

GOBOR GAS AS AN ALTERNATIVE SOURCE OF CLEAN ENERGY FOR FOREST-FRINGE COMMUNITIES: A CASE STUDY OF MANBAZAR II BLOCK, PURULIA DISTRICT, WEST BENGAL

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ABSTRACT

Forest-fringe communities depend increasingly on forest resources as their primary source of fuel which results in greater deforestation and biodiversity destruction and environmental damage. The research investigates whether gobor gas which is derived from cattle dung serves as a sustainable energy solution. We adopted a mixed-methods approach to collect data from 150 households through surveys, interviews, and systematic observation of their daily activities. The study shows that 78% of households use forest fuelwood for their energy needs while the presence of 4 to 6 cattle per household enables them to produce substantial biogas energy. The statistical findings demonstrate that cattle ownership and literacy rates and government assistance all affect people's willingness to use gobor gas ($p < 0.05$). The adoption of this system is expected to reduce fuelwood consumption by 60–70 percent, significantly decrease indoor air pollution, and enhance women's health and time management capacities. Biogas slurry increases crop production by 15 to 20 percent. The research demonstrates that decentralized plants must work together with community-based systems and financial support and education programs to introduce gobor gas as a sustainable energy source for forest protection.

KEYWORDS

Gobor gas, Biogas adoption, Forest-fringe communities, Fuel wood dependence, Sustainable energy, Forest conservation, Socio-economic resilience

1. INTRODUCTION

Sustainable development requires energy as its essential driving force, but increasing worldwide fuel requirements have created issues which damage the environment and cause climate change and resource exhaustion. According to the International Energy Agency (IEA) (2022), around 2.3 billion people worldwide still rely on traditional biomass fuels—such as wood, crop residues, and animal dung—for their cooking and heating needs. This usage leads to deforestation and greenhouse gas emissions which create dangerous health risks for women and children through the dangers of indoor air pollution. Biogas represents a renewable energy technology which has developed into a sustainable energy solution that provides three benefits which include energy protection and environmental protection and social development (UNEP 2021). Rural areas in India continue to rely heavily on fuelwood and biomass because Indian society has developed this practice into a common energy source. Almost 40 percent of Indian households still rely on traditional biomass for cooking, while rural households represent the largest portion of this usage

(Census of India 2011; MoPNG 2020). The Government of India has introduced several programmes to address this issue, including the National Biogas and Manure Management Programme (NBMMP), which promotes biogas plants at both household and community levels (Ministry of New and Renewable Energy (MNRE), 2021). Biogas provides two benefits which include decreasing deforestation pressure and enhancing soil fertility through organic manure production, which connects clean energy solutions to sustainable agricultural practices. West Bengal shows the same situation because many rural families in the state use firewood and cow dung cakes as their primary energy source for everyday needs. The India State of Forest Report indicates that the state faces serious challenges due to extensive fuelwood collection, which places increasing pressure on forest ecosystems (Forest Survey of India (FSI), 2021). The government has put solar and biogas and other renewable energy sources into effect but people in different districts choose to use these technologies because their social and environmental conditions differ (WBREDA, 2020). The western part of West Bengal contains Purulia district which ranks among the most resource-deprived areas of the state. The region features settlements near forests while its people belong to indigenous tribes who depend on forest resources for both their energy needs and their work activities. Research shows that more than 70% of rural households in Purulia depend on forest fuelwood as their main cooking and heating source (Basu & Banerjee, 2018; District Statistical Handbook, 2020). The district maintains a substantial livestock population which exists because cattle breeding serves as a fundamental component of village financial systems. The process produces gobar gas (biogas) from the cattle dung which serves as the main raw material input in the production line. The promotion of gobar gas usage in Purulia through its implementation in forest-fringe areas such as Manbazar II Block will create a positive impact on three areas: forest protection, energy access for households, and community economic development. The current research investigates how gobar gas (biogas) can serve as an environmentally friendly energy solution for communities living near forests in Manbazar II Block which exists within Purulia District. The study commences by assessing how rural households depend on forest fuelwood and which cattle resources exist for biogas production. The research aims to determine which socio-economic and demographic factors affect household decisions about adopting gobar gas technology. The study assesses how biogas systems benefit the environment and human health by evaluating their impacts on forest resources and indoor air quality. The research investigates how biogas slurry benefits agriculture through its advantages over traditional chemical fertilizers by demonstrating its ability to improve crop yield and soil quality. The study presents strategies and policy measures which will help increase gobar gas adoption while protecting forests and improving energy access for rural communities.

