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Transforming agricultural waste to agricultural wealth through a locally feasible conversion process

Babita Chatterjee

babitachatterjeerd@gmail.com

Indian Institute of Technology Bombay

Haricharan Behera

Indian Statistical Institute

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Abstract

Intensive farming and the excessive use of chemical fertilizers have a negative impact on both rural and global environments. The authors selected Bankura district for this study, located in the southwestern part of West Bengal. This article discusses the inefficient handling of agricultural waste (AW), livestock manure, and other residues that contribute to a significant quantity of toxic substances in the environment. The study focuses on Sustainable Development Goal 12, which aims for the responsible use and production of resources, by highlighting practical methods to turn farm waste into valuable resources. The study explores reliable methods for utilizing locally available resources efficiently to minimize adverse environmental impacts. We obtained primary data from 200 respondents using a multi-stage sampling technique and secondary data from some authentic sources. The findings of the present study indicate a potential natural and human resource base in the region. It illustrates that substantial landowners with 5 to 10 acres of cultivable land expend more than small and marginal farmers. Consequently, around fifty percent (50%, N = 200) of our respondents spend a significant amount on chemical fertilizers, expending a greater amount than small and marginal farmers to attain optimal yield from cultivation. The absence of an institutional support system in the state poses obstacles to the application of organic manure and bio-fertilizer. Therefore, it is essential to establish an integrated and comprehensive setup for promoting the sustainable management of agro-based leftovers and fostering healthy workforce participation.

1. Introduction

Agriculture is the cornerstone of the Indian economy, where 70% of the population is directly or indirectly dependent (Kumar *et al*., 2020). The focused region of Bankura district exhibits topographical variation and topsoil loss due to the fallow land, high temperature range, and seasonal precipitation (Dhibor & Siddique, 2017). This problem has expanded quickly in the research region due to external causes and human influence. Therefore, it is necessary to safeguard the topsoil. Green manure can maintain soil fertility or develop the soil surface (Kumar *et al*., 2020). Agricultural residues (such as crop husks, crop skins, leaves, stems, bark, flowers, and others) and agro-industrial detritus (including residues from food processing industries) are a concerning matter nowadays (Thorenz *et al*., 2018). There is a lack of coordinated initiatives to recycle agricultural leftovers in the studied region. Producers show concern regarding the quantity of residue generated or its potential harm. Consequently, improper and untreated disposal practices, such as burning remnants in the field, harm the environment after harvest. This situation has raised concerns, as highlighted by Bettles *et al*. (2021). Subsequently, the enormous amount of trash that is not being gathered affects natural resources by leading to eutrophication, loss of soil fertility, low biological oxygen levels, and high BOD and COD levels (Mateo-Sagasta *et al.,* 2018). This paper depicts the present pattern of handling agricultural residues at the national and regional levels. The earlier waste disposal methods include landfills, compost pits, and burning. However, these methods come with the challenge of greenhouse gas (GHG) emissions, which lead to ashes, foul odors, and contaminated water (Ferronato & Torretta, 2019). The socioeconomic circumstances of developing nations, such as India, are a matter of concern. A study indicates that this impoverished nation produces biogas from agricultural waste, which offers enormous benefits from both social and economic perspectives. The overall use of cow manure generates a significant profit of approximately $890,300 per financial year (Gabisa & Gheewala, 2019). One of the most significant challenges in the world is the need to reconcile environmental sustainability with economic growth (Gabisa & Gheewala, 2019). The global market value of biowaste-to-bioenergy (BtB) technology is nearly $25.32 billion, and it is expected to reach $40 billion by 2023. Recently published statistics cite an example of China utilizing organic substances, such as biogas and green manure derived from agricultural waste. According to the Chinese government's estimate, the annual methane production could be 15.8 billion cubic meters, equivalent to 11 million tonnes of high-quality coal. On the other hand, the annual conversion of 3.1 million tonnes of chemical fertilizers into nitrogen produces 71 million tonnes of methane waste (Xue *et al*., 2020). To make the global economy more eco-friendly and

accessible to everyone, we need to separate resources and effects to encourage long-term approaches to making and using things. This study focuses on the primary sources of agricultural waste and their current utilization. The application of scientific management methods to agricultural waste has demonstrated effective strategies for identifying long-term solutions in the selected study area. Another concerning matter is the use of agricultural leftovers in low-carbon and energy-intensive ways (Sharma *et al*., 2021). Continuous efforts are required to make the conversion processes economically and environmentally viable, which produce organic waste materials like livestock manure. Biowaste-to-bioenergy (BtB) research focuses on four key areas (Thorenz *et al*., 2018). These are—

a. low-carbon and energy utilization of agricultural waste,

b. the influence of rural waste emissions,

c. the material and energy flow of agricultural waste, and

d. the prevention and control of rural waste pollution.

A recent study by Duan *et al*. (2022) stresses the micro-level suitability mapping of entrepreneurial possibilities to close the distance between a production center and customers. The bottom-up approach of this study reflects policy planning to effectively utilize locally available resources for entrepreneurship development, enabling the local government to implement sustainable agricultural practices (Priyadarshini & Abhilash, 2020; Mohan *et al*., 2018). Seed residue, crop skin, and straw are excellent sources in the agro-sector. Wheat, paddy, maize stover, and barley have more than 80% of their dry content as lignocellulose (Thorenz *et al*., 2018). Agronomy is a rapidly growing field, driven by the increasing demand for organic products from a rising global population. They lead to the expansion of the national gross domestic product (Priyadarshini *et al*., 2020). The current study examines residue management issues and recommends collaborating with entrepreneurs. It demonstrates the value of taking immediate administrative actions to address the prevailing challenges.

The increased amount of residuals costs more for disposal. This paper explores locally adaptable methods for converting residuals into valuable products. About 350 million tons of AW are generated in India annually, producing more than 18,000 megawatts (MW) of energy each year and contributing to the production of green manure, as estimated by the Ministry of New and Renewable Energy (Priyadarshini & Abhilash, 2020). Agricultural waste (AW) contains significant levels of toxic substances. It is usually caused by the extensive application of intensive cultivation methods and chemical fertilizers, which have a remarkably negative impact on both rural and global environments. Improper treatment of livestock manure and other types of farm waste contributes to greenhouse gas (GHG) emissions, which in turn lead to eutrophication and contamination of water, air, and soil (Ferronato & Torretta, 2019). This study concentrated on Sustainable Development Goals (SDGs), particularly Goal 12: Foster environmentally sustainable manufacturing and consumption practices. This study also addresses Goal 1: Eradicating poverty in all its manifestations globally, and Goal 9: Developing resilient infrastructure, encouraging sustainable industrialization, and stimulating innovation. These addresses Target 1A: Ensure substantial mobilization of resources from diverse sources, primarily through improved development cooperation. Target 9.3: Enhance access to financial services for small-scale industries and other firms, particularly in emerging nations. Target 9.B: Foster domestic technological advancement, research, and innovation in emerging nations; Target 12.4: Achieve ecologically sustainable management of chemicals and all waste throughout their life cycle.

