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Transforming Waste into Wealth: A Circular Economy Framework for Agricultural Residue Management in Tripura, India.

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ABSTRACT

Agricultural waste management in Tripura, a state with a predominantly agrarian economy, poses a significant environmental and socio-economic challenge. Predominant practices of open burning and indiscriminate disposal of crop residues lead to severe air pollution, soil nutrient loss, and greenhouse gas emissions. This paper proposes a paradigm shift by integrating Circular Economy (CE) principles to transform this agricultural "waste" into valuable bioenergy and bio-products. Through a mixed-methods approach incorporating GIS-based spatial analysis, comprehensive field surveys, and techno-economic case studies, this research identifies and quantifies crop residue hotspots, critically assesses prevailing management practices, and evaluates the potential for establishing a sustainable bioenergy ecosystem. The findings indicate that the annual biomass potential of approximately 50,000 tons can significantly contribute to the state's energy matrix, reduce environmental degradation, foster rural entrepreneurship, and enhance energy security. The study concludes with a robust policy framework to catalyze this transition towards a more sustainable and resilient agricultural system in Tripura

1. Introduction

Tripura, a jewel in India's northeastern region, is characterized by an economy deeply rooted in agriculture, engaging over 70% of its populace (Department of Agriculture, Tripura, 2023). The state's high cropping intensity and diverse agro-climatic conditions support the cultivation of staple crops like rice and jute, alongside a variety of horticultural products. However, this agricultural prosperity generates a substantial by-product: millions of tons of crop residues annually. The management of this agricultural waste remains rudimentary and unsustainable, with open field burning being a prevalent, low-cost solution for farmers (Kumar, 2024). This practice is a significant source of particulate matter (PM2.5 and PM10), black carbon, and other pollutants, contributing to the deteriorating air quality in the region and exacerbating global climate change (Singh, 2017). The linear "take-make-dispose" model is no longer tenable. In contrast, the Circular Economy model presents a transformative framework aimed at eliminating waste and continually using resources (Ellen MacArthur Foundation, 2019). In the context of agriculture, CE principles promote the valorization of crop residues—viewing them not as waste, but as feedstock for new production cycles. This aligns with global sustainability goals and India's national missions on clean energy and sustainable agriculture. For Tripura, with its limited fossil fuel resources and growing energy demands, leveraging its agricultural biomass is a strategic imperative. This paper elaborates on the potential of converting crop residues into bioenergy (e.g., biogas, bio-pellets, syngas) and bio-products (e.g., compost, biochar), thereby addressing the dual challenges of waste management and energy security while fostering rural economic development (Kapoor et al., 2020; Sadh et al., 2023).

2. Methodology

2.1 Study Area

The study encompasses the entire state of Tripura, covering its eight districts: West Tripura, Sepahijala, Khowai, Gomati, South Tripura, Dhalai, Unakoti, and North Tripura. The state's varied topography and agro-climatic zones, ranging from the low-lying plains to the hilly terrains, provide a microcosm of agricultural diversity ideal for this analysis.

2.2 Data Collection and Analysis

A triangulated methodology was employed to ensure robustness and validity:

a) *GIS-Based Spatial Analysis*: Spatial data on crop distribution and yield were procured from the Tripura Crop Map (NESDR). Using ArcGIS 10.8, these data were processed to estimate residue generation using crop-specific residue-to-product ratios (RPR) established by the Indian Council of Agricultural Research (ICAR, 2022).

b) *Field Surveys and Primary Data*: Structured interviews and surveys were conducted with 150 farmers across 30 villages and 15 agricultural extension officers. This qualitative data provided critical insights into existing waste management practices, socio-economic barriers, and farmer perceptions.

c) *Literature and Technological Review*: A comprehensive review of existing literature, government reports, and technology providers (e.g., SERVODAY) was conducted to assess viable conversion technologies and their applicability in the Tripura context.

2.3 Data Synthesis

The spatial data was synthesized to generate hotspot maps, while survey data was analyzed thematically. The biomass potential was calculated and matched with appropriate bioenergy technologies to assess feasibility.

3. Results and Findings

3.1 Spatial Distribution and Hotspots of Crop Residues

The GIS analysis unequivocally identified rice and jute as the primary contributors to the agricultural waste stream in Tripura. The spatial distribution is heterogeneous, with clear hotspots emerging.

