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Smart Biogas for Rural Farming

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***Abstract*—Energy plays a vital role in national development, and renewable sources like biogas are becoming increasingly important for sustainable growth. Biogas is generated when organic materials such as animal waste decompose in the absence of oxygen. It can be used for cooking, electricity generation, and as a natural fertilizer.Efficient production depends on maintaining proper environmental conditions such as temperature, pressure, humidity, and pH. This project proposes a smart monitoring system that integrates IoT technology with sensors and microcontrollers like Arduino and NodeMCU to track these parameters in real time. The collected data can be accessed through mobile applications, allowing users to respond quickly to any changes.In addition, IoT-based agricultural automation helps improve irrigation efficiency and crop productivity. This combined approach enhances both biogas generation and smart farming, supporting sustainable rural development.**

I. INTRODUCTION-

Biogas production happens when factors like temperature, pressure, humidity, and moisture are kept at the right levels. This allows for effective anaerobic digestion and boosts methane output. In real situations, maintaining these conditions manually can be difficult."

An IoT-based biogas monitoring system that uses NodeMCU ESP32S can track and maintain these ideal conditions. The system includes sensors like DS18B20 for temperature, YL-69 for soil moisture, BME280 for temperature, pressure, and humidity, and MQ-4 for methane, all connected to the microcontroller. Data from these sensors shows up in a mobile app made using platforms like Android Studio. Users get alerts through notifications or buzzers if any parameters go out of the ideal range. This reduces the need for manual checks and enables quick action to keep biogas production efficient, while also supporting renewable energy from organic waste.

Gobar gas, or biogas, is a clean fuel created from the anaerobic breakdown of organic materials like cattle manure. It offers a sustainable energy solution for rural areas dealing with energy shortages and waste management issues. However, biogas production can be inconsistent, making it hard to use efficiently. Smart biogas systems employ sensors and monitoring tools to gather data on factors such as temperature, feedstock makeup, and pressure inside the digester. This information helps predict and optimize gas production.

In agriculture, many people rely on farming for their income, but issues like falling crop productivity, water waste, soil is fertility problems, and climate change challenge food production. The integration of the Internet of Things (IoT) and wireless sensor networks can help solve these issues. These technologies connect devices and deliver real-time data, making it possible to have automated irrigation systems that provide the right water at the right time. This improves resource use, cuts down on labor, and increases and crop yield. Limited energy sources and the growing need for sustainable power have spurred the Development of renewable energy options like biogas comes from organic materials, such as cow manure, through anaerobic fermentation in biodigesters. Biogas mainly contains methane and carbon dioxide, and its energy quality relies heavily on methane concentration. However, traditional biogas systems often lack proper monitoring and automation, which makes it hard to maintain optimal production conditions.

To improve efficiency, modern smart biogas systems use sensors and microcontrollers to track parameters like temperature, pressure, pH, methane concentration, and humidity. Technologies such as Arduino, wireless sensor networks, and IoT allow for automatic data collection, remote monitoring, and early warning systems. This makes it easier for users to oversee biogas production and keep stable operating conditions.

These systems promote better waste management, renewable energy generation, and sustainable agricultural development by improving biogas production efficiency and environmental sustainability. Indonesia faces significant waste management is challenges, with millions of tons of waste produced annually, much of which remains unmanaged. A large portion of this waste consists of organic material like food and market waste, which can create methane gas and lead to environmental issues if not treated properly.

However, organic waste has great potential to be turned into renewable energy through biogas production using anaerobic digestion.

Biogas is mostly made up of a methane and carbon dioxide. It can be used as a clean fuel source that also cuts down on greenhouse gas emissions. Recent studies show that combining IoT technology with biogas systems makes it possible to monitor important factors like temperature, pressure, humidity, and methane concentration in a real time. Microcontrollers like the ESP32 or Arduino are linked to sensors like the DHT22, BMP180, and MQ-4.