The authors emphasized SDGs Goals 12, 1, and 9 by addressing both the significant objectives of this research. The SDGs could fulfill these objectives. Target 9.3: Enhance access to financial services for small-scale industries and other firms, particularly in emerging nations; Target 9.B: Foster domestic technological advancement, research, and innovation in emerging nations; Target 12.4: Attain the ecologically sustainable management of chemicals and all

waste throughout their life cycle; Target 1A: Ensure substantial mobilization of resources from diverse sources, primarily through improved development cooperation.

The current study was conducted within the framework of sustainability, which defines the research problems. There are efficient ways to reduce GHG emissions from AW. The implementation of AW management policies needs to be corrected or appropriately addressed. Multiple pockets of the nation urgently need corrective measures or attention regarding the execution of numerous AW management policies.

The essential elements for implementing sustainability recognized are —

i) The proper regulatory framework from the administrative level,

ii) Different awareness programme,

iii) Environmental protection,

iv) Technological improvement, and

v) Economic improvement.

The current paper proceeds by answering the following questions: (i) How do the farmers process agro-based waste materials? (ii) What are the sources of residues in a rural area? And, iii) What are the possibilities for reusing those wastes in rural areas? This study evaluates the factors, especially in the underdeveloped region, and tries to ascertain how BtB and ZBNF would benefit the cultivators. Our work thus seeks to illuminate this area by focusing on the existing issues. This study aims to i) understand the existing waste management methods in our focused area, and ii) analyze the feasibility of scientific conversion processes and entrepreneurial investment using locally available agro-waste on a small scale.

The article also focuses on the development of BtB and other innovative business models and techniques to recycle waste without harming the ecosystem. Next, it examines the relationship between recovered products and their economic importance. We have employed specific measurable techniques to understand the local population's food system and issues. The analysis involves agricultural-based livelihood analysis, crop selection, and chemical usage in the field, and related expenses incurred in the study area. This article provides a framework that helps conservation development planners encourage pro-conservation behavior in a specific context, promoting environmental conservation while enhancing economic and societal prosperity.

2. Research Tools

2.1 Study Area

The Bankura district is located between coordinates 22°38 and 23°38 North and 86°36 and 87°46 East. The ancient alluvial plain and the upland of Chota Nagpur sandwich the district's distinctive topography in West Bengal. The Damodar Creek divides it from the Barddhaman region in the north and northeast. Hooghly is located in Bankura's southeastern region. The geographical borders connect the Paschim Medinipur and Purulia districts to the south and west. The region encompasses an area of 6881 square kilometers in total. For this study, six Community Development Blocks (CDBs) from the Bankura district were chosen—Khatra, Taldangra, Ranibandh, Raipur, Simlapal, and Sarenga—so that the situation can be shown more accurately in Figure 1. This map illustrates the study area. These six CDBs produce more rice than the others. Rice and paddy are the primary agricultural residue sources in the focused area, discarded in the current fallow land or dumped on rural roadsides.

2.2 Methods

The present study is considered an example of a developing nation. The current work has focused on the Bankura district, located in the southwestern part of West Bengal. About 95% of the mature age group in this area is actively participating in farming. The selected area faces physiographic obstacles such as soil dryness, inadequate rainfall, and an average summer temperature of 42°C. Given these challenges, we chose this district to focus our study on. This paper establishes and adheres to a distinct approach to achieve its objectives. Considering the worldwide waste management challenges, this study looked for detrimental externalities on sustainability and the ecosystem. The Economic Survey of India 2021–22 was thoroughly reviewed for further clarification. Also, some articles have been considered from reputed online journals and on the Department of Environment and Public Welfare of the Government of India's website.

Secondary data has been collected from the Economic Survey Department of Fertilizers, Ministry of Chemicals & Fertilizers, Statistical Appendix, and Directorate of Economics & Statistics, Department of Agriculture and Farmers Welfare, 2021–22. The Reports on Agriculture Census, 2015–16, Department of Agriculture, Cooperation, and Farmers Welfare, Government of India 2020, have been reviewed. We have analyzed the statistical information using both primary and secondary data sources. A simple random sampling technique was used to collect the primary data from 200 respondents using a field survey method. The survey was conducted in six selected community development blocks (CDBs) from the chosen district, Khatra, Ranibandh, Sarenga, Raipur, Taldangra, and Simplapal, between May and July 2022, among the mature age group 30-60. A total of 33 respondent interviews were taken from each CDBs, where 35 respondents were considered in the Simlapal CDB. We used IBM SPSS version 24 to analyze the quantitative data and the ArcGIS 10.4 software to prepare the maps.

2.3 Data Analysis

Green manure is a substitute for chemical fertilizer to restore soil fertility and strengthen agricultural ecosystems. It leads to maintaining proper composition in productive soil. For instance, silage effluent contains about 75% of the livestock nutrients, including a good NPK balance. Table 1 shows the use of chemical fertilizers for eight consecutive financial years from 2014-15 to 2021-22 (projected). It depicted the total manure production in the country and the total amount of fertilizer imported at a high cost from other countries. It elaborates on the potential of using green manure in countries like India to save production costs, especially for small and marginal farmers.

Table: 1 Nitrogen, Phosphorus, and Potassium (NPK) consumptionin India (Thousand tons of nutrients)

		2014-15	2015-16	2016-17	2017-18	2018-19	2019-20	2020-21	2021-22*
A.	Nitrogenous fertilizers	12394	13416	13354	13386	13344	13685	13715	7870
	Production	4766	5068	3385	3588	4701	5191	5633	2500
	Imports	16946	17372	16735	16958	17628	19100	NA	NA
B.	Phosphatic fertilizers	4121	4394	4595	4723	4594	4791	4739	2798
	Production	1832	2888	2130	2047	3167	2413	2543	1584
	Imports	6098	6979	6705	6854	6968	7662	NA	NA
C.	Potassic fertilizers	2537	2053	2325	2895	2629	2280	2670	995
	Imports	2532	2402	2508	2779	2779	2607	NA	NA
D.	All fertilizers (NPK)	16515	17810	17949	18109	17938	18476	18454	10668
	Production	9135	10009	7840	8530	10497	9884	10846	5079
	Imports	25576	26753	25948	26591	27375	29369	NA	NA

Na- not available, Source: Economic Survey 2021-22 Statistical Appendix, Department of Fertilizers, Ministry of Chemicals & Fertilizers.

