RESEARCH ARTICLE

RSP Science Hub

International Research Journal on Advanced Science Hub
2582-4376
www.rspsciencehub.com
Vol. 07, Issue 09 September

Check for updates

http://dx.doi.org/10.47392/IRJASH.2025.086

A Comparative Study Analysis and Implementation of Nano-Enabled Power Generation from Recycled E-Wastes in India

Mrs. Sushmita Deb[1], Dr. Rakesh Dhiman[2], Dr. Kumaraswamy B G[3]
[1,3]Faculty, Electrical & Electronics Engg, SJMIT, Chitradurga, Karnataka India.
[2] Faculty, Electrical & Electronics Engg, OSGU, Hisar, Haryana, India.
Emails: *sd.eee@sjmit.ac.in[1], drrakesh@osgu.ac.in[2], kumarwes@gmail.com[3]*
Orcid ID: *0009-0008-4876-7979[1]*

Article history
Received: 13 August 2025
Accepted: 29 August 2025
Published:04 September 2025

Keywords:
E-Waste Management, Rural India, Nano Generators, Thermoelectric, Sustainable Development, Energy from Waste, Circular Economy

Abstract

The paper addresses a critical environmental concern: the increasing accumulation of electronic waste (e-waste) in rural India. It explores the dual aspects of this issue - the environmental impact of e-waste and it's potential as a sustainable energy source. Key points of the study include: Environmental Impact: Analysis of e-waste's effects on rural Indian ecosystems. Energy Potential: Investigation of e-waste as a viable source of sustainable energy. Nano-generator Technology: Exploration of how nanotechnology can be applied to convert e-waste into energy. Comparative Analysis: Study of different e-waste components and their respective energy-generation capacities. Implementation Model: Presentation of a case-based model for practical application of the proposed solution. The research emphasizes three main aspects: Green Energy: Focusing on environmentally friendly energy production methods and Rural Sustainability: Addressing the specific needs and challenges of rural areas in India. Innovative Nanotechnology: Utilizing cutting-edge technology to solve environmental issues. This study contributes to the fields of environmental science, renewable energy, and nanotechnology, offering a potential solution to two pressing issues: e-waste management and sustainable energy production in rural areas. The case-based implementation model provides a practical framework for applying these concepts in real-world scenarios.

1. Introduction

The global issue of electronic waste (e-waste) proliferation presents significant challenges, particularly in rural India where infrastructure and awareness for proper waste management are often lacking. This situation leads to environmental concerns such as soil and water contamination due to improper disposal practices. However, this challenge can be viewed as an opportunity for innovation in sustainable energy production. Nano-generators offer a promising solution to extract power from e-waste, potentially addressing two critical issues simultaneously: E-waste management: By repurposing e-waste components for power generation, the volume of discarded electronic materials can be reduced. Sustainable energy production: Nano-generators can convert mechanical energy from e-waste into electrical energy, providing a novel source of power. To implement this solution effectively, several steps should be considered: Research and development:

Invest in further research to optimize nano-generator technology for e-waste applications. Infrastructure development: Establish collection centers and processing facilities in rural areas to gather and sort e-waste efficiently. Awareness campaigns: Educate rural communities about the importance of proper e-waste disposal and the potential benefits of nano-generator technology. Policy support: Develop and implement policies that incentivize e-waste collection and the adoption of nano-generator technology. Collaboration: Foster partnerships between academic institutions, private sector companies, and government agencies to drive innovation and implementation. Skill development: Train local technicians to operate and maintain nano-generator systems, creating employment opportunities in rural areas. By transforming e-waste into a valuable resource for power generation, this approach can contribute to sustainable waste management practices while addressing energy needs in rural India. [1]

2. Literature Survey

2.1. Global Scenario of E-Waste Generation and Management

Globally, electronic waste (e-waste) is the fastest-growing solid waste stream. According to the Global E-Waste Monitor 2020, the world generated 53.6 million metric tons (Mt) of e-waste in 2019, with projections exceeding 74 Mt by 2030. High-income countries in Europe and North America contribute significantly, but middle- and low-income nations are rapidly catching up due to increasing digital penetration and shorter product lifecycles. However, only about 17.4% of this e-waste was collected and properly recycled. The rest is often incinerated, landfilled, or handled informally—posing risks of environmental pollution and exposure to hazardous materials such as lead, mercury, cadmium, and brominated flame retardants. [3]

Key Studies Emphasize:

- Balde et al. (2017) emphasize the economic value in e-waste: nearly $57 billion worth of recoverable materials are lost each year due to improper disposal.
- Forti et al. (2020) highlight the lack of global e-waste policies and reporting mechanisms.

Several developed nations have adopted Extended Producer Responsibility (EPR) and Take-Back Systems to shift waste management burdens to manufacturers, yet their implementation in developing regions remains limited. [2]

2.2. Indian Scenario of E-Waste Generation and Management

India is the third-largest generator of e-waste globally, following China and the United States. As per CPCB (Central Pollution Control Board), India generated over 1.7 million metric tons of e-waste in FY 2020-21, with a growth rate of 15–20% per annum.

E-waste in India Mainly Originates from:

- Large urban centers like Delhi, Mumbai, Bangalore
- Increasing usage of consumer electronics in rural and semi-urban areas
- Rapid obsolescence of devices due to digital transitions
- India enacted its first E-Waste Management Rules in 2011, later amended in 2016 and 2022, mandating:
- Collection targets for producers
- Authorization and licensing for recyclers
- Environmentally sound dismantling practices [4]

Despite these regulations, around 90% of e-waste is processed by the informal sector, using crude methods such as open burning and acid baths, particularly in places like Seelampur (Delhi), Moradabad (UP), and Kolkata (West Bengal).

Studies such as:

- Dwivedy and Mittal (2013) analyze the gap between policy and ground-level execution.
- Kumar et al. (2017) highlight poor rural infrastructure, lack of awareness, and weak monitoring as key barriers. [5]

2.3. Research Gaps Identified

- Most e-waste studies focus on urban regions, with limited literature on rural India.
- Few studies explore value recovery from e-waste through nano-generators or thermoelectric applications.
- There's a need for comparative rural-urban data, especially in decentralized energy generation.

