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Rebranding Bioenergy and Energy Efficiency for Rural Energy Sector of Bangladesh

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Abstract

This paper examines the vital role of biomass and biogas as sustainable energy sources for rural areas in Bangladesh and South Asia, where energy needs are primarily met through direct combustion for cooking, agricultural processing, and small-scale industries. The study highlights the urgency for policy reforms and technological advancements to promote renewable energy beyond solar electricity, particularly in regions heavily dependent on imported fossil fuels. One key approach is diversifying biomass sources, including agricultural residues, municipal solid waste, and byproducts from agro-industrial processes. The paper emphasizes the potential of biogas production from various biodegradable waste streams. These include animal excreta, food waste rich in starch, and wastewater from industries, offering a renewable fuel option for rural households and small industries. Additionally, it explores the recovery of energy from high-temperature wastewater in sectors such as textiles and food processing industries. The findings emphasize the need to integrate renewable energy solutions into regional energy policies to support sustainable development.

Keywords: Biomass energy, biogas production, renewable energy, energy recovery

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Introduction

The application of renewable energy more often or not to the public at large and policymakers is limited to solar and the generation of electricity. Solar electricity has a significant role to play in the world's shift to the new nexus of sustainable growth. Rural electrification has seen substantial growth but it is important to understand that electricity is a highly valued energy and should be reserved in its use to high value, especially when as a nation Bangladesh is dependent on imported fossil fuel to operate its power plants(Khan et al., 2023). Over the past fifteen years, the policy was to install coal or diesel-fired power plants to generate electricity and with an emphasis on the supply of electricity to rural Bangladesh.

In the singularly focused policy of electricity generation capacity increase, what is missed is that a significant fraction of the energy consumption in South Asia is used for direct combustion for cooking and also energy for industrial use (Reza et al., 2021). In rural environments, the dependency is still on biomass or fossil for direct combustion to meet the needs of daily cooking, and agro-processing and small to mid-scale rural industries also are dependent on biomass augmented with fossil fuel to thermal energy requirements. Policymakers need to understand for sustainable development the importance of the direct combustion of biomass or biomass-derived energy used by the majority of the population who live in rural Bangladesh. The policies and the technology enhancement have to focus on fostering this need of the hour for sustainable rural development. There are three areas that need to be enhanced: a. Expanding sources of biomass for rural energy use, b. conversion of imported fossil fuel-based power plants to use biomass, c. biogas production from waste to energy, and promotion of energy recovery and energy-efficient processes.

Alternative Renewable Sources of Energy

Expanding the source of biomass

The biomass used for direct burning to produce energy mainly for cooking and small-scale agro-based processes is limited to firewood, foraged leaves and twigs, dried cow dung or cow dung wrapped jute plant

stem, and in areas where these are not available, hay is the abundant but unenthusiastic substitute due to its low bulk density requiring larger amount in volume to produce units of thermal energy(Rafiq, Apurba, & Khandaker, 2024b). What is ignored and needs to be brought into the mix as mass-scale combustibles are waste agricultural products such as grass, rise husks, and dried water hyacinth (Rafiq, Sultana, et al., 2024; Rafiq & Khandaker, 2024). To the combustible mix mass scale use of agro-processing waste such as bagasse the sugar cane stem generated from sugar processing industries in mass scale, and from the timber industry sawdust wood chips needs to be utilized. The municipal solid waste generated from households that are combustible needs to be brought into the mix of biomass as a sustainable fuel option (Bashar et al., 2024; Rafiq, Apurba, & Khandaker, 2024a).

The drawback of low bulk density that is mass to volume ratio needs to be addressed if such waste will be readily accepted as a viable fuel option for domestic and small-scale agro-based industries. The process of making these options denser such that Kilo Joules per Kilogram of biomass is high can be achieved by simple compaction augmented by binding agents such as simple cow dung, starch, and molasses that are readily available in rural environments.

Figure 1: Low density straw or hay also used as combustible biomass in rural Bangladesh for cooking

Biomass is a sustainable energy source and renewable with the mere fact that it is grown and also sequesters carbon dioxide as the plant grows in essence is a net zero emitter of carbon dioxide and has the potential to replace imported fossil fuels such as coal, deiseal, and natural gas common fuels for the boilers in power plants of Bangladesh should be phased out and replaced with biomass as their combustible fuel source to power their boilers. What is needed on a mass scale is to have an organized supply chain to acquire agro-based waste products, compaction to energy-dense biomass, and transport to the power plants to meet the energy security needs of countries in South Asia such as Bangladesh and Nepal. This is more pronounced for Nepal which is a landlocked country.

