Methodology for assessment of biogas technology usage in the hilly regions of Himachal Pradesh using CART model on survey data

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Renewable energy, particularly biogas, stands as a pivotal solution amidst global energy challenges, offering sustainable alternatives to fossil fuels. Himachal Pradesh, a mountainous region in North India, exemplifies this shift with a growing network of biogas plants to alleviate energy poverty and environmental degradation. However, the operational success of these biogas plants remains precarious, marked by a significant non-functionality rate. The present study examines 180 biogas plants across Hamirpur and Kangra districts, revealing that 74.81% of these plants are non-operational. Key reasons include inadequate cattle populations, lack of interest and constructional issues. Classification and regression tree (CART) model was used to identify the reasons and found that inadequate cattle population, coupled with socio-economic factors like declining interest and migration were primary barriers to sustained biogas plant functionality. These findings highlight the urgent need for targeted interventions, including technological upgrades and policy reforms, to enhance biogas plant sustainability and foster rural energy resilience in hilly terrains. By addressing these challenges, Himachal Pradesh can harness its rich agricultural resources more effectively, thereby advancing towards a greener and more sustainable energy future and informing policymakers on enhancing biogas technology's effectiveness in addressing energy poverty and promoting sustainable practices in rural communities.

Keywords: Biofuel, biogas technology, classification and regression tree, hilly regions, machine learning, renewable energy.

RENEWABLE energy sources constitute an indispensable climate change and the growing dependence on renewable energy have spurred researchers to explore biogas production[2]. An estimated 3 billion people worldwide lack access to modern energy services and often rely on traditional biomass fuels such as wood, manure, and agricultural waste (United Nations Development Program, 2009). Wood serves as a significant fuel source in rural areas, amounting to approximately 3.2 million tonnes annually, a practice observed in around 49% of households across India[3]. Notably, wood fulfils nearly 70% of the population's requirements for heating and cooking purposes[4]. However, this widespread reliance on wood fuel has substantially depleted forest resources, leading to deforestation and adverse climate impacts[5]. Only 8% of global energy production currently emanates from renewable sources, while a significant portion (84%) is derived from non-renewable sources[6]. This underscores the imperative to explore sustainable alternatives to address environmental concerns and mitigate the impact of resource-intensive practices on ecosystems and climate dynamics. Replacement of fossil fuels and untreated traditional solid biomass (wood) with clean bio-fuels such as biogas, for cooking, lighting, and electricity generation would also help in curtailing greenhouse gas emissions[5,7,8].

Biogas, as a renewable energy source, presents a substantial opportunity to address environmental challenges like resource depletion and pollution[9], and it significantly contributes to alleviating energy poverty in rural areas of developing countries. Biogas is produced through the anaerobic digestion of organic materials such as agricultural waste, manure, municipal waste, plant material, sewage, green waste and food waste. It typically consists of 55–7 methane (CH_4) and 30–45% carbon dioxide (CO_2)