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A Net Zero Transformation of College Campus: A Quantitative Analysis

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Abstract: This paper presents a detailed quantitative analysis of achieving a Net Zero transformation on a college campus through effective strategies in energy efficiency, solid and liquid waste management, and renewable energy integration. Data was collected from various segments of the campus to establish a baseline, evaluate feasible interventions, and propose a sustainable roadmap toward achieving net-zero emissions. The project provides a replicable model for other educational institutions.

I. INTRODUCTION

The concept of net zero refers to achieving a balancing the greenhouse gases put into the atmosphere and those taken out. Educational campuses are high-density environments where energy, water, and resource usage converge, making them ideal prototypes for sustainable development. Transforming these campuses into net-zero zones not only contributes to climate mitigation but also educates and inspires the next generation.

II. PROBLEM STATEMENT

Existing systems in some college campuses are not designed with sustainability in mind. High energy consumption, inefficient waste disposal systems, and a lack of renewable energy integration contribute to significant carbon footprints. This project seeks to address these gaps through a quantitative analysis and strategic planning for transformation.

III. OBJECTIVES

1) To Identify current energy consumption and assess efficiency measures.
2) Explore strategies to reduce solid and liquid waste generation.
3) Propose feasible, cost-effective solutions for achieving net-zero status.
4) Identify the Challenges in implementing solutions and propose feasible solution for it.

IV. LITERATURE REVIEW

Transitioning campuses to net-zero carbon emissions has become a focal area in sustainability research. Numerous studies and institutional case reports highlight practical, scalable interventions and the theoretical frameworks necessary to guide such transformations.

McCollum (2021) outlines the importance of establishing net-zero energy systems globally. His study emphasises decarbonization strategies through energy transition, which directly supports the implementation of solar power and sensor-based energy efficiency methods on campuses.

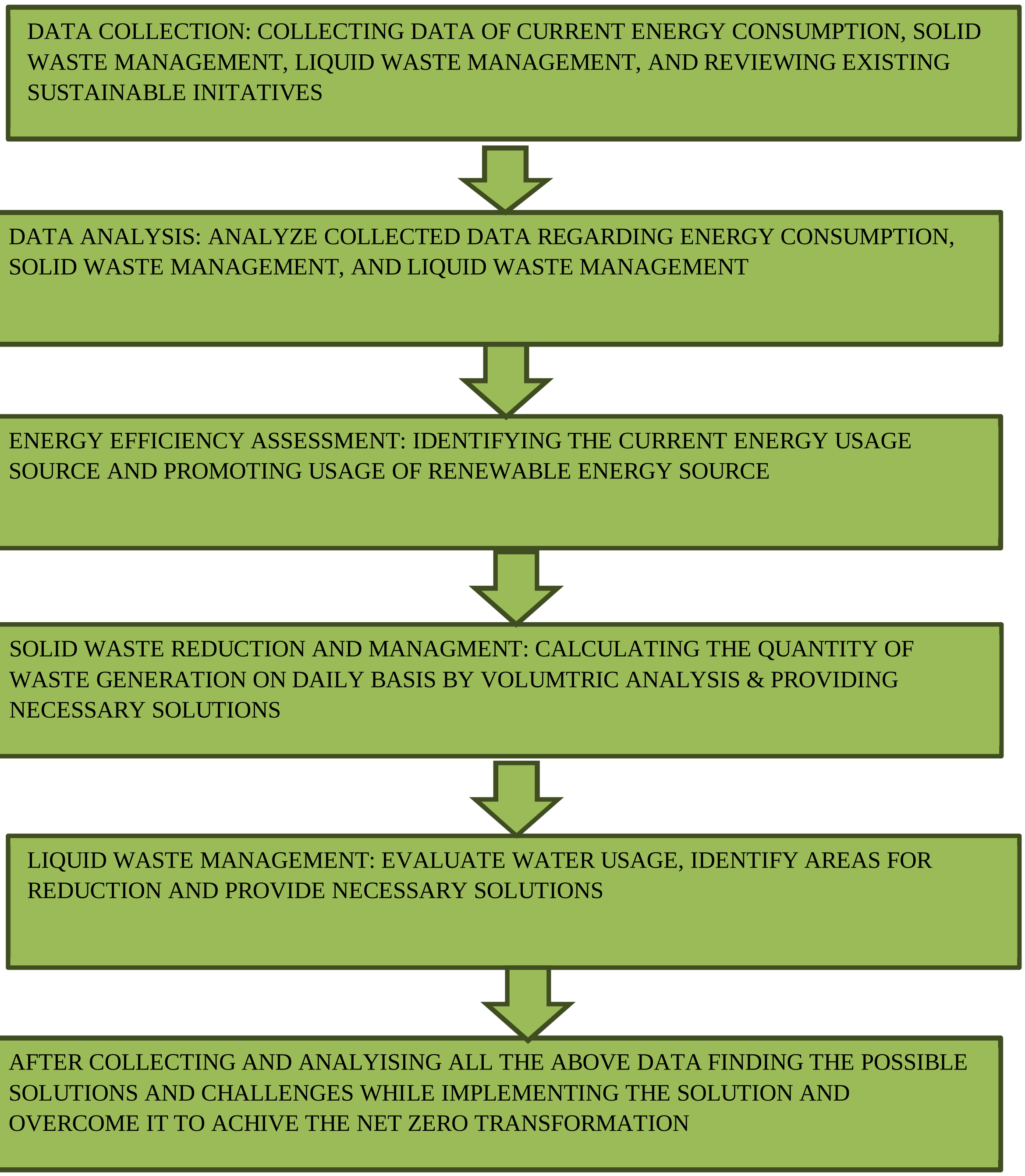
Zhu et al. (2020) investigated green development models at Stanford University and emphasized the integration of smart infrastructure, data-driven energy management, and behavioural change programs. Their study shows that academic institutions can serve as living laboratories, aligning closely with the present research's use of biogas, composting, and water recycling units.

