
AI Based Smart And Sustainable Biogas System For Rural Empowerment

Dattatray Waghole¹, Smita Wagh², Shreetej Korde³, Joel Chandanshiv⁴, Shreyas Aher⁵

^{1,2,3,4,5}Department of Computer Engineering

JSPM's Jayawantrao Sawant College of Engineering Pune, India

¹dattatraywaghole@jspmjscoe.edu.in, ²smitawagh@jspmjscoe.edu.in,

³shreetejkorde@gmail.com, ⁴joelchandanshiv@gmail.com, ⁵shreyasaheer1534@gmail.com

Abstract.

The AI-Based Smart Biogas System automatically converts organic waste into renewable biogas and nutrient-rich biofertilizer. Sensors and microcontrollers monitor temperature, pH, and nutrient levels, while AI algorithms optimize anaerobic digestion. Compared with traditional systems, it improves biogas yield by approximately 30%. The biogas is purified through scrubbing for cleaner energy use, while the treated and oxygenated slurry serves as an enhanced biofertilizer. An IoT dashboard enables real-time monitoring and control, promoting clean energy, sustainable agriculture, and improved efficiency in rural areas.

Keywords: Smart Biogas System, AI-Based Automation, Anaerobic Digestion, IoT Monitoring, Renewable Energy, Biofertilizer, Rural Sustainability, Waste-to-Energy.

1. INTRODUCTION

Anaerobic digestion sustainably converts organic waste into methane-rich renewable fuel and nutrient-rich biofertilizer. It is especially valuable in rural areas with abundant organic waste but limited energy access, addressing energy shortages, waste management, and environmental concerns [1], [2]. The resulting slurry also supports sustainable agriculture by reducing reliance on artificial fertilizers [3]. Traditional biogas systems depend on manual monitoring and lack effective control of temperature, pH, gas composition, retention time, and feedstock variations, resulting in unstable microbial activity and inconsistent methane yield [4], [5]. IoT and AI enable real-time monitoring, prediction, and automated control [6]. Sensors collect process data, while LSTM and XGBoost models predict gas yield, detect abnormalities, and optimize digestion [7], [8]. The proposed system integrates AI, IoT, water treatment, UV disinfection, and nutrient enrichment. It aims to increase methane production by approximately 30%, improve fertilizer quality, and provide remote monitoring through an Android dashboard [9]. This self-regulating solution promotes decentralized renewable energy, sustainable agriculture, and rural empowerment.

2. LITERATURE SURVEY

IoT-based biogas monitoring systems improve efficiency by enabling real-time tracking of temperature, pH, and gas production [1], [2]. However, they mainly focus on data collection and often lack predictive capabilities. Machine-learning techniques address this limitation by modelling complex relationships between input parameters and biogas yield, thereby improving system accuracy and performance [9]. Time-series models such as LSTM

effectively predict biogas production trends, while ensemble-learning methods such as XGBoost provide reliable classification and regression results [3], [10]. AI-based optimization further improves anaerobic digestion by enabling better control of process parameters [8]. IoT-enabled systems have also been integrated with agricultural applications to promote the use of biogas slurry as an organic fertilizer [4].

2. PROPOSED SYSTEM/METHODOLOGY

- **Input and Mixing:** Organic waste is collected and mixed to form a uniform slurry.
- **Monitoring and Digestion:** Sensors monitor the digester's temperature, pH, and turbidity to support efficient biogas production.
- **Biogas Purification:** The produced biogas is water-scrubbed to obtain cleaner methane.
- **UV Disinfection:** UV light removes harmful bacteria from the residual slurry.
- **Enrichment:** Oxygenation and continuous NPK monitoring improve the slurry's nutrient content.
- **Output Processing:** The enriched slurry is dried or pelletized into nutrient-rich biofertilizer.
- **Monitoring and Control:** An IoT-based Android application enables real-time monitoring and control.

3. ARCHITECHTURE

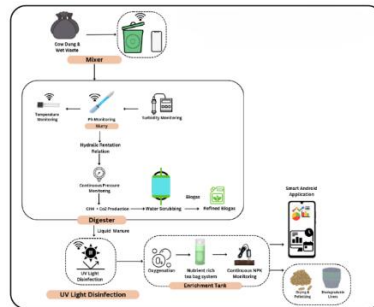


Figure 1. System Architecture

The proposed AI-based smart biogas system converts cow dung, kitchen waste, and agricultural residues into methane-rich biogas and biofertilizer. An anaerobic digester uses sensors to monitor temperature, pH, turbidity, and pressure, while LSTM and XGBoost predict gas yield and control system components. Water scrubbing improves methane quality. Digestate undergoes UV disinfection, oxygenation, and nutrient monitoring for fertilizer production. An IoT-enabled Android dashboard supports remote monitoring and control, providing a scalable solution integrating waste management, renewable energy, AI, and sustainable agriculture.

