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BIOECONOMY HUB: TOWARDS MORE ADVANCED SUSTAINABLE WASTE MANAGEMENT APPROACH FOR BANGLADESH

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ABSTRACT

Bangladesh faces increasing waste management challenges due to rapid urbanization and population growth. There is an urgent need for a more advanced and sustainable waste management system. This paper proposes the establishment of a Bioeconomy Hub to address these challenges by converting waste into valuable resources using circular economy principles. Our Bioeconomy model focuses on the 3Rs (Reduce, Reuse, Recycle) to create a sustainable waste management strategy to minimize environmental impact. By conducting sustainable waste management case studies in Sweden, India, and Denmark, we aim to demonstrate how Bioeconomy hubs could help achieve the Sustainable Development Goals (SDGs) through efficient waste management in Bangladesh. We recognize significant challenges, including technological and policy obstacles, and offer suggestions for implementing a bioeconomy-based waste management approach in Bangladesh. Drawing from global experiences is crucial in establishing a sustainable waste management system for Bangladesh's future.

***Keywords**: Bioeconomy Hub,3Rs (Reduce, Reuse, Recycle), Circular economy principles, Sustainable development goals (SDGs*

INTRODUCTION

Bangladesh is facing significant waste management challenges due to rapid urbanization and population growth. Currently, approximately 45% to 76% of waste is collected, with an average efficiency of around 55%. However, the existing infrastructure requires substantial improvement. Over the past thirty years, waste generation has doubled every 15 years, and poor segregation exacerbates the problem. Additionally, a considerable portion of the population lacks adequate waste disposal services. In response, the government has implemented the National 3R (Reduce, Reuse, and Recycle) Strategy; however, the system remains overwhelmed by increasing waste volumes, underscoring the need for a more sustainable approach (Ministry of Environment and Forests, 2010). Recycling methods in Bangladesh are ineffective, leading to significant waste management issues and environmental damage, particularly in urban areas (ASEF Summer University ASEF Education Department, n.d.). Waste is often disposed of in open landfills or rivers, which contaminates soil and water. This inadequate waste processing contributes to greenhouse gas emissions and strains natural resources, hindering sustainable urban development.

In Sweden, efforts are underway to establish a bioeconomy hub aimed at transitioning from fossil fuels to sustainable, bio-based resources. This initiative aligns with environmental goals to reduce greenhouse gas emissions and create a sustainable energy system. The framework focuses on integrating biomass from forestry into innovative processes for producing fuels, chemicals, and bio-based materials. This approach promotes responsible resource use, economic efficiency, and local employment. Regional hubs, such as those in Västernorrland and Värmland, exemplify this strategy by creating value-added wood products and fostering cross-industry collaboration (Jolly, n.d.).

Denmark is also making strides in the bioeconomy, addressing its substantial production of municipal waste, which averages approximately 800 kg per person—ranking among the highest in Europe. By adopting strategies centered around the circular economy and bioeconomy, Denmark aims to alleviate pressure on natural resources, align with the United Nations Sustainable Development Goals (SDGs), and transition towards a sustainable economic framework. Nonetheless, Denmark faces significant challenges in managing its high waste generation and developing effective recycling systems. Despite having a strong framework in place, the circularity rate in Denmark was only 4% as of 2023, which is below the global average (Joanna et al., n.d.).

India urgently needs to establish a bioeconomy hub to tackle significant waste generation, environmental pollution, and reliance on fossil fuels. Transitioning to a bioeconomy could convert

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waste into valuable renewable resources (Mohan et al., 2019). A key model for sustainable waste management is the "waste biorefinery," which employs a closed-loop system to transform waste into feedstocks for bioenergy, biofuels, and bio-based chemicals through biotechnological methods such as biomethanation, composting, and lignocellulosic refining (S et al., 2017).

A sustainable approach to waste management is essential for Bangladesh, given the rapid urban growth, population increase, and inadequate processing facilities that lead to pollution and health risks. By learning from Sweden, Denmark, and India, Bangladesh could establish a Bioeconomy Hub to implement circular economy principles. Sweden's resource optimization and Denmark's biowaste recycling focus on transforming organic waste into biofuels and fertilizers, thereby reducing reliance on fossil fuels and landfill usage. Additionally, India's waste biorefineries illustrate the economic benefits of bioproducts and renewable energy, turning waste from a burden into a valuable resource.