Van Den Broek and van der Linden (2019) proposed a low-carbon transition pathway by viewing university campuses as small-scale analogs of urban systems. Their model advocates systemic thinking, which supports the integration of renewable technologies and waste treatment plants proposed in this study.

Costello et al. (2017) focused on zero waste and resource optimization at a college football stadium in the U.S. They used detailed waste audits to demonstrate potential greenhouse gas (GHG) reductions from improved solid waste management — a methodology reflected in the daily volumetric tracking and compost-biogas strategies applied in this research.

Nilofar Saifi and Bandana Jha (2024) explored Pune's municipal waste management strategies, highlighting decentralized treatment and public-private collaboration. These findings reinforce the feasibility of institutional STPs and biogas units with CSR (Corporate Social Responsibility) partnerships for funding and maintenance. Balaji Kalluri et al. (2023) assessed net-zero readiness across Indian campuses and emphasized the need for automated control systems (such as PIR sensors), renewable installations, and reuse strategies. This aligns directly with the integrated multi-modal solutions proposed in this research. Ciara O'Flynn et al. (2021) presented a comprehensive net-zero action plan for a university campus in Ireland, underlining the role of policy, governance, and academic-community synergy. Their emphasis on data transparency and iterative improvement is mirrored in the long-term monitoring strategies included in our roadmap.

V. METHODOLOGY



VI. DATA COLLECTED AND PROPOSED SOLUTION

A. Data and Solution for solid Waste

	Dustbin capacity	No. of bins allotted	Waste in kg per bin	Total waste per day (Kg)
Kitchen Waste	100 L	9	50	450
Garden Waste	60 L	30	1.5-2	45-60
Plastic Waste	60 L	8	3-5	25-40

Table No.1: Solid waste data

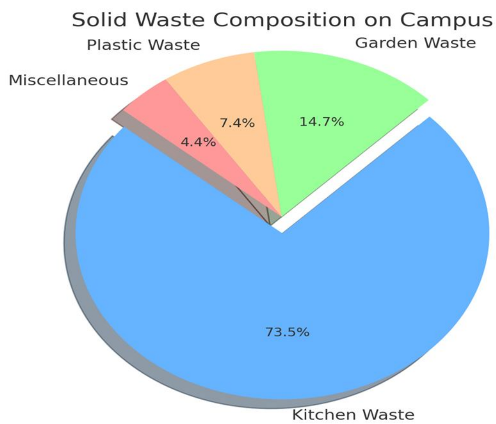


Figure 1: Solid Waste Composition on Campus

1) Solution for Kitchen Waste

Our college has a biogas plant design for processing of kitchen/organic waste. Based on the components visible in the image the working of the system is as follows

Figure 2: Shredder/Grinder

Figure 3: Digester tank

- Waste is collected for processing: 50 kg/bin
- The waste is feed into shredder (stainless steel funnel) the waste is broken down into smaller particles
- Waste is mixed with water for proper digestion and smooth flow
- The digester tank shown in the fig. having capacity 3000 l where the waste is mixed with water is feed into the tank. Inside the tank anaerobic bacteria break down the organic matter producing biogas.
- The biogas rises to the top and is collected.
- The black pipe shown in the image above the digester tank transport the gas to the storage from where it can be used in stove/ burner for cooking purpose
- The digested material that is organic slurry exit through a separate outlet pipe this slurry is rich in nutrient and can be used as a biofertilizer for plants.