4. MATHEMATICAL MODEL

The following is a mathematical representation of the system:

Sensor Data Acquisition:

$$S(t) = [T(t), pH(t), G(t), N(t)] \quad (1)$$

Preprocessing:

$$S' = \psi(S) \quad (2)$$

Prediction Model (Hybrid):

$$Y = f LSTM(S') + f XGB(S') \quad (3)$$

Output Optimization:

$$O = g(Y) \quad (4)$$

Where: $S(t)$ = Sensor data (temperature, pH, gas, nutrients), S' = processed data, Y = predicted biogas yield/efficiency, O = optimized output (biogas + biofertilizer).

5. RESULT ANALYSIS

The proposed system addresses conventional biogas limitations through IoT- and AI-based monitoring and control. Real-time sensors monitor key parameters, while LSTM and XGBoost models predict biogas yield and improve process efficiency. Purification and UV disinfection enhance biogas and biofertilizer quality, while the IoT dashboard enables remote monitoring and automation. However, system performance depends on sensor accuracy and data quality.

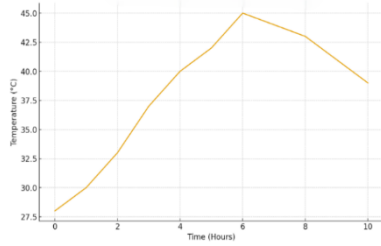


Figure 3. Temperature vs Time Graph

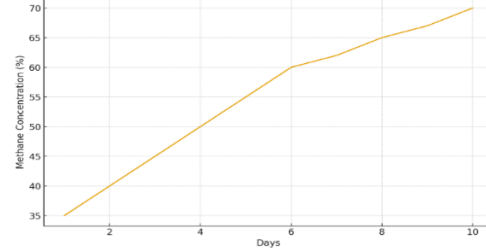


Figure 4. Methane Concentration vs Days Graph

		Sum of Squares	df	Mean Square	F	Sig.
VAR00001	Between Groups	533173.867	2	266586.933	15878.619	<.001
	Within Groups	83911.672	4998	16.789		
	Total	617085.538	5000			
VAR00002	Between Groups	123614.137	2	61807.069	650.585	<.001
	Within Groups	474821.625	4998	95.002		
	Total	598435.762	5000			
VAR00003	Between Groups	8017.269	2	4008.634	183.532	<.001
	Within Groups	109164.256	4998	21.842		
	Total	117181.524	5000			
VAR00004	Between Groups	8.593	2	4.296	18.710	<.001
	Within Groups	1147.698	4998	.230		
	Total	1156.291	5000			
VAR00005	Between Groups	983.143	2	491.572	19.088	<.001
	Within Groups	126716.438	4998	25.754		
	Total	129699.581	5000			

Table 2. Bayesian Correlation Analysis for a Smart and Sustainable Biogas System Using AI

6. CONCLUSION

The conclusion from the above system description states that it is an AI-based smart biogas system that combines IoT, LSTM, and XGBoost for real-time monitoring and optimization,

presented in this paper. The technology further ensures improved process stability and output quality while increasing biogas production efficiency by about 30%. Purification, disinfection, and enrichment procedures are added to improve the overall sustainability and efficacy of the system. The future work focuses on expanding the dataset with diverse real-world scenarios, integrating multi-sensor data, developing lightweight edge-AI models, and implementing adaptive learning for continuous system improvement.

7. REFERENCES

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Biographies



Dr. Dattatray Waghole is the Dean of Research and Development at JSPM's JSCOE, Pune. He has 13 years of experience, 70+ publications, and 16+ patents. His interests include AI, ML, IoT, WSN, and quantum computing.



Prof. Smita Wagh is an Assistant Professor at JSPM's JSCOE, Pune, and is pursuing a Ph.D. in CSE. She has 6+ years of academic experience, 15+ publications, and two international patents. Her interests include AI, machine learning, and blockchain technology.



Shreetej Korde holds a bachelor's degree in Computer Engineering from JSPM's JSCOE, Pune. His interests include AI, machine learning, IoT, and intelligent systems. Winner of National & International Hackathon with experience in innovative research projects.



Joel Chandanshi holds a bachelor's degree in Computer Engineering from JSPM's JSCOE, Pune. His interests include cloud computing, DevOps, AI and IoT. Winner of National & International Hackathon with experience in innovative research projects.



Shreyas Aher holds a bachelor's degree in Computer Engineering from JSPM's JSCOE, Pune. His interests include Flutter development, AI, Cloud Computing. Winner of National & International Hackathon with experience in innovative research projects.