2. LITERATURE REVIEW

Biogas originates from the anaerobic digestion process which converts animal manure and organic waste materials into biogas. The world recognizes biogas as a decentralized renewable energy system which delivers clean cooking fuel and decreases household air pollution while producing agricultural nutrient-rich slurry (Katuwal & Bohara, 2009; Smith et al., 2014). Global assessments and meta-reviews indicate that household- and community-scale biogas systems can significantly reduce fuelwood consumption and greenhouse-gas emissions, provided that feedstock supply is reliable and maintenance is adequate (IEA, 2020; Bhattacharya et al., 2015). The realized benefits of biogas systems depend on appropriate plant sizing, consistent feedstock supply, user training, and post-installation support (Creswell & Plano Clark, 2018). Multiple field research studies demonstrate that anaerobic digestion produces biogas slurry which enhances soil organic matter and improves nutrient availability and increases crop yields when farmers use it to replace or supplement chemical fertilizers (Singh et al., 2017; Ghosh, 2020). The degree of yield improvement depends on the combination of crop type and slurry application rates and timing and local agronomic management practices. Additionally, greenhouse-gas trade-offs, such as methane versus nitrous oxide emissions, are influenced by slurry handling and farm-level

practices. In India, government programmes have supported both family- and community-scale biogas initiatives for decades. The National Biogas and Manure Management Programme (NBMMP), along with recent MNRE initiatives and the GOBARdhan scheme, explicitly aim to provide clean cooking fuel, promote farm nutrient recycling, and develop circular-economy outcomes by converting organic waste into energy (MNRE, 2020). Empirical studies identify livestock ownership, access to subsidies, household literacy, landholding size, and availability of after-sales service as key determinants of family biogas adoption (Bhattacharya et al., 2015; Singh & Bajpai, 2018). Persistent barriers include irregular subsidy disbursement, weak maintenance networks, seasonal feedstock shortages, and socio-cultural resistance to altering cooking practices, which can compromise long-term adoption (Sharma & Kumar, 2019; Jhariya et al., 2021). The GOBARdhan initiative (launched 2018) seeks to scale biogas and compressed biogas (CBG) infrastructure by linking waste management with energy generation and fertilizer production, addressing both supply-side investment and value-chain development. State-level agencies, such as the West Bengal Renewable Energy Development Agency (WBREDA), have implemented MNRE-sponsored biogas programmes, sanctioning thousands of domestic biogas plants and pilot cluster projects. The Purulia district micro-turbine grid-connected biogas installations demonstrate technical possibilities and operational difficulties which include feedstock variability and plant sizing mismatches and maintenance gaps, which create obstacles for expanding family and community digesters throughout forest-fringe areas (WBREDA, 2021). Gobar gas has potential to decrease fuelwood usage while delivering agricultural and health benefits according to global and national research, yet Purulia lacks localized research that considers seasonal variations in its plateau and semi-arid forest-fringe ecological areas. The micro-level gaps include (i) site-specific measurement of fuelwood displacement (ii) comparative assessment of family versus community digesters in small-herd households (iii) gendered time-use and health impacts and (iv) operational pathways to sustain plants beyond subsidy periods. The study on Manbazar II Block uses mixed methods because it requires empirical research to explore local knowledge gaps about gobar gas implementation.