Our Bioeconomy framework emphasizes the 3Rs: Reduce, Reuse, and Recycle, with the goal of establishing a sustainable waste management system that minimizes environmental harm. This research includes case studies from Sweden, India, and Denmark to demonstrate how Bioeconomy Hubs can help Bangladesh achieve its Sustainable Development Goals (SDGs) by converting waste into valuable resources while promoting economic resilience and environmental sustainability.

LITERATURE REVIEW AND METHODOLOGY

Bangladesh generates a large amount of waste, especially in urban areas, due to rapid urbanization and population growth. By 2021, daily waste production reached approximately 33,574.3 tons, with individuals contributing an average of 0.52 kg each. Organic waste makes up about 79.5% of urban waste, while non-biodegradable waste, particularly plastics, accounts for around 7.89%. The factors such as, urban population of Bangladesh was 65 million in 2021 and is projected to reach 85 million by 2030, leading to increased waste production in cities like Dhaka and Chittagong. The per capita waste generation has risen from 0.31 kg per day in 1991 to 0.52 kg per day in 2021, correlating with GDP growth (Waste Concern, n.d.). The rise in plastic packaging usage and the growth of consumer-driven economies are contributing to higher levels of plastic and electronic waste, significantly impacting waste generation in the country. Landfills in Dhaka, such as Matuail, face significant environmental issues due to inadequate waste separation and leachate treatment, leading to water pollution and methane emissions. Only 2.43% of municipal waste is processed in regulated facilities. Incineration is underutilized and often lacks pollution controls, resulting in harmful emissions. The high moisture content from organic waste further complicates incineration, and much waste is either disposed of illegally or burned, exacerbating pollution. The application of the 3R principles (Reduce, Reuse, Recycle) is ineffective due to poor waste sorting, limited recycling facilities, and a lack of public awareness. Currently, only 15.59% of waste is recycled, with underutilization of plastics, paper, and organic materials (Waste Management Department (WMD), n.d.). The Sustainable Development Goals (SDGs) face challenges, particularly Goal 12 (Responsible Consumption and Production) and Goal 11 (Sustainable Cities). According to SDG 11.6.1, only 19.05% of wastewater and 2.43% of solid waste are treated properly, while SDG 12.5.1 highlights low national recycling rates due to ineffective collection systems (Climate Change and Disaster Statistics (ECDS), 2022). This research focuses on developing a bioeconomy hub in Bangladesh by studying global best practices in circular waste management, particularly in Sweden, Denmark, and India. These countries provide valuable insights into transforming waste into bioproducts, renewable energy, and fertilizers, highlighting effective frameworks for establishing circular economies.

Sweden’s Model

Sweden's waste management strategy exemplifies a circular economy through efficient waste collection, advanced recycling, and waste-to-energy (WtE) systems. Households must sort waste at the source, improving recycling quality and recovery rates. Non-recyclable waste is converted into electricity and district heating, significantly reducing landfill use to under 1%. Organic waste is processed through anaerobic digestion to produce biogas for vehicle fuel and biofertilizers. The "landfill ban" on organic and recyclable materials promotes waste diversion and recycling, reinforcing Sweden's commitment to environmental sustainability and resource reintegration.