Biogas generated for 50 kg kitchen waste
Waste = 50 kg/bin
0.4-0.6 m^3 gas is generated for 1 kg kitchen waste
Hence assuming 0.5 m^3 per kg
50 x 0.5 = <u>25 m^3</u>
The pipe is connected above the digester tank transport the gas to the storage from where it can be used in stove/ burner for cooking purpose.

2) Solution for Garden Waste
Proposal of Composting Plant for Garden Waste.
For fast decomposition, bio-culture powder can be used which will take 45-60 days for decomposition
<u>COST ESTIMATION FOR THE PLANT</u>
Garden waste generated in a day = 60 kg
Therefore for 45 days = 60 x 45 = 2700 kg
15000 litre of container is required to decompose 2700 kg of garden waste
Quantity of powder:
1kg of powder is required for 100kg of waste (1% ratio)
Therefore,
1/100 x 2700 = 27kg
The cost of bio-culture powder in India varies from 350-3250rs
Considering 400 ₹ /kg
therefore,
400x27=₹10,800
<u>Container Details:</u>
1.Plastic tank (₹1,30,000 - ₹1,80,000)
Pros:
- Light weight and easy to move/install
- Low maintenance, rust-free

Cons:
- Less breathable, may need additional aeration
- Can degrade over time under extreme heat

2. Fiberglass Reinforced Tank (₹1,00,000 - ₹2,00,000)
Pros:
- More durable than plastic, resists wear and tear
- Lightweight yet strong

Cons:
- Expensive compared to plastic tanks
- Harder to modify once built

3. Zincalume Steel Tanks (Metal Tanks) (₹45,000 - ₹1,50,000)

Pros:
- Extremely durable, lasts 20+ years
- Naturally breathable (better aeration)
- Can handle high composting temperatures well

Cons:
- Requires insulation in extreme temperatures
- Heavier, not easily movable

4. Concrete Tanks (₹50,000 - ₹2,00,000, depends on construction)

Pros:
- Very strong, lasts for decades
- Good thermal insulation for microbial activity

Cons:
- Not portable
- Takes time and effort to build

Best Recommendation:

For flexibility & cost-effectiveness, a Zincalume Steel Tank is the best choice due to:

Good aeration without modification. Long lifespan with minimal maintenance. Lower cost compared to plastic and FRP tanks.

Figure 4 : Zincalume Steel Tank

We have to provide 2 tanks for composting, as it requires 45days to decompose the waste in one tank. The other tank can be used to fill waste for next 45 days & the cycle will continue for 45 days.

Figure 5: Composting cycle

Challenges While Implementing this Solution:

1.Waste Handling and Preprocessing: Garden waste (leaves, twigs, branches) is often bulky and uneven in size. Large materials decompose slowly and reduce effective tank volume.

2. Moisture Management: Garden waste can be too dry or too wet depending on season. Low moisture slows decomposition; excess moisture causes anaerobic conditions.

3.Temperature Control: Composting needs temperatures of 50–65°C to be effective. Poor heat retention in thin plastic tanks can delay composting.

4.Bio-culture Dosing and Distribution: Uneven mixing of bio-culture powder with waste. Patchy decomposition and longer composting time.

5.Operational Labor and Monitoring: Monitoring moisture, and temperature require labor and training Poor maintenance can lead to composting failure.

6.Time and Space Management: Composting takes 45–60 days. Space must be available to cure compost before final use or sale. This can lead to delay in continuous processing.

Solutions to overcome these challenges:

1.Waste Handling and Preprocessing: Shred or chop waste to increase surface area and improve decomposition speed.

