DISCUSSION PAPER
January 2020

CROP RESIDUE MANAGEMENT: SOLUTION TO ACHIEVE BETTER AIR QUALITY

THE ENERGY AND RESOURCES INSTITUTE
Creating Innovative Solutions for a Sustainable Future

Authors

Arindam Datta, Fellow, Centre for Environmental Studies, TERI

Mrinal A. Emmanuel, Project Associate, Centre for Environmental Studies, TERI

N. K. Ram, Senior Fellow & Area Convenor, Renewable Energy Technology Applications, TERI

Sunil Dhingra, Senior Fellow & Associate Director, Renewable Energy Technology Applications, TERI

Reviewers

Sumit Sharma, Senior Fellow & Director, Centre for Environmental Studies, TERI

Ajay Shankar, Distinguished Fellow, Director-General's Office, TERI

Acknowledgements

Authors greatly acknowledge the support received from Bloomberg Philanthropies.

Suggested Format for Citation

Datta, A, M A Emmanuel, N K Ram and S Dhingra. 2020. Crop Residue Management: Solution To Achieve Better Air Quality. New Delhi: TERI

Design

Sushmita Ghosh, Sudeep Pawar, TERI Press

PUBLISHED BY

The Energy and Resources Institute (TERI)

FOR MORE INFORMATION

Centre for Sustainable Mobility, TERI, Darbari Seth Block, IHC Complex, Lodhi Road, New Delhi 110 003, India |
Tel.: +91 11 2468 2100 or 2468 2111 | Fax: +91 11 2468 2144 or 2468 2145 Email: pmc@teri.res.in | Web: www.teriin.org

TABLE OF CONTENTS

INTRODUCTION

Residents of different cities (probably villages too) of India breathe some of the least healthy air of the globe. During 2017, about 76.8% of the population of India were exposed to annual population-weighted mean $PM_{2.5}$ greater than the limit recommended by the National Ambient Air Quality Standards (NAAQ: 40 mg/m^3) (Balakrishnan, Dey, Gupta, *et al.* 2019). Over last five years, the annual population-weighted mean ambient $PM_{2.5}$ concentrations were significantly higher over the Indo-Gangetic Plain (IGP) region in comparison to other parts of the country. It should also be noted that polluted air is the second highest health risk factor in India (Balakrishnan, Dey, Gupta, *et al.* 2019).

All over the globe coal-based power plants, industry, gasoline or diesel vehicular emission, and natural dusts are regarded as the major sources of ambient air pollution. There are also certain area-specific and even season-specific pollutant sources that create regional and seasonal air pollution crisis. The seasonal burning of crop residues, particularly in the north-western parts of the IGP, impose gargantuan effect on the air quality of the region as well as on the economy of the country through major disruption in transportation, closure of schools, and increasing ailment among the productive population. Studies suggested that the seasonal burning (particularly during the first 10 days of November) of crop residue in agriculture fields contribute 30% to 35% of PM_{10} concentration in Delhi (PTI 2019a).

During different harvesting seasons, crop residues of rice, wheat, sugarcane, maize, cotton, soya bean, mustard, among others, are burnt in the crop lands in various areas of the country. More than 683 million tonnes (Mt) of crop residues of different crops are produced, of which a major part is used as fodder, fuel, and in various industrial processes. Despite this, about 178 Mt of surplus crop residues are available around the country (TIFAC 2018). An estimated 87 Mt of surplus crop residues is burnt in different croplands (TERI 2019). The air pollution emission intensity of different crop residues also varies. For example, the $PM_{2.5}$ emission (g/kg) from the burning of different types of crop residues *in situ* follows the order: sugarcane (12.0) > maize (11.2) > cotton (9.8) > rice (9.3) > wheat (8.5) (TERI 2019). Crop residue burning also emit SOx, NOx, NH3, and volatile organic compounds (VOCs) (Jain, Bhatia, and Pathak 2014) which are precursors for the formation of particulates in the atmosphere. In addition, Jain, Bhatia, and Pathak (2014) have estimated that more than 8.5 Mt of carbon monoxide is emitted to the atmosphere during the burning of crop residues.

Studies have also reported the several ill-effects of crop residue burning on soil organic carbon and fertility including reduction in the productivity in the long term (Hesammi, Talebi, and Hesammi 2014; Ponnamperuma 1984).