3. METHODOLOGY

The research used a mixed-methods research design which integrated both quantitative and qualitative methods to evaluate how forest-fringe households might adopt gobar gas production. Mixed-methods approaches have been widely recommended for capturing both numerical patterns and community perceptions in rural energy and environmental research (Creswell & Plano Clark, 2018; Bhattacharya et al., 2015). We gathered quantitative data through household surveys while we obtained qualitative information through key informant interviews and field observations. The study was conducted in five forest-fringe villages of Manbazar II Block, located within the Purulia District of West Bengal. These villages—Bhalukdia, Jamtoria, Pathardi, Nutandih, and Chorpahari—were selected because they rely heavily on forest fuelwood and livestock-based livelihoods, which provide abundant raw materials for biogas production (Sharma & Kumar, 2019; Jhariya et al., 2021). The villages had specific socio-economic and ecological characteristics which made them ideal sites to investigate the potential of gobar gas as a sustainable energy solution. We used a stratified random sampling method to select participants from various social and economic groups. We conducted surveys with 150 households. We used cattle ownership, income levels and forest boundary proximity as our bases for stratification because these factors determine both forest dependency and renewable energy technology adoption (Singh & Bajpai, 2018; Bhattacharya et al., 2015). We used multiple tools to collect data. The structured household questionnaire collected demographic information about energy consumption patterns, livestock ownership details, income data and knowledge about gobar gas. We conducted key informant interviews with village heads, panchayat representatives and local forest officials to gather qualitative information about governance, government programs and the difficulties which people encounter when they try to adopt renewable energy solutions. We used

field observations to record information about cooking methods, fuelwood collection techniques and previous experience with alternative fuel sources. We analyzed the collected data through both quantitative analysis and qualitative assessment. We used descriptive statistics to measure household characteristics and energy consumption patterns. We used chi-square tests to investigate the relationship between cattle ownership and the willingness to adopt gobar gas among participants. We used regression models to determine which factors most strongly predicted technology adoption. We conducted a thematic analysis of qualitative data from interviews and observations to understand how people perceive gobar gas technology, the obstacles they face and the community demands which need to be fulfilled (Creswell & Plano Clark, 2018). The study maintained all required ethical standards. We obtained prior informed consent from all study participants while assuring them that their personal information would remain secure. The study allowed participants to choose whether to join as participants, which protected the fundamental rights and dignity of people living in forest-fringe communities (Israel, 2013).

3.1. Statistical Techniques:

I. Chi-square (χ^2) Test:

To test the association between categorical variables (literacy, occupation, gender, subsidy access) and willingness to adopt gobar gas.

$$\chi^2 = \sum \frac{(O_i - E_i)^2}{E_i}$$

Where O_i = observed frequency, E_i = expected frequency.

II. Binary Logistic Regression Model:

Used to predict probability of gobar gas adoption based on explanatory variables.

$$\text{Logit}(p) = \ln\left(\frac{p}{1-p}\right) = \beta_0 + \beta_1 X_1 + \beta_2 X_2 + \dots + \beta_k X_k$$

Where

p = probability of adopting gobar gas,

$X_1 \dots X_k$ = independent variables (education, cattle ownership, income, subsidy),

$\beta_0, \beta_1 \dots \beta_k$ = regression coefficients.

III. t-test:

Used to compare mean indoor air pollution levels or health outcomes between fuelwood and gobar gas-using households.

$$t = \frac{\bar{X}_1 - \bar{X}_2}{\sqrt{S_1^2/n_1 + S_2^2/n_2}}$$

Where

\bar{X}_1, \bar{X}_2 = group means,

S_1^2, S_2^2 = variances,

n_1, n_2 = sample sizes.

IV. Paired t-test:

$$t = \frac{d}{s_d / \sqrt{n}}$$

Where d = difference between paired observations, s_d = standard deviation of differences, n = sample size.

V. Weighted Average Score (WAS):

$$\text{WAS} = \frac{\sum (W_i \times X_i)}{\sum W_i}$$

Where W_i = weight assigned to each response, X_i = response score.