II. LITERATURE SURVEY

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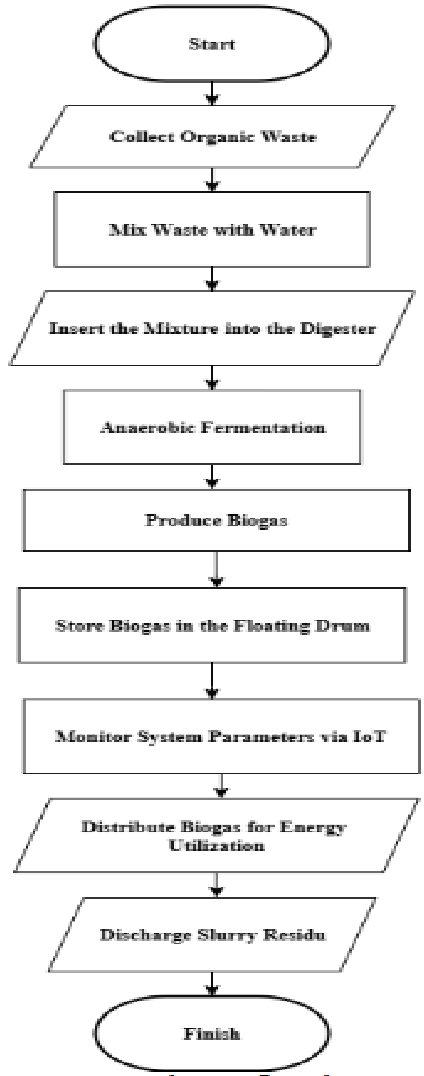

Fig. 7. Smart biogas flow diagram

[1] This paper discusses an IoT-based biogas monitoring system that uses NodeMCU ESP32S to improve biogas production efficiency. Biogas forms through the anaerobic digestion of organic waste. It's important to maintain optimal conditions like temperature, humidity, pressure, and moisture for maximum gas production. The proposed system includes sensors such as the DS18B20 temperature sensor as , YL-69 soil moisture sensor, BME280 humidity and pressure sensor, and MQ4 methane sensor to monitor these conditions within a biogas reactor. These sensors connect to a NodeMCU ESP32S microcontroller, which gathers data and sends it to a database via Wi-Fi. A mobile application made with Android Studio displays the sensor readings. If

any parameter exceeds the set limit, the system notifies the user and activates a piezo buzzer, allowing timely action to maintain optimal conditions. The prototype biogas reactor was built using a 12.5-liter container filled with kitchen waste and water, where microorganisms break down organic matter to produce methane. Data from sensors is sent in JSON format and updates every 30 seconds, enabling real-time monitoring via the mobile app. This system cuts down on manual monitoring work, boosts biogas production efficiency, and helps users maintain suitable environmental conditions in the reactor. Results show that methane production is highest at temperatures between 30 to 40°C and moisture levels of 40 to 60%, with biogas generation typically happening within 7 to 10 days.

[2] This study focuses on creating a smart biogas production system that uses poultry and pig dung as raw materials through anaerobic digestion. The system aims to a convert animal waste into useful energy, including biogas for cooking, electricity, and organic fertilizer. A small-scale fixed dome digester with a gas storage unit and mixing mechanism was made from materials and like galvanized steel sheets, pipes, and fiberglass for temperature stability. A monitoring unit based on an Arduino Uno microcontroller was integrated with sensors to measure important factors such as temperature, pressure, and pH during the digestion process. Animal waste mixed with water was fed into the digester and allowed to decompose for several days while the system continuously recorded operational data. The results indicated that biogas production rises with a higher organic loading rate and suitable environmental conditions. The study shows that monitoring key factors with sensors can improve the efficiency and stability of the biogas production process, providing a practical method for a small-scale renewable energy generation from animal waste.

[3] This study presents the development of a prediction and monitoring system for smart biogas (Gobar gas) plants meant for rural areas. Biogas is generated through the anaerobic digestion of organic materials like cattle manure and acts as a clean, renewable energy source. Nevertheless, the irregular nature of biogas production makes effective management a challenge. The proposed system uses sensors to gather critical data such as temperature, humidity, gas pressure, and feedstock conditions inside the biogas digester. This data is sent wirelessly through a network to a cloud server, where it can be accessed through a mobile or web application. An AI-based model, using techniques like neural networks and LSTM models, is employed to analyze the collected data and predict future biogas production. The smart monitoring device also includes a camera, display, Wi-Fi modem, and alert system that notifies the user when parameters exceed safe limits. This approach enhances monitoring, prediction accuracy, and decision-making for operating biogas plants, helping to improve efficiency and support sustainable energy use in rural communities.

