, 2020

DISTRICT NUMBER	RICE (TONNES)	RICE STRAW (TONNES)
AMRITSAR	923 890	1 136 385
BARNALA	898 764	1 105 479
BATHINDA	810 907	997 415
FARIDKOT	711 660	875 342
FATEHGARH SAHIB	617 700	759 771
FAZILKA	570 051	701 163
FIROZPUR	1 228 178	1 510 659
GURDASPUR	1 014 659	1 248 031
HOSHIARPUR	488 469	600 817
JALANDHAR	1 189 454	1 463 029
KAPURTHALA	762 461	937 827
LUDHIANA	1 884 418	2 317 834
MANSA	862 790	1 061 231
MOGA	1 363 154	1 676 679
MOHALI	150 965	185 687
MUKTSAR	1 207 696	1 485 466
PATHANKOT	157 157	193 303
PATIALA	1 565 827	1 925 967
RUPNAGAR	232 531	286 013
SANGRUR	2 284 816	2 810 323
SHAHID BHAGAT SINGH NAGAR	404 393	497 403
TARN TARAN	1 136 644	1 398 072
TOTAL	20 466 582	25 173 896

Source: Government of Punjab, 2020.

4.2. CURRENT USE OF RICE STRAW IN PUNJAB

While there are several uses for rice straw, various estimates suggest that that around 70 – 80 percent of the rice straw produced is burnt in the field after rice harvest. This has primarily been attributed to the short timeframe between the harvesting of rice and slowing down of the wheat harvest when farmers have to prepare their fields for wheat sowing. Based on a survey[5] conducted in 2020 of 1 707 rice farmers in Punjab, an average of two weeks is available for the farmers to prepare the fields for wheat sowing after the rice harvest.

While several estimates have been made of how much rice is burnt, the Ministry of Agriculture and Farmer Welfare tracks the area under paddy production that is burnt in each district of Punjab. The latest estimate available is from 2018 (see **Table 12**).

[5] The survey was financed by FAO and implemented by CRRID in Punjab between June – August 2020.

TABLE 13.

AREA UNDER RICE PRODUCTION BURNT ACROSS DISTRICT IN PUNJAB IN 2019

DISTRICT NAME	AREA UNDER PADDY (HECTARES)	PADDY AREA BURNED (HECTARES)	AREA BURNT (%)
AMRITSAR	180 000	84 110	47%
BARNALA	114 000	70 990	62%
BATHINDA	167 000	110 360	66%
FARIDKOT	116 000	89 150	77%
FATEHGARH SAHIB	86 000	45 930	53%
FAZILKA	114 000	49 850	44%
FIROZPUR	186 000	160 640	86%
GURDASPUR	172 000	80 560	47%
HOSHIARPUR	75 000	20 970	28%
JALANDHAR	173 000	94 430	55%
KAPURTHALA	118 000	50 240	43%
LUDHIANA	259 000	128 310	50%
MANSA	116 000	65 590	57%
MOGA	181 000	129 870	72%
SRI MUKTSAR SAHIB	179 000	93 860	52%
PATHANKOT	28 000	4 900	18%
SBS NAGAR	60 000	12 430	21%
PATIALA	234 000	161 840	69%
ROOPNAGAR	41 000	10 040	24%
SANGRUR	287 000	185 420	65%
SAS NAGAR	31 000	9 370	30%
TARN TARAN	186 000	122 070	66%

Source: MoA&FW, 2019.[6]

In addition to open burning, rice straw is also currently being used in bioenergy plants, paper and cardboard mills as well as being managed *in situ* using the Happy Seeder (see **Table 13**). According to the Ministry of Agriculture and Farmer Welfare in 2019, around 1 million tonnes of straw was used across 7 bioenergy plants in Punjab that generate around 62.5 MW of the power. Additionally, 0.10 million tonnes of straw were used in paper and cardboard mills; furthermore, around 3.52 million tonnes of straw were managed *in situ*.

While there is no official target or statistic that identifies the share or the residues that should be used to preserve soil fertility, FAO encourages the *in situ* uses of residues to ensure soil fertility. A 2016 survey of farmers enquiring about their awareness of the various uses of rice straw points to the fact that most farmers are aware that rice straw can be used as animal feed, fuel for energy production and incorporation in soil.

[6] https://farmech.dac.gov.in/revised/1.1.2019/REPORT%20OF%20THE%20COMMITTEE-FINAL(CORRECTED).pdf

TABLE 14.

USES OF CROP RESIDUES IN PUNJAB 2019

RESIDUE END USE	TOTAL CONSUMPTION (MILLION TONNES)
PADDY STRAW USED IN 7 BIOENERGY PLANTS (AGGREGATE CAPACITY OF 62.5 MW)	1.0
PAPER/CARDBOARD MILLS	2.70
IN-SITU MANAGEMENT	3.52
TOTAL USED	7.22

Source: MoA&FW, 2019.

TABLE 15.

AWARENESS AMONG FARMERS (PERCENT) REGARDING VARIOUS ALTERNATIVES OF PADDY STRAW MANAGEMENT IN PUNJAB IN 2016

ALTERNATIVES OF MANAGEMENT	PUNJAB (%)
ANIMAL FEED	93.3
FUEL PURPOSE	93.3
INCORPORATION IN SOIL	70.0
PRODUCTION OF ENERGY	63.3
MUSHROOM PRODUCTION	50.0
THATCHING	50.0
COMPOST MAKING	36.6
BIOGAS PRODUCTION	20.0
PAPER MILL FEED STOCK	16.6
PACKING MATERIAL	16.6
HAPPY SEEDER/ZERO TILLAGE	16.6
MULCHING MATERIAL	11.6
CHARCOAL PRODUCTION	0.0
METHANE	0.0
BIO CHAR	0.0

Source: CRRID, 2020.

However, given the very large quantity of rice straw that is produced and burnt, all of the possible uses of crop residues that are viable and sustainable should be pursued. During discussions with experts and policy makers from the Ministry of Agriculture and Farmer Welfare in 2018, the ministry stated that it is envisaged that around 70 percent of the rice straw produced would be managed *in situ*, while the remaining 30 percent could be managed *ex situ*. **Based on this, the current assessment considers three levels of rice straw availability for *ex situ* uses viz. 5, 15 and 30 percent**. Based on the three levels of rice straw availability for *ex situ* uses, Table 15 estimates the quantity of rice straw available for *ex situ* uses in each district.

TABLE 16.

GHG EMISSION FROM BURNING OF RICE STRAW

DISTRICT NUMBER	5 PERCENT	15 PERCENT	30 PERCENT
AMRITSAR	56 819.24	170 457.71	340 915.4
BARNALA	55 273.96	165 821.87	331 643.7
BATHINDA	49 870.77	149 612.30	299 224.6
FARIDKOT	43 767.09	131 301.27	262 602.5
FATEHGARH SAHIB	37 988.55	113 965.65	227 931.3
FAZILKA	35 058.14	105 174.41	210 348.8
FIROZPUR	75 532.97	226 598.91	453 197.8
GURDASPUR	62 401.54	187 204.62	374 409.2
HOSHIARPUR	30 040.83	90 122.49	180 245.0
JALANDHAR	73 151.44	219 454.32	438 908.6
KAPURTHALA	46 891.33	140 673.98	281 348.0
LUDHIANA	115 891.72	347 675.16	695 350.3
MANSA	53 061.57	159 184.72	318 369.4
MOGA	83 833.95	251 501.86	503 003.7
MOHALI	9 284.35	27 853.04	55 706.1
MUKTSAR	74 273.28	222 819.84	445 639.7
PATHANKOT	9 665.16	28 995.47	57 990.9
PATIALA	96 298.35	288 895.06	577 790.1
RUPNAGAR	14 300.66	42 901.97	85 803.9
SANGRUR	140 516.16	421 548.48	843 097.0
SHAHID BHAGAT SINGH NAGAR	24 870.15	74 610.45	149 220.9
TARN TARAN	69 903.59	209 710.78	419 421.6
TOTAL	**1 258 695**	**3 776 084**	**7 552 169**

Source: Authors' calculations

4.3. GHG EMISSIONS FROM BURNING OF RICE STRAW

Based on the data available from 2018 from the Ministry of Agriculture and Farmer Welfare, rice straw is burnt in all districts of Punjab, albeit in varying degrees. **Table 13** details the percentage of area under rice production that are currently being burnt. Based on the share of are under rice production burnt, the total quantity of rice straw burnt is calculated based on the yields of rice star in each district.

Based on the data, **Table 17** estimates the emission of major greenhouse gasses and PM2.5 in each district of Punjab based on current levels of burning..

TABLE 17.

GHG EMISSION FROM BURNING OF RICE STRAW

DISTRICT NAME	CO_2 (TONNES)	CO (TONNES)	CH_4 (TONNES)	N_2O (TONNES)	CO_2 EQV (TONNES)	PM 2.5 (TONNES)
AMRITSAR	809 163	49 137	1 442	37	856 356	4 700
BARNALA	1 038 377	63 057	1 851	48	1 098 938	6 031
BATHINDA	997 316	60 563	84 891	46	1 055 482	5 793
FARIDKOT	1 021 130	62 009	1 820	47	1 080 686	5 931
FATEHGARH SAHIB	610 058	37 046	1 087	28	645 639	3 544
FAZILKA	467 395	28 383	833	22	494 655	2 715
FIROZPUR	1 968 238	119 523	3 508	91	2 083 033	11 433
GURDASPUR	888 660	53 965	1 584	41	940 490	5 162
HOSHIARPUR	254 866	15 477	454	12	269 731	1 480
JALANDHAR	1 219 069	74 029	2 173	56	1 290 169	7 081
KAPURTHALA	610 947	37 100	1 089	28	646 580	3 549
LUDHIANA	1 755 760	106 620	3 129	81	1 858 161	10 198
MANSA	916 426	55 651	1 633	42	969 876	5 323
MOGA	1 828 922	111 063	3 259	85	1 935 590	10 623
PATHANKOT	52 714	3 201	94	2	55 788	306
PATIALA	2 013 310	122 260	3 588	93	2 130 733	11 694
ROOPNAGAR	103 994	6 315	185	5	110 060	604
SANGRUR	2 767 466	168 057	4 932	128	2 928 874	16 075
SAS NAGAR	84 395	5 125	150	4	89 317	490
SBS NAGAR	158 249	9 610	282	7	167 478	919
SRI MUKTSAR SAHIB	1 170 250	71 065	2 086	54	1 238 503	6 797
TARN TARAN	1 397 932	84 891	2 491	65	1 479 464	8 120
TOTAL	**22 134 635**	**1 344 149**	**39 448**	**1 023**	**23 425 603**	**128 571**

Source: Authors' calculations

4.4 VALUE CHAIN STRUCTURE

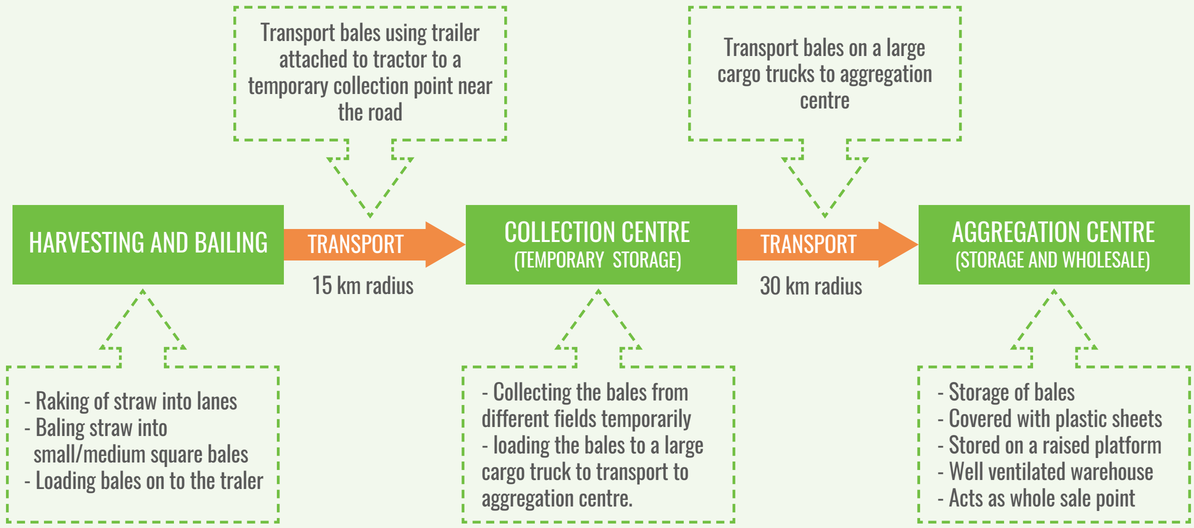
Developing a value chain of rice straw requires the deployment of specific equipment as well as the availability of storage infrastructure. Based on the results of the biomass assessment that estimated the quantity of rice straw produced in Punjab and their spatial distribution across the districts, a value chain of rice straw has been developed in this section. The aim is to:

- understand the requirements for developing a value chain of rice straw in the state of Punjab and identify scenarios that would be profitable for collecting and mobilizing rice straw;
- assess the machinery, storage space and investment required to collect and mobilize rice straw;
- identify the total investment needed to establish a rice straw value chain.

The value chain includes three major steps, which are: harvesting and baling rice straw, and transporting it to temporary collection centres. Temporary collection centres can simply be open fields close to major roads where baled straw can be picked up and subsequently transported to aggregation centres. Aggregation centres are warehouses where long term storage of straw would be possible. The specific activities that are carried out at each step of the chain are outlines in **Figure 8**.

FIGURE 8.

MODEL VALUE CHAIN OF RICE STRAW



Source: Authors' calculations

4.4.1. Components of the value chain

Different equipment is required at different stages of the value chain. At the harvesting and baling stage of the chain, the main machinery needed is tractors, rakes and balers. Both balers and rakes need to be attached to the tractors in order to operate. The rakes align the rice straw in the field in piles allowing for the balers to then run over the piles of straw and produce bales.

Temporary collection centres are essentially fields close to the main roads, where bales collected from different fields can temporarily be gathered before being taken to the aggregation centres. At temporary collection centres, the main operations are unloading bales delivered from the fields and loading them onto trucks that subsequently transport the bales to the aggregation centres. Aggregation centres are warehouses where bales are stored for the long term. Under this model, aggregation centres also act as wholesale point points.

4.4.2.Structure of analysis and methodology

There are two major constraints that are specific to the rice -wheat systems in Punjab that define how the value chain might be developed and what kind of equipment might be required. These are:

- The short time frame between the 2 cropping seasons (around 20 days)
- Total straw to be collected (maximum of 30 percent of the total produced straw)

Based on these two constrains the analysis tries to assess how a maximum of 30 percent of the produced rice straw can be mobilized in 20 days. The assessment is carried out in three blocks.

4.4.2.1. Step 1. Collection quantity and cost

©Flickr/CIAT(CC BY-SA 2.0)

The first block assesses the overall impact of the total target quantity of rice straw that needs to be mobilised on collection cost. Between 2018 and 2019, several meetings were held with ministry of agriculture and farmers welfare to discuss the possible development of a value chain in rice straw in Punjab. The view of the ministry was that around 70 percent of the crop residues should be managed ***in -situ*** and the remining 30 percent could be used for ***ex-situ*** purposes.

More specifically, the calculation comprised two main steps. First, the model calculated the number of logistic units needed to collect and mobilize the targeted rice straw production across all the districts. The second step calculates the annualized collection and mobilization costs. All the following step and methodology is based on the BEFSRA: Biomass supply and mobilization tool, and more detail on the methodology can be found in the user manual (Food and Agriculture Organization of the United Nations (FAO), 2014).

4.4.2.1.1. NUMBER OF LOGISTIC UNITS CALCULATIONS

The primary constraint considered is the 20 days time frame that exists to collect the rice straw. This feature will remarkably impact the number of logistic units needed for the collection process. Then, the assessment calculated the number of bales. This information and the standard bale sizes and volumes allowed calculating the number of balers and the storage area required.