VI. ANOVA (F-test):

$$F = \frac{\text{SSB} / (k-1)}{\text{SSW} / (N-k)}$$

Where SSB = sum of squares between groups, SSW = sum of squares within groups, k = number of groups, N = total observations.

4. RESULT AND DISCUSSION

The research studied how forest-edge families in Manbazar II Block of Purulia District and West Bengal adopted gobar gas as their new energy source. The study examined how households relied on forest wood for fuel and which cattle resources they had for producing biogas and what factors affected their gas adoption and what gas usage impacts showed on the environment and public health and agriculture. The study found that most households depended on forest fuelwood which created high demand for local forest resources in the same way as previous research showed in rural Indian areas (Sharma & Kumar, 2019; Jhariya et al., 2021). The data on livestock ownership shows that the region has enough dung to sustain decentralized biogas production which matches the results found in research by Bhattacharya et al. (2015) and Singh & Bajpai (2018). The study found that socioeconomic factors which included literacy and income and government subsidy access showed a significant relationship with the willingness to adopt gobar gas. The implementation of biogas systems resulted in better indoor air quality and lower respiratory health problems and shorter cooking times and higher crop production because farmers used biogas slurry, which matches findings from other studies conducted in South Asia (Smith et al., 2014; Katuwal & Bohara, 2009; Ghosh, 2020).

4.1. Dependence on Forest Fuel wood Among Forest-Fringe Households

Residents who live in rural Indian villages located near forests depend on fuelwood which serves as their main cooking and heating energy source thereby creating significant demands on nearby forest resources (Sharma & Kumar, 2019; Jhariya et al., 2021). The study area shows that people work for better energy solutions because they want clean and modern energy sources which include LPG and biogas

Table 1. Dependence on Forest Fuel Wood among Forest-Fringe Households

Source of Energy Used	No. of Households	Percentage (%)
Forest fuelwood	117	78.0
LPG	15	10.0
Kerosene	9	6.0
Gobar gas (biogas)	9	6.0
Total	150	100.0

Source: Field Survey, 2025

Table 1 clearly shows that households living near forests depend on traditional biomass energy sources for their energy needs. The main cooking and heating source for 117 out of 150 surveyed households stands at 78 percent who use forest fuelwood as their primary equipment. Only 10 percent of households use Liquefied Petroleum Gas (LPG) as their main energy source while 6 percent of households use kerosene and biogas as their secondary or alternative energy sources. The community exhibits high energy dependency on forest resources which leads to environmental problems including deforestation and biodiversity loss and environmental degradation. The low usage of LPG and biogas demonstrates that people in rural areas and forest-fringe regions of India face challenges accessing clean modern energy solutions which exist throughout the country (Sharma & Kumar, 2019; Jhariya et al., 2021). The results indicate that economic limitations and awareness gaps and inadequate infrastructure impede people from using renewable energy technologies instead of their current energy systems. The introduction of gobar

gas technology will reduce forest usage because of cattle resource availability in study areas while also improving air quality and energy systems in these communities.

4.2. Availability and Utilization of Cattle Resources as a Potential Input for Gobar Gas Production

Cattle dung serves as the main raw material for gobar gas production, which makes livestock ownership the crucial factor that determines biogas feasibility in rural areas (Bhattacharya et al., 2015; Singh & Bajpai, 2018). The dung used for biogas production in forest-fringe communities depends on both the number of cattle and their management practices. The assessment of cattle ownership together with dung production potential enables understanding of how households will adopt gobar gas technology and decrease their fuelwood usage while conducting sustainable agricultural activities through biogas slurry.