Table 1: Estimated Annual Crop Residue Generation by District in Tripura.

District	*Predominant Crops*	*Estimated Residue (Tons/Year)*	*Classification*
West Tripura dist.	Rice, Jute, Vegetables	14,500	High Potential
South Tripura dist.	Rice, Jute	12,800	High Potential
Sepahijala dist.	Rice, Pineapple	9,200	Medium Potential
Gomati dist.	Rice, Horticulture	8,500	Medium Potential
Khowai dist.	Rice, Bamboo	6,100	Medium Potential
Dhalai dist.	Rubber, Rice	4,500	Low Potential

District	*Predominant Crops*	*Estimated Residue (Tons/Year)*	*Classification*
North Tripura dist.	Rice, Horticulture	4,200	Low Potential
Unakoti dist.	Rice, Oilseeds	3,800	Low Potential
Total		~63,600	

3.2 Current Waste Management Practices: A Linear Model of Loss

Field survey data painted a stark picture of unsustainable practices:

a) *Open Burning (65% of respondents)*: The most common method due to its low cost and convenience for land clearing.
b) *On-field Decomposition (20%)*: Allowing residues to decompose naturally, which is beneficial but slow and not universally practiced.
c) *Disposal in Water Bodies/Dumping (15%)*: Leading to siltation and water pollution.

This linear approach results in the annual loss of valuable organic carbon and nutrients, estimated to be worth millions of rupees, while simultaneously polluting the environment (Reddy, 2025).

3.3 Bioenergy and Bioproduct Potential: A Circular Alternative

The total technically harvestable residue is estimated at ~50,000 tons annually. This biomass can be channeled into various valorization pathways:

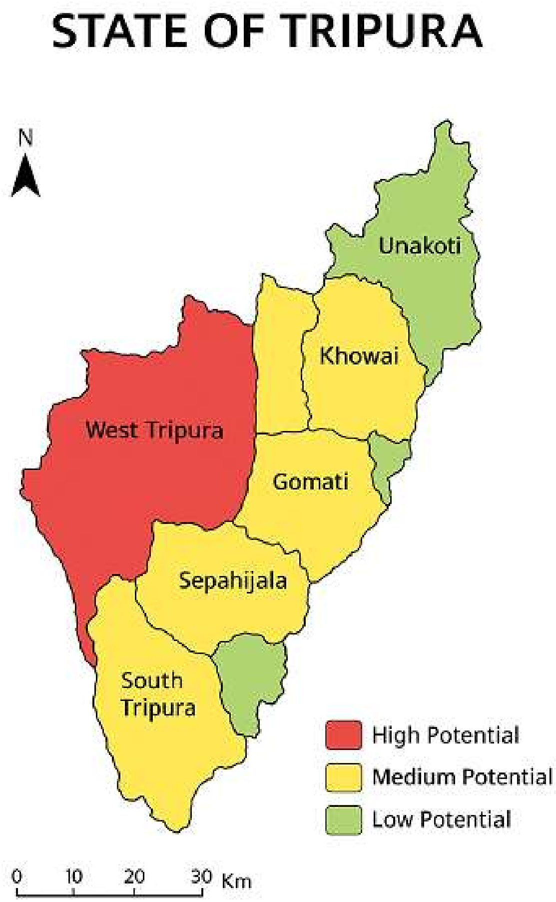


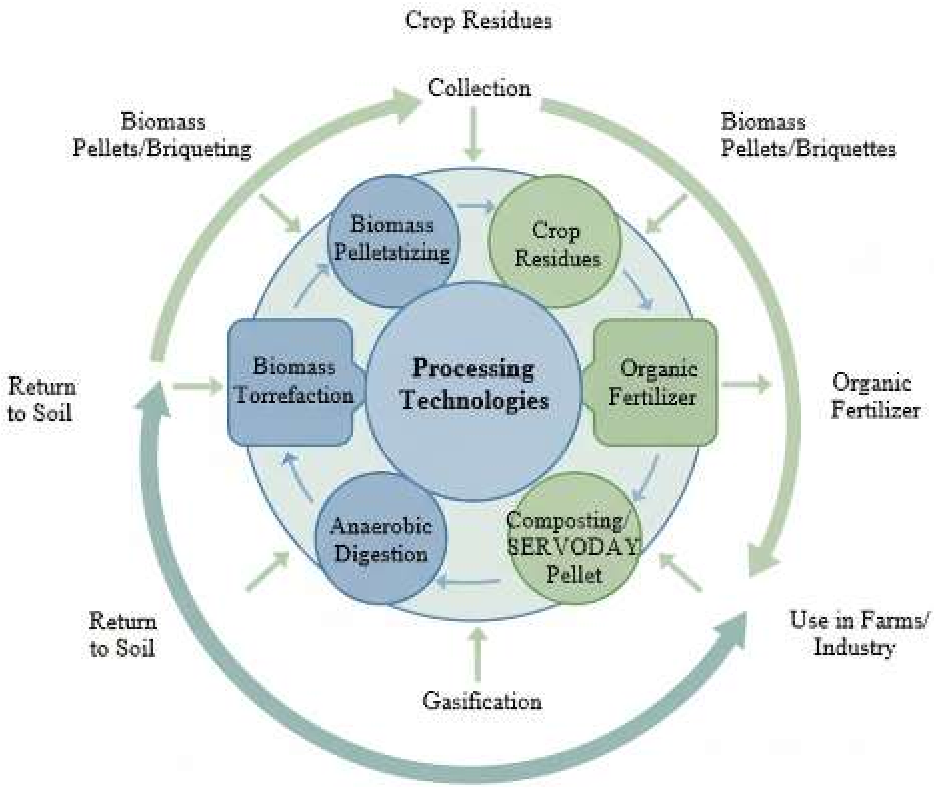
Fig.1: Annual Crop Residue Generation by different Agri-districts in Tripura.

Table 2: Potential Valorization Pathways for Tripura's Crop Residues.

Technology	*Output Product*	*Application*	*Key Advantage for Tripura*
Briquetting/Pelletizing (e.g., SERVODAY Pellet Mill)	Biomass Pellets/Briquettes	Replacement for coal in industrial boilers, domestic cooking	Easy to transport, high energy density

Technology	*Output Product*	*Application*	*Key Advantage for Tripura*
Biomass Torrefaction (SER VODAY Torrefaction Plant)	Bio-coal	High-grade solid biofuel	Superior energy content, water resistance
Anaerobic Digestion	Biogas, Organic Fertilizer	Cooking fuel, electricity generation, soil amendment	Produces both energy and fertilizer
Composting/Pelletizing (SERVODAY Compost Pellet Plant)	Organic Compost Pellets	Soil conditioner, reducing chemical fertilizer use	Enhances soil health, easy to apply
Gasification	Syngas	Electricity generation, thermal applications	Suitable for decentralized power

Figure 2: Proposed Circular Economy Model for Agricultural Waste in Tripura



4. Discussion: Weaving a Sustainable Future

4.1 Environmental and Climate Benefits

Transitioning to a CE model can yield profound environmental dividends. By preventing open burning, Tripura can significantly reduce its emissions of PM2.5, carbon monoxide (CO), and carcinogens like polycyclic aromatic hydrocarbons (PAHs). Furthermore, replacing fossil fuels with bioenergy creates a closed carbon loop, contributing to net-zero goals (Garg, 2024). The application of biochar and compost can rejuvenate degraded soils, enhance water retention, and sequester carbon, creating a positive feedback loop for agricultural sustainability (Thaha, 2025).

4.2 Socio-Economic Empowerment and Rural Development

The establishment of a biomass-based value chain can be a catalyst for rural prosperity.

a) *Job Creation*: From residue collection and logistics to plant operation and maintenance, new employment opportunities can be generated locally.

b) *Additional Farmer Income*: Farmers can transition from seeing residue as a disposal problem to a sellable commodity, creating a new revenue stream.
c) *Energy Access*: Decentralized bioenergy plants can provide reliable electricity and clean cooking fuel to remote, grid-constrained villages, enhancing the quality of life.

4.3 An Integrated Policy and Implementation Framework

To overcome barriers such as high initial investment costs, lack of supply chain infrastructure, and limited awareness, a multi-pronged policy strategy is essential. This framework must be aligned with the Tripura Energy Vision 2030 and national policies.