[4] This paper presents an IoT-based Smart Agriculture Monitoring System aimed at enhancing farming efficiency through automation and real-time monitoring. The system utilizes sensors, including those for temperature, humidity, soil moisture, water level, and rain detection, connected to an Arduino and NodeMCU to gather environmental data from agricultural fields. The collected data is transmitted via a wireless sensor network and IoT platform, allowing farmers to monitor field conditions from a distance using a mobile phone or web interface. The system can automatically control irrigation, activating a water pump when soil moisture or water levels drop below the required threshold. It also includes alert mechanisms, such as SMS notifications and buzzers, to warn farmers about environmental changes or animal intrusion. By integrating IoT and sensor technologies, the system helps reduce water waste, minimize manual labor, improve resource a management, and boost crop productivity, making it a practical solution for modern smart farming.

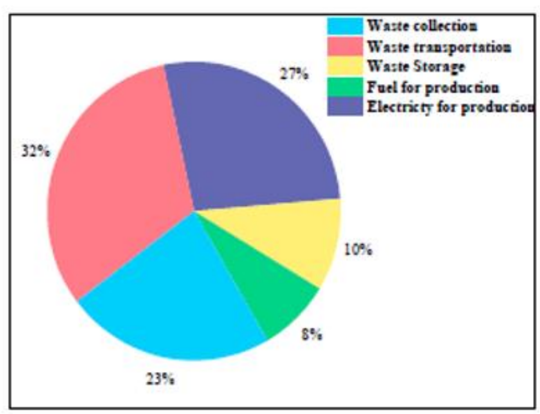

Figure 4. Carbon emission proportion diagram of different stages.

This paper presents an IoT-based Smart Agriculture Monitoring System designed to improve farming efficiency through automation and real-time monitoring. The system uses sensors such as temperature, humidity, soil moisture, water level, and rain detectors connected to an a Arduino and NodeMCU to collect environmental data from agricultural fields. The data is transmitted through a wireless sensor network and IoT platform, allowing farmers to monitor field conditions remotely using a mobile phone or web interface. The system can automatically control irrigation by activating a water pump when soil moisture or water levels drop below the needed level. It is also includes alert mechanisms like SMS notifications and buzzers to warn farmers about environmental changes or animal intrusion. By integrating IoT and sensor technologies, the system helps reduce water waste, lessen manual labor, improve resource management, and boost crop productivity, making it a practical solution for modern smart farming.

This paper proposes an intelligent biogas digester monitoring system based on a Wireless Sensor Network (WSN) to improve safety, automation, and efficiency in biogas plants. The system uses a distributed sensor nodes to gather environmental parameters such as temperature, humidity, and pressure inside the biogas digester. This data is transmitted through ZigBee-based wireless sensor networks to a GPRS intelligent gateway, which processes and forwards the information to a cloud server for storage and analysis. Users and supervisory authorities can access real-time data remotely via mobile devices and monitoring software. The system also includes an early warning mechanism to detect potential risks and trigger alarms when abnormal conditions occur. Experimental results show that the proposed system provides reliable data transmission, low power consumption, strong resistance to a interference, and effective long-term monitoring, enabling smart management of biogas digesters.

This study examines the role of soil temperature in controlling plant growth timing, particularly the start of vegetation growth in high-latitude areas. Plant phenology, which refers to the timing of seasonal life-cycle events, is strongly influenced by environmental factors such as temperature, water availability, and day length. While air temperature is often used to model vegetation growth, several studies suggest that soil temperature and thawing might be better indicators of the growing season's beginning. Frozen soil restricts plant activity by limiting water availability and root processes, and vegetation growth resumes only after the soil thaws. Experimental and observational studies show that rises in soil temperature can impact plant physiological processes including root growth, respiration, leaf development, and flowering. Therefore, the study tests the idea that soil thawing plays a vital role in regulating the onset of spring vegetation growth in high-latitude ecosystems while its influence decreases in areas where soil freezing occurs less often.