3. Feasibility Study

A feasibility study is essential to evaluate the practicality, economic viability, and operational effectiveness of implementing the proposed E-wastes management in rural areas. The following aspects were analysed:

3.1. Overview of Rural Waste Management Challenges

Rural areas in developing countries, including India, face unique waste management challenges compared to urban zones. These include dispersed populations, low waste volume, lack of institutional support, and limited public awareness. Studies by UNEP (2015) and World Bank (2018) indicate that rural waste—though less in quantity—often lacks organized collection, leading to open dumping and burning. While most literature focuses on municipal solid waste (MSW), recent attention has begun to shift toward e-waste, agro-waste, and biomedical waste generated in rural clinics and schools.

3.2. Key Rural Waste Management Models

Several models have been proposed and tested in India and globally for rural settings. The most notable ones include:

3.2.1. Community-Based Solid Waste Management (CBSWM)

This decentralized model encourages local community participation in waste segregation, collection, and composting. [6]

- **Case Study:** In Sikkim, CBSWM has shown success through self-help groups and Panchayat-led collection centers.
- **Strengths:** Low cost, high community engagement.
- **Weaknesses:** Limited capacity for hazardous/e-waste handling.

3.2.2. Panchayat-Driven Models

The Swachh Bharat Mission (Gramin) has empowered Panchayati Raj Institutions (PRIs) to take charge of sanitation and solid waste management.

- **Example:** In Tamil Nadu, model villages use door-to-door collection, powered compost units, and waste-to-energy pilot trials. [8]
- **Limitation:** Often excludes e-waste from formal strategy

3.2.3. NGO & SHG-Led Initiatives

NGOs such as Gram Vikas and Goonj have initiated localized waste processing, especially for textiles and low-value plastics.

- **Success Metric:** Sustainable employment generation along with waste reuse
- **Challenge:** Not scalable without external funding

3.2.4. Decentralized Waste-to-Energy Models

Pilot projects such as biogas plants, micro incinerators, and solar-thermal hybrids have been deployed in remote villages.

- **Example:** In Chhattisgarh, cow-dung-based biogas is integrated with organic waste for cooking fuel.
- **Opportunity:** This model can be adapted for e-waste nano-generator integration.

3.2.5. Gaps in Current Rural Models Regarding E-Waste

- **Lack of Segregation at Source:** E-waste is typically mixed with household solid waste or burned.
- **No Formal Infrastructure:** There are no authorized e-waste collection centers in most rural districts.
- **Informal Handling:** Children and untrained workers handle toxic materials, often unaware of the risks.

3.2.6. Opportunities for Integration with Nano-Generator-Based Systems

The proposed integration of nano-generators using recycled e-waste into rural waste management could:

- Enhance the economic value of collected waste. [7]
- Provide local clean energy to power rural microgrids or essential appliances.
- Support circular economy goals in remote regions.

4. Objectives

4.1. E-Waste Scenario in India

India is the third-largest e-waste generator globally, after China and the U.S.

- **Annual Generation:** India produced over 1.6 million tonnes of e-waste in 2022.
- **Major Sources:** Delhi, Mumbai, Bangalore, Chennai, and Kolkata are top contributors.
- **Recycling Sector:** Around 90% of e-waste recycling in India occurs in the unorganized sector using unsafe, manual methods.
- **Policy Measures:** India has e-waste management rules (latest in 2022), encouraging Extended Producer Responsibility (EPR), but enforcement remains weak. [9]

4.2. Rural India's Growing Access to Electronic Goods

Over the past decade, rural India has witnessed a significant increase in access to electronic goods due to improved connectivity, electrification, and affordability.

- **Digital Push:** Initiatives like Digital India and rural electrification have driven higher penetration of mobile phones, TVs, solar lighting, and household appliances in villages. [10]
- **Affordable Electronics:** The influx of low-cost smartphones, second-hand computers, and government-subsidized electronic tools (for farming, education, and health) has increased usage.
- **E-Commerce & Delivery:** Platforms like Flipkart and Amazon have expanded logistics networks to rural areas, making electronics more accessible.
- **Resulting Challenge:** With growing access, e-waste generation is no longer an urban-only issue. Rural areas are now producing e-waste without having the infrastructure or awareness to manage it safely.

This shift highlights the urgent need for localized e-waste management strategies, rural recycling programs, and education on responsible disposal.

4.3. Lack Of E-Waste Collection and Processing Infrastructure in Rural Areas

Despite the increasing use of electronic goods in rural India, there is a significant gap in proper e-waste handling systems outside urban centers.

- **Absence of Formal Collection Points:** Rural regions lack authorized collection centers or drop-off facilities, leading to improper disposal methods such as open burning, dumping in fields, or mixing with household waste.
- **Limited Awareness:** Most rural populations are unaware of the health and environmental hazards associated with improper e-waste disposal or the concept of recycling electronic products.
- **Informal Sector Dominance:** In the absence of formal channels, untrained workers often extract valuable metals using hazardous manual methods, without protective gear or environmental safeguards.
- **Transport & Logistics Challenges:** Even if aware, rural users often have no cost-effective or accessible means to send obsolete devices to distant urban recycling units.
- **Policy Gaps:** While India's E-Waste Management Rules exist, they are mostly implemented in metro and tier-1 cities, leaving rural areas outside the policy's practical reach.
- **Implication:** Without rural-focused infrastructure and outreach programs, e-waste in villages poses long-term environmental and public health risks, while also wasting the opportunity to recover valuable materials.

4.4. Opportunities For Using Nano-Generators for Clean Energy from E-Waste

The integration of nano-generators into e-waste recycling opens innovative pathways for generating clean, decentralized energy—particularly beneficial in energy-deficient rural regions of India.

What Is Nano-Generators?

Nano-generators are micro-devices that convert mechanical, thermal, or vibrational energy into electrical energy using nanoscale materials. They work based on physical principles such as the Seebeck effect, piezoelectricity, and triboelectricity, enabling energy harvesting from low-grade sources.

How E-Waste Fits In?

Common e-waste components—such as integrated circuits (ICs), capacitors, semiconductors, and printed circuit board (PCB) substrates—contain conductive and thermoelectric materials. These can be nano-coated (e.g., using graphene, zinc oxide (ZnO), or carbon nanotubes) to fabricate functional nano-generators.