The collection distances and number of aggregation centers were then estimated using a constrained Non-linear Programming (NLP) model. This model was designed to minimize and the storage and transport costs subject to constraints of maximum storage area (100 000 sqft) and maximum collection distance (30 km).

$$Min\ z = \sum_i \frac{1}{X_i} (TSA_i * USC + TSQ_i * UTC * Y_i)$$

$$s.t.$$

$$Y_i \geq AC\ tranport\ distance$$

$$X_i \geq \frac{TSA_i}{Max\ storage\ area}$$

Where:

TSA_i = Total storage area needed in district i (sqft)
TSQ_i = Total storage quantity in district i (tonnes)
USC = Unitary storage cost (INR/sqft)
UTC = Unitary transport cost (INR/t/km)
X_i = Number of AC in district i (integer)
Y_i = Transport distance from Collection Centre to Aggregation Centre in district i (km)
Moreover, solving this model it was possible to calculate the storage area per AC per district i as follows:

$$Storage\ area\ per\ AC_i = \frac{TSA_i}{X_i}$$

On the other hand, since a baler will be the core component of a collection crew, it was assumed that each baler would be accompanied by one raker, one trailer, one tractor in each collection crew. This set-up will ensure to perform in-field activities in parallel and deal with the short collection frame constraint.

The number of trucks needed to mobilize the produced rice straw bales were calculated, departing from the number of trips required to collect all the bales from the field using a standard 45 tonnes truck and assuming a maximum speed of 60 km/h. Then, it was considered the 20 days collection frame to estimate the tola number of trucks needed.

4.4.2.1.2. TOTAL COLLECTION COSTS

Once the number of logistic units was defined, it was possible to calculate the total collection costs.

Total collection costs = OPEX + CAPEX + Other costs

4.4.2.1.2.1. OPERATIVE EXPENDITURE (OPEX)

The OPEX costs in this case is composed by the labor and energy costs, since no transformation is carried out for rice straw at this stage. The number of workers required by collection and transport crews is summarized in (**Table 17**). It was also assumed that crew would need at least two shifts to collect all residues within collection time frame. The daily shift for all workers will be 8 hours. The aggregation center personnel will operate all year long, the number of workers was estimated using the approach described by (LOGIWA, 2020). All the above information allowed the labor costs calculation, considering specific wages for Punjab.

Energy costs comprised all the logistics unit fuel consumptions and local fuel costs. Regarding, electricity the cost included the amounts consumed in aggregation centers.

TABLE 18.

LABOUR FACTORS USED IN THE MODEL

COLLECTION CREWS	LABOUR UNSKILLED	# WORKERS PER CREW	10.5
	LABOUR SKILLED	# WORKERS PER CREW	1.75
TRANSPORT CREWS	LABOUR UNSKILLED	# WORKERS PER CREW	4.5
	LABOUR SKILLED	# WORKERS PER CREW	0.75

Source : (Reddy and Raghaveni, 2015.)

TABLE 19.

COLLECTION UNITS	FUEL CONSUMPTION (L/HA)	6.21
TRUCKS	FUEL CONSUMPTION (KM/L)	4.00
WAREHOUSE	ELECTRICITY CONSUMPTION (KWH/M2/YR)	4.00

Source : (EIA USA, 2003; ICAR, 2008.)

4.4.2.1.2.2. CAPITAL EXPENDITURE (CAPEX)

The CAPEX for all equipment, building and installation costs, departed from calculating the total capital costs of all logistic unit. CAPEX was calculated using a specific depreciation factor for each unit (see **Table 19**), and the maintenance costs for all units and installations (12 percent of annual depreciation).

TABLE 20.

DEPRECIATION FACTORS USED IN THE MODEL

	DEPRECIATION FACTORS
BALERS	23.08%
RAKERS	9.38%
TRAILERS	9.38%
TRACTORS	8.57%
PACKING EQUIPMENTS	9.38%
TRUCKS	5.00%
BUILDING & INSTALLATIONS	5.00%

4.4.2.1.3. Other costs

Other costs were needed to account for unforeseen expenses, as well as administrative and technician labor costs. The assessment also considered miscellaneous costs to account for possible unforeseen labor costs (15 percent of labor costs). Moreover, the model included general and administrative costs (3 percent of operative costs). Finally, the assessment included a farmer's income factor. It accounts a compensation to farmer for allowing the collection company to take the rice straw from their fields. It's worth noting that farmers shall not carry out any activities to collect and mobilize rice straw.

This assessment therefore considers three target quantities of rice straw to be mobilized, 5 percent, 15 percent, and 30 percent. Under this block the analysis estimates the effect the three different target volumes on the collection cost and account for how economies of scale will impact the collection costs; when larger rice straw amounts can be collected.

4.4.2.2. Step 2: Logistical units – baler size

The second block assesses the impact of using different sizes of balers that are available in the India market to collect the straw from the field. Balers are the most important piece of equipment in the value chain. Balers allow for compacting the rice straw allowing for easy transport. Based on the results from a survey conducted in 2020, three different sizes of balers were identified. Three different bale sizes were included in the assessment as they seem to be the most preferred bale size in the surveyed districts. All three bales are square bales as opposed to round bales. The reason for this preference might be the fact that rectangular bales are easy to transport and can be easily stacked to store.

TABLE 21.

THREE DIFFERENT SIZES OF BALES CONSIDERED IN THE ANALYSIS

PARAMETER	BALE SIZE 1	BALE SIZE 2	BALE SIZE 3	UNIT
BALERS	22	36	36	INCHES
RAKERS	30	24	20	INCHES
TRAILERS	13	12	18	INCHES
TRACTORS	0.15	0.17	0.21	m^3/BALE

Source: Survey conducted by CRRID in 2020.

4.4.2.3. Step 3: Market price and profitability

Block three analyses the impact of market prices of rice straw on profitability. Currently, there is no formal market for rice straw in India and the market price of rice straw varies greatly from location to location. Therefore, the analysis assesses the profitability of collecting rice straw based on different market prices and estimate the potential income that farmers can generate by selling straw to private sector.

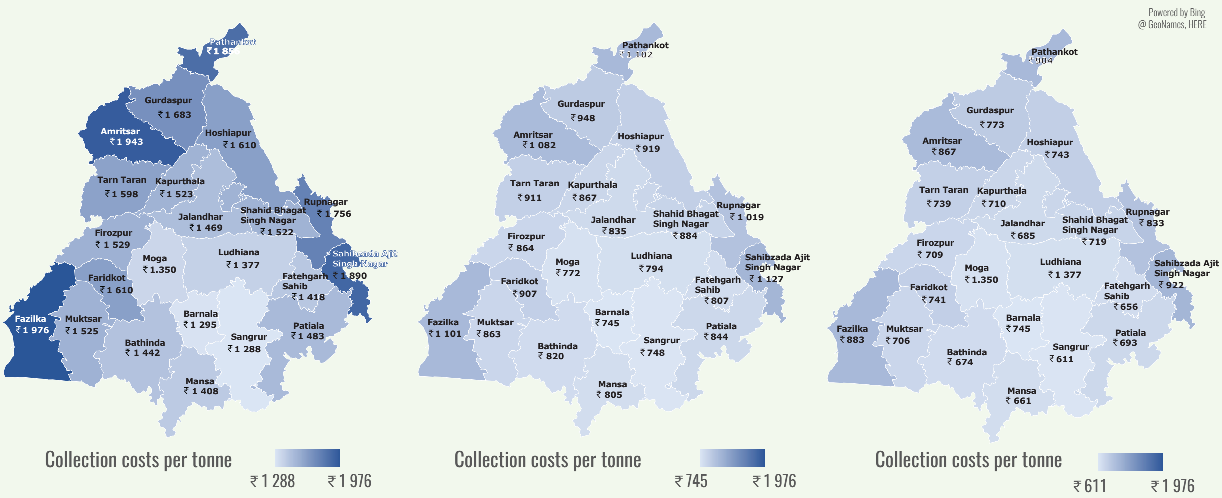
4.4.3. Results: Impact of target collection quantity on collection cost

The first set of results estimate the collection cost of rice in each district of Punjab at the target collection quantities of 5, 15 and 30 percent. The results suggest that collecting more straw reduces the per unit cost of collection. While the collection costs per tonne of straw varies across districts of Punjab, the breakeven[7] price ranges in Punjab ranges from INR 733/tonne at a 30 percent collection target to INR 1571/tonne for 5 percent collection target.

FIGURE 9.

PER UNIT COLLECTION COST AT 5, 15 AND 30 PERC COLLECTION TARGETS

5% STRAW COLLECTED	15% STRAW COLLECTED	30% STRAW COLLECTED



AVERAGE = 1 570 INR/TONNE	AVERAGE = 899 INR/TONNE	AVERAGE = 733 INR/TONNE

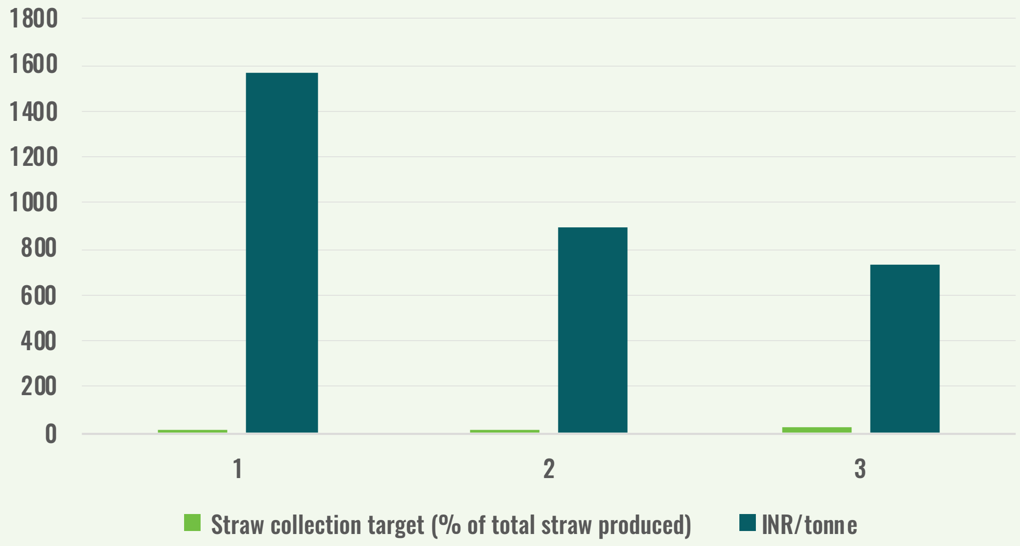
Source: Authors' calculations

This is in line with the principle of economies of scale which suggests that the per unit cost of the collection of straw would reduce as the total quantity collected increases. **Figure 10** shows the inverse relation between collection cost per tonne of straw collected as it corresponds to the target collection quantity. It is evident that as the collection quantity increases, the collection cost per tonne of straw decreases.

[7] The breakeven price is the price at which the entrepreneur makes no profit and no loss.

FIGURE 10.

RELATION BETWEEN COLLECTION COST AND QUANTITY COLLECTED

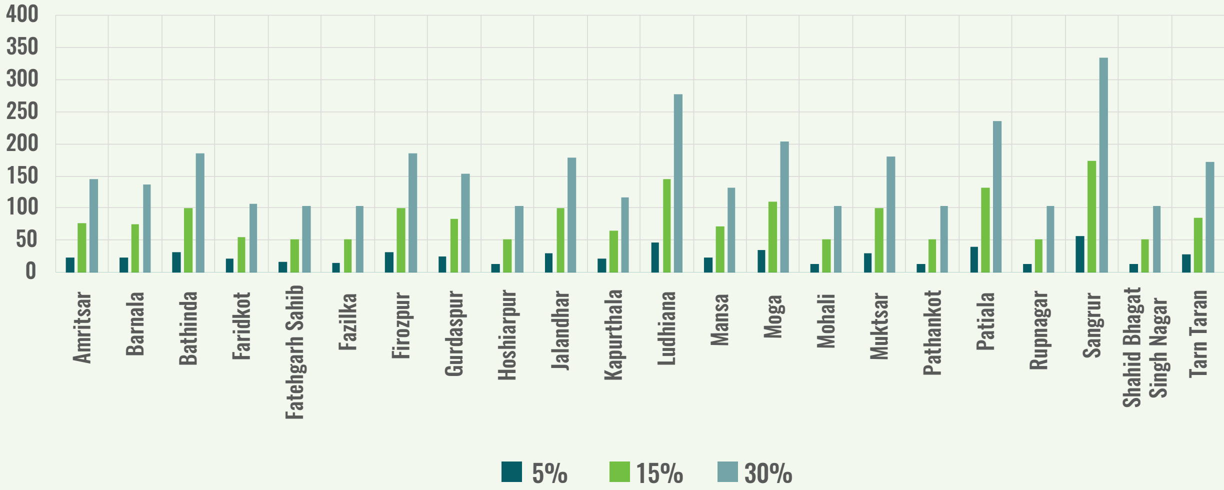


Source: Author's calculations

The collection cost includes the cost of reaping, baling, transporting, and storing straw at the aggregation centres. Furthermore, changes in the target quantity of straw collection would also change the total storage area required to store the baled straw in each district of Punjab (**Figure 11**).

FIGURE 11.

NUMBER AGGREGATION CENTRES NEEDED AT DIFFERENT TARGET LEVELS OF STRAW COLLECTION

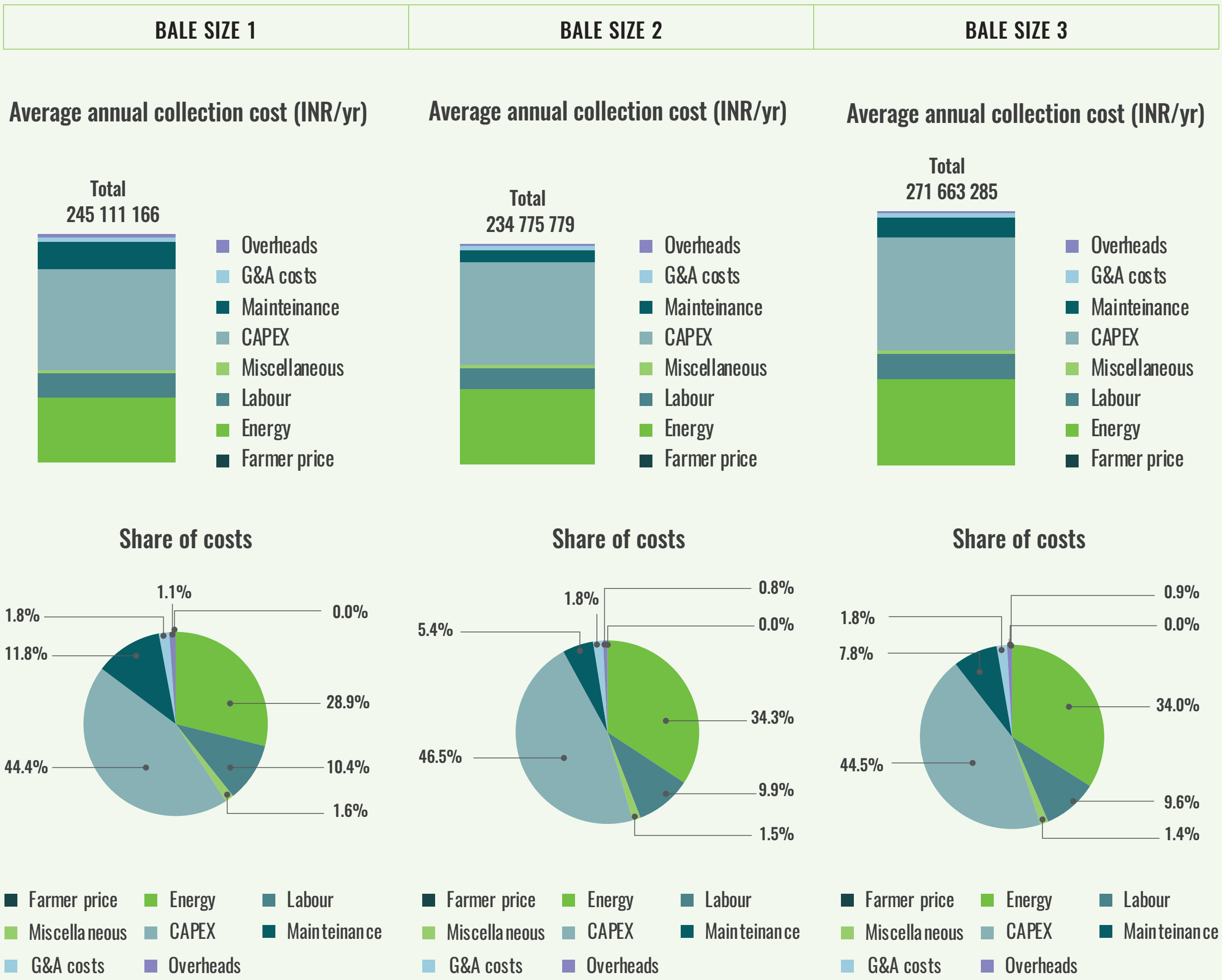


Source: Author's calculations

Given that collecting the maximum target of 30 percent straw seems to be overall the most economically viable, the assessment further analyses the impact of using different types of balers on the collection cost of straw. The three sizes of bales that were considered are detailed in **Table 20**. The results estimate the total collection costs per year for the three bale sizes and estimate the composition of costs as shown in **Figure 12** and the average collection cost per tonne of straw **Figure 13**.