This study proposes a Smart Biogas system integrated with Internet of Things (IoT) technology to transform organic waste into renewable energy while allowing real-time monitoring of the digestion process. The system uses sensors such as DHT22 (temperature), BMP180 (pressure), and MQ-4 (methane) connected to an ESP32 microcontroller to monitor key parameters inside the biogas digester. Organic waste undergoes anaerobic digestion through hydrolysis, acidogenesis, acetogenesis, and methanogenesis to produce methane-rich biogas, which can be converted into electricity for community use. The monitoring system sends sensor data to a cloud-based platform, allowing remote access, visualization, and early detection of abnormal conditions. Experimental results show stable operating conditions with temperatures between 33 and 37 °C, pressure between 1.2 and 1.8 kPa, and methane concentration around 58 to 64%, indicating effective fermentation. The study estimates that 113 tons of organic waste can produce about 5,650 m³ of biogas each day, generating roughly 33,900 kWh aand of energy daily. The results demonstrate that combining IoT technology with communal biogas systems improves efficiency, safety, waste management, and renewable energy production, making it a sustainable solution for urban waste and energy challenges.

This paper discusses the causes, impacts, and global challenges of global warming, with a focus on its effects on third-world and developing countries. Global warming, mainly caused by increased greenhouse gas emissions from fossil fuels, deforestation, and industrial activities, leads to rising temperatures, sea-level rise, irregular rainfall, droughts, floods, and threats to biodiversity and human health. Developing countries are expected to face the most severe consequences despite contributing the least to global emissions. Regions like

Sub-Saharan Africa and Southeast Asia encounter heightened risks of food shortages, water scarcity, climate-related diseases, and natural disasters. The paper highlights the need for international is cooperation, renewable energy adoption, emission reduction, and financial support from developed nations to assist vulnerable countries in adapting to climate change. Overall, it emphasizes that global warming is a crisis that requires immediate collective action to ensure sustainable development an environmental stability. protection.

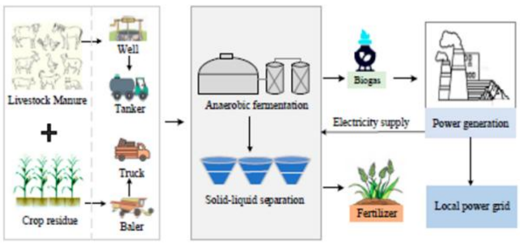

Figure 1. System boundary diagram of the biogas production system.

This study dives into building an AI-powered model to predict how much biogas smart Gobar gas systems can produce in rural areas. Biogas comes from breaking down organic stuff like cattle manure without oxygen—so it's clean, renewable, and helps rural communities tackle waste and energy shortages. The problem is, biogas output isn't steady. It goes up and down, which makes planning hard.

To fix that, the researchers suggest putting smart monitoring systems in place. These use sensors to track temperature, humidity, gas pressure, the type of feedstock, and how much biogas the plant makes. All this data gets sent to a processing unit, which is hooked up to a camera, a screen, and Wi-Fi. From there, it shoots the information up to a cloud server using wireless networks like ZigBee, GPRS, or just the internet. Operators can check everything from their phone or computer. Plus, the system can send out alerts if things get too hot or if something risky happens around the plant.

Once the data is in, they clean it up and use AI—like LSTM networks and neural networks—to figure out and predict future biogas production. They test these models with things like mean squared error and R-squared to see how well they work. In the end, the goal is a reliable prediction system that helps plant operators manage feedstock better, keep an eye on the plant's health, plan how to use energy, and run the place more safely and efficiently.

Now, looking at household biogas digesters, these are smaller setups that turn stuff like animal manure, food scraps, and crop leftovers into biogas using the same anaerobic digestion process. The gas is mostly methane and carbon dioxide, and people use it for cooking, heating, lighting, or making electricity. The leftover liquid, or slurry, is packed with nutrients and works great as a fertilizer.

How well these digesters work depends on things like temperature, pH, what's getting digested, the carbon-nitrogen ratio, how much stuff gets added, mixing, and how long everything stays in the system. There are a few common designs—fixed dome, floating drum, and plug flow digesters—and which one works best depends on local conditions and costs.

Countries like China, India, and Nepal rely on these biogas digesters, especially out in the countryside. They make a big difference: people waste less, cut down fewer trees, depend less on fossil fuels, and enjoy cleaner surroundings with fewer greenhouse gases. Sure, there are some issues—getting one set up isn't cheap, temperature changes mess with the process, gas can leak if a things go wrong, the process takes time, and a lot of folks just don't have the know-how or tools to keep them running smoothly. But even with all those bumps, household biogas tech really helps: it gives families greener power, better ways to deal with waste, less pollution, and overall, it boosts rural living.