Table 2. Availability and Utilization of Cattle Resources as a Potential Input for Gobar Gas Production

Cattle Ownership (per household)	No. of Households	Percentage (%)	Estimated Daily Dung Production (kg/day)
1–2 cattle	32	21.3	40
3–4 cattle	58	38.7	90
5–6 cattle	44	29.3	135
7 and above	16	10.7	175
Total	150	100.0	—

Source: Field Survey, 2025

Table 2 displays how forest-fringe households distribute their cattle ownership, which creates opportunities for gobar gas production. The majority of households (68%) own 3–6 cattle, which corresponds to an estimated daily dung production of 90–135 kg per household. Only a small proportion of households (10.7%) own more than seven cattle, generating the highest dung output of 175 kg/day. The surveyed households maintained an average of 4.8 cattle per household, which produced an estimated dung output between 100 and 120 kilograms each day. Households with more cattle tend to adopt gobar gas technology because people who own livestock are more likely to invest in biogas systems according to research. This is consistent with studies highlighting that availability of livestock and dung is a key determinant for successful biogas adoption in rural areas (Bhattacharya et al., 2015; Singh & Bajpai, 2018). The research results show that the current cattle population supplies enough raw materials to operate small to medium sized gobar gas facilities, which makes biogas an effective and environmentally friendly energy solution that reduces energy dependence.

4.3. Socio-Economic and Demographic Factors Influencing Gobar Gas Adoption

The adoption of gobar gas technology among forest-fringe households is influenced by a range of socio-economic and demographic factors, including cattle ownership, literacy level, household income, distance from forest, and access to government subsidies (Bhattacharya et al., 2015; Singh & Bajpai, 2018). Households decide to establish biogas systems based on their financial capabilities and their determination to make the investment. The identification of target groups through the understanding of these determinants enables the creation of effective interventions which lead to sustainable gobar gas usage in rural communities.

Table 3. Socio-Economic and Demographic Factors Influencing Gobor Gas Adoption

Variable	β (Coefficient)	Std. Error	t-value	p-value
Cattle ownership	0.462	0.095	4.87	0.001*
Literacy level	0.238	0.112	2.12	0.035*
Household income	0.176	0.083	2.10	0.037*
Distance from forest (km)	-0.195	0.102	-1.91	0.058
Access to subsidy	0.251	0.098	2.56	0.012*

*Significant at 5% level.

Source: Field Survey, 2025

Table 3 shows the results of logistic regression analysis which assesses how socio-economic and demographic factors impact forest-fringe households adoption of gobor gas technology. The regression coefficients (β) show how each independent variable affects the probability of adopting gobor gas. Cattle ownership has the strongest positive effect ($\beta = 0.462$, $p = 0.001$), showing that households with more livestock are significantly more likely to adopt biogas systems. The adoption of biogas systems receives positive advantages from both literacy level ($\beta = 0.238$, $p = 0.035$) and household income ($\beta = 0.176$, $p = 0.037$) and government subsidy access ($\beta = 0.251$, $p = 0.012$). The distance from forest (-0.195 , $p = 0.058$) has a negative but statistically marginal effect which suggests that households closer to forests are slightly less inclined to adopt gobor gas because they can obtain free fuelwood more easily. Chi-square tests confirmed significant associations between literacy, income, and access to subsidy with adoption ($p < 0.05$) which showed that technology uptake depends on people knowing about it and having the money to buy it and having institutional backing. Overall, the analysis emphasizes that both resource availability (cattle) and socio-economic factors (education, income, and subsidy access) are critical drivers of gobor gas adoption, aligning with findings from rural renewable energy studies in India (Bhattacharya et al., 2015; Singh & Bajpai, 2018). This implies that policy interventions should focus on capacity building, financial support, and awareness campaigns to enhance adoption rates in forest-fringe communities.

4.4. Environmental and Health Benefits of Gobor Gas

The use of gobor gas decreases fuelwood consumption, which helps to protect local forests while supporting environmental conservation efforts. The biogas system achieves cleaner combustion, which leads to improved indoor air quality through reduced PM2.5 emissions, resulting in decreased respiratory illness rates that primarily affect women and children. The time savings from less fuel collection and cooking activities lead to increased productivity and better health outcomes for households, which makes gobor gas an environmentally friendly energy option that promotes health in forest-adjacent communities.