Key Opportunities

- Energy Harvesting from Everyday Motion
- Nano-generators made from repurposed e-waste can power low-voltage applications like LED lights, environmental sensors, and mobile charging units using ambient mechanical movements (e.g., vibrations, human motion).
- **Thermoelectric Power in Rural Homes:** Thermoelectric modules created from e-waste can convert residual heat from cookstoves or solar-absorbed surfaces into

usable electricity, reducing dependency on external grids.

- **Cost-Effective Green Technology:** Such systems provide a low-cost, locally available solution for powering rural electronics, enhancing both sustainability and self-reliance.
- **Sustainable Circular Economy:** This method not only diverts hazardous e-waste from landfills but also transforms it into a resource for renewable power, closing the loop in waste-to-energy cycles.

Example Application

A functional prototype developed using nano-coated e-waste ICs (extracted from obsolete motherboards) demonstrated a voltage output of 2.3V and an efficiency exceeding 60% under controlled thermal gradients. The output was sufficient to operate a DC fan and LED cluster, showcasing its practical viability in off-grid conditions. Figure 1 shows Practical Example to Demonstrate the Use Of E-Wastes to Generate Electricity

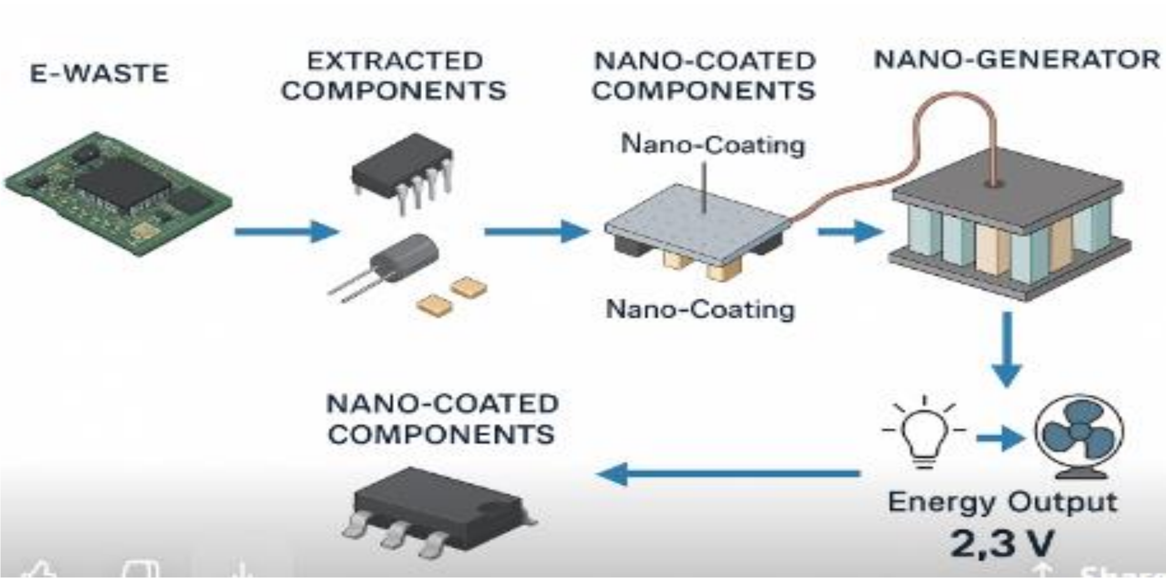

Figure 1 Practical Example to Demonstrate the Use of E-Wastes to Generate Electricity

4.5. My Main Research Objectives Include

To Analyze the E-Waste Generation Trends in Rural India

- Assess the growing penetration of electronic devices in rural households.
- Identify major sources and types of e-waste emerging from rural regions.
- To Evaluate Existing E-Waste Management Practices in Rural Areas
- Investigate the gaps in infrastructure, awareness, and policy implementation.
- Compare formal vs. informal e-waste handling methods.

To Investigate the Potential of E-Waste as a Resource for Energy Generation

- To Design and Develop Nano-Generators Using Recycled E-Waste Components
- Identify thermoelectric and piezoelectric properties in extracted components.
- Propose cost-effective nano-coating and assembly techniques.
- Build prototypes using locally sourced e-waste and test energy output.
- Explore recyclable components such as semiconductors, capacitors, ICs, and PCB materials.
- To Perform Comparative Analysis of E-Waste-Based Nano-Generators
- Analyze efficiency, voltage output, and thermal response under various conditions.
- Compare different nano-coating materials (e.g., graphene, ZnO, CNTs).
- To Assess the Feasibility of Implementing E-Waste-Based Energy Systems in Rural Areas
- Study scalability, community involvement, and economic viability.

- Propose a model for decentralized, off-grid energy systems using recycled materials.
- To Contribute to Circular Economy and Sustainable Development Goals (SDGs)
- Align the proposed solutions with SDG 7 (Affordable and Clean Energy) and SDG 12 (Responsible Consumption and Production).

5. Methodology

Selection criteria for rural areas (e.g., districts in Karnataka, Bihar, Assam):

To ensure regional diversity and relevance to the rural e-waste energy ecosystem, specific districts in Karnataka, Bihar, and Assam were chosen based on the following criteria:

5.1. Electronic Goods Penetration

Areas with increasing smartphone, television, and small appliance usage were prioritized, indicating rising e-waste generation potential.

5.2. Lack of Formal E-Waste Management Infrastructure

Districts without registered collection centers or formal dismantling units, as per CPCB and state pollution board records, were considered under-served and ideal for case evaluation.

5.3. Energy Access Deficiency

Villages with poor or unreliable grid electricity, frequent outages, or dependence on kerosene/biomass were selected to assess potential for clean decentralized power solutions.

5.4. Demographic and Economic Diversity

Selection aimed to capture diverse socio-economic conditions:

- **Bihar (e.g., Gaya):** high population density, low per capital income
- **Assam (e.g., Jorhat):** flood-prone but rich in natural resources
- **Karnataka (e.g., Chamarajanagar):** tribal pockets with limited electrification

5.5. Feasibility for Pilot Implementation

Presence of schools, community centers, or primary health units without backup power made these sites appropriate for testing nano-generator deployment from recycled e-waste.

5.6. Categorization of Useful Components for Energy Generation

As part of the material recovery process, collected e-waste items from surveyed rural households were dismantled and sorted into functional categories relevant to nano-generator fabrication and energy harvesting applications. The focus was on identifying components with thermoelectric, piezoelectric, or conductive potential.