Biogas tech isn't new, either. Since the 1970s, millions of families, mainly in India and China, have had small biogas plants in their backyards that turn a animal manure into fuel for cooking, heating, and lighting. What you get is a gas that's roughly half methane and half carbon dioxide, good enough for all those things. Beyond just providing energy, these digesters tackle problems like indoor air pollution and poor sanitation. But here's the catch—without regular maintenance or enough technical support, a lot of plants end up breaking down. So if we want more people using them, better support networks and smarter designs are a must. There's a lot of room to get more bang for the buck, too; adding stuff like kitchen scraps, old crops, weeds, or even human waste can really ramp up gas output and make these systems even more sustainable.

In places where getting electricity from the main grid isn't easy, biogas is a real game changer. It runs on all kinds of organic waste—farm leftovers, manure, and human waste. Lately, by teaming up this tried-and-true tech with Internet of Things (IoT) devices, people have made these systems even smarter. With sensors keeping tabs on temperature, pressure, gas quality, and the rest, it's easier to spot problems early, fine-tune performance, and cut down on repairs or breakdowns. IoT even lets you manage things remotely through cloud platforms and apps. Converting this gas to electricity is pretty straightforward, too—internal combustion engines, gas turbines, small-scale microturbines, or even fuel cells can do the trick. Countries all over—Germany, Sweden, Kenya, China, India—are seeing success with IoT-based biogas setups powering up rural spots and microgrids. These systems do need upfront cash, decent internet, and people who can keep them running. Data security's another thing to watch. But the payoff? More efficient, reliable, and sustainable rural energy.

Europe is already way ahead of the game. According to Nicolae Scarlat and his team, the European Union's been cranking out biogas from everything under the sun—farm waste, manure, sludge, food scraps. In 2015, the EU alone pumped out around 18 billion cubic meters of methane, making up nearly half of the world's biogas. They run over 17,400 plants, pack more than 10 gigawatts of power, and provide enough juice for millions of homes. A big part of this push comes from policies like the Renewable Energy Directive, which aims to turn Europe into a low-carbon, cleaner economy. Biomethane is showing a lot of promise, too. By purifying regular biogas, it can go straight into natural gas pipelines or fuel cars and buses. Europe's got hundreds of biomethane plants and almost 700 fueling stations—so, yeah, the future for clean energy looks more and more like biogas.sector.Overall, the research concludes that biogas production has significant potential to contribute to renewable energy targets, reduce greenhouse gas emissions, support rural development, and improve waste management systems. However, further technological advancements, policy support, and sustainable feedstock management are necessary to fully exploit the biogas potential in Europe and worldwide.

[15]Global Policy and Environmental Impact of Biogas SystemsThe adoption of biogas technology is heavily influenced by national policies and environmental goals. **Shirinda and Phiri (2025)** examined the state of biogas in South African farms, noting that while the technical potential is high—meeting up to 4% of national energy demand—the actual commercial implementation remains limited to a few registered plants. Their study highlights that biogas can reduce national greenhouse gas emissions by 2%, but emphasizes that a lack of government incentives and high capital costs are the primary barriers to widespread adoption. Similarly, **Zhang Bo**discussed the situation in China, suggesting that while household-scale technology is mature, its growth is slower than total energy consumption. Both studies conclude that international cooperation and enhanced financing channels are critical for moving from experimental to practical large-scale application.

[16] Technical Innovations and Smart Grid Integration Modern biogas systems now hook right into existing energy networks. Anbu Elango R. came up with a setup for Indian villages using gas engines tweaked for biogas—think adjusted compression ratios and spark-plug ignition with firing controllers. One of the smart moves here is using direct-coupled alternators and synchronizing panels, so these rural biogas plants can actually send excess electricity back to the local grid. In bigger setups, like the one Fan and his team reported in Beijing, the trick is to store biogas right above the slurry in the fermentation tank and then run a Combined Heat and Power system. They managed to crank out 160 kW of electricity while using the leftover heat for the process. It's a smart way to squeeze the most out of the system.

17] Economic Feasibility and Multi-Product Revenue Streams

Biogas only really pays off when you look at everything it creates, not just the energy. Islam and his colleagues took a close look at poultry farms in Bangladesh and figured out that the best way to make money is to sell both electricity and bio-fertilizer. They ran the numbers—Net Present Value (NPV), Internal Rate of Return (IRR)—and found that selling the leftover slurry as organic fertilizer sometimes brings in as much or more money than the electricity. Fan's work backs this up, too; the Beijing set-up churns out three revenue streams: heat, clean power, and organic fertilizer. That combo helps farmers earn back their investment faster.