FIGURE 12.

COLLECTION COSTS FOR THREE DIFFERENT BALE SIZES



Source: Authors' calculations

The assessment shows that using size 2 bales (36 x 24 x 12 inches) would result in the lowest cost per tonne of rice straw collected, which on average would be INR 703/tonne if 30 percent of the straw is collected (**Figure 13**).

Since the size 2 bale is the most economical, the analysis further estimates the number of aggregation centres, collection points and collection equipment needed for 30 percent of the rice straw produced in each district of Punjab in 20 days. **Table 21** shows the details of these results for each district of Punjab.

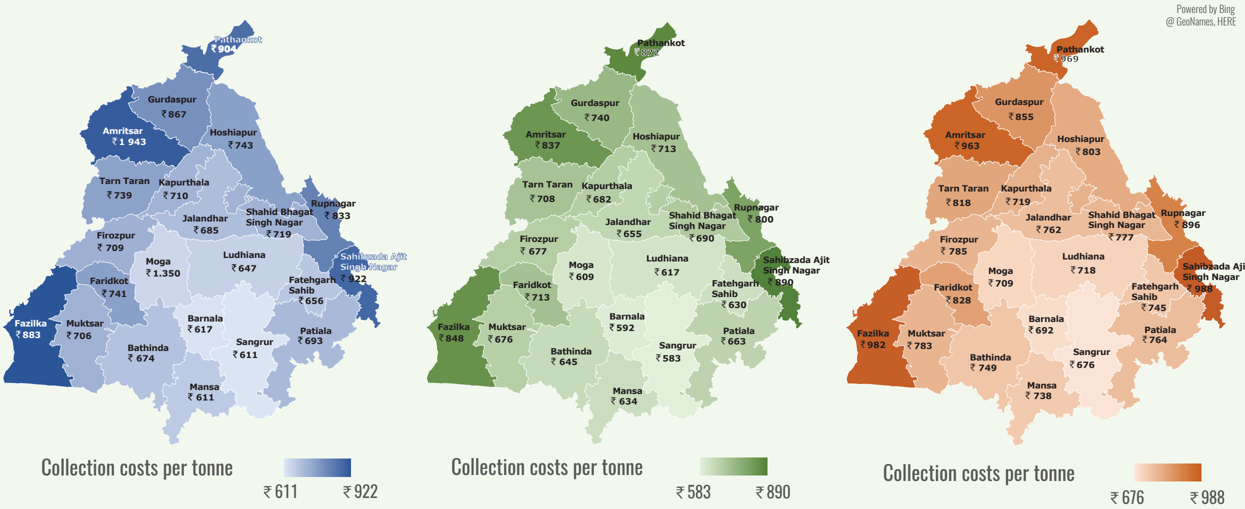
Corresponding to the number of collection equipment, trucks and storage and aggregations centres outlined in **Table 21**, **Table 22** presents the total investment required to collect 30 percent straw in each district of Punjab in 20 days.

The investment indicated are estimated for each district and for each type of equipment needed. The differences in the investment are primarily due to differences in the quantity of straw in each district, and crop density.

FIGURE 13.

AVERAGE COLLECTION COST OF STRAW FOR THREE BALE SIZES

AVERAGE = 733 INR/TONNE	AVERAGE = 703 INR/TONNE	AVERAGE = 868 INR/TONNE



Source: Authors' calculations

TABLE 22.

NUMBER OF AGGREGATION AND COLLECTION CENTRES, EQUIPMENT AND TRUCKS NEED TO COLLECT 30 PERCENT STRAW IN 20 DAYS

PARAMETER	BALE SIZE 1	BALE SIZE 2	BALE SIZE 3	UNIT
AMRITSAR	175	525	388	74
BARNALA	175	525	242	72
BATHINDA	223	669	372	98
FARIDKOT	144	432	244	57
FATEHGARH SAHIB	103	309	183	50
FAZILKA	103	309	244	46
FIROZPUR	223	669	397	98
GURDASPUR	193	579	366	82
HOSHIARPUR	103	309	167	39
JALANDHAR	223	669	368	94
KAPURTHALA	151	453	247	61
LUDHIANA	323	969	543	148
MANSA	167	501	255	69
MOGA	245	735	384	108
MOHALI	103	309	59	13
MUKTSAR	223	669	389	96
PATHANKOT	103	309	60	13
PATIALA	294	88	492	124
RUPNAGAR	103	309	85	19

SANGRUR	388	1 164	610	182
SHAHID BHAGAT SINGH NAGAR	103	309	130	33
TARN TARAN	212	636	388	92

Source: Authors' calculations

TABLE 23.

INVESTMENT NEEDED TO COLLECT 30 PERCENT STRAW IN 20 DAYS USING BALE SIZE 2

DISTRICT	AGGREGATION CENTRES (CRORE)	TRACTORS (CRORE)	BALERS (CRORE)	RAKERS (CRORE)	TRAILERS (CRORE)	TRUCKS (CRORE)	TOTAL INVESTMENT REQUIRED (CRORE)	TOTAL INVESTMENT REQUIRED (MILLION USD)
AMRITSAR	29	13	51	10	3	10	117	16
BARNALA	28	8	32	6	2	10	86	12
BATHINDA	38	13	49	9	3	13	126	18
FARIDKOT	22	8	32	6	2	8	79	11
FATEHGARH SAHIB	19	6	24	5	2	7	63	9
FAZILKA	18	8	32	6	2	6	73	10
FIROZPUR	38	14	52	10	3	13	131	18
GURDASPUR	32	13	48	9	3	11	116	16
HOSHIARPUR	15	6	22	4	1	5	54	8
JALANDHAR	37	13	49	9	3	13	124	17
KAPURTHALA	24	9	33	6	2	8	81	11
LUDHIANA	59	19	72	14	5	20	188	26
MANSA	27	9	34	6	2	9	87	12
MOGA	43	13	51	10	3	15	134	19
MOHALI	5	2	8	1	1	2	18	3
MUKTSAR	38	13	51	10	3	13	128	18
PATHANKOT	5	2	8	1	1	2	19	3
PATIALA	49	17	65	12	4	16	164	23
RUPNAGAR	7	3	11	2	1	3	27	4
SANGRUR	71	21	81	15	5	24	218	31
SHAHID BHAGAT SINGH NAGAR	13	5	17	3	1	4	43	6
TARN TARAN	35	13	51	10	3	12	125	18
TOTAL							**2 201**	**309**

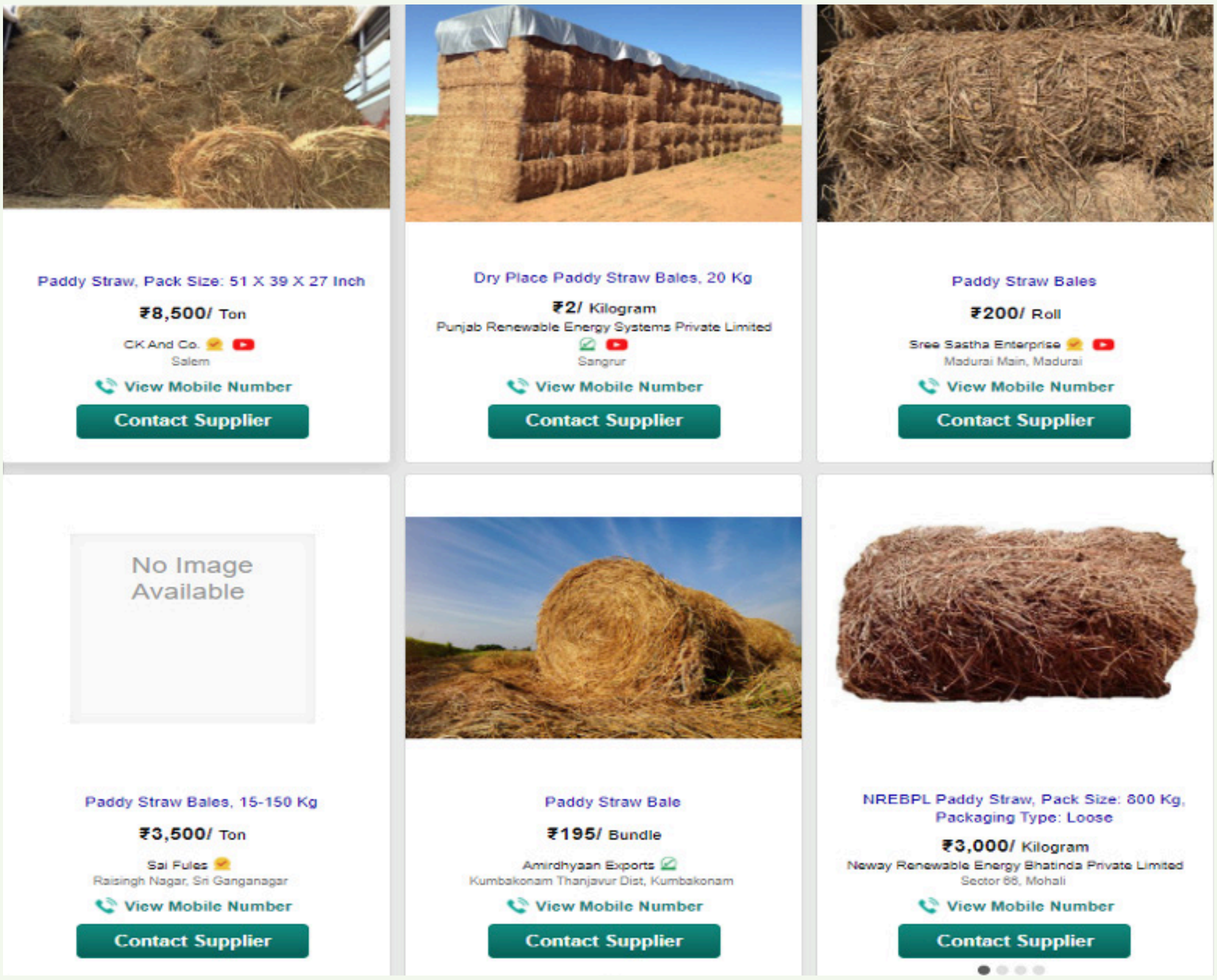
Source: Authors' calculations

4.4.3.1. Impact of market price on profitability and farmer income

So far, the analysis has estimated the collection cost of rice straw and not the selling price. The selling price or the marketing of straw would include the collection cost plus a profit for the aggregator. Generally, in a formal mature market of any product the market price is determined by the dynamics of supply and demand. In Punjab, however, the market for rice straw is still at a nascent stage and therefore, the market price can vary greatly. This was made evident by a quick search on indiamart.com, a leading online marketplace for wholesale trading of goods in India. The price of rice straw on indiamart.com can vary anywhere between INR 2000/tonne to INR 8000/tonne as shown in **Figure 14**. The market price of rice straw defines the profitability for the entrepreneur and the income that farmers can expect to earn from selling the rice straw to an entrepreneur.

FIGURE 14.

MARKET PRICE OF RICE STRAW ON INDIAMART.COM. SOURCE: AUTHORS CALCULATIONS.



Source: Indiamart, 2021

During 2021, FAO sponsored a survey of companies in India that are collecting and selling rice straw. The results indicated that in May-June 2021 the interviewed companies were selling rice straw on average at INR 1 500/tonne. However, on indiamart.com the prices were substantially higher than the interviewed companies. Therefore, the different market prices were used to assess the impact of the market price of straw on profitability and on income from farmers.

TABLE 24.

MARKET PRICES USED TO ASSESS PROFITABILITY IN THE ANALYSIS

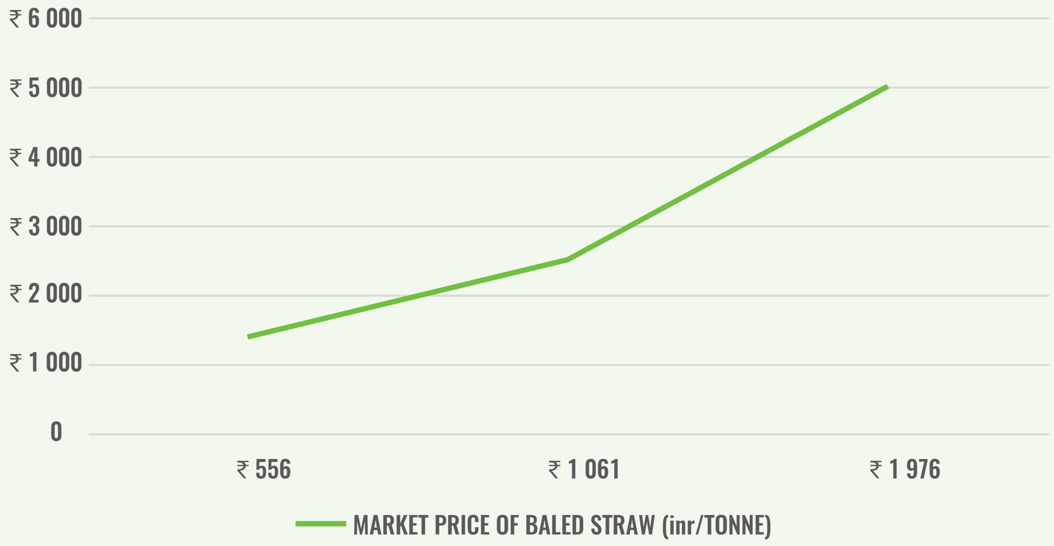
MARKET PRICE	SOURCE
INR 1 400	SURVEY CONDUCTED IN 2020
INR 2 500	INDIAMART.COM
INR 5 000	INDIAMART.COM

Source: Own survey and indiamart.com.

Based on the expected price by farmers, the analysis further analysed the relationship between the remuneration that the farmers can expect from selling straw to companies and its impact on the market price of straw. Based on the data on market prices detailed in **Table 23**. Market prices used to assess profitability in the analysis**Table 23**, **Figure 15** showcases the price per tonne of rice straw that farmers can expect to receive by allowing the entrepreneur to access their fields and collect and bale rice straw.

FIGURE 15.