In India, rice is grown in nearly 44 million hector area (NFSM 2016). Food Corporation of India procurs about 40% of the total kharif rice (44.4 Mt) from Uttar Pradesh, Haryana, and Punjab of northwestern IGP region, of which Punjab alone supplies 60% of this (MoA&FW 2018). More than 80% of the agricultural activities in northwestern India are based on rice-based cropping system (above 4.1 million ha). Cropping system is the cornerstone to the food security of a country. Traditionally, rice used to be grown in eastern part of IGP, while wheat was grown in the western part of the plain. Introduction of high-yielding, input responsive, and short duration varieties during the Green Revolution of India made it possible to grow both rice and wheat in the same year in one field. But intensive use of these varieties over the decades led to the degradation of the soil quality and over-extraction of ground water for rice cropping reduced the levels significantly in the northwestern region. Wheat seeds generally germinate in a temperature range from 20°C to 25°C and during the ripening period, the temperature of 14°C to 16°C is favourable. For matured rice crop, the harvest temperature is in the range from 20°C to 27°C and the sowing temperature is in the range from 30°C to 35°C. Thus, there is an overlapping of ambient temperature during the harvesting season of rice and the sowing season of wheat. As a result of shortage of groundwater, rice cropping in northwestern India mostly depends on monsoon which arrives around last week of

June. Rice harvesting occurs during September–October. In northwestern India, the ambient temperature starts to fall below 20ºC after the second week of November which leaves the farmers' with a period of 20 to 30 days during October and November to harvest the rice crop and sow the rabi season crop (e.g. wheat, potato) seeds.

In 2009 the state governments of Punjab and Haryana introduced the Preservation of Subsoil Water Act, 2009 with the aim to control the shrinking groundwater level and reduce the water loss to the atmosphere through transpiration. Under this act, owing to high ambient temperature, farmers' were barred from sowing rice seeds before 10 May and transplant rice seedlings before 10 June. The state governments also made the provision of deciding the transplantation date of the rice crop any time after 10 June following the advice from the concerned department(s). This reduced about 5 to 10 day time between rice harvest and wheat sowing in the region and allowing a period of 15 to 25 days for the activity.

The removal of rice straw from the field is a labour intensive process. Labourers from eastern Uttar Pradesh and Bihar are mainly employed in the farms of northwestern India for harvesting of the rice crops. The introduction of Mahatma Gandhi National Rural Employment Guarantee Act in 2006 led to farms experiencing significant labour crunch and gradually the farmers shifted to mechanical harvesting of rice crop. However, while using the mechanical harvesting when the standing straw cutting height is decreased below 15 cm, it leads to significant rice grain loss (Bawatharani, Bandara, Senevirathne, et al. 2015). On an average, 1.8 to 2.5 times higher rice straw is produced compared to grains. So the usage of mechanical harvesters leaves at least 15 cm of standing crop in the field along with large amount of straw and this straw bed is not suitable for the establishment of wheat seedlings.

As discussed above, narrow timeline between rice crop harvest and sowing of wheat seed vis-à-vis intensive use of mechanical harvesters force farmers' to burn crop residues in preparation of the land for the next crop. Moreover, certain rice varieties, such as basmati, are always hand-harvested; while certain varieties such as parmal are machine harvested. The variety of wheat also affects the burning of rice crop residues as some wheat varieties (e.g. CSW18) require early sowing.

Almost no use and no attractive monetary return of the surplus crop residues and the labour cost associated with the collection of crop residues demotivate farmers in collecting the residues from the field and instead they burn it *in situ*. This leads to massive pollution in northern India during the starting of winter every year. The effect is acerbated in Delhi and adjoining areas with low wind speed and drop in ambient temperature. This discussion document is prepared with the objective to develop a sustainability road map for effective management of surplus crop residues through *ex situ* and *in situ* applications.

Current Status of the Sector

It is estimated that burning of crop residues *in situ* releases about 627 kilo tonnes (Kt) of PM_{10} and 4677 Kt of carbon monoxide to the atmosphere annually in India (TERI 2019).