Table 2 shows the area under major crops across India during the four financial years from 2017-18 to 2020-21. This table depicts the proportion share of cultivated food grains; cereals occupied the highest rank, followed by rice and wheat. The cultivation of these crops has risen every calendar year, which is a positive sign of consistent crop production and residue generation. It offers enough scope to set up crop residue-based industries in rural areas. This means easily accessible sources of raw materials for bioenergy and biochar production.

Table: 2 Gross Area under Major Crops (Million hectares)

Commodities	2017-18	2018-19	2019-20	2020-21
Foodgrains	127.5	124.8	127	129.3
Cereals	97.7	95.6	99	100.5
Nutri / Coarse Cereals	24.3	22.1	24	23.8
Pulses	29.8	29.2	28	28.8
Rice	43.8	44.2	43.7	45.1
Wheat	29.7	29.3	31.4	31.6
Jowar	5	4.1	4.8	4.2
Bajra	7.5	7.1	7.5	7.6
Maize	9.4	9	9.6	9.9
Tur	4.4	4.6	4.5	4.8
Gram	10.6	9.6	9.7	9.9
Oilseeds	24.5	24.8	27.1	28.8
Groundnut	4.9	4.7	4.8	6.1
Rapeseed and Mustard	6	6.1	6.9	6.7
Sugarcane	4.7	5.1	4.6	4.9
Cotton	12.6	12.6	13.5	13
Jute and Mesta	0.7	0.7	0.7	0.7

Source: Economic Survey 2021-22 Statistical Appendix,

Directorate of Economics & Statistics, Department of Agriculture and Farmers Welfare.

This article provides an overview of the crops that are more commonly grown in the selected area. Figure 2 shows the three-year trend of primary crop production from 2016-17 to 2020-21. In most cases, positive production growth has been seen. It symbolizes a favorable environment to set up a recycling industry in collaboration. The utilization of optimized crop residues to produce various value-added products is an urgent requirement. You can use the residues to prepare chemical products, building block materials, biochar, paper, packaging goods, and more.

Figure 3 shows this figure shows the dominant produced crops in the focused area. It depicts that the CD Blocks Ranibandh, Raipur, and Simlapal cultivate maximum paddy. Sarenga, Khatra, and Taldangra blocks come consecutively. These CD blocks are highly suitable for producing residue-based plants. Furthermore, a large market exists in this region to consume the farmers' finished products.

Table 3: Shows Annual Expenses for Chemical Fertilizers

Total Respondents (%)	Arable Land (acre)	CF (kg/Y)	Approx. Cost (Rs.)
6	<1	200	6000
12	10	4000	120000
37	5	1800	54000
45	2	1000	30000

Total= 100%, Source: Field Survey

Table 3 shows the scenario of the participants annual expenses for chemical fertilizers in the study area in the financial year 2021-22. It depicts that large landholders who possess 5 to 10 acres of arable land spend a larger amount than the small and marginal farmers (who own 2 to less than 1 acre of arable land). From this, it can be said that almost fifty percent (50%, N=200) of our respondents use chemical fertilizers by spending a higher amount in comparison to small and marginal holders to get maximum output from cultivation. To increase farm production, farmers are encouraged to switch over from traditional manure to chemical fertilizer application in their crop fields. The absence of an institutional support system in the state poses obstacles to the application of organic manure and bio-fertilizer (Table 3).

The Stepwise Regression Analysis tool has been used to understand the variables better. Therefore, the authors observed how the variance explained, the value of R and $R^{2,}$ and the coefficient are changed by adding (or removing) each predictor to the model once at a time. Table 4 shows the details of the variables entered and removed. Here we have considered average annual income from cultivation (Rs. in thousands) as a dependent variable and arable land, cropping patterns and average annual expenses (Rs.) for chemical fertilizers (CF) as independent variables.

Table 4 Variables Entered/Removed[a]

Model	Variables Entered	Variables Removed	Method
1	Arable land	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
2	Cropping patterns	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
3	Average annual expenses for chemical fertilizar	.	Stepwise (Criteria: Probability-of-F-to-enter <= .050, Probability-of-F-to-remove >= .100).
a. Dependent Variable: Average annual income from cultivation			

Table 5 Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.951[a]	.904	.903	829.49393
2	.957[b]	.916	.914	780.57346
3	.959[c]	.920	.918	765.36145

a. Predictors: (Constant), Total arable land,

b. Predictors: (Constant), Total arable land, cropping patterns

c. Predictors: (Constant), Total arable land, cropping patterns and average annual expenses for chemical fertilizer

We can see that Table 5 built three models based on Arable land, cropping patterns and average annual expenses for chemical fertilizer. All these four models finally illustrated the most suitable one in the next step means the Coefficient table in Table 6. Using the model value is better than using the mean value in this context. Model Summary Table 5 properly explains the selected variables. The value of R is always greater than 95%. This means it can explain more than 95 to 96 % of the total considered 100%. That means a highly significant R^2 value for all the models is enormously significant that is >90%. In Table 6 ANOVA, the significance value is <0.005 and that is 0.000, here the null hypothesis is rejected and the alternative hypothesis is accepted.

Table 6 ANOVA[a]

Model		Sum of Squares	df	Mean Square	F	Sig.
1	Regression	624067712.405	1	624067712.405	907.442	.020[b]
	Residual	66053777.625	96	688060.184		
	Total	690121490.03	97			
2	Regression	632259431.276	2	316129715.638	533.317	.0120[c]
	Residual	57883017.703	95	609294.923		
	Total	690142448.979	97			
3	Regression	623078205.543	3	211584302.127	371.252	.002[d]
	Residual	55063145.623	94	585778.145		
	Total	678141351.166	97			

a. Dependent Variable: Average annual income from cultivation in thousand

b. Predictors: (Constant), Total arable land

c. Predictors: (Constant), Total arable land, cropping patterns

d. Predictors: (Constant), Total arable land, cropping patterns and average annual expenses for chemical fertilizer

Table 7 Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	14370.126	1179.849		12.060	.000
	Total arable land in acre	57.285	109.759	.024	.528	.325
	Cropping patterns	87.717	153.784	.034	.505	.243
	Average annual expenses for chemical fertilizer	213.673	186.355	.067	1.214	.152

a. Dependent Variable: Average annual income from cultivation in thousand

Now come to Table 7, the Coefficient table. It talks about the individual significant model. Come to the Unstandardized Coefficients and B value. This table illustrates the significance level of variables based on the dependent variable. Our dependent variable is average annual expenses for chemical fertilizer of the respondents. Here, the constant is significant. The significant level of all the cases is based on the value of most cases > 0.005. This means it is highly positive. Therefore, it can be said that the independent variables total arable land, cropping patterns, and average annual expenses for chemical fertilizer have a strongly significant effect on the dependent variable average annual income from cultivation.

