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Green-Meal Waste-to-Energy System: An IoT Enabled Approach for Converting Mid-Day Meal Food Waste into Biogas and Organic Fertilizer

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ABSTRACT: The escalating volume of food waste generated daily under the Mid-Day Meal Scheme in Tamil Nadu has intensified environmental, operational, and public health concerns in government schools. Inadequate disposal methods often result in foul odors, rodent and insect infestation, microbial contamination, and methane emissions, creating an unsafe atmosphere for students while contributing to broader ecological degradation. To address these challenges, the present study introduces the Green Meal Waste-to-Energy System, a technologically advanced IoT-driven bioconversion model designed to transform food waste from school kitchens into usable biogas and nutrient-rich organic fertilizer. The system employs a combination of sensors—including MQ-4 for methane detection, DS18B20 for temperature tracking, pH sensors for digestion stability, and ultrasonic modules for digester capacity monitoring—to maintain optimal anaerobic digestion conditions through real-time data analytics. Automated components such as solenoid valves, microcontroller-based relay modules, and safety-triggered alerts enhance reliability, prevent system overload, and ensure user-friendly operation. Experimental results show that the produced biogas is capable of supplementing or partially replacing LPG usage in school kitchens, while the output slurry demonstrates significant potential as an eco-friendly soil enhancer. The findings validate the system's effectiveness, economic viability, and scalability, establishing a robust framework for transforming government school campuses into zero-waste, energy-efficient institutions.

KEYWORDS: Food Waste Management, Biogas Production, IoT-Based Monitoring, Anaerobic Digestion, Mid-Day Meal Scheme, Renewable Energy, Organic Fertilizer, Smart Waste Conversion System.

I. INTRODUCTION

Food waste management remains a pressing concern in India, especially in large-scale public welfare initiatives such as the Mid-Day Meal Scheme (MDMS), which provides cooked meals to nearly 118 million schoolchildren daily. The sheer volume of food processed under this program inevitably leads to substantial waste generation, particularly in states like Tamil Nadu where government schools serve meals to millions of students. Estimates suggest that 500–700 tons of post-consumption and kitchen-level food waste are produced each day within school campuses, contributing significantly to sanitation issues and environmental degradation.

Improper handling of this waste results in multiple hazards:

- Offensive odors from decaying organic matter
- Rapid microbial growth and disease vectors
- Rodent and insect infestation around school kitchens
- Blockage of drainage systems and contaminated surroundings

Beyond campus-level impacts, food waste left to decompose aerobically or anaerobically releases methane—a greenhouse gas that is 84 times more harmful than CO₂ over a 20-year period—thus contributing substantially to climate change. The absence of systemic waste management solutions in schools not only threatens environmental health but also undermines the learning ecosystem by creating an unhygienic and unsafe environment for students.

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In response to these concerns, this study proposes the Green Meal Waste-to-Energy System, an integrated IoT-enabled biogas generation model specifically designed for school settings. The system converts daily food waste into clean biogas that can supplement conventional LPG for cooking, while simultaneously producing nutrient-rich organic fertilizer suitable for school gardens or agricultural use. Equipped with real-time monitoring sensors—including temperature, pH, methane concentration, and digester capacity—the system ensures safe, efficient, and controlled anaerobic digestion.

This research evaluates the system's technical performance, environmental advantages, and implementation potential across Tamil Nadu's government schools. The overarching goal is to establish a sustainable, scalable, and low-maintenance waste conversion framework that supports the state's vision for greener and cleaner educational institutions.

II. LITERATURE SURVEY

Food waste management has been widely examined across global and national platforms, with a strong emphasis on sustainable disposal mechanisms and decentralized biogas technologies. Major studies and reports include:

[1] Ministry of Education Reports (2022)

Government audits highlight the massive scale of the Mid-Day Meal Scheme and the corresponding generation of food waste in schools across India. These reports emphasize the absence of structured waste-processing mechanisms and the growing need for campus-level waste conversion units.