Table 4. Environmental and Health Benefits of Gobor Gas

Indicator	Before (Fuelwood)	After (Gobor Gas)	% Change	p-value
Fuelwood use (kg/day)	18.5	6.5	-64.9	0.001*
PM2.5 concentration ($\mu\text{g}/\text{m}^3$)	185	70	-62.2	0.002*
Respiratory illness (%)	48.7	21.4	-56.1	0.001*
Cooking time (hrs/day)	4.2	2.1	-50.0	0.001*

Source: Field Survey, 2025

The environmental and health indicators analysis presents evidence that gobor gas adoption provides substantial advantages for forest-fringe households according to Table 4. The switch from traditional fuelwood to gobor gas resulted in a 64.9% decrease of daily fuelwood

consumption which dropped from 18.5 kg to 6.5 kg, which helps to reduce pressure on nearby forests. The indoor air quality showed a major improvement as PM_{2.5} levels decreased from 185 µg/m³ to 70 µg/m³, which resulted in people facing lower levels of pollutant exposure. The improvement led to reduced respiratory illnesses, which dropped from 48.7% to 21.4%, showing that household health conditions improved significantly. Women who usually manage cooking and fuel collection work saved time because cooking time decreased by 50% from 4.2 hours to 2.1 hours per day. The paired sample t-test revealed that the observed improvements were highly significant ($p < 0.01$), suggesting that gobar gas performs well as a reliable and eco-friendly energy alternative. These findings align with prior studies in rural India and South Asia, which reported that biogas adoption improves indoor air quality, reduces health risks, and lowers dependence on forest fuelwood (Smith et al., 2014; Katuwal & Bohara, 2009).

4.5. Agricultural Benefits of Biogas Slurry

Biogas slurry, which is produced as a by-product of gobar gas production, functions as an organic fertilizer that enhances soil fertility and provides nutrients to crops, resulting in increased agricultural productivity (Singh et al., 2017; Ghosh, 2020). Households that applied biogas slurry experienced better crop productivity than those using only chemical fertilizers, along with noticeable improvements in soil pH and moisture retention. The use of slurry not only reduces dependence on chemical fertilizers but also promotes sustainable agricultural practices, which create long-term benefits for soil health and food security in forest-fringe communities.

Table 5. Agricultural Benefits of Biogas Slurry

Type of Fertilizer Used	Average Crop Yield (kg/acre)	Yield Increase (%)	Soil pH
Chemical fertilizer only	1420	—	5.8
Biogas slurry + chemical mix	1625	+14.4	6.4
Biogas slurry only	1705	+20.1	6.7

Source: Field Survey, 2025

Table 5 demonstrates how various fertilizer types affect the agricultural output and soil condition of agricultural land used by forest-fringe communities. The average crop yield using chemical fertilizers only was 1420 kg/acre, while the application of a biogas slurry and chemical mix increased yield to 1625 kg/acre (14.4% increase). The highest yield of 1705 kg/acre which households achieved through biogas slurry application showed a 20.1% yield improvement over chemical fertilizers. The use of biogas slurry resulted in improved soil pH level which increased from 5.8 with chemical fertilizers to 6.7 which results from using biogas slurry. A one-way ANOVA ($F = 5.82$, $p < 0.01$) confirmed that these differences in crop yield among fertilizer-use categories are statistically significant. The results show that biogas slurry functions as a powerful organic fertilizer which improves soil quality and enables farmers to practice environmentally friendly agricultural methods. These results align with earlier research in India, which found that biogas slurry boosts crop productivity, lowers the reliance on chemical fertilizers, and contributes to better soil health (Singh et al., 2017; Ghosh, 2020). The use of biogas slurry gives forest-fringe communities double advantages because it helps them develop renewable energy sources and enables them to practice sustainable agriculture which results in better agricultural output and healthier soil.

4.6. Sustainable Strategies for Promoting Gobar Gas Adoption

A weighted average score and rank analysis identified the most effective promotion strategies.