3. Results and Discussion

Organic waste from Table 2 can be used to create high-quality fertilizers containing elements like Na, K, Mg, and P. Table 3 reveals that our interviewees, the farmers in the research region, spend a significant amount of money on chemical fertilizers, with big landowners spending significantly more than small landowners. They represent 12% of all responses. They spent Rs. 20,000 on the same item over a year. Two acres of fertile land belonged to medium cultivators, who paid Rs. 3000 annually. Additionally, marginal farmers who own less than one acre (1 acre) of property and make less than Rs. 6000 annually pay a small sum. They make up just 6% of our entire sample of 100% responses. Wood waste can be reused and recycled to create domestic goods, organic fertilizers, and fuel for fires in remote regions. Major crops like rice, wheat, and sugarcane straw can be used to develop environmentally responsible goods for a viable future. The refuse produced by agro-farming animal byproducts can be managed with biofertilizers. Use biological refuse as fuel as opposed to other non-renewable resource-based fuels. Figures 2, and 3 depict the country and the research area's actual agricultural residue condition. It can also said from Table 7 that a bio-based recycling or processing business be established using readily accessible and affordable labor.

It can be lucrative to absorb the extra laborers in the study area, the Ranibandh, Raipur, Simlapal, Sarenga, Khatra, and Taldangra CD blocks of the district. Therefore, the rural community should collectively set up small-scale domestic enterprises. The gram panchayat officials will oversee factory setup, funding, the conversion process, revenue generation, and labor engagement to ensure proper program execution. Each village will have a unit of microfirms that recycles agricultural waste into green manure. This arrangement will provide easy access for the beneficiaries. The farmers have to pay a minimum cost to recycle their agro-waste into resources (biofertilizers). We will adequately store the final product for the next cropping season. The proposed model in Figure 4 shows a feasible way for rural farmers to utilize agro-based wastes as green manure, reducing the per-unit production cost for micro and small farmers. The

entire farming process, a part of ZBNF, will be affordable for them. There would be an excellent opportunity to absorb the daily wagers at locally established microenterprises. It would be a viable source of guaranteed income.

The entire procedure can contribute to SDG Targets 1.A, 9.3, 9.B, and 12.4 in Figure 4. The procedure aims to mobilize substantial resources and improve small-scale firms' access to financial services through domestic technological advancement and innovation. This will achieve ecologically sustainable waste management by leveraging social capital from gram panchayats. It will be allocated in the state government's annual budgets, individual (beneficiary), and collective sources (selling the bio-fertilizers).

Therefore, Figure 4 depicts the resilient ways of reusing and recycling the agro residues in the focused area. Paddy is the primary grain produced in West Bengal and the study area. Except for the rainy season, all the months are dry here. As a consequence, the residents only use straws as animal fodder. The information in Figures 2 and 3 shows the range of organic fertilizers and energy output. Table 1 illustrates the increased demand for fertilizer across the country. A sizable percentage of it is also shipped to meet the rising demand and make a decent amount of money. Therefore, establishing a local small-scale industry in collaboration with a public-private partnership is necessary. It would promote entrepreneurship and self-sufficiency among rural farmers through regenerative rural farming (Figure 4). The generated leftovers in the specified area can be divided into the following categories:

I. Rice, wheat, and barley stalks

II. Plant-based fiber

III. Social initiatives based on products from agroforestry,

IV. Including oil seeds and other products. To accomplish the objective of ensuring that everyone—regardless of wage level—has a realistic, better, and active future, SDGs1, 9 and 12 should be emphasized.

4. Suggestion

4.1 Possible Application in daily life

4.1.1 Transformation of agricultural waste

Straw-based products in interior design, such as furniture making and wall decoration, will help to protect forest resources. Instead of relying solely on wood substrates to process culinary fungus, straw from paddy, wheat, jute, and other sources should be used to make substrates. A new study related to this one revealed that MCM-48 mesoporous silica can be made by extracting silica gel from rice skin ash and mixing it with nickel oxide (Shaban *et al*., 2017a, 2017b).

4.1.2 Utilization as cattle fodder

It helps preserve the nutrient content for a long time and disease-resistant instant capacity. The green and yellow straw used for animal fodder can be converted into silage straw feed by reducing minimum nutrient loss and improving palatability.

Lastly, the Comprehensive Utilization of Agricultural (CUA) residue management methods play a crucial role in the food supply of low-income countries. For example, the mixed farming culture in a rice and fish co-cropping system is essential in managing food security in Asian countries, especially India and Bangladesh (Saha *et al*., 2018).

4.1.3 The bio-economic potentiality of crop residues

We are fond of following the path of a linear economy. According to economists, it is unstable and unsustainable. leading to adverse effects on humans. This economy is grounded mainly on the interlinkages of production, consumption, and wastage of commodities. However, following such an economic model must be restricted as it is materialistic. Therefore, it should prioritize following an alternative path of energy sources. It is projected that by 2050 our population will be about 10 billion. It might result in a massive crisis in food, grain, and energy (Hassan *et al*., 2019). It will create harsh conditions by depleting natural resources, leading to a waste explosion. Therefore, it becomes necessary to emphasize dependency on bio-based economies with alternative bioenergy. The utilization of optimized crop residues to produce various value-added products is an urgent requirement. The residues can be used to prepare chemical products, materials for building blocks, biochar, paper, packaging goods, and others. Doing this can fetch positive outcomes, such as a reduction of environmental imbalances, economic support for farmers, and aid in sustainable growth through the optimum use of organic materials.

Furthermore, water and air are polluted as they are not treated appropriately. The open burning of AW produces methane. All these collectively take part in removing the fertile topsoil, creating an imbalance in soil nutrients. So, it deprives farmers in terms of chemical fertilizer and energy costs. In Italy, the expected crop and forest wastage is 20,027,874 tons and 2,180,581 tons annually, where the gross amount is 22,208,455 tons per year. The energy produced by these biomasses is 191,336,760 GJ (Paiano & Lagioia, 2016). Remains from agroforestry and social forestry create products with an ecological value addition. By 2050, the European Sustainable Electricity Council wants to produce only sustainable electricity (Jacobson *et al*., 2017).