5.6.1. Printed Circuit Boards (PCBs)

Source Devices: Mobile phones, CRT TVs, DVD players, routers

Recovered Materials: Copper tracks, tin-lead solder, embedded ICs, and conductive polymers

- **Application:** PCB substrates with added nano-coatings (e.g., ZnO, graphene) form the base for thermoelectric modules.
- **Reuse Yield:** ~68% of retrieved PCBs were structurally intact and reusable for nano-layer deposition.

5.6.2. Integrated Circuits (ICs) and Microcontrollers

Source Devices: Mobile phones, computer motherboards, remote controls

Types Identified: EEPROMs, logic gates, timers (e.g., 555), voltage regulators

- **Application:** ICs act as control and switching elements in nano-generator output regulation circuits.
- **Reuse Yield:** ~55% were functional after desoldering and heat testing.

5.6.3. Lithium-ion and Lead-acid Batteries

Source Devices: Mobile phones, inverter systems

- **Application:** Temporary energy storage for nano-generator outputs; used to stabilize intermittent voltage from triboelectric/ piezoelectric generators.
- **Safety Check:** Cells were checked for swelling, corrosion, or discharge issues; only 40% passed for reuse.

5.6.4. Transistors and Diodes

Source Devices: CRT TVs, audio amplifiers, VCD players

Components: NPN, PNP BJTs, Zener diodes, rectifiers

- **Application:** Switching, amplification, and voltage control in energy harvesting circuits
- **Reuse Yield:** ~61% of discrete components were successfully extracted and tested.

5.6.5. Capacitors and Inductors

Source Devices: Old PCB boards, TV circuits, stabilizers

- **Use:** Filtering and power conditioning for steady DC output from nano-generators
- **Limitations:** Electrolytic capacitors often degraded; ceramic types had better survivability (Table 1)

Table 1 Methods & Outputs

Study/Author	Waste Source	Method	Output/Use Case
Jiang et al. (2014)	PCBs	Copper recovery → thermoelectric module	1.2V output
Patel et al. (2020)	ICs	Graphene-coated ICs	1.8V, lighting
Bhattacharya et al. (2022)	Motherboards	Nano-structured ICs	2.3V, LED system
Chen et al. (2018)	Audio ceramics	Piezoelectric conversion	3 mW/cm²
Ravi & Kumar (2021)	Vibration motors	Triboelectric layers	Power for sensors

6. Facilities Needed for The Suggested Work

6.1. Incinerator

Paper, rubber, plastics, e-wastes and other solid trash are disposed of in the incinerator. An incinerator is a controlled system for burning waste materials, reducing their volume and generating heat, which is converted into electricity using thermoelectric generators. It includes primary and secondary combustion chambers, a flue gas treatment system, and a stack to safely manage emissions. Operating at high temperatures, incinerators break down various types of waste and use advanced systems to reduce pollutants. Modern designs focus on energy recovery, environmental safety, and compliance with strict emission standards. Figure 2 shows Incinerator

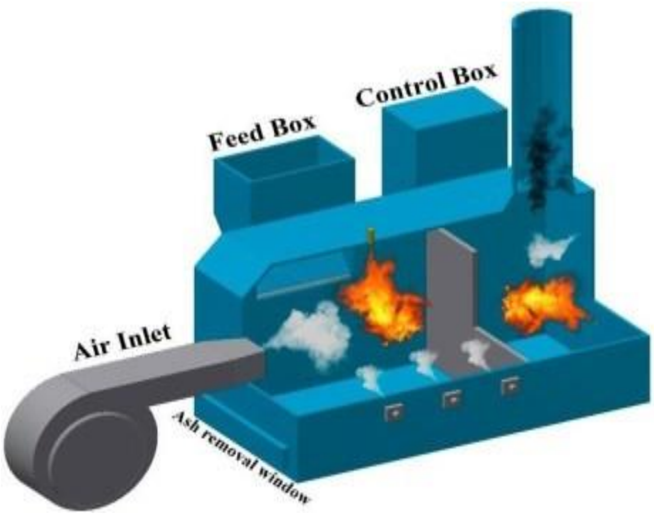

Figure 2 Incinerator

6.2. Thermoelectric Generator

Thomas See beck discovered the See beck effect in 1821, which is how a thermoelectric generator (TEG) turns heat into electricity. A voltage is produced when two distinct metals or semiconductors are connected and subjected to a temperature differential. TEGs use thermoelectric materials—usually p-type and n-type semiconductors—arranged in modules to maximize voltage output. Heat from sources like waste heat or combustion engines is applied to one side, while the other is cooled; creating a temperature gradient that drives electricity generation. Though efficient for small-scale or waste heat recovery, TEGs generally have lower efficiency compared to conventional power systems. Figure 3 shows Thermoelectric Generator

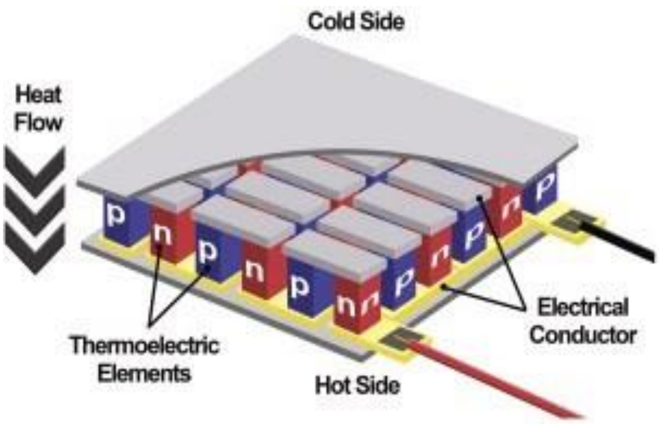

Figure 3 Thermoelectric Generator

6.3. IR Sensor

IR flame detectors pick up infrared (IR) radiation from hot gases from fires. Advanced types like Triple-IR (IR3) detectors use three specific IR wavelengths to distinguish real flames from false sources by detecting the unique IR signature of hot CO_2 during combustion. IR3 detectors offer high sensitivity and a long detection range, with strong immunity to false alarms. However, their performance can be affected by factors like water on the sensor window or background IR radiation. Figure 4 shows IR Sensor.