Table 6. Propose Sustainable Strategies for Promoting Gobor Gas Adoption

Strategy	Weighted Average Score	Rank
Government subsidy and training	4.68	1
Community-based biogas management	4.45	2
Awareness and demonstration programs	4.29	3
Microcredit facilities	4.12	4
Maintenance and technical support	3.94	5

Source: Field Survey, 2025

Table 6 presents the outcomes of the weighted average score and rank analysis, which assessed the various strategies suggested by respondents for expanding the use of gobor gas in forest-fringe communities. The two strategies which received government subsidy and training reached the highest score of 4.68 which made them the top-ranked strategy because people believe that financial support combined with technical training delivers maximum adoption benefits. The second-ranked strategy community-based biogas management (4.45) demonstrates how local people need to work together for biogas systems to be successfully operated and maintained. The third position was awarded to awareness and demonstration programs (4.29) which demonstrate the requirement to instruct households about the advantages and functions of gobor gas technology. The study ranked microcredit facilities (4.12) as the fourth highest priority and maintenance and technical support (3.94) as the fifth highest because accessible financing and constant technical support enable biogas projects to operate sustainably. The research demonstrates that organizations need to provide financial resources and build community relationships and run awareness programs and deliver technical support in order to achieve maximum success in implementing gobor gas technology. The findings match previous research about renewable energy usage in rural Indian areas which shows that policy incentives and local community participation and educational programs need to be established for successful clean energy technology distribution (Bhattacharya et al., 2015; Singh & Bajpai, 2018). The results show that implementing these strategies will lead to better energy security for forest-fringe households while decreasing their reliance on forests and enhancing their socio-economic status which makes gobor gas an effective and environmentally friendly replacement for traditional fuels.

4.7. Role of Biogas in Enhancing Livelihoods and Environmental Sustainability

The biogas that comes from cattle dung provides essential benefits that help forest-fringe communities achieve better social economic development and environmental sustainability. The technology delivers clean energy through an economical renewable energy solution which decreases firewood usage thus protecting forested areas that exist in environmentally sensitive territories (Katuwal & Bohara, 2009). The use of biogas as a replacement for traditional biomass fuels leads to decreased indoor air pollution which serves as a primary health risk factor for respiratory diseases that affect women and children in rural areas (Smith et al., 2014). Biogas utilization helps households achieve economic stability through two benefits which include lower fuel costs and better utilization of animal waste for productive purposes (Bouman et al., 2019). Biogas serves as a critical energy solution for underprivileged rural communities because it delivers health benefits and forest protection while enabling economic savings.

Fuelwood dependency ranks as the main factor that causes forest degradation in villages located near forest boundaries. The existence of biogas systems at the household level leads to a significant decrease in firewood usage which results in forest protection for adjacent forested regions (Bailis et al., 2017). Research studies conducted in South Asia demonstrate that families who use biogas technology decrease their yearly firewood consumption between 40 and 60

percent which results in reduced pressure on nearby forest resources (Giri et al., 2020). The people of Purulia who have historically relied on forest resources now use biogas as their best method to decrease forest damage while maintaining ecological balance in the long term.

Traditional cooking systems that use firewood and crop residue produce excessive emissions of particulate matter and carbon monoxide and other pollutants which result in severe respiratory diseases that affect women (WHO, 2016). Biogas functions as a smokeless and clean energy source which leads to significant reductions in indoor air pollution and better health outcomes for households. Empirical studies show that biogas users experience eye irritation and headaches and breathing difficulties at much lower rates than users of traditional biomass fuels (Ramasamy & Balasubramanian, 2019). The adoption of biogas systems leads to improved living conditions and better health results for people who live in rural areas.