RELATIONSHIP BETWEEN MARKET PRICE OF BALED STRAW AND FARMER INCOME FROM SELLING STRAW

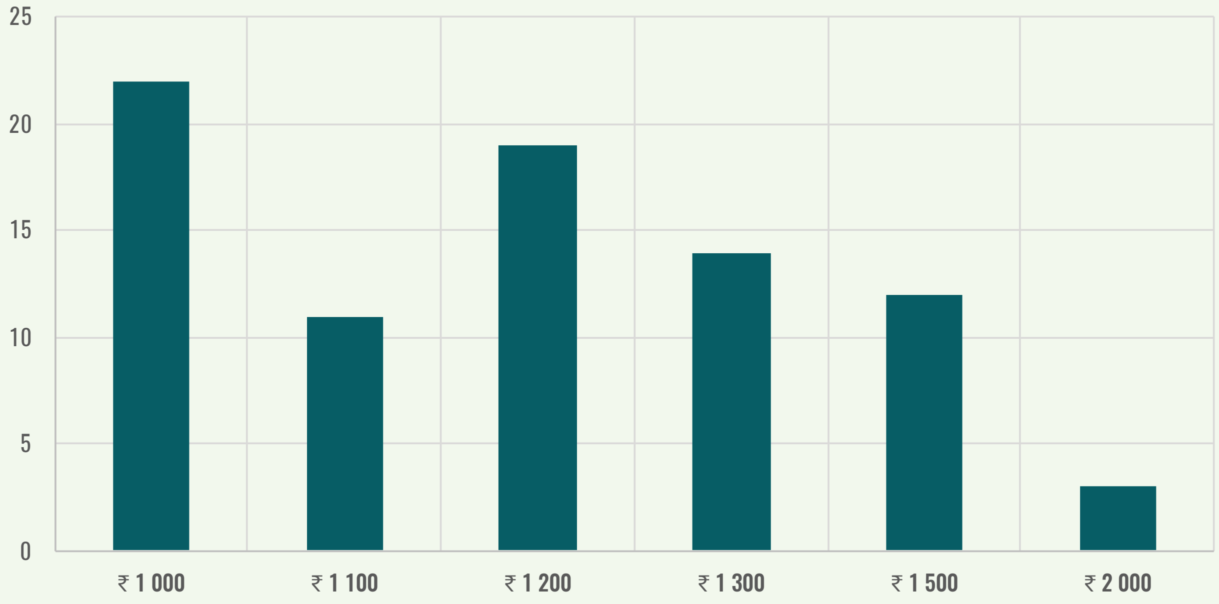


Source: Authors' calculations

The results detailed in **Figure 15** are in line with data collected from the survey on farmers in Punjab **Figure 16**. The results of the survey show that the prices for which farmers sold rice straw varied widely from Rs 700 to Rs 2 500 per tonne. The majority (96.3 percent) of those who sell the rice straw sold it at a rate between INR 1 000–2 000 per tonne. Most of the sales of rice straw (87.2 per cent) are recorded at six specific price points in this price range, as shown in Figure below. Over one-half of the farmers are selling rice straw at INR 1 000 or INR 1200 per tonne.

FIGURE 16.

PRICES AT WHICH FARMERS SOLD RICE STRAW IN 2020–2021



Source: Survey results.

CHAPTER

5

VIABILITY OF ENERGY TECHNOLOGIES

While rice straw has several uses, the Government of India has some ambitious plans for using rice straw to produce energy. This can be beneficial specifically to reduce India's bargaining dependence on imported fossil fuels to satisfy its domestic energy demand. India is the world's third-largest energy consuming country, thanks to rising incomes and the improved standards of living. Over 80 percent of India's energy needs are met by three fuels: coal, oil and solid biomass. Coal is the bedrock of electricity generation and remains the largest single fuel in the energy mix. Energy in the transport sector has increased fivefold over the last three decades reaching more than 100 Mtoe in 2019. Diesel and petrol are the two dominant fuels used in the transport sector, however, in recent years the use of natural gas as a transport fuel has increased substantially. There are currently around 3 million CNG vehicles in the country.

Rice straw can be used to produce energy carriers and fuels. Specifically, the Government of India has identified 2G ethanol and compressed biogas (CBG) as transport fuels and rice straw pellets that substitute coal in thermal power plants. Furthermore, specific targets have been set for the three energy carriers which are detailed in the following sections.

5.1. TRANSPORT FUELS: 2G ETHANOL AND COMPRESSED BIOGAS (CBG)

In 2018, India released its bioenergy policy which mandated the 20 percent blending of ethanol and petrol by 2030. In January 2021, the government pushed the E-20 goal forward from 2030 to 2025. Furthermore, the Indian 2018 National Policy on Biofuels specifically mentions developing India's

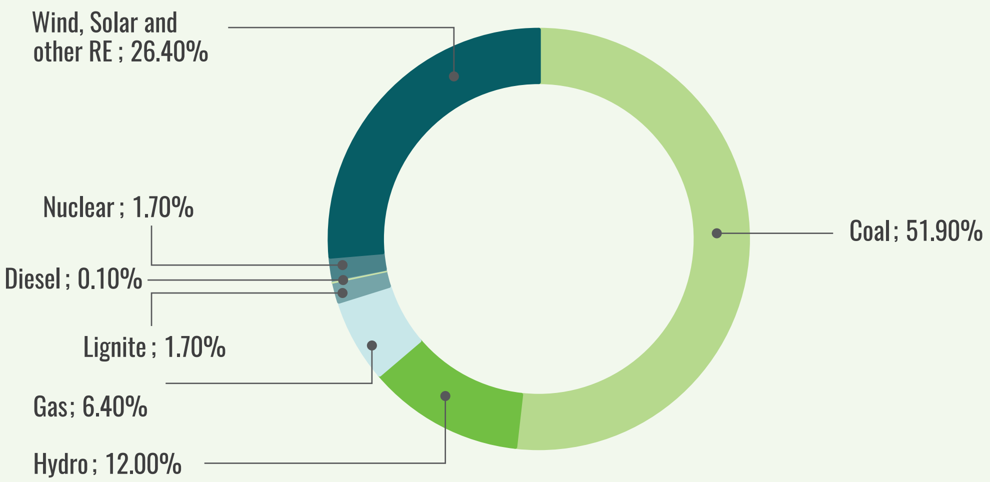
capacity to produce 2G ethanol. Blending ethanol in petrol is expected to be achieved through the Ethanol Blended Petrol (EBP) programme using ethanol derived from multiple feedstocks including through the development of Second Generation (2G) ethanol technologies and its commercialization. Based on the current trend on consumption of petrol in India, by 2025, India will need to produce around 9 billion litres of ethanol to reach the E20 blending target by 2025. Similarly, the 2018 bioenergy policy also envisages producing fields to produce compress biogas, bio-methanol, DME, bio-hydrogen, and bio-jet fuel from locally available feedstock. For compressed biogas (CBG), the Ministry of Petroleum and Natural Gas has a specific scheme called the Sustainable Alternative Towards Affordable Transportation (SATAT) scheme that aims to increase production of compressed biogas in the country. It has been planned to roll out 5 000 CBG plants by 2024. CBG plants are meant to be set up mainly through independent entrepreneurs. The CBG production will be transported through cascades or pipelines to the fuel station networks of Oil Marketing Companies (OMCs) and sold as green transport fuel. There are currently around 1 500 CNG station networks in the country. The target is set to produce 15 million tonnes of CBG per year by 2023.

5.2. RICE STRAW PELLETS

India is predominantly reliant on coal to produce electricity. In 2020 around 50 percent of the country's electricity supply comes from burning coal (MoP, 2020).

FIGURE 17.

INDIA'S ELECTRICITY MIX BY SOURCE, 2020



Source: Ministry of Power, Government of India.

While India has some of the largest reserves of coal, locally mined coal has a relatively low heating value and high ash content. Because of this, specific coal consumption in India is elevated and releases more pollutants with burning exacerbating air pollution. In addition to this, a global effort is being made to reduce reliance on coal for electricity production due to its high GHG emissions. In 2017, the national thermal power corporation (NTPC) started trials co-firing biomass pellets with coal in thermal power plants to reduce the reliance on coal for electricity production.

During the trial, the biomass pellet was blended at various ratios to evaluate its impact on the existing system. NTPC is India's single largest coal consumer and its largest power producer. It used about 169 million tonnes of coal during 2019-20, of which 2.3 million tonnes was imported. NTPC aims to use pellets made from biomass to co-fire with coal in 17 thermal power plants across India. The company has already invited bids for the procurement of biomass pellets, which included supplying, loading, transporting, and delivering the agro residue-based biomass pellets at the specified sites. Five million tonnes of pellets are expected to be used per year across 17 power plants.

5.3.STRUCTURE OF THE ANALYSIS

To analyse the techno-economic feasibility of the three technologies, the analysis follows a two-pronged approach. First, the analysis estimates the theoretical potential to produce the three energy carriers by using 30 percent of the straw and their contribution to the outlined targets. This helps to understand how much can be produced for each energy carrier using the rice straw available in Punjab.

However, examining the potential to produce these energy carriers does not guarantee their successful uptake. Therefore, the second step further analyses the economic viability of using straw to produce the three energy carriers. Assessing the economic viability is paramount because the energy carriers must be profitable when produced within the current market conditions of India in order to scale up. Under the economic analysis, the assessment estimates the production costs of the three energy carriers, their estimated production volumes, investment requirements, and the economic viability.

5.3.1. Results: 2G ethanol

India's net import of petroleum was 185 Mt at a cost of USD 551 billion in 2020-21. The majority of petroleum products in the country are used as transport fuels. Given the high imports of petroleum, India has an ambitious ethanol blending programme mandating the 20 percent blending of ethanol with petrol by 2025. It is estimated that the E20 programme can save the country USD 4 billion per annum (Niti Aayog, 2021).

By 2025, the demand for gasoline in India is expected to reach 45 billion litres. To reach 20 percent ethanol blending, the country would need 9 billion litres of ethanol in 2025. The current blending rate in India is around 8 percent. The blending target is expected to be reached by producing 1G, 2G ethanol as well as imports. The majority of ethanol produced in India is currently first-generation ethanol produced in sugar mills. In its biofuel policy, 2018, India has allowed for using excess food crops as well as residues for ethanol production.

TABLE 25.

PROJECTED DEMAND FOR GASOLINE AND ETHANOL IN 2025 (BILLION LITRES)

STATE/UNION TERRITORY	GASOLINE SALES IN	ETHANOL REQUIREMENT
ANDHRA PRADESH	1.88	0.37
BIHAR	1.35	0.27
DELHI	1.47	0.29
GUJARAT	2.57	0.51
HARYANA	1.56	0.31
KARNATAKA	3.3	0.66
KERALA	2.44	0.48
MADHYA PRADESH	2.16	0.43
MAHARASHTRA	5.29	1.05
ODISHA	1.25	0.25
PUNJAB	1.41	0.28
RAJASTHAN	2.37	0.47
TAMIL NADU	4.12	0.82
TELANGANA	1.93	0.38
UTTAR PRADESH	5.02	1
WEST BENGAL	1.56	0.31
REST OF INDIA	5.24	1.04
TOTAL	**45**	**9**

Source: GAIN report, 2021.

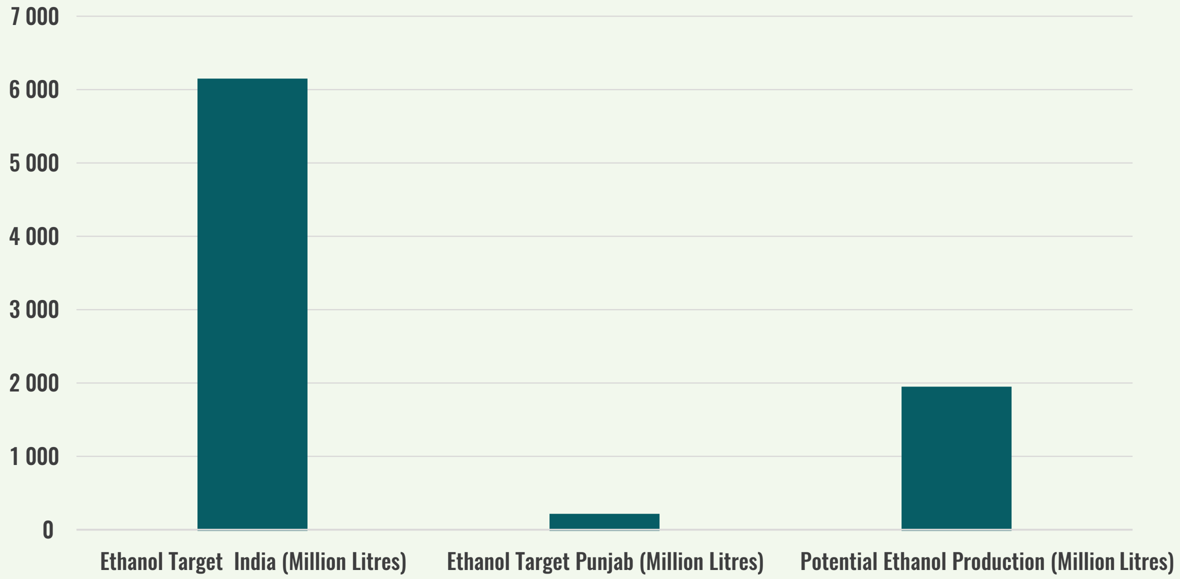
5.3.1.1. Technical potential to produce 2G ethanol

The data outlined in **Table 24** suggest that in 2025 total gasoline sales in the country would be around 45 billion litres. To achieve 20 percent blending, around 9 billion litres of ethanol would be needed at the national level. Additionally, by 2025 gasoline sales in Punjab are expected to reach around 1.41 billion litres. Consequently, to successfully reach E20 blending mandate, Punjab state alone would need to have 0.28 billion litres of ethanol by 2025.

2G ethanol can be produced using rice straw. The assessment suggests that if 30 percent of the straw generated in Punjab is used to produce 2G ethanol, around 1952 million litres of 2G ethanol can be produced (**Figure 18**).

FIGURE 18.

TARGET ETHANOL DEMAND IN INDIA AND PUNJAB AND POTENTIAL PRODUCTION QUANTITY BY USING RICE STRAW (2024)



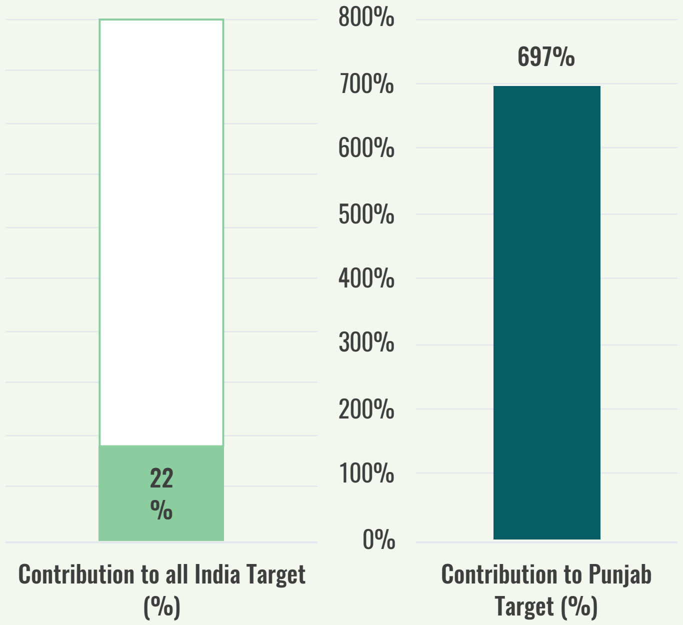
Source: Authors' calculations

In order to reach the E20 blending mandate by 2025 at levels in India, 1 952 million litres could satisfy 22 percent of the total ethanol demand, and around 697 percent of the total ethanol demand in Punjab could achieve the E20 target.

While the assessment shows that there is significant technical potential to produce 2G ethanol by using rice straw, the uptake 2G ethanol produce from rice straw would depend on its economic viability in addition to the technical potential.

FIGURE 19.

CONTRIBUTION TO E20 BLENDING TARGET BY 2025 FOR PUNJAB AND FOR ALL INDIA



Source: Authors' calculations

5.3.1.2. Economic viability of producing 2G ethanol

Producing 2G ethanol is a complicated and a technically advanced process. **Figure 20** shows the several steps needed to produce 2G ethanol. In order to be economically viable, the costs involved in producing ethanol from rice straw should be less than the market price of ethanol.