Additionally, the ever-increasing exploitation of fossil fuels is a developing trend in the current context. Along with a natural risk assessment, people should be aware of its consequences. However, the policies and strategies that have been formulated are currently only available in written form. As a result, the sustainable extraction process won't take too long (Sharma *et al*., 2021). Forestry and farming wastes such as bark, straw, and seeds create a growing market for green products. It will assist in reducing GHG emissions. Biofuel, a rapidly expanding non-renewable substance, has the potential to supply electricity and other ancillary materials. There is a growing propensity towards agro-residuals by considering the good sides crucial in maintaining environmental quality and leading to the country's economic development. Sustainable waste management can be done by following specific steps for essential products. It includes the primary sector, mainly agriculture. Straws have significant economic value as animal fodder. India primarily follows the 2R management techniques, similar to those of developing countries. Agro-based residues are plentiful and could be an essential parameter for control. It shows alternative livelihood options for future generations (Thorenz *et al*., 2018).

NDPs (National Development Programs) have some associated advantages, but they also call for institutional and favorable long-term policies and farm-level rewards. Tribal regions are non-renewable. Forest resources and animal habitats are not subjected to as much additional stress due to waste from farming lands and forestry activities. These renewable resources can be recycled and reused to help companies and technology progress responsibly and to increase job opportunities for small-scale or middle-class farmers (Lier *et al*., 2021). Technology such as composting, vermicomposting, and anaerobic digestion are used to balance such pollutants. Organic refuse can yield high-quality fertilizers containing minerals such as Na, K, Mg, and P. Reusing and recycling wood waste can be used to make household items, organic fertilizers, and fuel to burn in rural areas, directly lowering the amount of rice, wheat, and sugarcane straw produced. Animal by-products and the waste generated by agro-farming can be handled with the help of biofertilizers. Instead of using fuels from other non-renewable resources, organic waste can make affordable bio briquettes, biodiesel, and charcoal less harmful to the ecosystem (Kumar *et al*., 2020). Bio briquettes are formed using rice, wheat, corn, sugarcane fiber, and paper waste. This fuel is employed in thermal activities such as cooking. Fossil fuels can be replaced by vegetation production for biopower and biofuels.

The primary source of raw materials for chemicals and value-added materials can also be considered crop residue sustainably. To create a biobased economy, traditional industrial practices must adapt sustainably in light of finite resources (Thorenz *et al*., 2018). Compared to products made of petroleum or hazardous chemicals, using more bio-based products has a beneficial environmental impact. Some businesses enhance biofuel for the nation's economic and social development by involving people and raising consciousness. By generating numerous job opportunities and strengthening international trade as renewable alternatives to conventional products, bioproducts contribute to developing fruitful relations with other nations. Figure 5 shows how to reduce the production cost of farming by applying green manure. In our study area, it can serve as an emerging source of livelihood generation that developing nations may reference.

i. Effective utilization of natural resources.

ii. Safeguarding, preserving, and improving environmental resources.

iii. Rural livelihoods and societal well-being will increase due to sustainable

cultivation.

iv. The resilience of communities and ecosystems must be strengthened by

implementing sustainable agriculture.

v. Natural and human systems are essentially controlled by good governance.

Proper agricultural waste management leads to the sequestration of extra carbon and a balance in upper soil biomass. This technique protects plants and supplies raw materials for ancillary industries. Therefore, it must follow a win-win strategy to increase the economic value. With this method, everybody will be safe in the environment. This way, we can move from fossil fuels to a bio-based society. Figure 2 shows the production growth trend across three consecutive economic years from 2016-17 to 2020-21. It represents the pattern of production. In this scenario, there is enormous scope for biorefineries on agricultural sites. Furthermore, the analysis indicates a significant market for green manure.

Establishing a refinery based on proper technique is required, as this area produces sufficient raw material for the biorefinery plants. It should be noted that advanced vehicles should be used to collect raw materials from dispersed fields. Reasonable cooperation is highly demanded here to fulfill the target because of the cost of equipment and technologies. With Miscanthus and Crescentino, cellulosic bioethanol synthesis was successfully achieved using AW. This could reduce the overall cost of lignocellulose, making it a more affordable feedstock for biofuel production. Transporting goods to other states and requiring an insurance policy or financial debt are just a few limitations imposed by the laws and regulations.

5. Policy implications and limitation

The two emphasized areas are:

The first step is to avoid and control AW pollutants by utilizing advanced technologies, such as biomass production, across various cropping fields.

Second, evaluate the existing system from a policy perspective. Like Zero Budget Natural Farming (ZBNF), any management system related to residues aims to consider the wastes from an economic view, where maintaining the

exact environmental standards is the primary concern. For optimum functioning and greater clarity, the system must also be accessible to people.

Local communities need to promote the self-evaluation and management of waste biomass. Permanent fund allocation is essential for success in the compost and green fertilizer production model. The 4R method of reusing abandoned elements by recycling them can reduce agricultural waste and replace significant sources of pollutants and contribute to environmental protection. The entire procedure will produce enormous economic benefits to the rural people. Because of time constraints and funding issues, the authors selected only one district to represent the rural context of a developing nation.

6. Conclusion

There are no agro-residue management facilities in our study area except the traditional system of dumping, which is evident from the field inquiry. Figure 4 presents a recommended model, a sustainable waste management framework for rural areas, that would effectively address the challenges. To implement the resilient strategy, it is urgently required for public-private partnerships to be driven to mitigate the chronic issues of dumping and burning agricultural residues. This requirement is due to the initial funding needed to establish an industry that produces reusable products. Table 1 proves the high demand for chemical fertilizer in our country, even though it is expensive. Table 2, along with Figs. 2 and 3, illustrates the trends in crop production and the area cultivated in India and our study area. This information indicates that it is feasible to make green fertilizer from agricultural refuse at a low cost in our study area. Adding compost and green fertilizers to the production model for public-private partnerships reduces the distance between the entrepreneur's production hub and neighborhood consumers. Natural or composted dung has lower production expenses per unit area than artificial fertilizers. As a result, it will support ecosystem health, improve the basis for natural resource management practices, and increase the power of economically disadvantaged people in distant areas, as elaborated in Fig. 5.