India is a legislation-rich country, particularly with reference to pollution. According to section 9 sub-section of the Air (Prevention and Control) Pollution Act (1981), burning of any material which is not fuel and likely to cause air pollution should be prohibited. Again, Chapter 3 section 7 of the Environmental Protection Act (1986) prohibits any person to carry out activities that emit environmental pollutants in the excess of the prescribed national standard. Any person found to violate the Environmental Protection Act (1986) shall be deemed guilty (section 16). However, the manner of exercise of power has not been framed. The government invokes Section 144 of the Civil Procedure Code (CPC) to ban the burning of paddy, which is hardly implemented and little effort is made to sensitize the farmers on the same.

In 2014, the Ministry of Agriculture developed a National Policy for Management of Crop Residue (NPMCR) to prevent agricultural residue burning and circulated the same to all the states/union territories with the following major objectives: (i) promote technologies for optimum utilization and *in situ* management of crop residues, (ii) promote appropriate machineries for farming practices, (iii) use satellite-based technologies to monitor crop residue management with National Remote Sensing Agency (NRSA) and Central Pollution Control Board (CPCB), and (iv) provide financial support through multidisciplinary approach and fund mobilization in various ministries for innovative ideas and project proposals to accomplish the above. However, no significant progress has been made by government(s) to accomplish the objectives of NPMCR, except satellite-based monitoring of crop residue burning, particularly in Punjab, Haryana, and Rajasthan.

The National Green Tribunal (NGT) established under the National Green Tribunal Act (2010) laid down directives to states for curbing crop residue burning through recycling initiatives and awareness among the people. On December 10, 2015, the NGT banned crop residue burning in Rajasthan, Uttar Pradesh, Haryana, and Punjab. These states have reportedly imposed fines in the range of INR 2500 to 15000 on farmers found to burn crop residue (Jitendra et al. 2017).

During 2019–20, the Punjab government disbursed INR 19 crore among 29,343 non-basmati cultivating small and marginal farmers (INR 2500/acre) who did not burn paddy residue (PTI 2019b). The Conference of Indian Industries (CII) has adopted 100,000 acre of farm area in Punjab and Haryana to ensure zero crop residue burning by providing farm machineries and technical training, and through awareness campaign.

During March 2018, the Cabinet Committee for Economic Affairs approved INR 1151.80 crore under the central sector scheme (CSS) on 'promotion of agricultural mechanization for *in situ* management of crop residues in the states of Punjab, Haryana, Rajasthan, Uttar Pradesh and NCT of Delhi' to tackle air pollution and subsidize farm machineries required for *in-situ* management of crop residues. Various opportunities are available for managing paddy residues as evident from Figure 1. Accordingly, different variants of machineries were included in the scheme for individual farmers and through custom hiring centre (CHC). However, in 2018–19, 16.9% of total rice straw residue (7.93 Mt) in Haryana and nearly 50% of total rice straw residue (20.17 Mt) in Punjab were burnt *in situ* (MoA&FW 2019).

Turbo happy seeders have been included in the above scheme with 50% subsidy, keeping in view its reported effectiveness in increasing wheat production under the rice–wheat cropping system. It is reported that 1 happy seeder can manage 7–8 acres of rice straw residues for the sowing of wheat seed per day (Jat, Kapil, Kamboj, et al. 2013). During 2018/19, 9758 happy seeders were