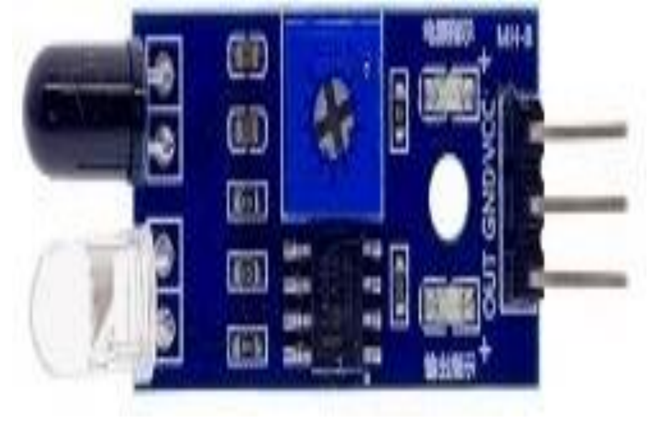

Figure 4 **IR Sensor**

6.4. PIR Sensor

Infrared radiation generated by objects is detected using passive infrared (PIR) sensors, primarily used in motion detection for security systems and automatic lighting. They sense changes in IR levels caused by movement, such as a person passing by, but cannot identify what or who moved. PIR sensors are available in various designs with different ranges and fields of view, typically up to 10–30 meters, and are customizable for specific coverage areas. Figure 5 shows PIR Sensor

Figure 5 **PIR Sensor**

6.5. LDR Sensor

An LDR, also known as a photo resistor, is a passive part that reduces resistance as light intensity rises. Though less sensitive than photodiodes or phototransistors, LDRs are widely used in applications like streetlights, laser security systems, and light-based audio effects. They respond slowly to light changes, making them unsuitable for detecting rapid light variations but useful for smooth, gradual responses. Figure 6 shows LDR Sensor.

Figure 6 **LDR Sensor**

6.6. Temperature Sensor

A digital temperature sensor with a single wire is the DS18b20. This indicates that all that is needed to communicate with the Arduino is one data line (along with GND). It has two power sources: an external power source or the data line (also known as "parasite mode"), which removes the need for an external power source. Figure 7 shows DS18b20 Temperature Sensor

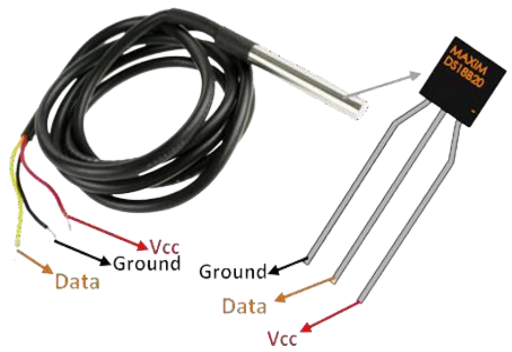

Figure 7 **DS18b20 Temperature Sensor**

6.7. LED'S

A semiconductor device known as a light-emitting diode (LED) releases light when electricity flows through it.Light is produced as electrons recombine with holes, releasing energy as photons, with the light's color depending on the material's band gap. White light is created using multiple semiconductors or phosphor coatings. First introduced in 1962, early LEDs emitted infrared light and were used in remote controls. Later, visible-light LEDs—initially red—were developed for use in indicators and displays. Advances have led to LEDs emitting light across the visible, UV, and infrared spectra, with applications in general lighting, displays, sensors, automotive lighting, communication, and medical devices.

- Advantages of LEDs include: Low power consumption,
- Long lifespan, Durability, Compact size, Fast switching
- Limitations include: Low-voltage DC power requirement.

Limited performance with pulsing DC or AC, Sensitivity to high temperatures. In waste-to-energy plants, LEDs are used for efficient lighting in control rooms and facilities, helping reduce energy use and maintenance costs. Their energy efficiency and durability make them a sustainable lighting solution across various sectors. Figure 8 shows LED

Figure 8 LED

6.8. Buzzer

An aural signalling device, a buzzer can be mechanical, piezoelectric, or electromechanical. Its primary purpose is to transform electrical impulses into sound, and it is frequently used in computers, printers, timers, alarms, and other alert systems. Buzzers usually run on DC voltage and have two terminals: a negative (–) (shorter pin, grounded) and a positive (+) (longer pin, powered by 6V). They can make a variety of sounds, including sirens, bells, music, and alarms, depending on how they are made. In piezoelectric buzzers, sound is generated when a voltage is applied across piezo crystals, creating a pressure difference. This causes the crystals to vibrate, pushing and pulling the conductors, which produces a sharp sound signal. Figure 9 shows Buzzer

Figure 9 Buzzer

6.9. W1209 Thermostat Module

The W1209 is a low-cost, incredibly useful digital thermostat controller that regulates electrical device power based on temperature using a high-accuracy NTC temperature sensor. It features a temperature control range of -50°C to 110°C, with a resolution of 0.1°C between -9.9°C and 99.9°C, and 1°C elsewhere. The module includes a 3-digit seven-segment display for real-time temperature and relay status. Users can set the trigger temperature using on board buttons, without any programming skills. It also includes 3 mini switches to configure settings like on/off trigger points. Up to 240V AC at 5A or 14V DC at 10A are supported by the on board relay. It operates on 12V DC power, with low power consumption and is suitable for use in environments with temperatures from -10°C to 60°C and 20–85% humidity Figure 10 shows Thermostat Module

Figure 10 Thermostat Module

6.10. Lithium ION Battery

Lithium-ion (Li-ion) batteries are rechargeable and use the reversible movement of lithium ions to store energy. Because of its high energy density, low self-discharge, and absence of memory effect, it finds extensive application in electric vehicles, portable devices, and grid-scale energy storage. Li-ion batteries may cost more initially than disposable ones but offer a lower total cost of ownership and reduced environmental impact due to their long rechargeable life. Some rechargeable types are compatible in size and voltage with standard disposable batteries. During charging, the positive electrode is oxidized (releasing electrons) and the negative electrode is reduced (gaining electrons), creating a current. The electrolyte allows ion flow between electrodes and may either assist or participate in the chemical reaction. Charging is typically done via battery chargers using AC power, or 12V DC vehicle outlets, with careful control of voltage to avoid battery damage. Figure 11 shows Storage Battery.