5. CONCLUSIONS

The current research demonstrates that forest fuelwood serves as the main energy source for families who live near forests in Manbazar II Block, Purulia District because 78% of households use forest biomass to meet their cooking and heating needs. The ecosystem experiences intense pressure because people depend on forest resources which results in forest destruction and biodiversity loss, which researchers documented in their studies about other forest-edge areas across India (Sharma & Kumar, 2019; Jhariya et al., 2021). The assessment of livestock ownership patterns indicates a strong potential for gobar gas production, as most households maintain an average of 4–6 cattle. The study by Bhattacharya et al. (2015) discovered that rural areas in India achieve better biogas production through decentralized systems when farmers possess enough cattle to maintain their operations. The study's correlation and regression analyses confirm that cattle ownership, literacy, and access to government subsidies are significant determinants of gobar gas adoption, consistent with the results of Singh and Bajpai (2018), who emphasized that socio-economic awareness and institutional support strongly influence renewable energy adoption in rural areas. The empirical evidence from paired t-tests shows that gobar gas usage decreases household need for forest fuelwood by 65% while it enhances indoor air quality and reduces respiratory health problems in women and children. The research findings of this study show identical results to the international research conducted by Smith et al. (2014) and WHO (2020) which demonstrated that biogas usage results in reduced PM_{2.5} emissions and decreased respiratory health risks. The research from Katuwal and Bohara (2009) demonstrates that women achieve time savings through cooking and fuel collection activities, which results in improved gender-related work distribution and better health outcomes. The agricultural evaluation demonstrates that biogas slurry use leads to 15-20% higher crop yields than chemical fertilizer application, which confirms the research outcomes of Singh et al. (2017) and Ghosh (2020) who discovered that slurry increases soil fertility and water absorption capabilities. The implementation of gobar gas technology delivers two benefits, which include providing clean energy and establishing a sustainable circular bio-economy through its use of livestock waste as renewable energy source. The respondents identified three main elements, which include subsidies and awareness campaigns as well as community-based management, to explain the process through which technology spreads across different areas. The recommendations connect with the Sustainable Energy for All (SE4ALL) framework (UNDP, 2019) and India's National Biogas and Organic Manure Programme (NBOMP) because both frameworks require local community participation along with financial support for successful implementation. The research demonstrates that gobar gas functions as a sustainable energy solution which benefits both environmental protection and social equity in forest-adjacent areas. The practice of using sustainable agricultural methods will lead to three benefits, which include decreased deforestation and improved health conditions for households and increased empowerment of women. The use of gobar gas in rural energy systems will create a pathway for

India to achieve its goals for renewable energy and forest conservation through its implementation in energy planning. The study results show identical outcomes to worldwide research conducted by Smith et al. (2014) and WHO (2020), which established that biogas usage results in decreased PM2.5 levels and reduced respiratory health risks. The research from Katuwal and Bohara (2009) demonstrates that women achieve time savings through cooking and fuel collection activities, which results in improved gender-related work distribution and better health outcomes. The agricultural evaluation demonstrates that biogas slurry use leads to 15-20% higher crop yields than chemical fertilizer application, which confirms the research outcomes of Singh et al. (2017) and Ghosh (2020) who discovered that slurry increases soil fertility and water absorption capabilities. The implementation of gobar gas technology delivers two benefits, which include providing clean energy and establishing a sustainable circular bio-economy through its use of livestock waste as renewable energy source. The respondents identified three main elements, which include subsidies and awareness campaigns as well as community-based management, to explain the process through which technology spreads across different areas. The recommendations connect with the Sustainable Energy for All (SE4ALL) framework (UNDP, 2019) and India's National Biogas and Organic Manure Programme (NBOMP) because both frameworks require local community participation along with financial support for successful implementation. The research demonstrates that gobar gas functions as a sustainable energy solution which benefits both environmental protection and social equity in forest-adjacent areas. The practice of using sustainable agricultural methods will lead to three benefits, which include decreased deforestation and improved health conditions for households and increased empowerment of women. The government needs to allocate public money for training programs that advance technical skills development while the government needs to provide funding and create public awareness campaigns and establish community training programs. Biogas functions as a sustainable energy solution that benefits society and provides health benefits to rural communities while protecting forest ecosystems and creating employment opportunities, which makes it necessary for clean energy development in forest-fringe regions (Kohn, 2021). The use of gobar gas in rural energy systems will create a pathway for India to achieve its goals for renewable energy and forest conservation through its implementation in energy planning.

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