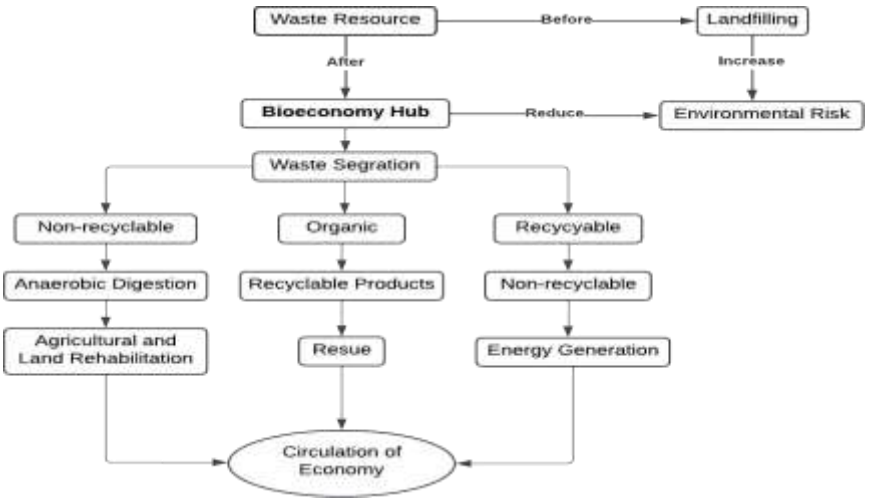

Figure 1. Centralized Waste-to-Energy and Recycling

The country generates around 164 million tons of waste each year, with approximately 141 million tons classified as mineral waste resulting from mining and construction activities (Abrahamsson, 2022). The overall waste amount, excluding mineral waste, is roughly 22.6 million tons, which includes 4.5 million tons generated by households. Sweden effectively handles municipal waste through bioeconomy centers and waste-to-energy facilities. About 56% of household waste is incinerated to recover energy, while 24% is processed for recycling. This approach reduces landfill usage to a mere 2%, bolstering the circular economy by converting waste into renewable energy and recyclable materials that hold economic value (Rajendran et al., 2013). The nation's centralized waste-to-energy model efficiently manages waste at scale, recovers energy, and reduces environmental impact. This model integrates biogas production from organic waste, supporting renewable energy goals while providing fertilizer for agriculture.

Denmark's Model

Denmark's biogas industry plays a crucial role in its circular economy by converting agricultural byproducts and food waste into renewable biogas through anaerobic digestion. This process not only provides clean energy but also produces organic fertilizers that improve soil health. Strict recycling and anti-landfill regulations enforce high material recovery rates, particularly for plastics and metals, reducing landfill waste and environmental hazards. Denmark's bioeconomy strategy encourages the development of bio-based products, which helps decrease reliance on fossil fuels. Government initiatives, including the "Green Tax Reform," support renewable energy, and heavy fines for non-compliance further promote waste diversion and resource recovery, fostering a sustainable circular economy (Korberg et al., 2020).

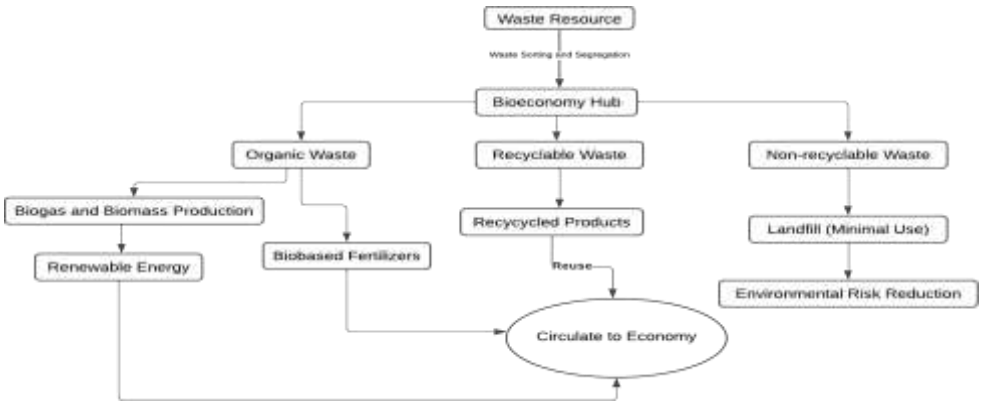

Figure 2. Biomass-Based Circular Economy and Policy-Driven Recycling

Denmark produces approximately 845 kg of waste per person annually, the highest in the EU, driven by strong economic activity and consumer habits. To manage this waste, Denmark has

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implemented effective bioeconomy strategies, recycling or repurposing about 69% of its total waste. The country employs advanced technology for biogas production and operates waste-to-energy facilities to convert organic waste into renewable energy (Bentsen et al., 2019). Non-recyclable waste is primarily handled through incineration in these plants, while the remainder is managed through recycling and composting efforts. Denmark's bioeconomy and circular waste management offer significant economic benefits. Waste-to-energy facilities reduce landfill reliance and support energy supply, while the recycling industry creates jobs and diminishes the need for imports, strengthening the local economy. It's model is marked by a robust policy framework that fosters a circular bioeconomy and enhances biogas production from organic waste. This system establishes a closed-loop economy that promotes sustainable agriculture, renewable energy, and markets for bio-based products.

India's Model

India has developed community-based biogas plants in rural and urban areas to convert organic waste into biogas and compost, reducing waste transport and offering local energy solutions. Biogas is used for cooking and transportation, while the compost supports agriculture. The system also involves sorting recyclable materials for the production of recycled plastics and metals. This decentralized waste management approach addresses regional needs, minimizes local environmental impacts, and promotes sustainability in areas lacking centralized waste processing.