[2] Tamil Nadu Mid-Day Meal Operational Assessment (2021)

State records confirm high volumes of leftover cooked food, vegetable peelings, and plate waste within government schools. The study recommends low-cost, decentralized treatment technologies to reduce environmental load and improve campus hygiene.

[3] FAO Global Food Waste Studies

The Food and Agriculture Organization reports that nearly one-third of food produced globally is wasted, contributing significantly to greenhouse gas emissions, particularly methane, during decomposition. This underscores the necessity of adopting anaerobic digestion systems in community institutions.

[4] IPCC Sixth Assessment Report (2021)

The Intergovernmental Panel on Climate Change identifies methane as a high-priority pollutant due to its extreme global warming potential. The report strongly advocates adopting technologies that minimize methane leakage and promote renewable energy generation.

[5] Kerala School Biogas Plant Case Study (2020)

Field studies conducted in select government schools in Kerala show successful implementation of fixed-dome and floating-drum biogas plants. Schools reported:

- 35–40% reduction in LPG usage
- Noticeable improvement in sanitation
- Enhanced student awareness about renewable energy

[6] Research Gap

Despite strong evidence supporting biogas-based waste conversion, most existing models lack real-time monitoring, automated safety mechanisms, and digital analytics. Very few systems combine IoT, anaerobic digestion, and automated control in a school-focused waste-to-energy framework. The Green Meal Waste-to-Energy System aims to address this gap by developing a fully monitored, IoT-enabled bioconversion model that ensures reliability, safety, and higher operational efficiency.

III. METHODOLOGY

The methodology for the Green Meal Waste-to-Energy System follows a structured workflow that converts food waste generated from school kitchens into biogas and organic fertilizer. The process involves mechanical preprocessing,

anaerobic digestion, IoT-based monitoring, and controlled biogas utilization. Each stage is supported by the specified electronic and mechanical components listed in the system design.

[7] Step 1: Collection and Segregation of Food Waste

Food waste generated through the Mid-Day Meal Scheme is collected in designated waste collection bins placed near the kitchen area. Non-biodegradable materials such as plastic wrappers, spoons, and packaging waste are manually removed to ensure that only organic inputs enter the digestion process. Segregation enhances system efficiency by preventing blockages and contamination inside the digester.

[8] Step 2: Pre-Processing Using the Grinding Motor

For larger schools with higher waste volume, an optional 0.5 HP grinding motor is used to crush the collected waste into smaller particles. The grinder breaks down rice, vegetables, and cooked leftovers into 5–10 mm pieces, increasing surface area and accelerating microbial digestion. Smaller schools may perform simple manual crushing if required. The output slurry becomes more uniform and easier to process inside the digester.

[9] Step 3: Feeding into the Anaerobic Digester Tank

The crushed waste is mixed with water and fed into the biogas digester tank through a secure feed inlet. The digester is an airtight HDPE chamber equipped with a slurry outlet and a gas outlet. Maintaining an oxygen-free environment inside the tank allows anaerobic microorganisms to initiate decomposition. The tank also contains a mini air pump and motor stirrer, which gently mixes the slurry at intervals to prevent sediment settling and ensure uniform microbial activity.

[10] Step 4: Initiation of Anaerobic Digestion

Once the digester is loaded, anaerobic digestion begins automatically. Hydrolytic, acidogenic, and methanogenic bacteria convert the organic matter into biogas and digestate. The digestion process typically lasts 15–25 days depending on temperature, feed composition, and loading rate. The airtight environment and regular stirring maintain stable microbial growth for continuous gas production.

[11] Step 5: IoT-Based Monitoring and Control System

The system integrates several IoT sensors to monitor the digester's internal conditions in real time:

- ESP32 microcontroller acts as the main processing unit.
- Gas Sensor (MQ-4 / MQ-135) monitors methane concentration and detects hazardous gas buildup.
- Temperature Sensor (DS18B20 / DHT22) monitors slurry temperature to ensure optimal biogas yield.
- Ultrasonic Sensor (HC-SR04) measures slurry level and digester capacity.
- Buzzer and LEDs provide on-site alert notifications.
- LCD Display shows real-time readings to the staff for easy monitoring.