Figure 11 Storage Battery

6.11. Power Supply

For the internal components of a computer, a Power Supply Unit (PSU) transforms mains AC power into low- voltage regulated DC power. Modern PCs use switched-mode power supplies, which are compact and efficient. Some PSUs have a manual voltage switch, while others auto-adjust to input voltage. Most desktop PSUs follow the ATX specification, providing consistent voltage and form factor standards. An ATX PSU supplies a constant 5V standby power (5VSB) to support standby functions and is controlled by signals from the motherboard, which also receives a signal when voltage levels are safe for booting. The latest ATX standard is version 3.0 (as of mid-2022). Early IBM PC PSUs delivered +5V and +12V (main outputs), and −5V and −12V (for specific legacy components). The +5V rail powered most microchips, while +12V was used for motors and fans. The −12V and −5V rails served older interfaces like RS-232 and ISA bus peripherals Figure 12 shows Power Supply

Figure 12 Power Supply

7. Block Diagram

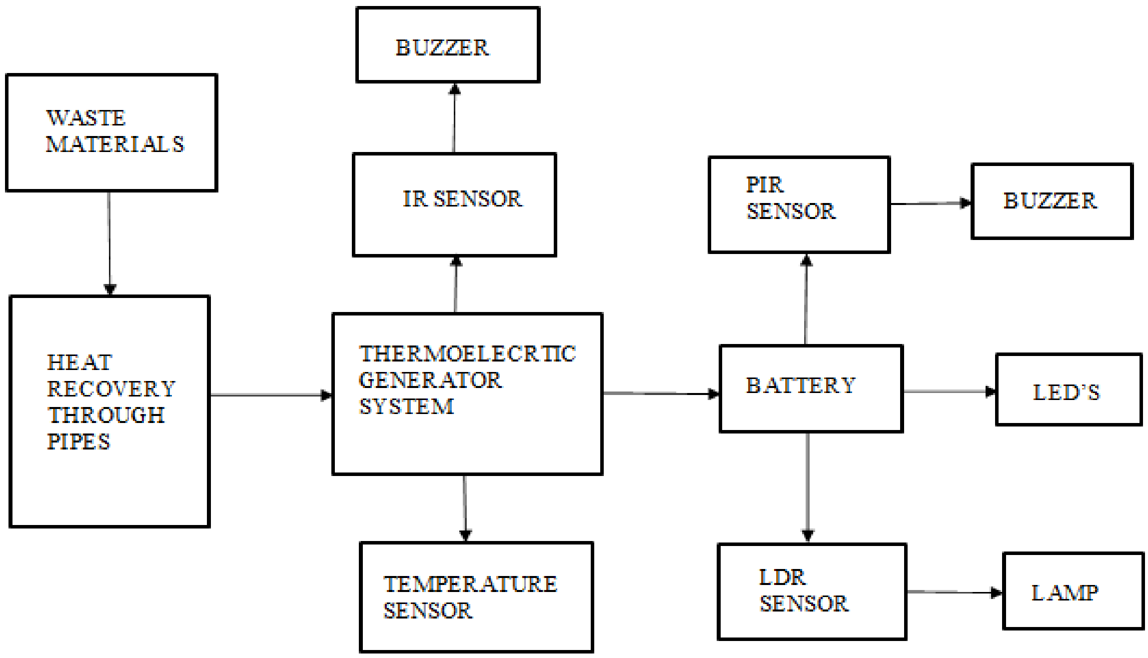

Figure 3 Block Diagram

The goal of this project is to employ a thermoelectric production system to transform the heat energy from burning solid trash—such as organic waste like dry leaves, newspapers, and e-waste—into electrical energy. Before developing the electrical and mechanical architecture for a conveyor belt system, the project scope had to be established. Following design completion, programming, circuit assembly, and hardware implementation were completed. The main controller is an Arduino Uno. A temperature sensor measures the heat produced in the incinerator and shows the information on an LCD screen. LEDs are powered by electricity generated by the thermoelectric generator, which is activated and stored in a battery when a threshold is reached.

7.1. Additional Features Include

- **PIR Sensor:** Detects unauthorized movement; activates a buzzer.
- **LDR Sensor:** Automatically controls street lights based on ambient light.
- **IR Sensor:** Detects fire presence and triggers an alarm.

Circuit and software changes were made in the last phases to enhance performance and facilitate troubleshooting. The method is sustainable and environmentally beneficial, helping with waste management. Waste-to-energy (WTE) generation is the process of converting waste materials into electricity, either directly or by heat conversion. Usually, there are three primary steps in the process:

- Gathering waste products from several sources.
- Calorific value-based separation and purification.
- The garbage is burned in a controlled environment to produce heat, which is then converted to power.

The electricity generated can power enterprises, local communities, or the national grid. Ash is a significant by-product that is collected and disposed of in landfills. WTE is an environmentally friendly method of waste management that:

- Reduces landfill volume
- Produces renewable energy
- Reduces greenhouse gas emissions, particularly methane released by decaying trash.

Overall, this offers both energy recovery and environmental benefits.

8. Result And Discussion

The TEG is triggered and begins converting the heat energy into electrical energy when the solid municipal waste materials are heated inside the incinerator. An LED indicates the output. About 40% of the project's municipal solid waste (MSW) was made up of organic matter, 30% was made up of paper and cardboard, 20% was made up of plastics, and 10% was made up of other materials (glass, metals, etc.), per the waste composition study. It was found that the trash's overall calorific value was impacted by its around 25% moisture content. The combustion process achieved an average efficiency of 85%, indicating effective conversion of waste into heat energy. The project's waste-to-energy system was capable of producing

5 MW of power.

- After adjusting for conversion process losses and system inefficiencies, the project's actual power output was roughly 4.2 MW.
- The findings of the emission monitoring showed that strict rules and emission guidelines were being followed.
- Particulate matter emissions, which averaged 20 mg/Nm³, were continuously within the allowed levels.
- Emissions of nitrogen oxides were kept substantially under the necessary bounds, at less than 200 parts per million.
- The efficacy of the emission control methods was demonstrated by the dioxin emissions, which were

Now a days, waste material is present everywhere. Following specific steps could allow us to collect everything and use the prototype to generate more energy for human usage. This taught us that this kind of energy production is fairly easy to use with a little care. This prototype can help us learn more about garbage utilization. Thanks to this project, we may increase our own energy for industrial uses and use it for specific demands. LEDs are used to sense and display temperature, IR sensors are used to detect fires, PIR sensors detect human presence, and LDR sensors are utilized in home automation systems.