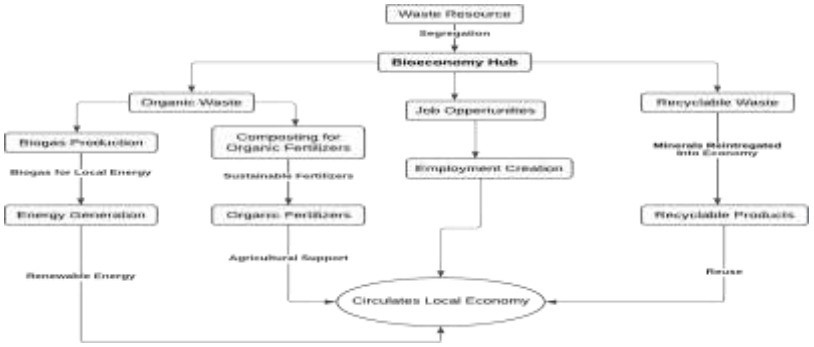

Figure 3. Decentralized and Community-Based Bioeconomy

India generates about 170,338 tonnes of solid waste daily, totaling around 62.1 million tonnes annually (S et al., 2017). However, only about 91,512 tonnes are treated each day, leaving a significant amount untreated. The Central Pollution Control Board (CPCB) monitors this issue as urban waste generation rises. Key initiatives in India's bioeconomy focus on waste-to-energy plants and composting, producing approximately 0.15 million tonnes of compost annually. Waste-to-energy technologies are increasingly implemented in urban areas to generate electricity and reduce landfill dependence, though specific data on waste processed by bioeconomy hubs is limited. Waste management initiatives are crucial for India's economy as they improve energy security and strengthen the recycling industry. Generating organic compost reduces reliance on chemical fertilizers, benefiting agriculture (Singh et al., 2024). Extended Producer Responsibility (EPR) policies are encouraging private investment and promoting a circular economy, which could result in job creation, reduced imports, and enhanced resource efficiency. India's focus on localized, community-oriented waste management tackles infrastructure deficiencies and promotes resource recovery in outlying regions, encouraging a bottom-up approach to the circular economy.

Inadequate infrastructure, including the absence of regulated landfills and modern recycling facilities, severely limits effective waste management, with only 2.43% of municipal waste being processed properly. Informal dumping and burning worsen environmental and public health issues by contaminating soil, air, and water. Despite these challenges, Bangladesh has immense opportunities to transform its waste management into a circular economy by leveraging its organic waste for biogas and biofertilizers through anaerobic digestion. This could reduce reliance on fossil fuels and chemical inputs in agriculture. Community-based composting and biogas initiatives, inspired by successful models in India, could address the needs of urban and rural populations while creating green jobs. Additionally, improving recycling infrastructure could enhance the recovery of materials like plastics, metals, and paper, promoting a sustainable resource loop.