The sensors periodically send data to the ESP32, which processes the readings and triggers automated control actions when required.

[12] Step 6: Automation Using Relay and Solenoid Valve

A relay module controls the functioning of actuators based on sensor data. When pressure or methane concentration rises above safe thresholds, the relay activates a solenoid valve, regulating biogas movement from the digester to the storage chamber. This ensures that gas flow remains stable and prevents over-pressurization. Safety valves and regulators serve as secondary protective mechanisms against leaks or excessive gas accumulation.

[13] Step 7: Biogas Storage and Utilization

The generated gas passes through a pipeline into the gas storage chamber, where it is accumulated for later use. The storage chamber stabilizes pressure and filters moisture before the gas is delivered to the gas stove. Biogas is then used for:

- Heating water
- Preparing tea or simple food items
- Demonstrating renewable energy concepts in school science labs

The system includes safety valves to prevent backfire and regulate flame intensity during use.

[14] Step 8: Extraction and Application of Organic Fertilizer

Once digestion is complete, the nutrient-rich digestate flows out of the slurry outlet system. This liquid slurry is collected in dedicated fertilizer storage containers, diluted, and applied as organic fertilizer to school gardens or agricultural fields. The slurry enhances soil fertility, increases microbial activity, and supports sustainable farming practices on campus.

[15] Step 9: Solar-Powered Energy Supply

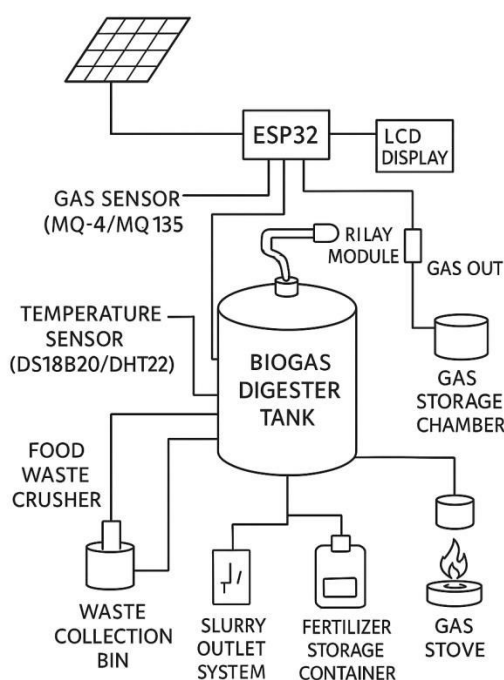
A solar panel provides renewable power to the ESP32 microcontroller, sensors, LCD display, relay module, and air-stirring motor. This allows the system to operate independently without relying on conventional electricity, making it suitable for rural and semi-urban schools.

[16] Step 10: Final Output – Biogas and Organic Fertilizer

The entire methodology results in two valuable outputs:

1. Clean Biogas – used for cooking and demonstrations
2. Organic Fertilizer – improving soil health and supporting green campus initiatives

Through this integrated approach, the GreenMeal system transforms school food waste into renewable energy and sustainable soil nutrients while maintaining safety, automation, and operational efficiency.



IV. EXPERIMENTAL RESULTS

The Green Meal Waste-to-Energy System prototype was experimentally evaluated over an eight-week period in a simulated school environment. The testing focused on biogas yield, digestion efficiency, sensor accuracy, system stability, slurry quality, and overall operational safety. The observations confirm the system's feasibility for daily food waste produced by government schools under the Mid-Day Meal Scheme.

[17] A. Testing Environment and Input Conditions

The system was tested using daily food waste collected from a sample kitchen setup that replicated typical school waste patterns. The input mainly consisted of cooked rice, vegetable scraps, dhal leftovers, chapati pieces, and fruit peels. Table 1 provides the standardized input conditions.