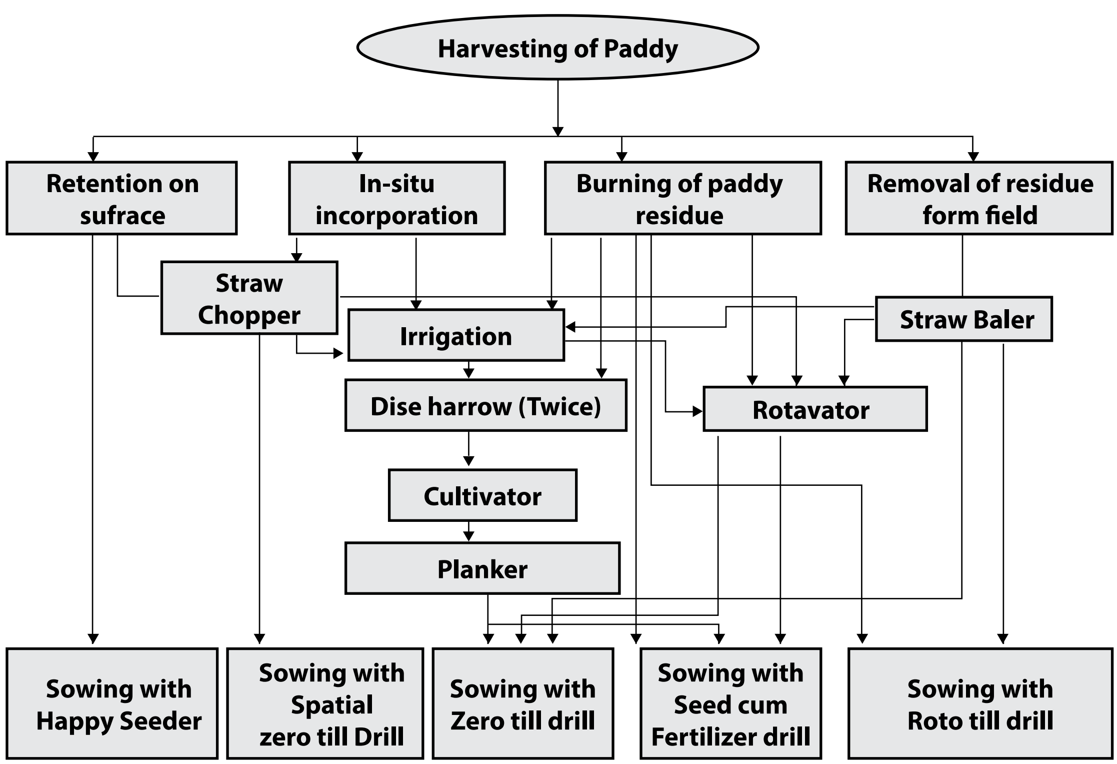

Figure 1. Different opportunities to manage paddy residues

Source Lohan, Jat, Yadav, *et al.* (2018)

distributed in Punjab, and 2376 happy seeders in Haryana; in 2019–20, 2936 and 1500 happy seeders were distributed in Punjab and Haryana, respectively (MoA&FW 2019). Accordingly, these happy seeders addressed about 50% of unmanaged paddy crop land area in Punjab (19.3 million ha) and about 42% of paddy crop land area in Haryana (7.31 million ha) (MoA&FW 2019). The 6000 combined fitted with Super–Straw Management System (S-SMS) can, likewise, harvest 0.7 million ha at the rate of 12–15 acres daily over 25 days. It becomes evident that these machineries are not sufficient to manage the entire paddy crop residue within 25–30 day time.

Farmers' have however raised concern about investment in one machine that can be used only during one season rather than investing on a machinery, such as tractor, that can be used year long.

The existing *in situ* crop residue management machineries can manage only upto 2 to 4 tonnes/ha of crop residues (NAAS 2018) while far higher crop residues are produced. Keeping this obligation of *in situ* crop residue management in view, governments have formulated different opportunities to manage the crop residues *ex situ*:

- **The Punjab government** announced 'New and renewable sources of energy policy' in 2012 to promote renewable energy in the state.
  - Under this policy, a capacity target of 600 MW from biomass and 500 MW from cogeneration (both bagasse and non-bagasse) has been set by 2022. However, only 62.5 MW has been commissioned till date through 7 power projects which annually use 0.5 Mt of paddy straw. In addition, another 58 MW projects are in various stages of planning and implementation, which can utilize 0.72 Mt of paddy straw annually.
  - The Punjab Energy Development Agency (PEDA) has invited expression of interest from the interested project developers for setting up of 150 MW capacity 100% rice straw-based biomass power plants on viability gap funding-based competitive bidding.
- **The Haryana government** formulated the Haryana Bioenergy Policy 2018 to utilize its surplus crop residues to generate bio-CNG/bio-manure/bio-fuel. It is proposed to achieve a target of 150 MW biomass-based power generation (or equivalent) by 2022.
  - The Haryana Renewable Energy Development Authority (HAREDA) agency, which promotes renewable energy in the state, has identified and awarded a cumulative of 50 MW capacity biomass power projects based on 100% paddy straw technology in the districts of Fatehabad, Kurukshetra, Jind, and Kaithal**.** These biomass power plants will be able to utilize about 0.3 Mt of paddy straw annually.
- **Central Electricity Authority (CEA), Government of India,** has issued a policy advisory for biomass utilization for power generation through co-firing in pulverized coal-fired boilers (CEA 2017). The document highlights successful demonstration of co-firing of 7% blend of biomass pellets with coal by NTPC. In order to promote the use of biomass pellets, all fluidized bed and pulverized coal units (coal-based thermal power plants) of public- and private power-generating utilities are advised to use 5–10% blend of biomass pellets, primarily agro residues, along with coal. With the overall thermal power generation capacity 203 GW (CEA 2019), the estimated daily biomass pellets requirement would be about 146,498 tonnes (assuming 2.75 lakh tonnes of biomass pellets for 7% blending in a thermal power plant of 1000 MW capacity). This would utilize about 53.5 Mt of crop residues annually, which is about 30% of the total annual surplus crop residue in the country.
- **The Ministry of New and Renewable Energy (MNRE), Government of India** launched a programme on energy from agricultural waste/residue in the form of biogas–bio–CNG, enriched biogas/power. Projects based on biowaste from urban and agricultural waste (paddy straw, agro-processing industry residue, green grasses, etc.) are eligible for Central Finance Assistance (CFA) in the form of capital subsidy and grant-in-aid under the programme (MNRE 2018).
- **The Ministry of Petroleum and Natural Gas (MoPNG), Government of India** brought out the National Policy on Biofuels on 8 June 2018. The policy promotes the target of 20% blending of ethanol in gasoline by 2030. The policy categorizes biofuels as (i) basic biofuels *viz.* 1G bio-ethanol, bio-diesel and (ii) advanced biofuels *viz.* 2G ethanol, bio-CNG, etc. Under the policy, a viability