FIGURE 20.

PROCESSES NEEDED TO PRODUCE FUEL GRADE E2G ETHANOL

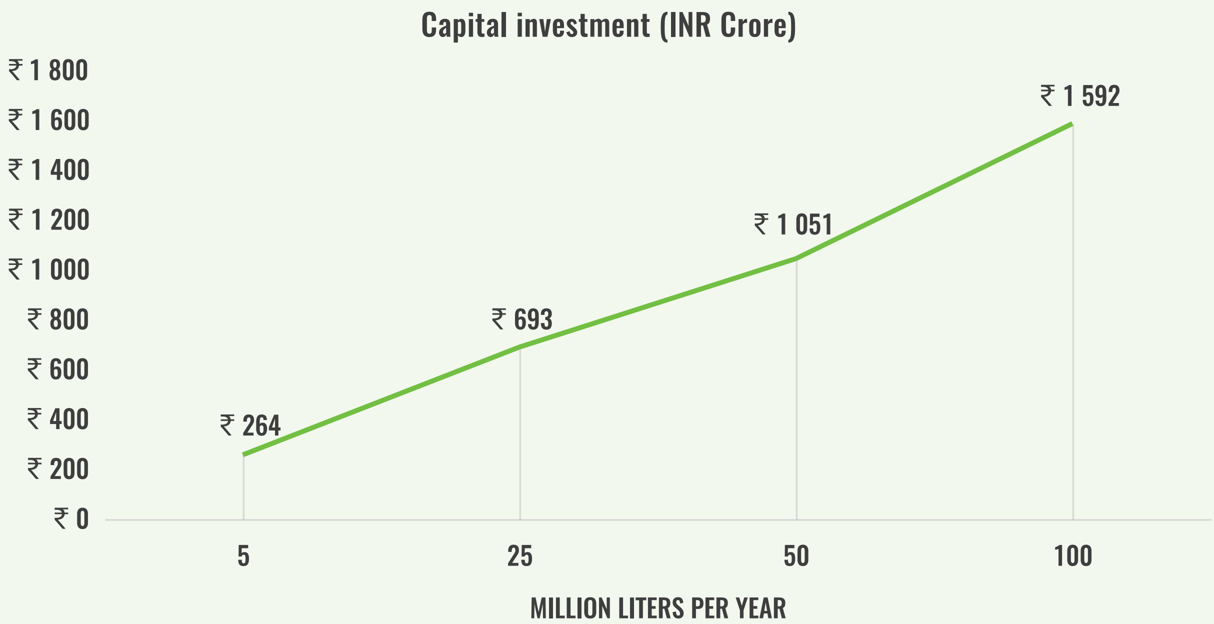
Source: Authors' calculations

Establishing a 2G ethanol factory is an expensive endeavour. To produce ethanol from the biomass biologically, hydrolysis is necessary to degrade rice straw into fermentable sugars such as glucose and xylose. Lignocellulosic biomass is the largest source of hexose and pentose sugars that can be used to produce ethanol. Unlike first-generation biomass where sugars are readily accessible to ferment the second-generation ethanol, cellulose is enclosed within hemicellulose and lignin, making it difficult to access cellulose that is needed to produce ethanol. Because of this, the cost of bio-fuel production is higher as compared to first- generation ethanol. These economic and technical obstacles must be overcome for the efficient and cost-effective biological conversion of lignocellulosic biomass into biofuels.

The capital investment required to produce 2G ethanol from rice straw increases in capacity and is shown in **Figure 21** and can range from INR 264 crore for a 5 million litre per year capacity to INR 1 592 for a 100 million litre capacity.

FIGURE 21.

CAPITAL COST REQUIREMENTS FOR PRODUCING 2G ETHANOL



Source: Authors' calculations

Looking only at the capital costs does not provide information about the profitability of producing 2G ethanol. A major factor affecting the profitability of 2G ethanol is the market price. The price of ethanol in India is set by the government and varies according to the feedstock used to produce ethanol. The latest prices of ethanol are produced in **Table 23**.

TABLE 26.

CURRENT PRICES OF ETHANOL IN INDIA

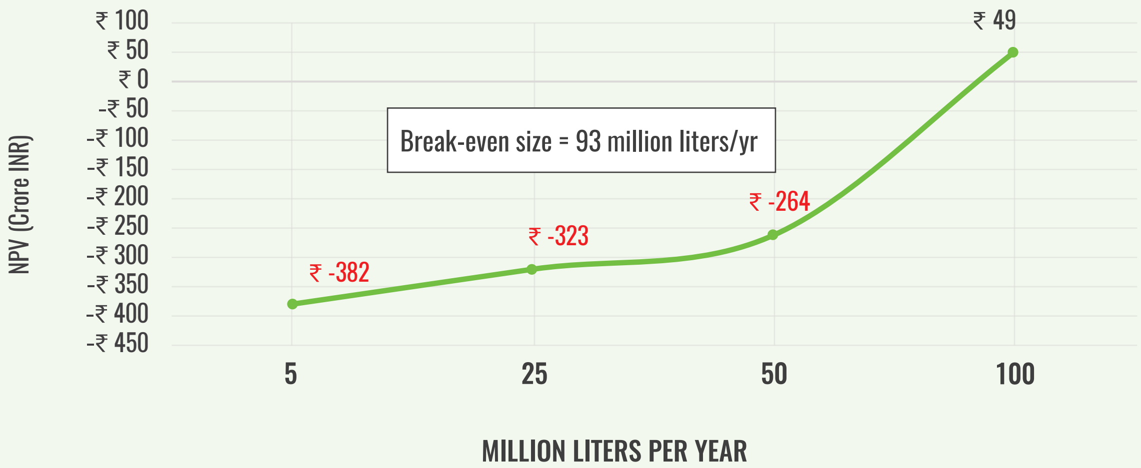
FEEDSTOCK	PRICE
C-HEAVY MOLASSES	INR 45.69/LITRE ($0.61/LITRE)
B-HEAVY MOLASSES AND PARTIAL SUGARCANE JUICE	57.61/LITRE ($0.77/LITRE)
100 PERCENT SUGARCANE JUICE/SUGAR/SUGAR SYRUP	INR 62.65/LITRE ($0.84/LITRE)
DAMAGED FOOD GRAINS UNFIT FOR HUMAN CONSUMPTION AND MAIZE	51.55 INR/LITRE ($0.68/LITER)
SURPLUS RICE PROCURED FROM THE FOOD CORPORATION OF INDIA	56.87 INR/LITRE ($0.76/LITER)

Source: GAIN, 2021.

While there is no set price for 2G ethanol, the government has specified that until any further guidelines are issued by the government, the price of 2G ethanol will be based on the maximum rate, as presently applicable for 1G ethanol ex-mill price of ethanol derived from 100 percent sugarcane juice for those mills, which is set to 62.65 INR/litre. This price is used to assess the profitability of 2G ethanol made from rice straw. Based on these factors, **Figure 22** shows the profitability of producing 2G ethanol at different production capacities. The results show that producing 2G ethanol from rice straw is not profitable at a production capacity of less than 93 million litres per year. Additionally, the break-even production capacity, which is the capacity at which 2G ethanol can be produced at no profit and no loss, is around 93 million litres per year.

FIGURE 22.

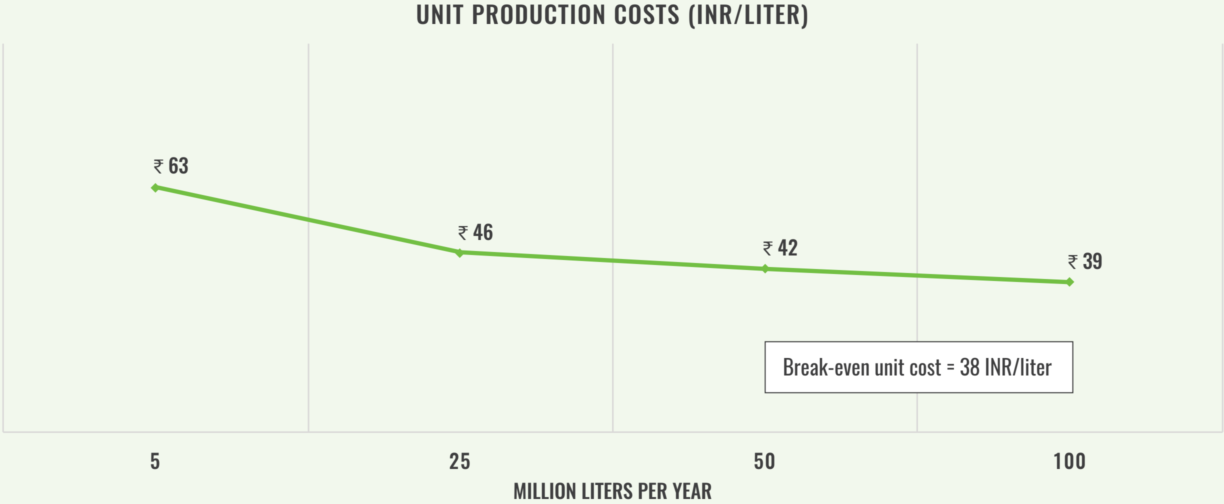
PROFITABILITY OF PRODUCING 2G ETHANOL



Source: Authors' calculations

FIGURE 23.

UNIT COST OF PRODUCING 2G ETHANOL (INR/LITRE)



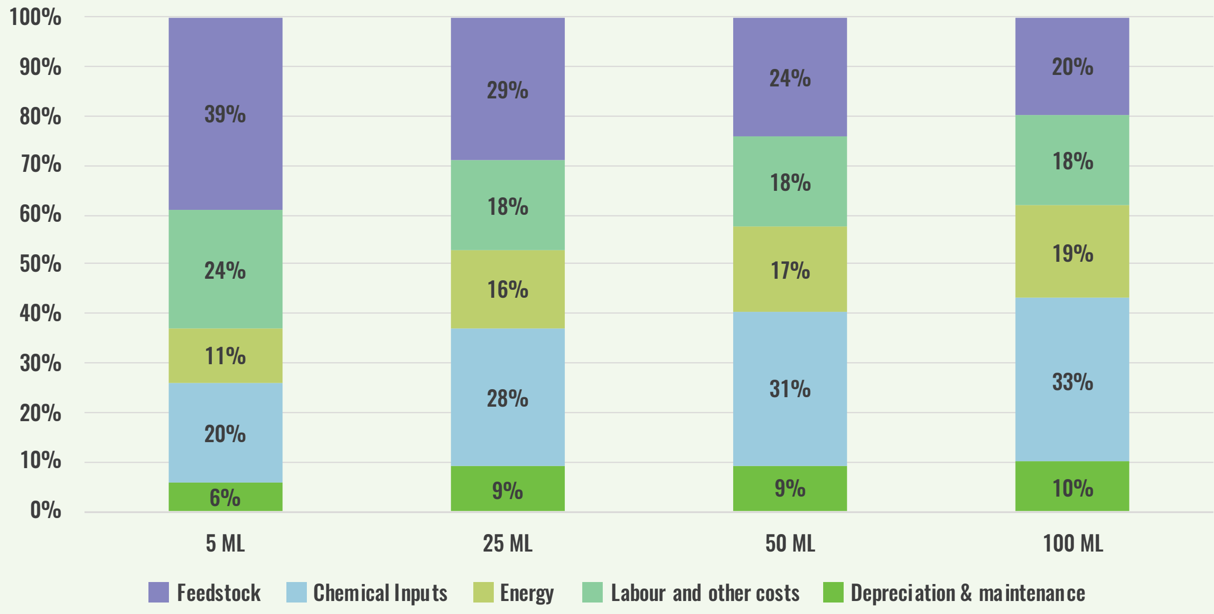
Source: Authors' calculations

The unit cost of producing 2G ethanol also varies with changes in the capacity and costs of other inputs such as labour, energy, chemicals. **Figure 23** shows the changes in per unit costs for producing 2G ethanol at different production capacities.

Furthermore, the composition of production costs is detailed in **Figure 24**. As indicated above, the costs of chemicals needed to pre-treat rice straw represents the largest share in the total production cost of 2G ethanol.

FIGURE 24.

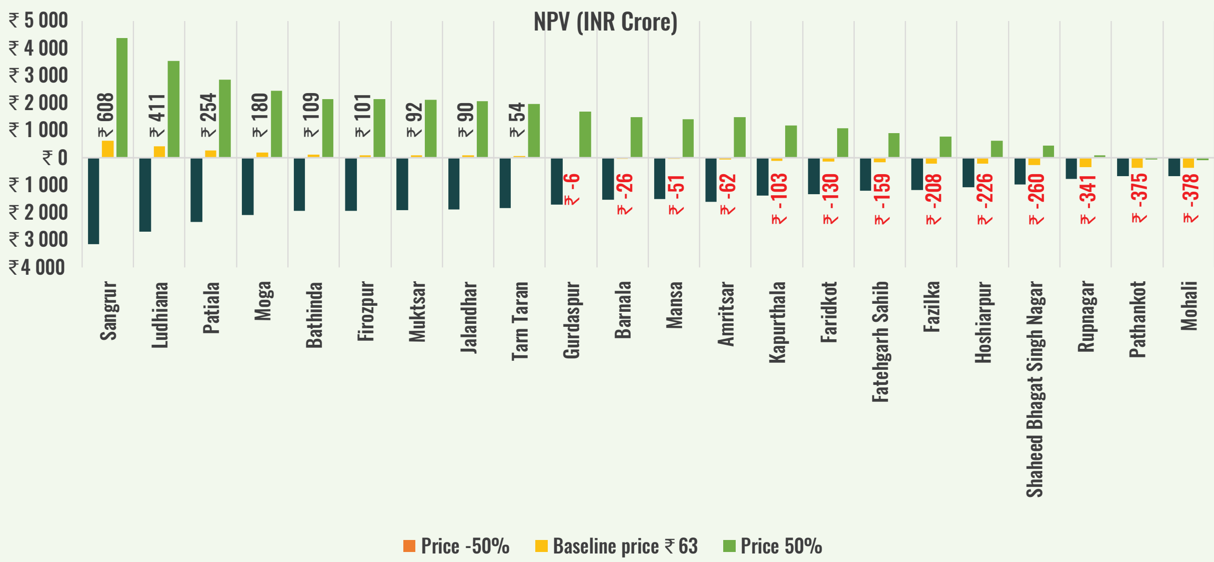
COMPOSITION OF PRODUCTION COST OF 2G ETHANOL



Source: Authors' calculations

FIGURE 25.

PROFITABILITY OF 2G ETHANOL IN EACH DISTINCT OF PUNJAB AT 2 DISTINCT MARKET PRICES



Source: Authors' calculations

Overall results suggest that at the current market price of 62.65 INR/liter, producing 2G ethanol is not economically viable in all of the districts in Punjab. At the current market price, 2G ethanol could be profitable in a total of nine districts including Sangrur, Ludhiana, Patiala, Moga. This is predominantly because of the fact that large quantities of rice straw are available in these districts. At a 50 percent higher market price, producing 2G ethanol could be economically viable in almost all of the districts of Punjab.

In sum, the results of the analysis show that 2G ethanol requires significantly high investments ranging from over INR 250 Crore for a 5 million litres per year plant to over INR 1 000 Crore for a 100 million litre plant. At the current prices, the INR 63 production of 2G ethanol is profitable only in certain districts of Punjab. The major factor for a production that is not viable is the high capital cost for setting up a 2G ethanol plant. The production could be made viable by either a higher price for 2G ethanol or by financial support to entrepreneurs to reduce overall capital costs.