The outcome of agro-based green manure will reduce production costs and the harmful impact of continuously using NPK, and it has a broad market. The national waste management policies must address problems at the grassroots level by considering the loopholes in waste management procedures in other states. The high trend of residue burning is caused by using harvesters for crop collection. Government support is vital in carrying out awareness campaigns and training activities, as well as providing financial aid in research and development (R&D). Another essential aspect to consider is the rural industrialization process, which involves integrating the rural unemployed into local micro- and small-scale firms within a green economy. Therefore, stakeholders must provide the entrepreneurs with crucial information regarding crop production and cropped areas. An employment franchise should collect the residues and transport them to the plant.

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Abbreviations

AW- Agricultural waste

GHG- Green House Gas

BtB- Biowaste to Bioenergy

R&D- Research and Development

CDB- Community Development Block

CUA- Comprehensive Utilization of Agricultural

US- United State

ZBNF- Zero Budget Natural Farming

Declarations

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Authorship contribution statement

BC conceptualized and designed the research framework, supervised the study, collected data, conducted data analysis, and led the manuscript writing. HCB provided critical feedback on manuscript drafts and participated in refining the analysis and framing the discussion. And reviewed and approved the final version of the manuscript for submission.

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Data Availability Statement

The datasets generated and/or analysed during the current study are publicly available from the corresponding author on reasonable request.

Declaration

This manuscript has not been submitted elsewhere for publication or is under consideration. It is an original document completed by the authors.

Clinical trial declaration

Not applicable

Ethical approval

This study was approved by the Institutional Ethics Committee of Indian Institute of Technology, Bombay and all procedures were carried out in accordance with relevant guidelines and regulations. A formal ethics approval document has been issued by the Institutional Ethics Committee and can be provided upon request.

Consent to participate

The authors took prior consent from all our participants before interviewing them. Only we recorded their responses. All our respondents are adults aged 30-60, and they are anonymous in this article. In some specific places, we used secondary data that is available on the Government of India website at censusindia.gov.in

Consent for publication

Not applicable

Conflicts of interest/Competing interests

According to the authors, there are no conflicts of interest.