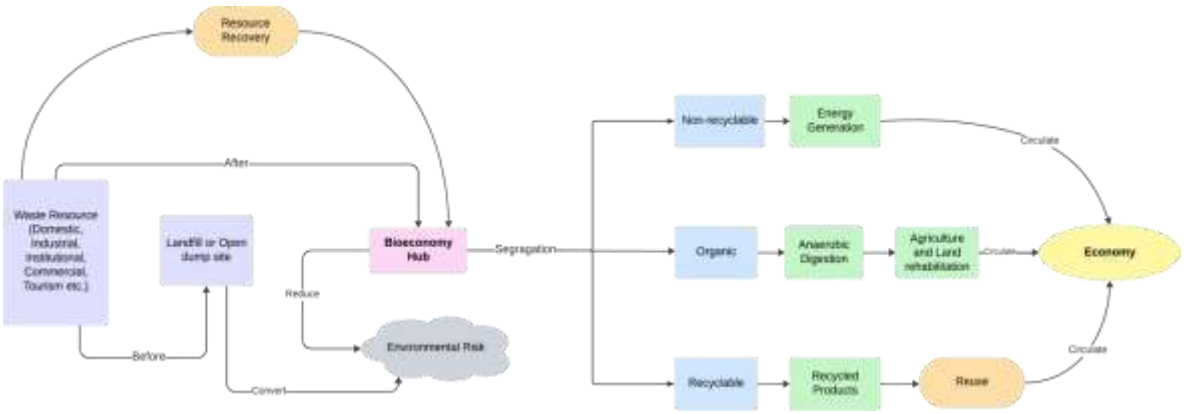

Figure 4.Proposed Bioeconomy-Hub based Waste Management System

Our Bioeconomy Hub initiative in Bangladesh will tackle the issues of waste management that arise from rapid urbanization and the increase in waste production. It encourages a circular economy by mandating the segregation of waste at the source, categorizing it into organic, recyclable, and non-recyclable types. This program includes a color-coded collection system and public awareness efforts designed to improve waste sorting and promote the 3R principles: Reduce, Reuse, Recycle. The framework generates biogas and biofertilizers, which helps to reduce reliance on fossil fuels and synthetic fertilizers, while recyclable materials are treated at state-of-the-art recycling facilities. Waste- to-energy (WtE) plants are essential for managing non-recyclable waste that has a high calorific value. These plants employ advanced pollution control methods to produce electricity while minimizing harmful emissions. Furthermore, the ash generated from the incineration process can be repurposed for construction or landfill rehabilitation, fostering resource efficiency. By redirecting waste away from landfills and dumps, the hub seeks to lower pollution and environmental harm, thereby satisfying the “Reduce” component of the 3R framework (Rodriguez-Anton et al., 2019). Organic waste is converted through anaerobic digestion, generating biofertilizers that enhance agricultural productivity, improve soil health, support sustainable land use (SDG 15), and encourage responsible consumption and production (SDG 12). Additionally, the recycling of valuable materials lessens the need for raw resources, aligning with sustainable urban development objectives (SDG 11) and climate action goals (SDG 13) by reducing greenhouse gas emissions (Ferraz & Pyka, 2023). The hub not only produces renewable energy from non-recyclable waste—contributing to affordable and clean energy targets (SDG 7)—but also boosts economic resilience by reintegrating resources into the economy. This approach offers Bangladesh a scalable model for a circular economy that promotes sustainable urbanization, efficient waste management, and economic sustainability.

Community-driven initiatives are essential in the BH model, particularly for peri-urban and rural areas. They include small-scale biogas plants and composting systems for managing organic waste, inspired by successful examples in India. A real-time waste tracking system monitors waste collection and recycling, supported by regulations can promote the 3R principles and corporate responsibility. Bangladesh has the potential to develop a sustainable and inclusive BH model by integrating Sweden’s infrastructure, India’s community-focused strategies, and Denmark’s bioeconomy innovations.

RESULT AND DISCUSSION

The establishment of a Circular Bioeconomy Hub (CBH) in Bangladesh aims to reduce environmental threats by promoting the 3R principles (Reduce, Reuse, Recycle) and fostering a circular economy. Currently, only 2.43% of municipal waste is processed in regulated facilities, leading to significant contamination and methane emissions. The CBH model proposes redirecting organic waste to anaerobic digestion plants and transforming non-recyclable waste into electricity through waste-to-energy (WtE) systems, thereby alleviating landfill pressure and enhancing sustainable practices. Key objectives include increasing the current recycling rate of 15.59% through advanced facilities and integrating informal waste workers. The model aligns with global Sustainable Development Goals (SDGs) and aims to boost the percentage of waste processed in regulated facilities to 25% over the next decade. Challenges include policy deficiencies, limited technology access, and public awareness of waste management practices. Overcoming these obstacles requires governmental support, stakeholder engagement, and community education. Opportunities for the CBH include public-private partnerships, community composting, and the formalization of informal waste workers, which can

enhance material recovery and create green jobs. Adapting successful strategies from countries like Sweden and Denmark can help Bangladesh build a sustainable waste management framework.

CONCLUSION AND RECOMMANDATION

The Circular Bioeconomy Hub (CBH) in Bangladesh aims to tackle waste management issues by utilizing the large volume of organic waste, which constitutes 79.5% of urban waste. It seeks to reduce environmental threats like methane emissions and water contamination, aligning with global Sustainable Development Goals (SDGs) such as SDG 12, SDG 7, and SDG 11. The CBH can enhance economic resilience through the creation of green jobs, improved resource efficiency, and renewable energy production. While challenges such as inadequate infrastructure, policy gaps, and low public awareness exist, strong policy support, community engagement, and international collaboration can drive sustainable economic development and serve as a model for other developing nations. Some recommendations:

- Implement mandatory waste separation for households, industries, and municipalities. Enhance Extended Producer Responsibility (EPR) for packaging and electronic waste. Establish strict rules promoting the 3Rs and enforce penalties for poor waste disposal.
- Develop modern waste-to-energy plants with pollution control systems for non-recyclable waste and invest in advanced recycling technologies, such as chemical recycling and biogas production.
- Promote small-scale composting and biogas systems in rural areas, and integrate informal waste workers into networks with training, fair pay, and safety measures.
- Provide financial incentives like subsidies and tax benefits to boost private investment in recycling and renewable energy. Promote public-private partnerships (PPPs) for developing and managing bioeconomy hubs.
- Promote nationwide initiatives for the 3R principles and waste separation, highlighting the economic and ecological benefits of waste recovery.

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