5.3.2. Results: Compressed Biogas (CBG)

Compressed biogas is expected to be used as a green transport fuel and replace imported natural gas. Currently, there are around 3 million vehicles that exclusively use compressed natural gas (CNG) as fuel and 1 500 CNG refilling stations in the country. The Sustainable Alternative Towards Affordable Transportation (SATAT) scheme by the Ministry of Petroleum and Natural Gas aims to increase production of compressed biogas in the country. It is planned to roll out 5 000 CBG plants with a production capacity of 15 million tonnes of CBG per year by 2023. It has been proposed to set up CBG plants mainly through independent entrepreneurs. The CBG plants produced will be transported through cascades or pipelines to the fuel station networks of OMCs and sold as green transport fuel. In 2020, around 6 540 MT of CNG was sold in the state of Punjab.

Producing compressed biogas is a technically advanced process that requires several steps to produce CBG. It requires pre-treatment of biomass after which it is subjected to anaerobic digestion to produce biogas consisting of methane, carbon dioxide and a small amount of nitrogen. In order to be used as transport fuel, biogas needs to be further cleaned and compressed so that it can be delivered to filling stations. The necessary steps involved in producing CBG are described in **Figure 26**.

FIGURE 26.

STEPS NEEDED TO PRODUCE CBG

Source: Authors' calculations

Using compressed biogas can be a way to reduce petroleum imports and increase energy security for India. The process used to make CBG also generates a digestate, which is viable fertilizer and can be used in the fields to maintain fertility. Therefore, along with the revenues generated from selling CBG, additional revenues can be generated from selling the digest from a CBG factory.

5.3.2.1. Technical potential to produce CBG

Anaerobic digestion is the technology used to produce biogas. The analysis of the technical potential estimates the total quantity of CBG that can be produced by using the available 30 percent of the rice straw produced in each district of Punjab.

TABLE 27.

PARAMETERS USED IN TECHNICAL ANALYSIS OF CBG PRODUCTION

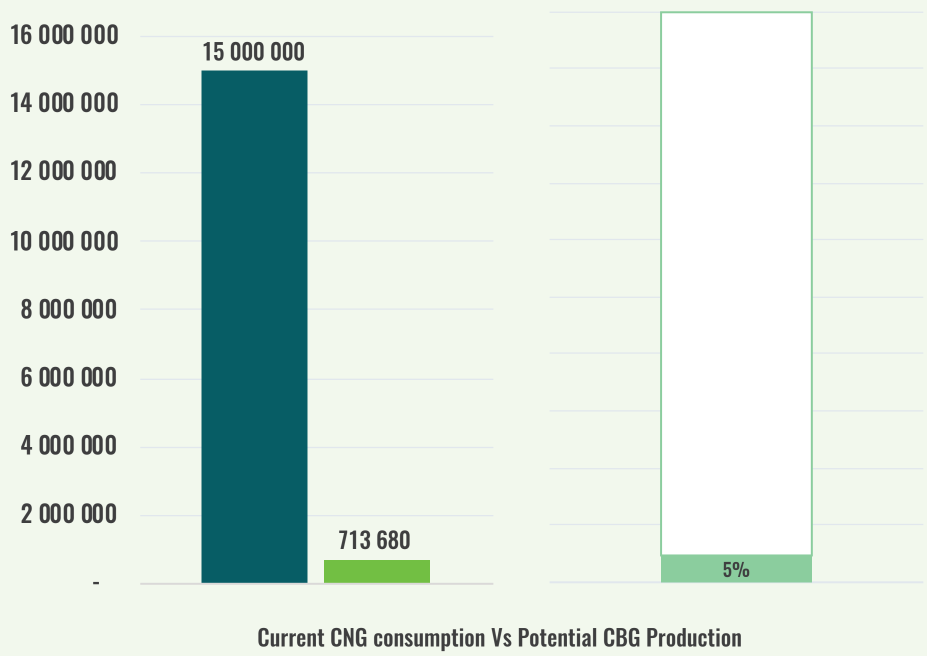
PARMETER	VALUE
DIGESTION REGIME	MESOPHILIC
TOTAL SOLIDS MIXTURE	9 %
HYDRAULIC RETENTION TIME (HRT)	30 DAYS
YIELD	210 m^3 METHANE/TONNE OF RICE STRAW

Source: (Chandra **et al.***, 2017)*

The results of the assessment suggest that a total of 713 680 tonnes of CBG can be produced by using 30 percent of the rice star available in Punjab. Given that the government has a target to produce 15 million tonnes of CBG annually by 2023, the assessment ascertains that 5 percent of the target set by the government can be reached by using 30 percent of the straw produced in Punjab to produce CBG.

FIGURE 27.

POTENTIAL TO PRODUCE CBG



Source: Authors' calculations

While there appears to be the potential to produce CBG by using rice straw, looking only at the technical potential to produce biogas does not guarantee its uptake. To ensure uptake, the predictions for CBG would need to be economically viable under the India market conditions. The subsequent section assesses the economic viability of producing CBG from rice straw.

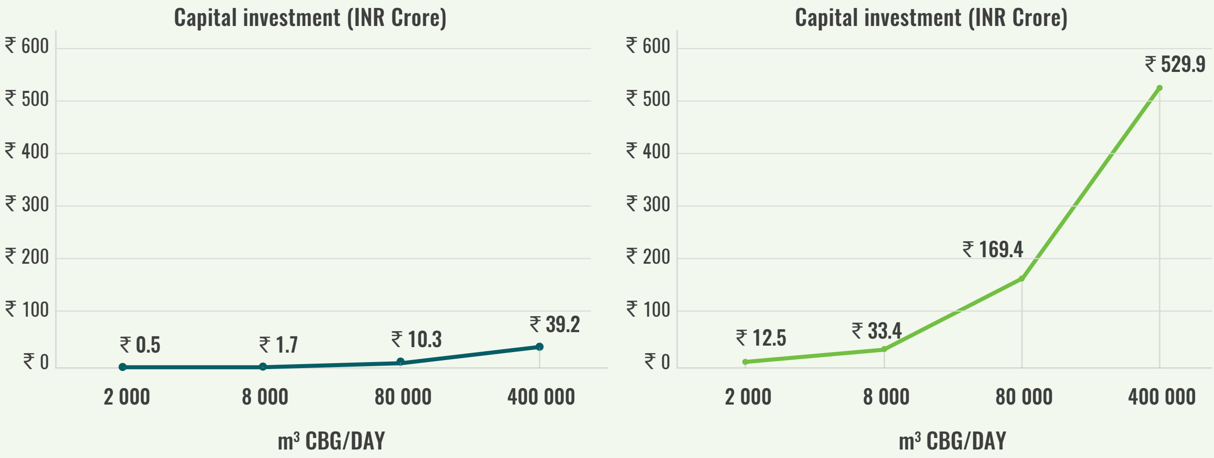
5.3.2.2. Economic viability of producing CBG

Given that the aim of the production of CBG is to augment the CNG supply that is used as a transport fuel, the CBG produced should be of fuel grade. Biogas produced from anaerobic digestion of biomass consists of methane, carbon dioxide and traces of nitrogen. In order to use the produced biogas in vehicles, it needs to be upgraded and cleaned. Upgrading and cleaning biogas consists of removing hydrogen sulfide, carbon dioxide and moisture. Finally, the cleaned gas is compressed so that it can easily be transported to filling stations.

Upgrading and cleaning biogas to obtain fuel grade is an expensive process. **Figure 28** shows the capital investment required at different production capacities (m³/day) of CBG with and without cleaning. The results indicate that there is a difference of almost 500 percent in the capital investment required to produce CBG with and without upgrading.

FIGURE 28.

CAPITAL COST OF PRODUCING BIOGAS WITH AND WITHOUT CLEANING AND UPGRADING



Source: Authors' calculations

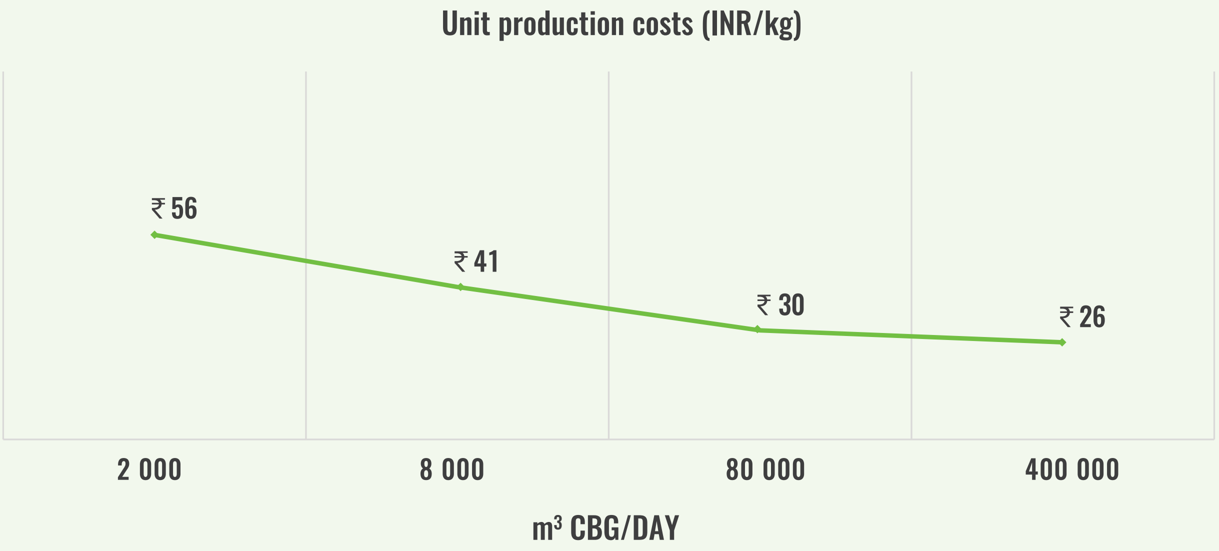
However, given that upgrading and cleaning are necessary for the use of CBG as a transport fuel, the analysis has considered only fuel grade CBG for further assessment. The next step of the analysis was to identify the minimum production capacity that can profitably produce CBG at the current market prices. Given that CBG will be used to increase the CNG supply, the market price of CNG was used to estimate the breakeven capacity, which is the production capacity at which CBG can be produced at no profit and no loss level.

Any production facility larger than the breakeven capacity is considered feasibly profitable. The per unit cost of CBG produced decreases as the size of the production facility increases. The current market price of CBG is set to INR 46/kg. The results suggest that only facilities with annual production capacity of more than 8 000 m³/day can produce CBG at less than the market price (**Figure 29**).

However, just producing CBG at less than the current market price does not guarantee profitability. To assess the profitability of producing CBG, an analysis of the net present value (NPV) is needed. The NPV analysis uses all the costs and all the revenues over a 20-year period to assess the overall profitability. The CBG production process also produces a by-product called digestate. Digestate is considered to be a good fertilizer and furthermore it can be sold for additional revenue, which impacts the overall profitability of the CBG plant. The current cost of digestate fertilizer in Punjab is around 3.3 INR/kg. Based on this information, **Figure 30** details the profitability of producing CBG with and without selling digestate.

FIGURE 29.

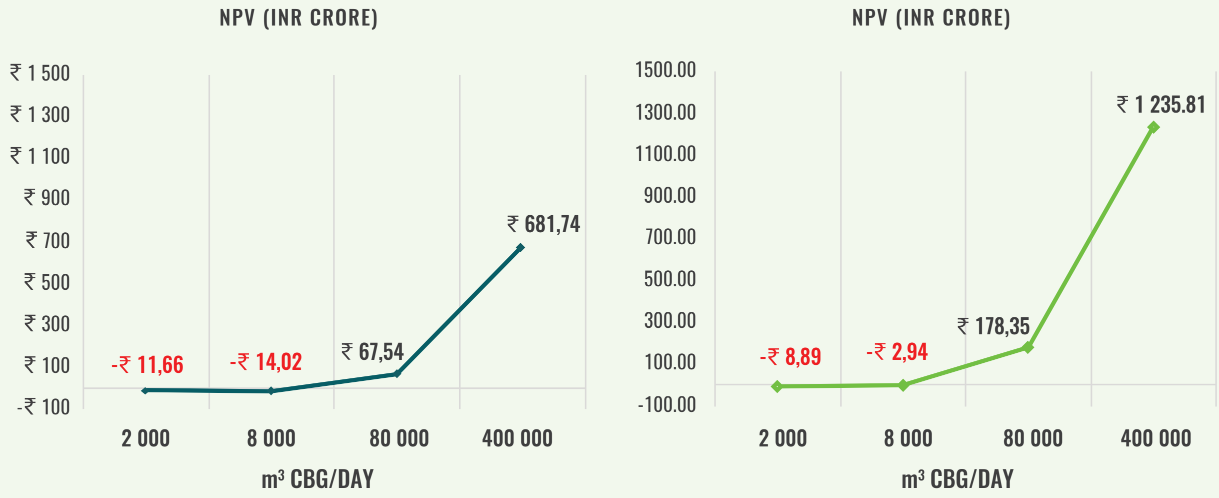
UNIT PRODUCTION COST OF CBG AT DIFFERENT PRODUCTION CAPACITIES



Source: Authors' calculations

FIGURE 30.

PROFITABILITY OF CBG PRODUCTION WITH AND WITHOUT SELLING DIGESTATE

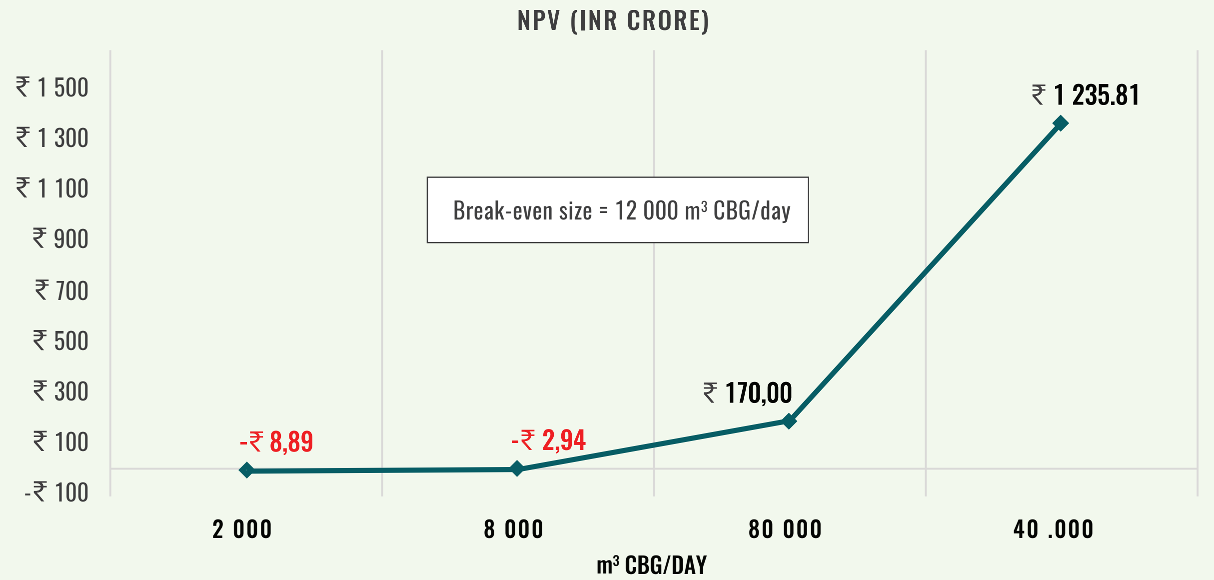


Source: Authors' calculations

The assessment suggests that the profitability of CBG production is substantially higher when digestate (**Figure 30**) is sold. Furthermore, the analysis suggests that the break-even capacity of a CBG plant that also sells digestate is around 12 000 m^3/day. This means that a CBG plant would need to have the capacity to produce more than 12 000 m^3 of CBG per day to be profitable.

FIGURE 31.