gap funding for 2G ethanol refineries of Rs. 5000 crore will be made available in 6 years besides additional tax incentives and higher purchase price (in comparison to 1G ethanol). Also, oil marketing companies are in the process of setting up twelve 2G bio-refineries with an investment of Rs. 10,000 crore (MoPNG 2018).

» The Indian Oil Corporation Ltd (IOCL) is setting up 100 Kilo litre per day (KLPD) of ligno-cellulosic 2G bioethanol plant at Baholi in the Panipat district of Haryana with an investment of INR 700 crore. It is estimated that about 0.2 Mt of agricultural biomass will be utilized annually by this plant.

» Hindustan Petroleum is setting up another 100 KLPD ligno-cellulogic 2G ethanol plant at Nasibpura in the Bathinda district of Punjab. This plant will utilize paddy straw as the main feedstock with an investment of about INR 1000 crore. It is estimated that the plant will utilize about 500–600 tonnes of paddy straw per day.

The estimated utilization of surplus crop residues under different government policies till date are given in Table 1.

However, still large amounts of non-addressed surplus crop residues (about 120 Mt) are available. The successful implementation of the above initiatives is also required to develop a road map for sustainable utilization of crop residues.

There are different opportunities to manage crop residues; however, it is required that a road map be developed by which sustainable utilization of crop residues occurs through different management options.

Prescribed Strategy

- **Crop rotation** in the IGP region needs to be re-evaluated by encouraging farmers to other cropping cycles rather than rice–wheat cropping system.
- **Conservative farming** needs to be promoted all over the country (like lower lignin (<20%) crops) for rice, wheat, maize, sugarcane to reduce soil compaction and to maintain soil fertility.
  - » Crop residues of 30 to 40% of lower lignin content (<20%) should be left in the crop land after harvest (Tandon 1996) and managed with *in situ* crop residue management mechineries.
  - » Crop harvesting machineries need to be developed that retain 30–40% crop residues in the field while bailing the rest of the amount.

Table 1: Estimated utilization capacity of crop residues under existing ex situ management options

Government policy	Estimated annual utilization of crop residues (Mt)
10% blend of crop residue biomass briquette in thermal power plant	53.5
New and renewable sources of energy policy (2012), Government of Punjab	1.2
Haryana Renewable Energy Development Authority (HAREDA)	0.6
Haryana Bioenergy Policy 2018	0.9
Ethanol poduction	1.5
Total utilization	**57.7**

Utilization of crop residues in state-level power plants: The total installed capacity of state-owned thermal power plants in Punjab and Haryana is about 2640 MW and 3160 MW, respectively (Table 2). The state governments can mandate existing thermal power plants to use 5–10% paddy straw in co-firing mode which can then utilize about 0.72 and 0.87 Mt annually.