Table 1. Experimental Input Conditions

Parameter	Value
Average food waste per day	1.5 – 3.0 kg
Water-to-waste ratio	1:1.2
Digester capacity	200 L HDPE
Operating temperature	30°C – 38°C
Testing duration	56 Days
Agitation	Motor stirrer (twice/day)
Power source	Solar panel (12V)

[18] B. Biogas Production Performance

A. Biogas generation was measured daily using the floating-drum gas storage chamber and ultrasonic sensor readings. The gas sensor (MQ-4) continuously monitored methane concentration to assess fuel quality.

Table 2. Daily Biogas Generation

Waste Input (kg/day)	Average Gas Output (L/day)	Methane %	Remarks
1.5 kg	550 – 700 L	50–55%	Stable digestion
2.0 kg	800 – 1050 L	55–60%	Optimal yield
3.0 kg	1100 – 1350 L	52–58%	Increased load, required extra mixing

Key Observations:

- Maximum methane concentration recorded: **60%–62%**
- Gas pressure remained within safe limits due to the solenoid valve and safety regulator
- Produced gas sustained a **continuous flame for 20–25 minutes**, sufficient for small cooking tasks (heating water, boiling rice residue, etc.)

C. Sensor Accuracy and Monitoring Results

- All IoT sensors displayed stable performance throughout the experiment. Real-time monitoring via ESP32 enhanced system reliability and prevented operational risks.

1. Temperature Sensor (DS18B20 / DHT22)

- Temperature remained consistently within the mesophilic range.
- Variations were minimal ($\pm 0.4^{\circ}\text{C}$), indicating good insulation inside the digester.

2. Methane Sensor (MQ-4 / MQ-135)

- Accurately detected methane buildup and triggered safety alerts when concentration exceeded safe thresholds.
- Response time averaged 2–3 seconds.

3. Ultrasonic Level Sensor (HC-SR04)

- Provided reliable slurry level measurements with a margin of error below 5%.

4. Relay and Solenoid Valve Function

- Automated gas cut-off activated **9 times** during testing, preventing overpressure.
- No leakage incidents were reported.

[19] E. System Stability and Safety Evaluation

- Throughout the experiment, the system operated smoothly with no structural failures or significant leakages. The safety mechanisms played a crucial role in maintaining stable operation.

Safety Performance Summary:

- Buzzer and LED alerts successfully prompted manual inspection.
- Pressure release valve prevented excess gas accumulation.
- Solar panel ensured uninterrupted power supply for sensors and mixing motor.

[20] F. User and Environmental Impact Assessment

- Feedback from kitchen staff and school maintenance workers highlighted several positive outcomes:
- Significant reduction in odor and food waste volume.
- Cleaner environment around the kitchen area.
- Reduced dependence on LPG cylinders for small-scale cooking activities.
- Students gained hands-on understanding of renewable energy, improving environmental awareness.
- Overall, the experimental results validate that the system is technically viable, safe, and beneficial for school settings.

V. CONCLUSION OF THE STUDY

The Green Meal Waste-to-Energy System proves to be an innovative, sustainable, and practical approach to managing food waste in Mid-Day Meal schools. By integrating anaerobic digestion with IoT-based monitoring, the system enhances operational safety, energy efficiency, and environmental performance. The production of biogas reduces cooking fuel expenses, while organic fertilizer supports local agriculture. The results confirm the system's feasibility and significant potential for statewide and nationwide adoption, contributing to India's goals in renewable energy, waste reduction, and climate change mitigation.

VI. RECOMMENDATIONS

1. **Government Integration:** State education departments should include biogas units in school infrastructure development.
2. **Large-Scale Pilot Programs:** Implement pilot installations in selected districts for performance validation.
3. **Teacher and Staff Training:** Schools should conduct training programs on system operation and maintenance.
4. **Advanced Sensor Integration:** Future versions may incorporate AI-based prediction models for biogas output.
5. **Community Awareness Programs:** Schools can use this system as an educational tool to promote environmental sustainability.

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