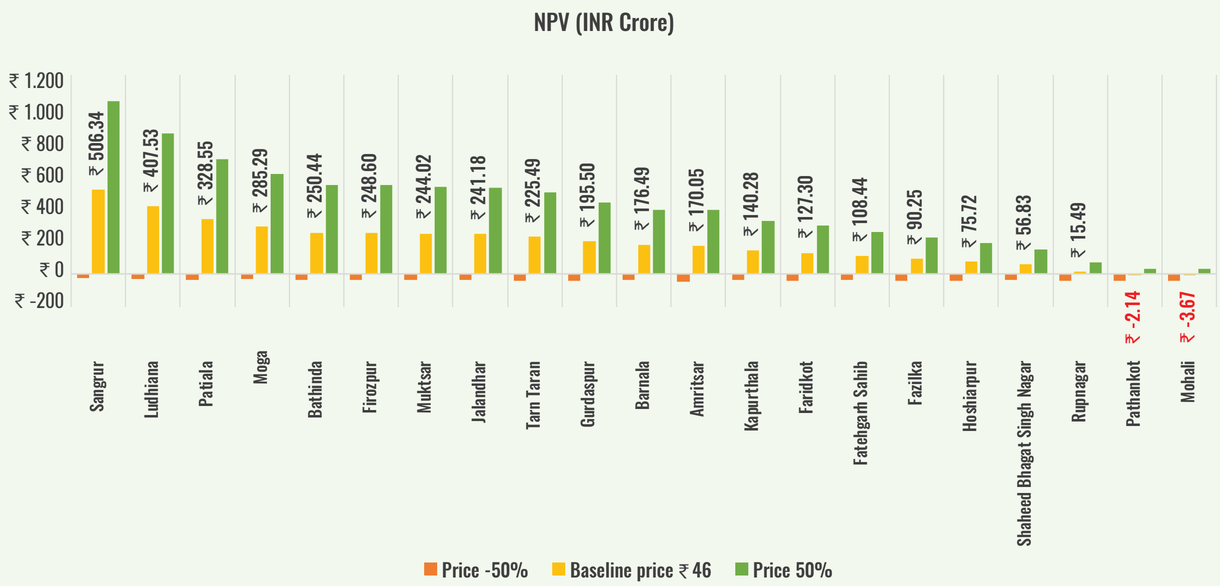
NPV AND BREAK-EVEN CAPACITY OF CBG PRODUCTION



Source: Authors' calculations

FIGURE 32.

NPV OF CBG PRODUCTION IN EACH DISTRICT OF PUNJAB AT THREE MARKET PRICES



Source: Authors' calculations

In terms of districts, at the current CNG price of INR 46, CBG production that includes selling digestate seems profitable in almost all districts of Punjab. The districts of Sangrur, Ludhiana, Patiala and Moga appear to be the most promising for CBG production.

CBG production from rice straw has the potential to help India reach its aim to use domestically produced cleaner vehicle fuels. If 30 percent of the rice straw is used, this can contribute to 5 percent of the CBG production target set by the SATAT scheme. Producing CBG can be beneficial for the state of Punjab by satisfying 100 percent of its own current CNG demand. Additionally, producing CBG could contribute to increasing local entrepreneurship, reducing open burning of rice straw and increasing farmers income. However, only production facilities with a production capacity of more than 1 000 m³/day will be economically viable.

5.3.3. Results: Rice Straw Pellets

Electricity production in India is highly dependent on coal and lignite,which is used in thermal power plants as fuel to produce electricity. The National Thermal Power Corporation (NTPC) is the largest power producer in India and its aim is to reduce reliance on coal by cofiring biomass pellets with coal. NTPC successfully co-fired 6 000 tonnes of biomass at its Dadri plant during the 2019-20 fiscal year and aims to procure 20 mn tonnes of biomass pellets over a 4-year period (5mn tonnes/year of pellets) at around INR 7 per kg.

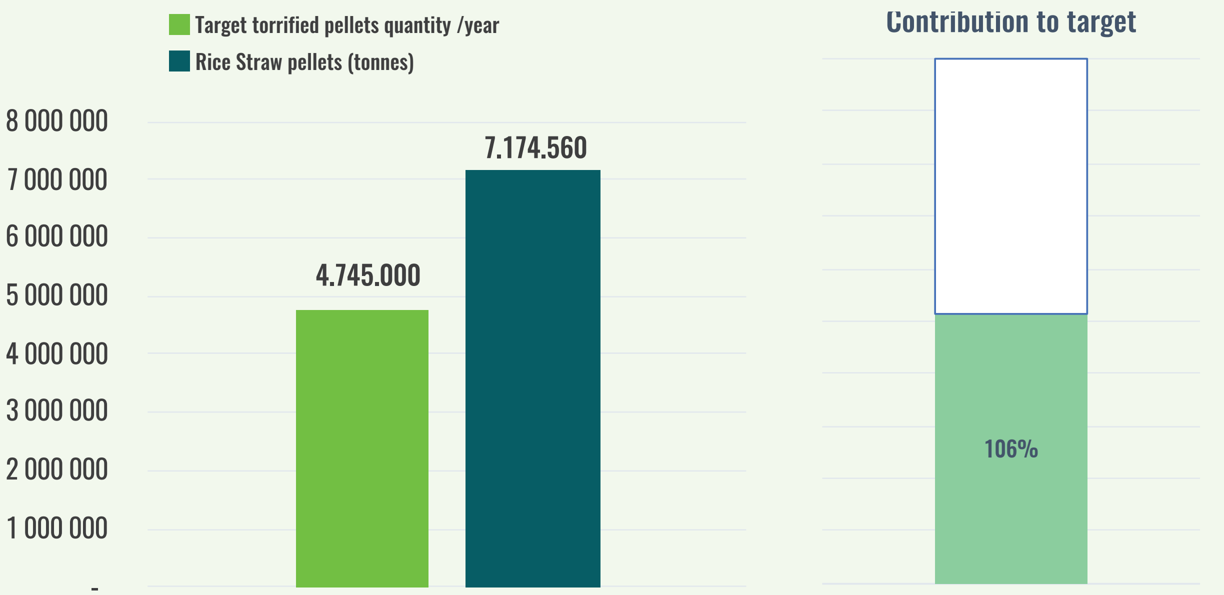
Biomass can be cofired with coal in thermal power plants to produce electricity, which is a method that also provides a way to use agro residue and avoid open burning. Additionally, farmers can generate extra revenue by selling rice straw. However, rice straw cannot be directly used in thermal power plants as they are not designed to pulverize the fibrous biomass (Central Electricity Authority, 2018). Therefore, rice straw and other biomass needs to be densified to form the pellets which can then be cofired with coal.

5.3.3.1. Technical potential to produce biomass pellets

Biomass pellets are produced by chopping and compressing biomass. The technical potential analysis estimates the total quantity of rice straw that can be produced by using 30 percent of the straw produced in Punjab. The technical potential to produce pellets from rice straw to co-fire thermal power plants is huge. For example, if 15 percent of the straw were to be used, 3.5 million tonnes of pellets could be produced, thus satisfying 72 percent of the target. If 30 percent of the straw were to be used, 7.1 million tonnes of pellets could be produced, which is the equivalent to 143 percent of the target set by NTPC (See **Figure 33**).

FIGURE 33.

POTENTIAL TO PRODUCE PELLETS VS NTPC TARGET



Source: Authors' calculations

While the analysis suggests that there is considerable potential to produce pellets from rice straw and to scale up their use, pellet production should also be economically viable under the current market conditions in India. The following section assesses the economic viability producing pellets from rice straw.

5.3.3.2. Economic viability of producing rice straw pellets

Rice straw is subjected to several processes before it can be transformed into pellets. After harvesting, rice straw needs to be chopped, compressed, and finally packaged to be transported before they can be used. The steps involved in producing biomass pellets are outlined in **Figure 34**.

Furthermore, the cost of production per kilogram of pellets will vary depending on the production capacity of the pellet making plant. The results suggest that the unit production cost of pellets can range from INR 47/kg of pellets at a production capacity of 4 kg/hour to INR 6/kg ay a production capacity of 4 000 kg/hr.

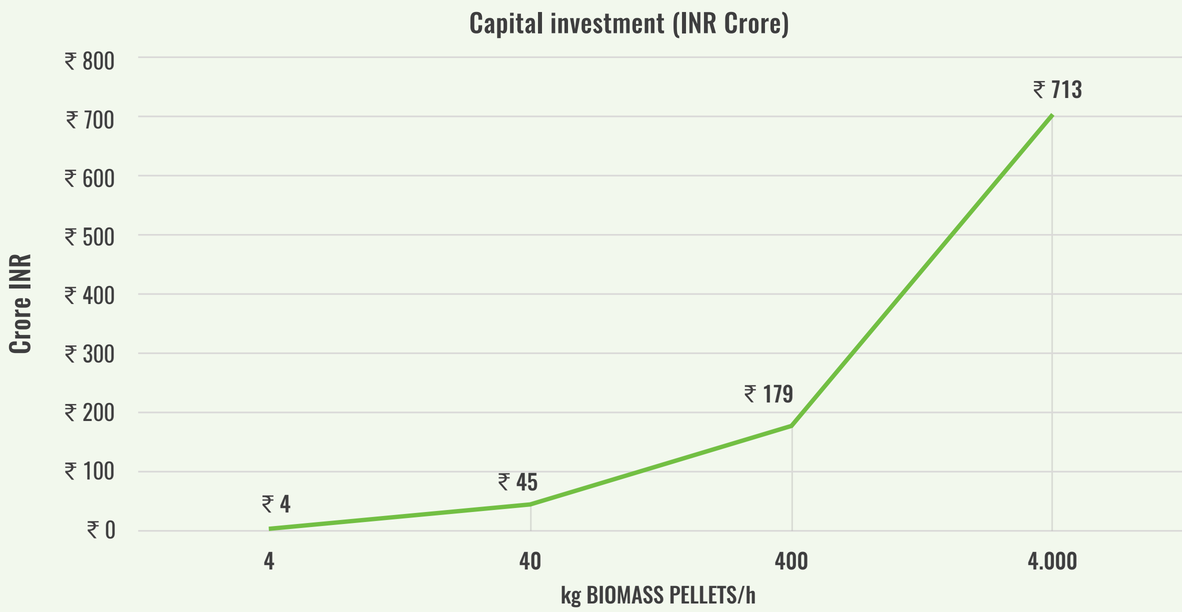
FIGURE 34.

STEPS INVOLVED IN PRODUCING PELLETS FROM RICE STRAW

Source: Authors' calculations

FIGURE 35.

CAPITAL COSTS PF PRODUCING RICE STRAW PELLETS AT DIFFERENT PRODUCTION CAPACITIES

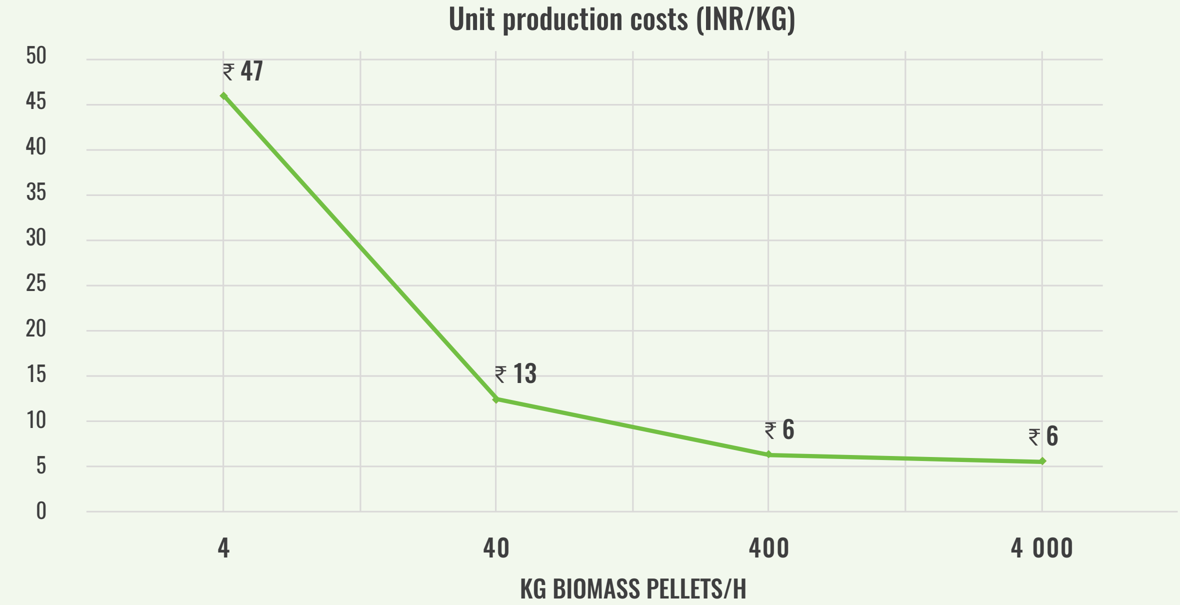


Source: Authors' calculations

The assessment, while taking into consideration all the costs involved, first estimates the total capital costs involved in producing biomass pellets at different production capacities. **Figure 35** shows the capital cost for producing pellets can range from INR 4 Crore at a capacity of 4 kg/hour production capacity to INR 713 at 4 000 kg/hour production capacity.

FIGURE 36.

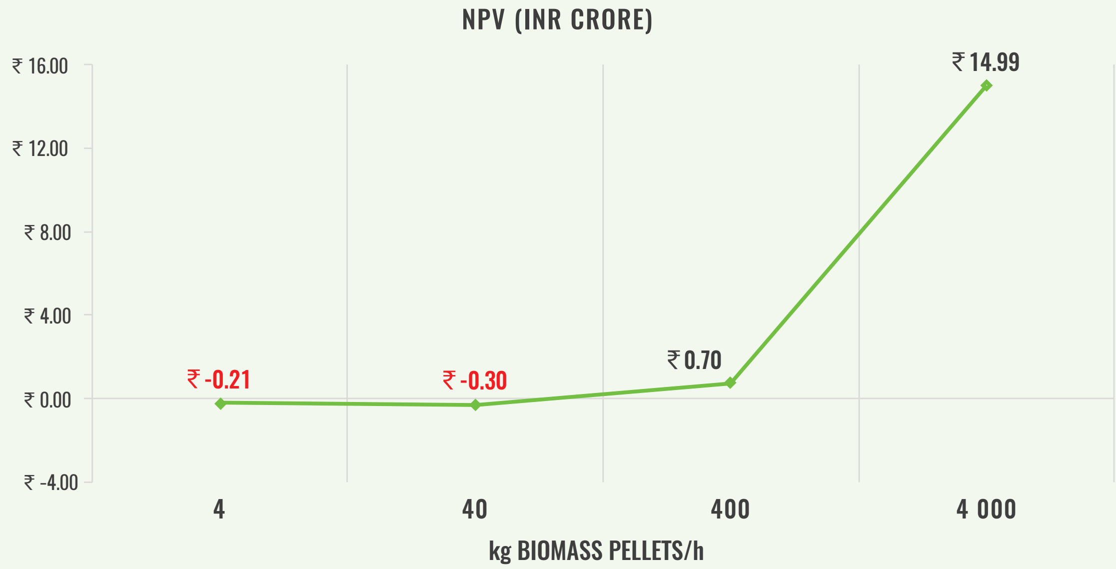
UNIT PRODUCTION COSTS OF PELLETS CORRESPONDING TO VARIOUS PRODUCTION CAPACITIES (INR/KG)



Source: Authors' calculations

FIGURE 37.