- **Enable mechanism of crop residue biomass aggregation:** The central government and state governments of India have notified several policies to manage the surplus crop residues. Additional policies are still needed on crop residue collection and aggregation that will encourage private investment in crop residue collection business and further provide options to the farmers in disposing their crop residues and build viable business models to establish a crop residue supply chain mechanism. This will allow the private sector in investing in processes to crop residue valorization through production of briquettes, char briquette, paper, tableware, fabric production, etc. Some of the specific recommendations are as follows:
    - » Create infrastructure for setting up biomass depots for the storage of bailed crop residue
    - » Mandate state/national organization (such as NAFED, HAFED PAIC) to aggregate crop residue
    - » Create special credit line/scheme for financing of farm equipment and high working capital for private sector participation
- **Create market for crop residue-based briquettes**
    - » Decentralized model of production of crop residue briquettes or char briquette involving

Table 2: Potential of utilization of crop residues in state power plants of Punjab and Haryana

S. No.	Name	Location	Installed capacity (MW)	Crop residue utilized annually for 7% blending (tonnes)
Punjab				
1	Guru Nanak Dev Thermal Power Plant, Bhathinda	Bathinda	460	126,500
2	Guru Gobind Singh Super Thermal Plant Ropar	Ropar	1260	346,500
3	Guru Hargobind Thermal Power Plant Lehra Mohabbat Bhathinda	Lehra Mohabbat, Bhathinda	920	253,000
Total			**2640**	**726,000**
Haryana				
1	Panipat Thermal Power Station Stage I	Panipat	920	253,000
2	Panipat Thermal Power Station Stage II	Panipat	440	121,000
3	Deen Bandhu Chhotu Ram Thermal Power Project	Yamuna Nagar	600	165,000
4	Rajiv Gandhi Thermal Power Project	Khedar, Hisar	1200	330,000
Total			**3160**	**869,000**

farmer producer organizations (FPOs), farmers' cooperatives, etc. need to be prioritized.

» The use of crop residue briquettes or char briquette in local industries and hotels/dhabas need to be promoted.

Decentralized use of crop residues: Gasification of coal and biomass has been known for over a century. India is one of the few countries having an active research and demonstration programme on small-scale biomass gasification technologies. In a gasifier, solid biomass fuels (wood, agriculture residues, briquettes, etc.) are converted into gaseous fuel (producer gas) by a series of thermo-chemical processes. The producer gas has a calorific value of about 1000 to 1200 kcal/Nm^3 and consists mainly of carbon monoxide, hydrogen, and nitrogen. The producer gas can be used as fuel in internal combustion engines to produce mechanical power and electricity. About 1.2 to 1.4 kg of biomass is required for producing 1 kWh of electricity (using 100% producer gas engine). The gasifier packages having capacities ranging from 10 kW to 1000 kW for various applications include those for electricity generation, by running an engine generator on producer gas; mechanical shaft power when the producer gas is used as a fuel in an engine and the engine is directly coupled to the appliance (e.g. water pump, grinder) or thermal applications in which the producer gas is directly burnt in a stove, furnace, or boiler to running cold storage.

Crop residues can be utilized as fuel for running biomass gasifier for trigeneration applications including electricity, agro-processing, and running decentralized cold storage at the village level. This can also provide farmers an alternate option to shift to horticulture crops for which farmers currently are reluctant owing to limited cold storage capacity at the local level. A 250 kWe capacity biomass gasifier plant can utilize about 2000 tonnes of paddy straw annually and support 50 tonnage refrigeration (TR) cold storage facility besides producing electricity.

A suggestive sustainable business model for the utilization of the crop residues is developed based on the discussions above (Figure 2).

Village-level cold storage with gasification unit; V1 to V5 are villages; CRC: Crop residue company under FPO. Solid arrow indicates crop residue/crop residue based product flow and dashed arrow indicate flow of money.

The cost-benefit analysis of various options for management of agricultural residues is being carried and will be further discussed with the stakeholders for finalization.