Table 3: Proposed Policy Framework for CE Adoption in Tripura

Policy Level	*Recommended Action*	*Key Stakeholders*
Financial & Fiscal	i. Capital subsidies for bioenergy units (30-50%) ii. Tax holidays for 5-10 years iii. Feed-in tariffs for bio-energy power	State Finance Dept., TREDA, MNRE
Infrastructure & Supply Chain	i. Establish Custom Hiring Centers (CHCs) for balers/chippers ii. Create decentralized collection & storage depots iii. Promote farmer-producer organizations (FPOs)	Agriculture Dept., TREDA, NABARD
Capacity Building & Awareness	i. Extensive farmer training on residue value ii. Demonstration projects in hotspot districts iii. Integrate CE concepts into agricultural education	KVKs, Agriculture Universities, NGOs
Research &	i. R&D on crop-specific valorization	State Universities, ICAR,

Policy Level	*Recommended Action*	*Key Stakeholders*
Development	technologies ii. Life Cycle Assessment (LCA) of different pathways	CSIR

5. Conclusion

Tripura stands at a crossroads. The current linear management of agricultural waste is a source of environmental degradation and economic loss. This study demonstrates that a transition to a Circular Economy is not just an environmental imperative but a viable socio-economic opportunity. By re-envisioning crop residues as a core resource, Tripura can build a self-sustaining ecosystem that generates bioenergy, improves soil health, creates green jobs, and bolsters energy security. The path forward requires concerted effort—a synergistic partnership between farmers, entrepreneurs, policymakers, and researchers. By implementing the recommended strategies, Tripura can transform its agricultural landscape, setting a benchmark for sustainable and circular agro-economies in the northeastern region of India and beyond.

References

- Department of Agriculture, Tripura. (2023). Annual Agricultural Report 2022-23. Government of Tripura.
- Ellen MacArthur Foundation. (2019). Completing the picture: How the circular economy tackles climate change.
- Garg, A. (2024). Biowaste to bioenergy nexus: Fostering sustainability and circularity. Journal of Environmental Management, 351, 119876. https://doi.org/10.1016/j.jenvman.2023.119876
- Indian Council of Agricultural Research (ICAR). (2022). Crop Residue Management with Conservation Agriculture. ICAR Technical Bulletin.
- Kapoor, R., Ghosh, P., Kumar, M., & Sengupta, S. (2020). Valorization of agricultural waste for biogas-based circular economy. Bioresource Technology, 318, 124036. https://doi.org/10.1016/j.biortech.2020.124036

- Kumar, M. (2024). An overview of crop residue management challenges, opportunities, and the way forward for sustainable food-energy security in India. Environmental Ecology, 30(October Suppl.), 71-85.
- National Institute of Rural Development and Panchayati Raj. (n.d.). Tripura Crop Map. NESDR. Retrieved from https://www.nesdr.gov.in/dataset/tripura-crop-map/resource/0b4d0a69-4c79-46cb-b351-23e245993bb7
- Reddy, A. S. (2025). Sustainable agricultural waste management in India. Journal of Cleaner Production, 450, 141234. https://doi.org/10.1016/j.jclepro.2025.141234
- Sadh, P. K., Duhan, S., & Duhan, J. S. (2023). Recovery of agricultural waste biomass: A path for circular bio-economy. Science of The Total Environment, 860, 160550. https://doi.org/10.1016/j.scitotenv.2022.160550
- SERVODAY. (n.d.). Rotary Drum Chipper: Efficient Biomass & Wood Processing for Bioenergy. Retrieved from https://woodchipper.in/
- Singh, J. (2017). Management of the agricultural biomass on decentralized power generation systems in India. Journal of Cleaner Production, 142, Part 4, 1235-1245. https://doi.org/10.1016/j.jclepro.2016.08.041
- Thaha, A. N., Prabowo, H., & Ogino, A. (2025). High impact biomass valorization for second-generation biofuels. Fuels, 5(1), 16-32. https://doi.org/10.3390/fuels5010002
- Tripura Renewable Energy Development Agency (TREDA). (2022). Tripura Energy Vision 2030 Roadmap. Government of Tripura.