BREAK EVEN CAPACITY FOR PELLETS PRODUCTION



Source: Authors' calculations

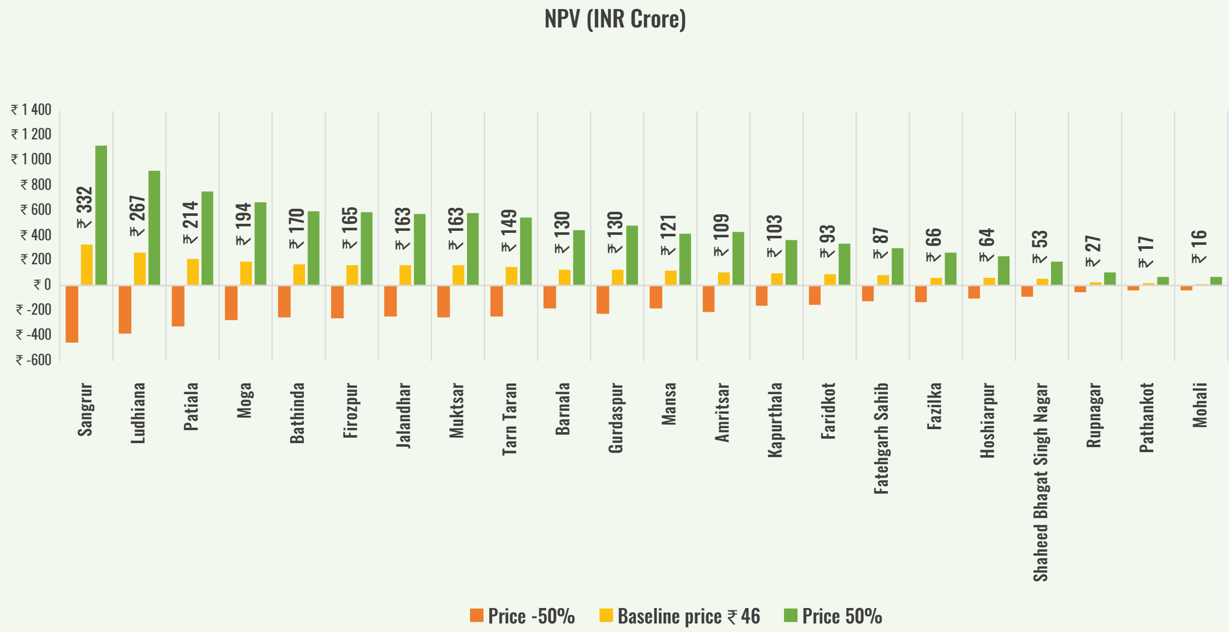
The next step of the assessment identified the minimum production capacity of pellet plants that can produce pellets in a profitable way. The results suggest that the breakeven capacity, which is the capacity at which pellets can be produced at no profit no loss, is around 130 kg of pellets per hour.

At a market price of INR 7/kg, pellets products seem profitable in all districts of Punjab, in particular the districts of Sangrur, Ludhiana and

Barnala seem to be the most profitable districts for pellets production.

FIGURE 38.

NPV OF PELLETS PRODUCTION ACROSS DISTRICTS OF PUNJAB



Source: Authors' calculations

Overall pellets production from rice straw is technically possible and economically viable in all districts of Punjab. Using biomass pellets from rice straw has the potential to reduce coal use in thermal power plants across India. For example, if 15 percent of the straw were to be used, 3.5 million tonnes of pellets could be produced, thus satisfying 72 percent of the target. On the other hand, if 30 percent of the straw were to be used, 7.1 million tonnes of pellets could be produced, equivalent to 143 percent of the target. At a purchase price of INR 7/kg, production facilities with a capacity larger than 130 kg/hour seem to be profitable. The districts of Sangrur, Ludhiana and Barnala appear to be the most profitable districts for pellets production.

CHAPTER

5

CONCLUSIONS

Rice straw is a valuable resource that can support India by increasing its local supply of energy while reducing its reliance on imports. Mobilizing rice straw withing the limited period of 20 days would require large amount of machinery and manpowered. The result suggests that to mobilize 30 percent of the rice straw produced in Punjab an investment of around ₹ 2,201 crore (USD $309 million) would be needed to collect, transport and store it within a 20 day period. This would reduce GHG emissiosn of about 12 million tonnes of CO_2 equivalent and around 66 000 tonnes of PM2.5 emissions. Furthermore, depending on the market price of rice straw, farmers can expect to earn between INR 550 and 1 500 per ton of rice straw sold. **Table 28** details the investment needed in each district to collect, bale and store straw.

[8] Including CO_2, CO, CH_4 and N2O emissions.

TABLE 28.

INVESTMENT NEEDED TO COLLECT 30 PERCENT STRAW IN 20 DAYS USING BALE SIZE 2

DISTRICT	AGGREGATION CENTRES (CRORE)	TRACTORS (CRORE)	BALERS (CRORE)	RAKERS (CRORE)	TRAILERS (CRORE)	TRUCKS (CRORE)	TOTAL INVESTMENT REQUIRED (CRORE)	TOTAL INVESTMENT REQUIRED (MILLION USD)
AMRITSAR	29	13	51	10	3	10	117	16
BARNALA	28	8	32	6	2	10	86	12
BATHINDA	38	13	49	9	3	13	126	18
FARIDKOT	22	8	32	6	2	8	79	11
FATEHGARH SAHIB	19	6	24	5	2	7	63	9
FAZILKA	18	8	32	6	2	6	73	10
FIROZPUR	38	14	52	10	3	13	131	18
GURDASPUR	32	13	48	9	3	11	116	16
HOSHIARPUR	15	6	22	4	1	5	54	8
JALANDHAR	37	13	49	9	3	13	124	17
KAPURTHALA	24	9	33	6	2	8	81	11
LUDHIANA	59	19	72	14	5	20	188	26
MANSA	27	9	34	6	2	9	87	12
MOGA	43	13	51	10	3	15	134	19
MOHALI	5	2	8	1	1	2	18	3
MUKTSAR	38	13	51	10	3	13	128	18
PATHANKOT	5	2	8	1	1	2	19	3
PATIALA	49	17	65	12	4	16	164	23
RUPNAGAR	7	3	11	2	1	3	27	4
SANGRUR	71	21	81	15	5	24	218	31
SHAHID BHAGAT SINGH NAGAR	13	5	17	3	1	4	43	6
TARN TARAN	35	13	51	10	3	12	125	18
TOTAL							**2,201**	**309**

Source: Authors' calculations

The techno-economic of the energy technologies suggests that in the current context, rice straw can be cost effective for the production of CBG and pellets. Producing 2G ethanol efficiently would require interventions that reduce the capital cost of producing 2G ethanol. Furthermore, establishing a dedicated pricing strategy for 2G ethanol separate from 1G ethanol would also be useful. Pellets production in Punjab is profitable in most districts and needs less capital investment. Although CBG has great potential it needs more investment; at the same time, it has the potential to produce higher profits in the long term. The districts of Sangrur, Ludhiana, Patiala, Moga and Barnala appear to be the most promising for both CBG and pellets. However, since pellets need less capital investment and are profitable in most districts, it is advisable to establish CBG plants in Sangrur, Ludhiana, Patiala and to spread pellets production across other districts.

2G ethanol requires substantial investments ranging from over INR 250 Crore from a 5 million litres per year plant to over INR 1 000 Crore for a 100 million litres plant. At the current prices, INR 63 production of 2G ethanol profitable only in certain districts of Punjab. The major factor for the production being unviable is the high capital costs of setting up a 2G ethanol plant. The production could be made viable by either:

- having a higher price for 2G ethanol;
- providing financial support to entrepreneurs to reduce overall capital costs.

Using 30 percent of the rice straw can contribute to 5 percent of the CBG production target set by the SATAT scheme. Moreover, producing CBG can be beneficial for the state of Punjab by satisfying 100 percent of its own current CNG demand. It could also be a way to increase local entrepreneurship, reduce open burning of rice straw and increase farmers income. However, only production facilities with a production capacity of more than 12 000 m^3/day will be economically viable. Using biomass pellets from rice straw has the potential to reduce coal use in thermal power plants across India. For example, if 15 percent of the straw were to be used, 3.5 million tonnes of pellets could be produced, thus satisfying 72 percent of the target. On the other hand, if 30 percent of the straw were to be used, 7.1 million tonnes

of pellets could be produced, equivalent to 106 percent of the target. At a purchase price of INR 7/kg, production facilities with a capacity larger than 130 kg/hour seem to be profitable. The districts of Sangrur, Ludhiana and Barnala seem to be the most profitable districts for pellets production.

However, in order for these energy carriers to be successfully upscaled, a constant supply of rice straw at an affordable price must be ensured. In order to achieve this, a formal and effective value chain of rice straw that can collect, transport and store rice within 20 days is imperative. It is equally important to encourage participation of the private sector to collect and store rice straw and transform it into various products. In order to do this, policies and financing should be made available that would encourage using rice straw for productive purposes.

REFERENCES

Central Electricity Authority. 2018. *Technical Specification for Agro Residue Based Bio-Mass Pallets for Co- Firing in Coal Based Thermal Power Plants Technical Specification for Agro Residue Based Bio-Mass Pallets for Co- Firing in Coal Based Thermal Power Plants*,. 0–17 pp.

Chandra, R., Trivedi, A., Jha, B., Verma, A.R. & Vijay, V.K. 2017. *Energy Generation from Paddy Straw An Analysis of Bioenergy Models.* The Indian Ministry for New & Renewable Energy Sources: 6.

EIA USA. 2003. *Commercial Buildings Energy Consumption Survey: Energy End-Use Consumption Tables* [online]. [Cited 18 December 2020]. https://www.eia.gov/consumption/commercial/data/2003/pdf/e06.pdf

Food and Agriculture Organization of the United Nations (FAO). 2021. *Bioenergy and Food Security Rapid Appraisal (BEFS RA) Tools and User Manual: Biomass supply and mobilization tool.* Rome, Italy.

Food and Agriculture Organization of the United Nations (FAO). 2021. *FAOSTAT.* Rome

GAIN. 2021. *Biofuels Annual*, India

ICAR. 2008. *Success stories on tractor operated straw baler.* Bhopal, India. https://aicrp.icar.gov.in/fim/wp-content/uploads/2016/12/42.TRACTOR-OPERATED-STRAW-BALER.pdf

LOGIWA. 2020. *Warehouse Labor Planning* [online]. [Cited 15 March 2020]. https://www.logiwa.com/blog/warehouse-labor-planning

Reddy, K. & Raghaveni, T. 2015. *Fuel consumption model of light commercial trucks.* International Journal of Science and Technology and Management, 4(11): 446–451. (also available at file:///C:/Users/lerin/AppData/Local/Temp/1449243381__P446-451.pdf).

Hoefnagels, R., *et al.*, *Lignocellulosic feedstock supply systems with intermodal and overseas transportation*. Biofuels, Bioproducts and Biorefining, 2014. 8(6): p. 794-818.

Delivand, M.K., *et al.*, *Optimal locations of bioenergy facilities, biomass spatial availability, logistics costs and GHG (greenhouse gas) emissions: a case study on electricity productions in South Italy.* Journal of Cleaner Production, 2015. 99: p. 129-139.

BEFS-FAO, BIOENERGY AND FOOD SECURITY RAPID APPRAISAL (BEFS RA). *User Manual. Ethanol and Biodiesel.* Food and Agricultural Organization of the United Nations. , 2014. Available at: http://www.fao.org/3/a-bp855e.pdf.

Nguyen, H.V., *et al.*, *Energy efficiency, greenhouse gas emissions, and cost of rice straw collection in the mekong river delta of Vietnam.* Field Crops Research, 2016. 198: p. 16-22.

Cardoen, D., *et al.*, *Agriculture biomass in India: Part 2. Post-harvest losses, cost and environmental impacts*. Resources, Conservation and Recycling, 2015. 101: p. 143-153.

Ren, L., *et al.*, *Analyzing and Comparing Biomass Feedstock Supply Systems in China: Corn Stover and Sweet Sorghum Case Studies*. Energies, 2015. 8(6): p. 5577.

Vanbeveren, S.P.P., *et al.*, *Operational short rotation woody crop plantations: Manual or mechanised harvesting?* Biomass and Bioenergy, 2015. 72: p. 8-18.

Eker, M., R. Spinelli, and N. Gürlevik, *Recovering energy biomass from sustainable forestry using local labor resources.* Journal of Cleaner Production, 2017. 157: p. 57-64.

Sørensen, C., *Workability and machinery sizing for combine harvesting.* Agricultural Engineering International: CIGR Journal, 2003.

Mathanker, S.K. and A.C. Hansen, *Harvesting System Design and Performance, in Engineering and Science of Biomass Feedstock Production and Provision*, **Y. Shastri,** *et al.*, *Editors*. 2014, Springer New York: New York, NY. p. 85-139.

Worley, M., *Biomass Drying Technology Update.* Harris Group Inc. BioPro Expo & Marketplace. Atlanta, GA, March 14-16, 2011, 2011.

Sammallahti, K. and J. Nurmi, *11. Baling logging residues on intermediate thinnings.*

Manandhar, A. and A. Shah, *Life cycle assessment of feedstock supply systems for cellulosic biorefineries using corn stover transported in conventional bale and densified pellet formats.* Journal of Cleaner Production, 2017. 166: p. 601-614.

Hess, J., *et al.*, *Commodity-scale production of an infrastructure-compatible bulk solid from herbaceous lignocellulosic biomass.* Idaho National Laboratory, Idaho Falls, ID, 2009. 6: p. 163.

Albashabsheh, N.T. and J.L. Heier Stamm, *Optimization of lignocellulosic biomass-to-biofuel supply chains with mobile pelleting.* Transportation Research Part E: Logistics and Transportation Review, 2019. 122: p. 545-562.

Lemos, S.V., *et al., Economic efficiency of two baling systems for sugarcane straw. Industrial Crops and Products*, 2014. 55: p. 97-101.

do Canto, J.L., *et al., Evaluation of two round baling systems for harvesting understory biomass Biomass and Bioenergy,* 2011. 35(5): p. 2163-2170.

Jafari Naimi, L., *A study of cellulosic biomass size reduction.* 2016, University of British Columbia.

Womac, A.R., *et al. Biomass pre-processing size reduction with instrumented mills. in 2007 ASAE Annual Meeting.* 2007. American Society of Agricultural and Biological Engineers.

MoAFW. *Report of the committee review of the scheme "promotion of agricultural mechanisation for in-situ management of crop residue in states of Punjab, Haryana, Uttar Pradesh and NCT of Delhi".* 2019

Purohit P, Chaturvedi V. *Biomass pellets for power generation in India: a techno-economic evaluation.* Environ Sci Pollut Res Int. 2018 Oct;25(29):29614-29632. doi: 10.1007/s11356-018-2960-8. Epub 2018 Aug 24. PMID: 30141169; PMCID: PMC6153682.

Roy P, Kaur M. *Economic analysis of selected paddy straw management techniques in Punjab and West Bengal.* Indian Journal of Economics and Development. 2016;12(1a):467-71.

Open burning of crop residue burning in India is a serious issue that not only impacts human health but is also detrimental to soil health in the long term. According to the estimates from the Ministry of New and Renewable Energy, about 500 million tonnes of crop residues are generated annually. While a portion of these residues is used for various purposes a larger portion is burnt in the fields. The problem seems to be specifically severe in Punjab where a large quantity of rice straw is burnt after harvesting rice to prepare the field quickly and cheaply for wheat cultivation. It is in this background that the project aimed to support the local government in Punjab and the national government of India to use rice straw productively and avoid open burning.

Rice straw is a useful resource that can be used in-situ to maintain soil fertility as well as ex-situ to produce value added products including energy. However, a key challenge in using crop residues, including rice straw is to mobilize it in systematically. This report presents a model crop residues value chain that can support the collection, transport, storage of rice straw which can enable productive uses of rice straw. Moreover, it estimates the quantity of rice straw produced in each district t in Punjab and further estimates the investment needed in developing a crop residue supply chain in the state. Finally, it also undertakes a techno-economic assessment of energy technologies to identify the most profitable way to use rice straw to produce sustainable energy.

Office of Climate Change, Biodiversity and Environment
https://www.fao.org/about/office-of-climate-change-biodiversity-environment/en/

**FOOD AND AGRICULTURE ORGANIZATION OF THE UNITED NATIONS (FAO)
ROME, ITALY**

ISBN 978-92-5-136094-1 ISSN 2226-6062

9 789251 360941
CB9659EN/1/05.22