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Figures

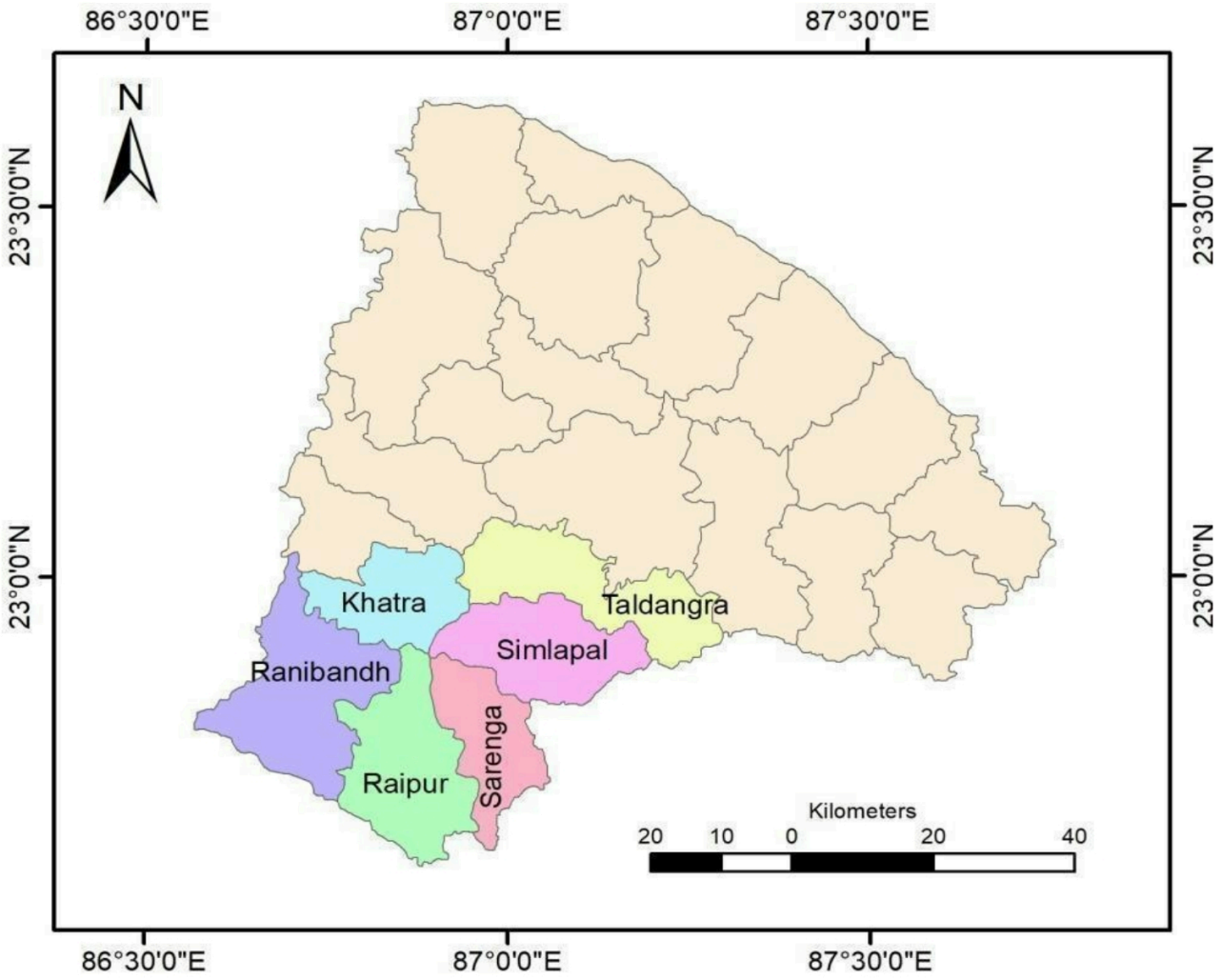


Figure 1

Geographical location of the selected study area

Prepared by the authors

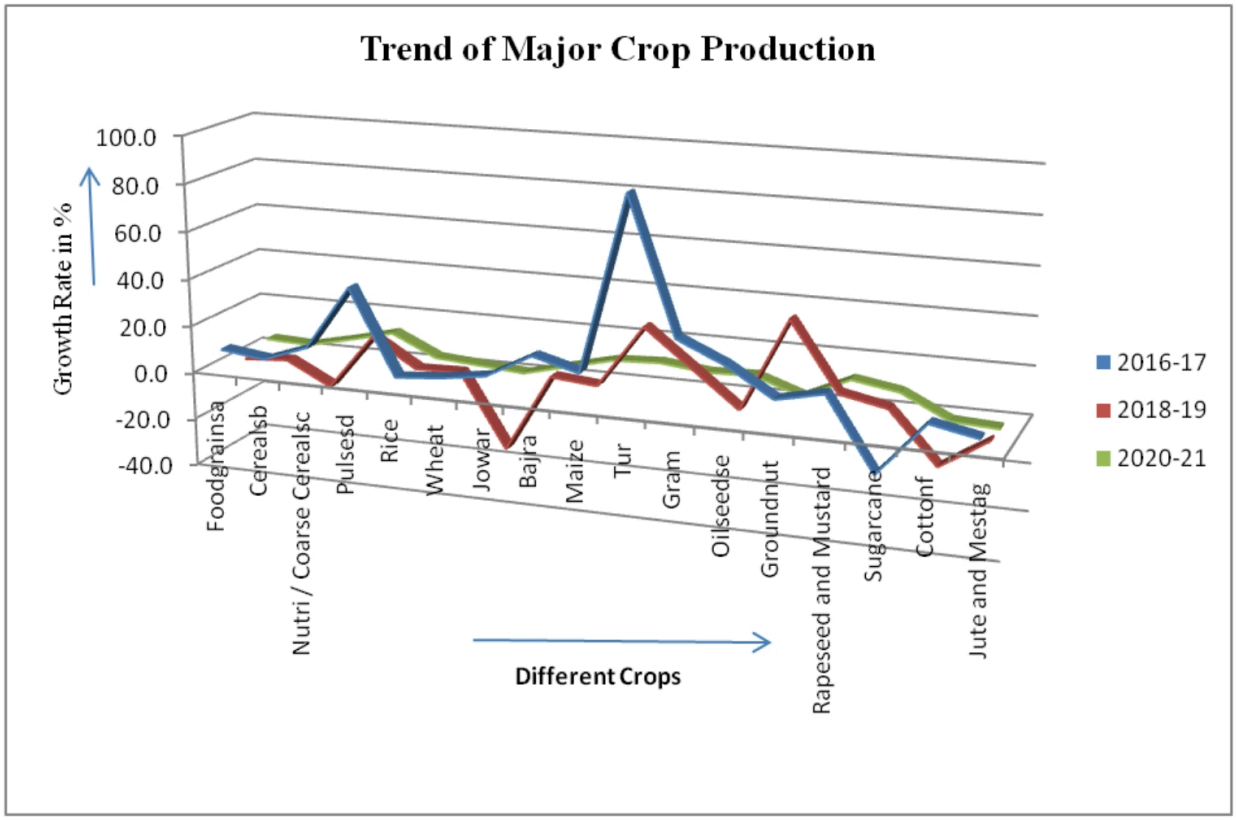


Figure 2

Growth trend of the selected crops

Prepared by the authors

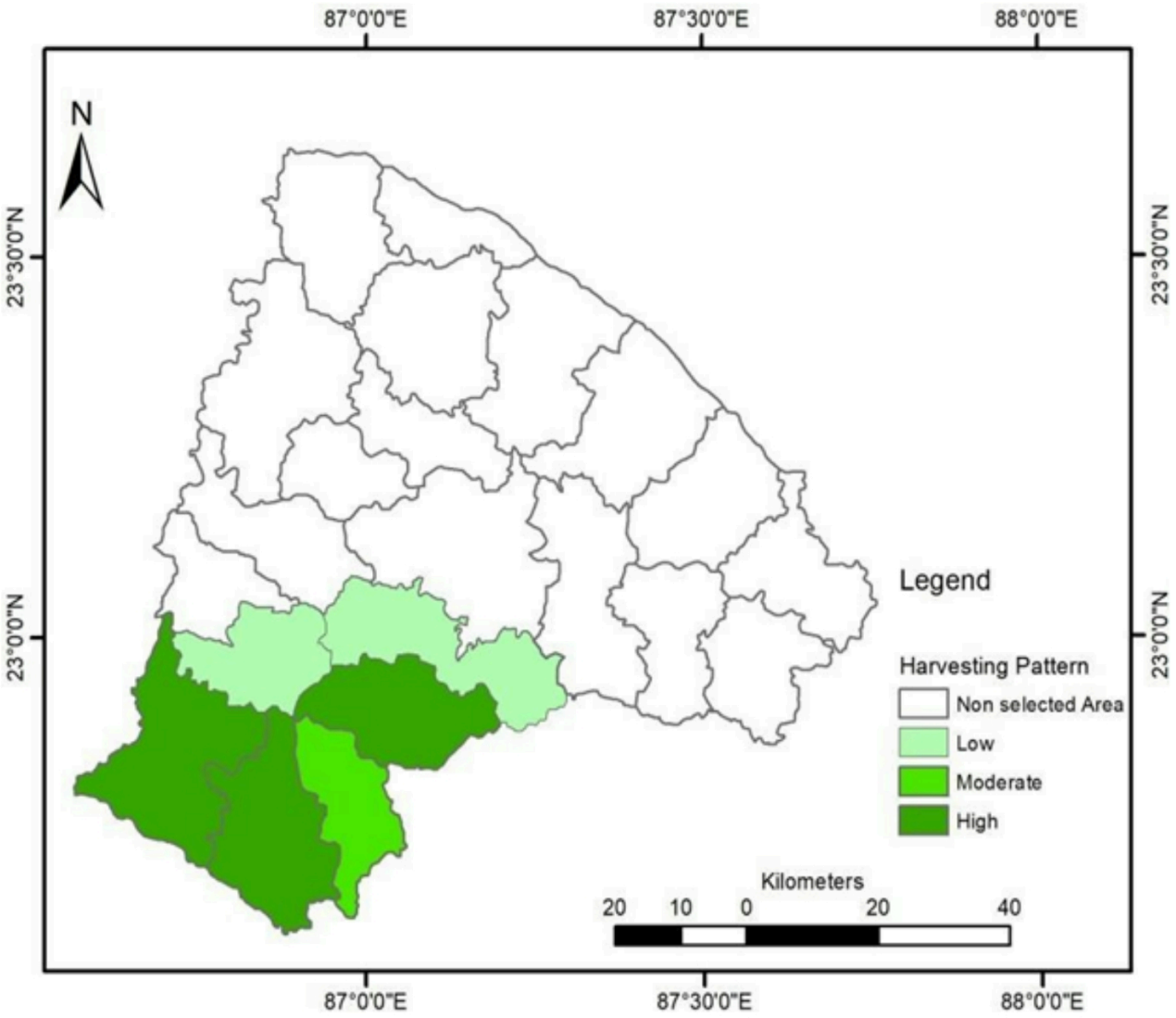


Figure 3