18] Integrated Bio-cycle and Circular Economy (The 7R Model)

Cahyono Agus goes beyond just burning biogas for electricity. He introduced the Integrated Bio-cycle

Farming System (IBFS) in Indonesia, thinking much bigger—focusing on the whole circular economy by following the 7R model: reuse, reduce, recycle, refill, replace, repair, and replant. With this approach, biogas becomes the heart of the community's energy, giving rural areas more control over their resources. Managing carbon, nutrients, and organic matter isn't just a side benefit—it's necessary if these communities want real, lasting food security and sustainability.

19] Computational Modeling and Optimization

You can't just build these systems and hope for the best—researchers lean on simulation software to get it right. Boadzo and Chowdhury (2011) used HOMER to size up both off-grid and grid-connected biogas systems for South African dairy farms. They looked at costs (Net Present Cost), how much energy came from renewable sources (Renewable Fraction), and fine-tuned setups using microturbines and diesel generators. Their work shows that these hybrid systems, while financially tricky, are solid choices for power—even in places where stringing up new grid lines just isn't practical.

20] Practical Technology Promotion and Barriers

Zhang Bo took a hard look at Chinese livestock farms and found something interesting: newer biogas tech does help efficiency, but residential adoption still lags behind overall energy use. If that's going to change, Zhang says China needs to boost international partnerships and open up more funding channels. That way, real-world biogas technology actually gets into the hands of small farmers—where it can make a difference.

21] Modeling and Optimization using HOMER

Boadzo and Chowdhury (2011) dig even deeper with HOMER, running simulations to test stand-alone and grid-connected biogas setups on South African dairy farms. They checked every angle—Net Present Cost, Renewable Fraction, equipment types like microturbines and diesel generators. The verdict? Biogas systems aren't easy to finance, but they give farms reliable power, and open up options where the grid just doesn't reach.

They give you a dependable energy source in places where running new power lines just doesn't make sense. The study highlights how HOMER's sensitivity analysis really comes in handy—it lets you play with changing fuel prices and shifting electricity demands, so you can see how the system holds up under all sorts of conditions. When the authors compare the Levelized Cost of Energy (LCOE), it's clear: bringing biogas into the mix cuts CO2 emissions and delivers steadier power than just sticking with diesel, especially out on remote dairy farms.

They dig into how microturbines stack up against regular diesel generators. Sure, microturbines cost more upfront, but they're much better at capturing and using leftover heat. In the end, when you look at the Net Present Cost (NPC), the long-term savings on running the system, plus a high Renewable Fraction, make this approach a solid option for making agriculture more sustainable.

Ref No.	Research Topic	Technology Used	Sensors / Components	Application Area	Key Contribution / Result
[1]	IoT-based Biogas Monitoring System	NodeMCU ESP32S	DS18B20, YL-69, BME280, MQ-4	Biogas Plant Monitoring	Real-time monitoring of temperature, humidity, and methane to improve biogas production efficiency.
[2]	Smart Biogas Production from Animal Waste	Arduino Uno	Temperature, Pressure, pH sensors	Renewable Energy Production	Demonstrated efficient biogas generation using poultry and pig dung in a small-scale digester.

[3]	AI-Based Smart Biogas Prediction System	AI models, IoT	Temperature, Humidity, Gas Pressure sensors	Smart Energy Management	Predicts future biogas production using machine learning models.
[4]	IoT Smart Agriculture Monitoring System	Arduino, NodeMCU	Soil Moisture, Temperature, Rain sensors	Smart Farming	Automated irrigation and remote monitoring improve farming productivity.
[5]	Smart Agriculture Automation	Wireless Sensor Network	Soil moisture, Water level sensors	Precision Agriculture	Reduces water wastage and labor through automated irrigation systems.
[6]	Wireless Sensor Network for Biogas Digester	ZigBee, GPRS Gateway	Temperature, Humidity, Pressure sensors	Biogas Safety Monitoring	Enables remote monitoring and early warning system for biogas plants.
[7]	Soil Temperature and Plant Growth Study	Environmental monitoring systems	Soil temperature sensors	Agricultural Research	Shows soil temperature significantly affects plant growth cycles.
[8]	IoT-Based Smart Biogas System	ESP32 IoT system	DHT22, BMP180, MQ-4	Waste-to-Energy Systems	Improves energy generation from organic waste through real-time monitoring.
[9]	Global Warming and Environmental Impact	Climate analysis models	Environmental monitoring tools	Climate Research	Highlights need for renewable energy to reduce greenhouse gas emissions.
[10]	AI-Based Biogas Production Prediction	Neural Networks, IoT	Temperature, Humidity, Gas sensors	Rural Energy Systems	Improves efficiency and planning of biogas plants.
[11]	Household Biogas Digesters	Fixed dome / Floating drum digesters	Gas outlet valves, pressure systems	Rural Household Energy	Provides renewable energy and improves waste