9. Comparative Analysis: Power Generation from Equal Masses of Waste

Table 1 Power Generation from Equal Masses of Waste

Waste Type	Mass (Grams)	Voltage output (Volts)	Efficiency (%)	Combustion Quality
Newspaper Waste	10	0.1	4	Very Good
Medical Waste	10	0.15	6	Good
E-Waste	10	1.2	15	Poor (but efficient with TEG)

The above table presents the comparative performance of different waste categories (organic, paper, plastic, and mixed e-waste) in terms of power generation when subjected to the same mass input (10 g each). This approach allows a direct comparison of their calorific value contribution and corresponding voltage output through the thermoelectric generator (TEG). It highlights the variability in energy potential across different waste streams. Figure 4 shows Graph of Voltage Output vs Waste Mass (10g each)

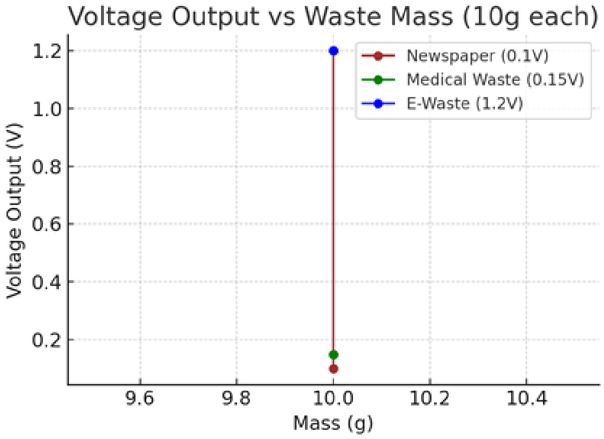

Figure 4 Graph of Voltage Output vs Waste Mass (10g each)

The above graph illustrates the relationship between voltage output and equal mass (10 g) of different waste materials. The plot shows how plastic and e-waste components generally yield higher voltage outputs due to their higher energy density, while organic matter and paper provide comparatively lower outputs. This visualization reinforces the importance of waste categorization and material selection in optimizing waste-to-energy conversion efficiency. Figure 5 shows Experimental Setup.

Figure 5 Experimental Setup

Figure 6 Burning

Figure 7 Burning of Waste Materials (e.g: Dry leaves, Newspapers, Medical wastes, E-wastes) with LED Indication

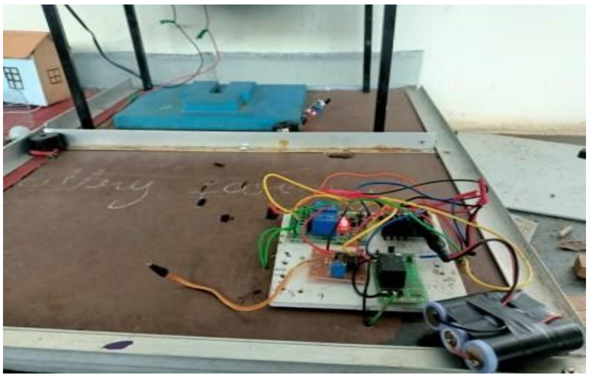

Figure 8 Temperature Displayed on LED

Figure 9 Interfacing with Temperature Sensor, PIR Sensor With Buzzer, IR Sensor and LDR Sensor

10. Advantages, Disadvantages & Applications

10.1. Advantages

- The proposed approach is an innovative and ecologically conscious strategy to simultaneously manage municipal solid waste (MSW) and generate electricity.
- It uses waste incineration to create heat, which powers turbines to produce electricity, rather than traditional fuel.
- This unconventional, environmentally friendly approach is easy to implement, reasonably priced, and appropriate for both local and large-scale uses.
- Low charging time, mobility, and ease of maintenance are important features.
- The technology assists with plastic recycling, drastically lowering the amount of waste that ends up in landfills, and providing a renewable energy source to aid with the power outage, particularly in cities.
- Its viability is supported by a feasibility study, and the technology has great potential for broad use in energy recovery, waste reduction, and sustainable urban development. (Figure 6,7,8,9)

10.2. Disadvantages

- **Environmental Impacts:** When MSW is burned, a number of pollutants are released into the atmosphere, such as dioxins, heavy metals, particulate matter, and greenhouse gases. Some pollutants may still be emitted into the atmosphere in spite of emission control devices, which could endanger the health of those nearby. To lessen these effects, strict laws and adequate oversight are required.
- The TEG's intricate design could be harmed by improper temperature gradient fluctuation.
- **Cost considerations:** Waste-to-energy facility construction and management can be costly, involving a sizable initial investment and continuing running expenses. The availability of garbage, energy costs, government subsidies, and waste management regulations are some of the variables that affect the projects' economic feasibility. In certain situations, burning MSW to produce electricity may be more expensive than using other energy sources, which reduces its appeal from an economic standpoint.

10.3. Applications

- This method can be used to generate electrical energy locally or on a huge scale. Utilizing TEGs, waste materials are burned to generate power.
- An unusual energy source that is easily converted into electrical power is heat. It is therefore easy to install and maintain.
- Additionally, we can use it in our homes and other domestic areas. This makes it possible to use and store the electricity that is produced. One benefit of our project is that it takes an environmentally conscious approach to waste management.
- It is free of pollution. The most popular method is the conversion of unconventional energy to conventional energy.
- Energy production is one of the primary applications of power generating from the burning of municipal solid waste.
- In waste-to-energy (WtE) facilities, the heat generated by burning MSW is converted into steam, which drives a turbine that is connected to a generator. This technique generates electricity that can be supplied into the grid or used locally to power homes, businesses, or industries.
- **Waste Management:** Effective waste management is facilitated by WtE facilities' capacity to burn municipal solid waste. Burning the waste lowers its volume and lessens the requirement for land disposal, as opposed to disposing of it in landfills, which can cause environmental problems including methane emissions and land pollution. This lessens the strain on already-existing disposal sites and promotes sustainable trash management.
- **Reduction of Greenhouse Gas Emissions:** One way to reduce greenhouse gas emissions is to burn municipal solid waste to produce power. As waste decomposes in landfills, methane, a potent greenhouse gas, is released. By keeping waste out of landfills and burning it in controlled combustion activities, methane emissions can be significantly reduced. The facilities also typically use emission control devices to

lower the quantity of pollutants emitted into the atmosphere.