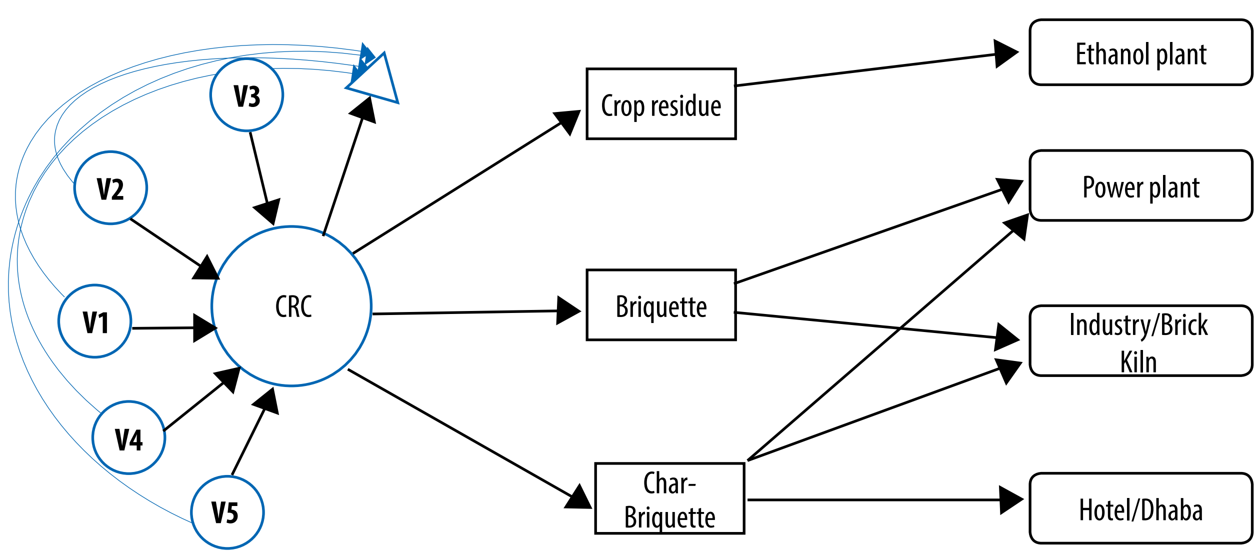

Figure 2 village levels *ex situ* crop residue management model.

△ Village-level green cold storage with gasification unit; V1 to V5 are villages;

CRC: Crop residue Co-operative as Farmers' Producers Organization. Solid blue arrow are utilization of cold storage by villages. Solid black arrow indicates crop residue/crop residue based product flow

References

Balakrishnan, K., Dey, S., Gupta, T., Dhaliwal, R. S., Aaron, M.B., Jeffrey, J.C., Stanaway, D., Beig, G., Joshi, T.K., Aggarwal, A.N., Sabde, Y., Sadhu, H., Frostad, J., Causey, K., Godwin, W., Shukla, D.K., Kumar, A. G., Varghese, C.M., Muraleedharan, P., Agrawal, A., Anjana, R.M., Bhansali, A., Bhardwaj, D., Burkart, K., Cercy, K., Chakma, J.K., Chowdhury, S., Christopher, D.J., Dutta, E., Furtado, M., Ghosh, S., Ghoshal, A.G., Glenn, A.D., Guleria, R., Gupta, R., Jeemon, P., Kant, R., Kant, R., Kaur, T., Koul, P.A., Bhargav, V.K., Larson, S.L., Madhipatla, K., Mahesh, P.A., Mohan, V., Mukhopadhyay, S., Mutreja, P., Naik, N., Nair, S., Nguyen, G., Odell, M.C., Pandian, D.J., Prabhakaran, D., Prabhakaran, P., Roy, A., Salvi, S., Sambandam, S., Saraf, D., Sharma, M., Shrivastava, A., Singh, V., Tandon, N., Thomas, N.J., Torre, A., Xavier, D., Yadav, G., Singh, S., Shekhar, C., Vos, T., Dandona, R., Reddy, K.S., Lim, S.S., Murray, C.J.L., Venkatesh,S., Dandona, L. (2019) The impact of air pollution on deaths, disease burden, and life expectancy across the states of India: the Global Burden of Disease Study 2017. *The Lancet Planetory Health*, 3(1): E26 – E39

Bawatharani, R., Bandara, M.H.M.A., Senevirathne, D.I.E. (2016) Influence of cutting height and forward speed on header losses in rice harvesting. International Journal of Agriculture, Forestry and Plantation 4 (Dec.) ISSN 2462-1757

CEA (2017) No. CEA/TETD-TT/2017/M-25/1137-1251 dated 24/11/2017. Office of the Secretary, Central Electricity Authority, Ministry of Power, Government of India. Details available at http://www.cea.nic.in/reports/others/thermal/tetd/Biomass%20Utilization%20Advisory.pdf, last accessed on 24 January 2020