Biogas from solid and wastewater

Biogas generation in rural South Asia is prevalent yet not fully utilized for it is only utilized to produce biogas from cow dung. This is limited by the ability of cow dung to support biogas digesters. What is needed as in the case of biosolids as fuel discussed in the earlier section is the diversification of source feed to produce biogas that is mainly methane through anaerobic transformation of microbially degradable organic substrate (Khandaker & Seto, 2010; Rafiq, Apurba, Rahman, et al., 2024; Sarker et al., 2018). Starch from cooked rice that is commonly decanted and discarded as waste in most rural and urban households in Bangladesh, Nepal, and other South Asian countries can be easily transformed to biogas by anaerobic degradation in cow dung seeded reactors, to these other biodegradable organics such as cooked rice and bread waste even easily degradable high in starch wastes can be added. Not only cow dung but chicken excreta, goat excreta, and pig excreta are excellent source substrates for anaerobic reactors to produce biogas.

In industrial-scale wastewater generated from sugar mills, food processing plants, breweries, and distilleries, petrochemical plants that have highly soluble organic matter as its constituents can be used as an excellent feed for anaerobic biotreatment to not only produce biogas but also as a method of wastewater treatment (Rafiq, Apurba, Rahman, et al., 2024; Sahil Rafiq et al., 2024). The potential for biogas generation is high and the biogas can be utilized as direct combustible fuel for home cooking and furnace gas or treated to take out impurities such as Sulphur dioxide

and siloxanes to produce impurity free biogas that can be used in complex machines such as internal combustion engines and gas turbines to produce electricity. In essence, anaerobic biotransformation of biodegradable waste be it solid or liquid can serve to produce biogas that will serve as renewable fuel and when harnessed can go a long way to provide the energy needs of a nation (Khandaker and Talha 2016).

Energy Recovery and Energy Efficient processes

Energy Kilo What Hour (KWh) of energy recovered or saved is KWh of energy produced without having to use fossil fuels that contribute to global warming, which South Asian countries such as Nepal and Bangladesh are affected (Rafiq et al., 2023). A lot of our processes generate high-temperature wastewater that is discharged and can be recovered using heat exchangers and then used to heat again through heat exchangers to heat process water (Haque et al., 2024; Rafiq, Apurba, & Khandaker, 2024; Rafiq et al., 2024). In the context of Bangladesh, this is especially true for textile processing wastewater and food processing wastewater. Even power plants discharge high-temperature wastewater from which energy can be retrieved. In the same topic of wastewater energy recovery and treatment, existing processes use a lot of energy to provide aeration required for treatment using biological processes, this can be greatly negated using anaerobic acetogenic processes and physiochemical processes based on locally available materials (Khandaker et al., 2020; Reza, Moshiur, & Salima, 2021). Sustainable operation through energy efficient and energy recovery processes can greatly enhance energy decoupling and thereby provide energy security for a nation (Hao, Li, et al., 2019; Hao, Wang, et al., 2019; Hawley & Fenner, 2012).

Future Challenges and Research Gap for Expanding Renewable Energy in Rural Bangladesh

One of the primary challenges is developing a reliable and efficient supply chain for sourcing, processing, and transporting biomass for energy generation. While agro-processing waste, sawdust, and municipal solid waste have the potential to become significant sources of fuel, the logistical challenges of collecting, compacting, and transporting these materials

across rural regions remain substantial. Furthermore, the cost of converting low-density materials into energy-dense biomass may be prohibitive without the development of affordable technologies. While biogas production from cow dung is already practiced in some rural areas, scaling up biogas generation using diverse feedstocks such as food waste, agricultural residues, and wastewater presents several challenges. First, the infrastructure for large-scale biogas production is underdeveloped, requiring significant investment in digesters, anaerobic reactors, and the necessary technical expertise for their maintenance. Moreover, the availability of feedstock throughout the year and the optimization of anaerobic digestion processes to handle diverse organic waste needs to be further investigated. The success of these renewable energy technologies depends on supportive policy frameworks that encourage innovation, investment, and scaling.

Currently, renewable energy policies in Bangladesh have been largely focused on electricity generation through solar and fossil fuel-based power plants. To address rural energy needs, policymakers need to expand their focus to include decentralized biomass and biogas solutions, ensuring access to financing for local communities and industries, and incentivizing private sector participation. Converting imported fossil fuel-based power plants to use biomass is an ambitious goal, but it poses several technical and financial challenges. These include adapting existing boilers and power generation systems to handle biomass fuels, ensuring the reliability and consistency of biomass supply, and addressing potential resistance from stakeholders who are invested in fossil fuel-based technologies. Moreover, the need for trained personnel to manage these new systems adds an additional layer of complexity.