					management.
[12]	Domestic Biogas Technology Development	Anaerobic digestion systems	Organic waste processing units	Sustainable Energy	Shows potential of organic waste for sustainable energy production.
[13]	IoT Integrated Biogas Energy System	ESP8266, Blynk App	Methane sensors, temperature sensors	Smart Energy Systems	Enables remote monitoring and efficient electricity generation.
[14]	Biogas Development in Europe	Renewable energy technologies	Large-scale biogas plant systems	Industrial Renewable Energy	Demonstrates successful large-scale biogas adoption in Europe.
15	State of Biogas Energy in South African Farms	Anaerobic digestion and standalone micro-grids	Bio-digesters, generators +1	Agriculture and rural livelihoods	Potential to reduce national GHG emissions by 2% and meet 4% of energy demand by 2030.
16	Biogas Power Plants for Indian Villages	Anaerobic digestion and smart grid integration +1	Modified gas engines (piston, compression ratio), firing controllers, synchronizing panels	Rural electrification and communal cooking +1	Design for direct-coupled alternators to connect with local or national grids.
17	Feasibility of Biogas in Bangladesh Poultry Farms	Commercial biogas plants for co-production +1	Digestors, slurry transportation systems +1	Commercial poultry farms (Small to large scale) +1	Established financial viability (NPV, IRR) for poultry waste-to-energy and bio-fertilizer.
18	Large-Scale Biogas Plant in a Beijing Dairy Farm	Combined Heat and Power (CHP) system	Integrated reactor (gas storage above slurry), 160kW CHP system +1	Industrial-scale livestock waste management	Proven model for 60t/d treatment capacity with efficient integrated gas storage.
19	Integrated Bio-cycle Farming	7R Management Model (Reuse, Reduce	Bio-cycle components (Food, Fuel, Fertilizer units)	Marginalized tropical farming	Transformation of organic waste into

	System (IBFS)	, Recycle, etc.)		communities	high-value products like liquid/solid bio-fertilizer.
20	Assessment of Dairy-based Biogas in South Africa	HOMER optimization software	Microturbines (MT), Diesel Generators (DG), load profiles +1	Stand-alone and grid-connected dairy farms	Balanced Net Present Cost (NPC) with Renewable Fraction (RF) for optimal equipment setup.
21	Chinese Household & Livestock Biogas Tech	Practical Energy Technologies (PET)	Household/farm-scale biogas units	Rural household energy efficiency	Identification of financing and policy barriers to scaling household biogas adoption.

III. ACKNOWLEDGMENT-

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IV. CONCLUSION-

This study introduces a Smart Biogas Monitoring System designed for rural farms, combining Wireless Sensor Networks and Internet of Things technology. With sensors wired up to microcontrollers, the system tracks temperature, pressure, humidity, and methane levels inside the biogas digester. So, farmers get real-time updates and can keep conditions just right—no guessing, no risky blind spots. That means more methane, safer operations, and a more reliable setup overall. The data shows that adding sensor networks to biogas systems makes waste management easier and boosts renewable energy output from organic waste.

The system cuts out most of the manual checks. Instead, farmers can check digester performance on their phones, making everything quicker and more convenient. By turning animal waste and other organic leftovers into energy, this setup keeps farms running sustainably while helping the environment. Smart monitoring also helps keep fermentation conditions in the sweet spot, which pushes gas production higher and gets better results from the plant.

Switching to renewable sources like biogas means farmers aren't stuck relying on fossil fuels, and energy gets a lot more affordable for rural communities. Looking ahead, there's room to add automated control, expand wireless coverage, and use artificial intelligence to predict biogas output and flag system issues early. All told, this smart biogas system is a solid step toward cleaner energy, smarter waste management, and stronger rural farming.

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