- **Resource Recovery:** Waste-to-energy facilities commonly employ state-of-the-art technologies to recover valuable resources from the waste stream. Thermal energy recovery, metal extraction for recycling, and ash capture for construction materials are a few examples. Recovering resources from the trash reduces the overall environmental impact and maintains important commodities in circulation.

Conclusion & Future Scope

Conclusion

The idea of converting solid waste into power is a viable and sustainable strategy for addressing both energy and waste management challenges. Technologies such as incineration, gasification, and anaerobic digestion enable the transformation of waste into renewable energy, reducing pollution and landfill dependency. Among these, incineration is widely used, where waste is burned to recover heat for electricity production. However, successful deployment requires proper planning, emission control, and community support to address challenges like high costs, regulatory compliance, and pollution concerns. With rapid technological advancement, e-waste volumes are increasing globally, posing both risks and opportunities. While e-waste combustion can provide significant energy, it must be approached cautiously due to the release of toxic substances. Alternatively, recovered heat can be directly converted into electricity via thermoelectric generators (TEGs) using the Seebeck effect, offering a cleaner and safer energy pathway. In India, a comparative study and analysis of nano-enabled power generation from recovered e-waste demonstrates the advantages of both tackling environmental issues and satisfying the country's expanding energy needs. The use of nanotechnology-based techniques like thermoelectric, piezoelectric, and triboelectric nano-generators provides a sustainable route for clean, decentralized power generation in light of the growing amounts of abandoned electronics, particularly in rural and semi-urban areas. According to the research, recovered PCBs, ICs, and semiconductor materials can be nano-coated and used again to create affordable, effective modules. These modules show great promise for uses in sensor-based systems, LED lighting, mobile charging, and small appliances—all of which are essential for enhancing rural energy access. The study also demonstrates that nanogenerators made from e-waste can lessen reliance on fossil fuels while lowering the ecological and health hazards connected to inappropriate e-waste disposal.

Future Scope

- **Scaling Up Prototypes:** To assess viability in real-world settings, pilot-scale programs are developed in a few rural regions (such as Karnataka, Bihar, and Assam).
- Advanced Nanomaterials: Investigating affordable nano-coatings (such as graphene, ZnO, and MoS_2) to improve thermoelectric module efficiency and Seebeck coefficient.
- Hybrid Energy Systems: These sustainable energy solutions for rural electrification combine nano-generators with solar PV, biogas, or microgrids.
- Policy and Infrastructure Support: To facilitate the recovery of electronic components, e-waste collection centers and collaborations with local government entities should be established.
- Socio-Economic Benefits: Promoting local business models that allow rural communities to set up, manage, and profit directly from systems based on nano-generators.
- Environmental and Health Safeguards: To guarantee environmental compliance, more research should be done on how to safely handle hazardous materials in e-waste during the manufacture of nano-generators.

References

[1]. Comparative Performance Analysis of Waste Materials for Sustainable Electricity Generation by Sushmita Deb,Dr. Rakesh Dhiman. Dr. Kumaraswamy B G, Proceedings of the International Conference on Modern Sustainable Systems (CMSS-2025) DVD Part Number: CFP250Q9-DVD; ISBN: 979-8-3315-6509-1. 979-8-3315-6510-7/25/$31.00 ©2025 IEEE

[2]. Waste to Energy: Arduino based Thermoelectric Energy Harvesting By Sushmita Deb, International Journal of Engineering Research & Technology (IJERT) Volume 11, Issue 05 Published by, www.ijert.org ISSN: 2278-0181,ICEI-2023

[3]. Power generation from waste heat using Heat Pipe and Thermoelectric Generator, M.F Remeli, Faculty of Mechanical Engineering, University Teknology MARA (UiTM), 40450 Shah Alam, Selangor, Malaysia. The7thInternational Conference on Applied Energy – ICAE2017.

[4]. Generation, Kewen Li, 1Stanford University, Stanford, CA94305, USA, Stanford University, Stanford, California, February 11-13, 2019.

[5]. Cucchiella, I. D'Adamo, M. Gastaldi. (2014, May). Sustainable Management of Waste- to Energy Facilities. Renewable and Sustainable Energy Reviews.

[6]. J. Manders, "Integrated Waste Management of MSW Across Europe: Waste to Energy as a Professional Route to Treat Residual Waste," CWEP, Belgium, 2013.

[7]. N. Abila. (2014, September). Managing Municipal Wastes for Energy Generation in Nigeria Renewable and Sustainable Energy Reviews. [Online]. 37,182-190.

[8]. 2014 IEEE International Conference on Automation Science and Engineering (CASE) Taipei, Taiwan, August 18- 22, 2014, 978-1-4799-5283-0/14/$31.00 ©2014 IEEE.

[9]. Generating electrical energy through urban solid waste in Brazil: An economic and energy comparative analysis by Rafaela Ediene dos Santosa, Ivan Felipe Silva dos Santosb,_, Regina Mambeli

[10]. Electric Power Generation Potential Based on Waste Heat and Geothermal Resources in South Africa , Changwei Liu, 2Stanford University, USA Stanford University,Stanford, California, February.

[11]. Mrs. Sushmita Deb, Presently working as Assistant Professor, SJMIT, Chitradurga, Karnataka. She is a PhD scholar also. She is having working experience of 19 years in this Academic field. In this tenure she has published many papers in National and International conferences and guided many B.Tech students.

[12]. Dr. Rakesh Dhiman, is a distinguished Professor in the School of Engineering & Technology, OSGU. He has 20+ years of academic and industrial experience. His 60+ Research papers/Articles have been Published in National/International Conferences /Seminars /Newspapers . He has guided 50+ research scholars in M. Tech. and Ph.D. He takes care of the overall development of students as Dean Student Welfare at Om Sterling Global University.

[13]. Dr. Kumaraswamy B G is a Professor and Head of the Department of Electrical and Electronics Engineering at the S.J.M. Institute of Technology (SJMIT) having an working experience of 32 years, Chitradurga.He has a Ph.D. from VTU-Karnataka. His research interests include renewable energy and high voltage. He has published many papers in National and International Conference. He is guiding many PhD scholars.