Energy recovery from wastewaters, particularly high-temperature discharges from textile and food processing industries, offers significant potential for reducing energy consumption and increasing energy efficiency. However, the development of appropriate heat exchangers and energy recovery systems for diverse industrial applications is still in the early stages. The challenge lies in adapting these technologies for use in rural industries with limited access to advanced infrastructure and technical knowledge. While biomass is considered a renewable energy source, the

sustainability of large-scale biomass utilization depends on responsible resource management. Overharvesting of biomass, deforestation, and soil degradation due to intensive farming practices could undermine the long-term viability of biomass as an energy resource. Therefore, careful planning is required to ensure that biomass use does not deplete natural resources or contribute to environmental degradation. In rural Bangladesh, there is often limited awareness of the potential benefits of alternative renewable energy sources like biomass and biogas. Educating the public about the advantages of these energy sources, their environmental benefits, and the methods for utilizing them effectively is crucial for ensuring widespread adoption. Moreover, there is a need for training programs to empower local communities and industries with the technical skills required to maintain and operate renewable energy systems. Many rural communities may struggle to afford the upfront costs of biomass energy systems or biogas digesters, especially in economically disadvantaged areas. To address this, government subsidies, microfinancing, and partnerships with private companies may be needed to make renewable energy technologies financially accessible to those in need. Furthermore, ensuring the economic viability of these systems over the long term, with competitive energy pricing compared to traditional fossil fuels, remains a key challenge.

Bangladesh is one of the most vulnerable countries to the impacts of climate change, including flooding, cyclones, and rising sea levels. The increasing unpredictability of weather patterns can affect the availability of biomass resources, particularly agricultural residues, and limit the effectiveness of renewable energy solutions. Developing climate-resilient energy systems that can adapt to these challenges is a pressing need for future energy policies. To succeed in the transition to a more sustainable energy future, collaboration is essential. This includes partnerships between government agencies, the private sector, research institutions, and local communities. Overcoming silos and fostering dialogue among stakeholders will be crucial for addressing the diverse challenges of scaling up biomass and biogas energy systems, and ensuring they are integrated into the broader energy landscape of Bangladesh.

Addressing these challenges will require innovative solutions, robust policy frameworks, significant investment in infrastructure, and active community engagement to ensure a sustainable and equitable energy future for rural Bangladesh.

While renewable energy solutions, particularly biomass, biogas, and energy recovery processes, have been recognized as vital components in enhancing energy security and promoting sustainable development in rural Bangladesh, several critical research gaps persist. First, while existing studies have explored the potential of various biomass sources, such as agricultural waste, municipal solid waste, and agro-processing residues, there remains limited research on the large-scale integration and supply chain development for these resources. Understanding the logistical challenges of biomass collection, compaction, and transport is essential to make biomass a viable energy source in rural areas.

Second, the current body of research largely focuses on specific feedstocks, such as cow dung for biogas production, but the diversification of feedstock for biogas generation (including food waste, industrial effluent, and animal excreta) has not been comprehensively studied. A deeper understanding of optimizing anaerobic digestion processes to accommodate diverse organic waste materials at a larger scale is essential for improving biogas production and its economic feasibility. Moreover, the integration of biomass into existing fossil fuel-based power plants, particularly coal or diesel-fired plants, has not been thoroughly studied from both a technical and financial perspective. Research is needed to understand the feasibility, technical challenges, and investment requirements for converting these plants to use biomass as an alternative fuel source. Finally, despite the growing recognition of biomass and biogas as key players in the transition to sustainable energy, there is a significant gap in the literature concerning the long-term sustainability of biomass as a renewable energy resource. Overharvesting and improper management of biomass sources could lead to environmental degradation, making it critical to study the impacts of large-scale biomass utilization on ecosystems and soil health.

Addressing these gaps will provide valuable insights into the development of integrated renewable energy solutions that can help rural Bangladesh move toward a more sustainable and energy-secure future.

Conclusion

Renewable energy has the potential to play a transformative role in addressing the energy needs of rural Bangladesh while contributing to environmental sustainability and energy security. This paper underscores the critical importance of shifting focus from centralized electricity generation to decentralized renewable energy solutions, particularly through the use of biomass, biogas, and energy recovery processes.

Biomass remains a viable energy source for rural households and small-scale industries due to its abundance and carbon-neutral properties. However, its full potential can only be realized through improvements in collection, processing, and densification techniques, as well as by integrating diverse agricultural and municipal waste into the biomass fuel supply chain. Similarly, biogas production from a variety of feedstocks—ranging from livestock excreta to food waste and industrial wastewater—offers significant opportunities for providing a clean and sustainable energy source. Scaling these technologies will require investments in infrastructure, enhanced technical expertise, and strong policy support.

Energy recovery and efficiency improvements, particularly in industrial wastewater and process heat management, can significantly reduce reliance on fossil fuels. These strategies not only reduce greenhouse gas emissions but also offer cost savings and improve energy availability in resource-constrained regions.

Despite the promising outlook, several challenges remain, including the development of robust supply chains, technical barriers to scaling up biogas production, integration of biomass into existing power infrastructure, and the need for enabling policies. Addressing these gaps will require collaborative efforts among policymakers, researchers, industries, and local communities.

By expanding renewable energy technologies and prioritizing energy-efficient processes, Bangladesh can build a resilient and sustainable energy framework tailored to its rural population. This transition will not

only enhance energy security but also contribute to the country's broader goals of sustainable development and environmental conservation.

Conflict of Interest: The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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