CEA (2019) All India installed capacity of power Stations. Details available at http://www.cea.nic.in/reports/monthly/installedcapacity/2019/installed_capacity-03.pdf

Hesammi, E., Talebi, A., Hesammi, A. (2014). WALIA journal. 30. 192-194

Jain, N., Bhatia, A., Pathak, H. (2014) Emission of air pollutants from crop residue burning in India. Aerosol and Air Quality Research 14: 422–430

Jat, M.L., Kapil., Kamboj, B.R., Sidhu, HS, Singh, M., Bana, A., Bishnoi, D., Gathala, M., Saharawat, YS, Kumar, V., Kumar, A., Jat, H.S., Jat, R.K., Sharma, P.C., Sharma, R.K., Singh, R., Sapkota, T.B., Malik, R.K.,Gupta, R. (2013). Operational manual for turbo happy seeder- technology for managing crop residues with environmental stewardship. International Maize and Wheat Improvement Center (CIMMYT), Indian Council of Agricultural Research (ICAR), New Delhi, India

Jitendra., Venkatesh, S., Kukreti, I., Pandey, K., Niyogi, D.G., Mukherjee, P (2017) Down to Earth. 2 June 2017.

Lohan, S. K., Jat, H., Yadav, A., Sidhu, H.S., Jat, M.L., Choudhary, M., Peter, J., Sharma, P. (2017). Burning issues of paddy residue management in north-west states of India. Renewable and Sustainable Energy Reviews 81:693-706

MNRE (2018). F. No. 20/222/2016-17-WTE dated 30/07/2018. Waste to Energy Division, Ministry of New and Renewable Energy, Government of India

MoA&FW (2018). Kharif Market Season (KMS) Procurement of Rice 2018-19. New Delhi: Ministry of Agriculture and Farmers' Welfare, Government of India

MoA&FW (2019). Report of the committee on 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". Deptt. of Agriculture, Cooperation & Farmers Welfare, Ministry of Agriculture and Farmers Welfare, Government of India

MoPNG (2018). Annual Report 2018-19. New Delhi: Ministry of Petroleum and Natural Gas, Government of India

NAAS (2018). Renewable Energy: A New Paradigm for Growth in Agriculture. Strategy Paper 10, National Acedamy of Agriculture Sciences, New Delhi

NFSM (2016). A status note on rice in India. Status paper. National Food Security Mission, India. Details available at https://www.nfsm.gov.in/StatusPaper/Rice2016.pdf; last accessed on 24 January 2020

Poonamperuma, F.N. (1984). Organic Matter and Rice. Los Banos, Phillippines: IRRI

PTI (2019a). According to the Ministry of Earth Sciences' air quality monitor SAFAR, smoke from stubble burning in Punjab and Haryana accounted for 44 per cent of pollution in Delhi on November 1, the highest this year." Details available at https://www.business-standard.com/article/pti-stories/stubble-burning-contributed-significantly-to-delhi-ncr-s-pollution-this-year-cpcb-member-secy-119111301401_1.html; last accessed on 24 January 2020

PTI (2019b). "29,000 Punjab farmers get Rs 2500 per acre for not burning crop residue". November 25, 2019. Details available at https://www.business-standard.com/article/pti-stories/29-000-punjab-farmers-who-did-not-burn-crop-residue-compensated-119111501440_1.html; last accessed on 24 January 2020

Tandon, H.L.S. (1996). Organic resources: an assessment of potential supplies, their contribution to agricultural productivity, and policy issues for Indian agriculture from 2000 to 2025. Kanwar, J.S. and Katyal, J.C. (Eds.) Proc. Symp. Plant Nutrient Needs, Supply, Efficiency and Policy Issues: 2000-2025, NAAS, New Delhi

TERI (2019) Development of Spatially Resolved Air Pollution Emission Inventory of India. New Delhi: The Energy and Resources Institute

For more information, please visit: **http://www.teriin.org/**

The Energy and Resources Institute (TERI)
Darbari Seth Block,
IHC Complex, Lodhi Road,
New Delhi - 110 003, INDIA

Tel: 71102100 or 24682100
Fax: 24682144 or 24682145
Web: www.teriin.org
E-mail: pmc@teri.res.in