Dominant crop cultivation in selected CD Blocks

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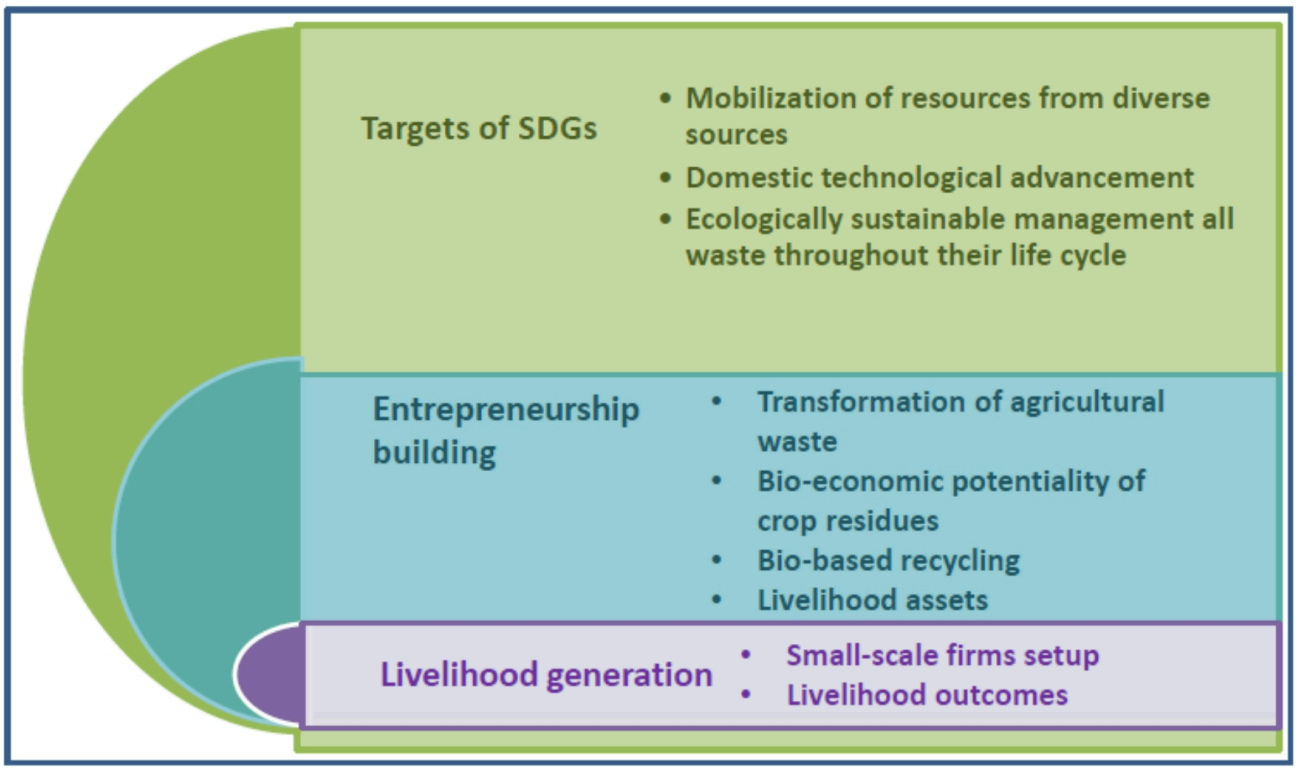


Figure 4

Sustainable waste management framework at the context of rurality

Prepared by the authors

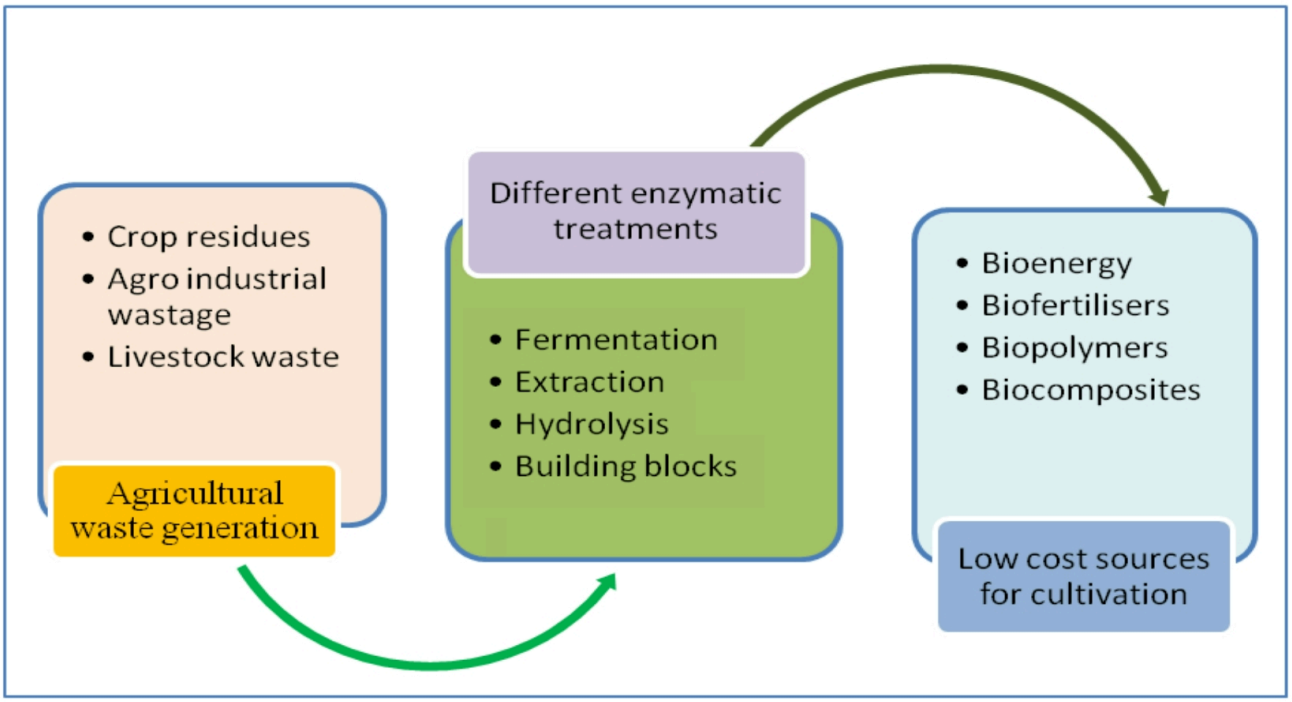


Figure 5

Relationship between waste treatment and low cost of production

Prepared by the authors