2. Moisture Management: Maintain 40–60% moisture, monitor with a squeeze test, and add water or dry materials as needed

3. Temperature Control: Insulate the tank (e.g., shade or wrap), or use black tanks to absorb heat.

4.Bio-culture Dosing and Distribution: Thoroughly mix bio-culture with moist waste in layers during filling.

5.Operational Labor and Monitoring: Train staff, create a simple monitoring checklist, and use thermometers and moisture meters if possible.

6.Time and Space Management: Use multiple tanks or a batch system to manage input/output cycles.

B. Data and Solution for Energy Consumption

ELECTRICTIY ENERGY CONSUMPTION:

The energy is provided by MSEDCL to the college.

The amount of electricity consumption per year varies from 250-500 kw.

During summer season the energy consumption is very high between 400-500 kw.

The Average electricity consumption per year is 310 KW

BILLING HISTORY			
Bill Month	Units	Bill Demand(KVA)	Bill Amount
JUL-24	75,590	372	13,97,624
JUN-24	87,561	406	16,02,359
MAY-24	1,19,468	442	21,27,317
APR-24	1,22,589	496	22,68,851
MAR-24	1,02,507	412	16,94,300
FEB-24	85,434	348	14,12,965
JAN-24	69,704	290	11,54,203
DEC-23	78,808	305	12,90,688
NOV-23	72,992	290	12,00,975
OCT-23	95,303	333	15,19,504
SEP-23	87,132	314	13,92,942
AUG-23	79,277	298	12,53,675

Figure 6: Units Consumption for Each month taken from electricity bill

Proposed Solution:

Design of Sensor based automation system for lights and fans

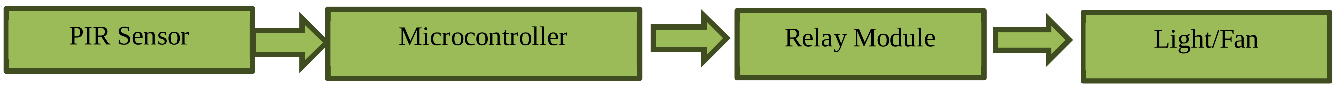
Sensor used: PIR (Passive Infrared) motion sensor

- PIR motion sensors are designed to detect motion based on infrared radiation, which is emitted by warm objects such as humans and animals.
- The sensor consists of two infrared (IR) sensors. These sensors are sensitive to changes in the infrared radiation in their field of view.
- Sensing principle:

When a person moves in front of the sensor, their body emits infrared radiation (heat). The PIR sensor detects this change in radiation by comparing it to a reference. The sensor will then send a signal indicating motion has been detected.

Controller: Smart relay module for lights and fans

- A smart relay is an electrically operated switch controlled by a microcontroller (like Arduino)
- When the PIR sensor detects motion (HIGH output), the microcontroller activates the relay, turning ON the lights and fans.
- When no motion is detected for a preset time (e.g., 5 minutes) The controller deactivates the relay, turning OFF the devices.



Cost Estimation:

Each classroom and lab have 4 Lights and 5 fans. In a typical classroom (10m) or lab, 1 well-placed ceiling-mounted sensor is usually sufficient.

Therefore,

Providing 2 sensors in each room for each fan group and lights.

Number of rooms = 55 classrooms + 49 labs = 104 rooms

Number of sensors required = 104 x 2 = 208

Each relay controls a two circuit i.e. 2 lights,2 fan

Therefore,

Fan Control Relays = No. of fans/2 = 520/2 = 260

Light Control Relys = No. of lights/2 = 416/2 = 208

Total Smart Relays = 468

Components	Estimated Quantity	Unit Price (INR)	Total Cost (INR)
PIR motion sensor	208	₹600	₹1,24,800
Smart relay modules	468	₹400	₹1,87,200
Wiring & Installation	Lump sum		₹1,00,000
Total Estimated cost			₹4,12,000

Table No.2: Cost Estimate of sensor and controller

The unit prices of Rs. 600 for PIR motion sensors and Rs. 400 for smart relay modules are based on current average market rates from Indian electronics and automation component suppliers.

Energy Saving Estimate:

Total Monthly Consumption = 77,877 units

Bureau of Energy Efficiency (BEE) India, - Energy audit report: BEE indicates that show lighting/fan loads contribute approx. 40% in schools, colleges, and office buildings.

So,

Lights & Fans Consumption = 40% of 77,877 kWh = 0.40 × 77,877 = 31,151 units/month

A 2018 IIT Bombay audit found 48% savings in lighting using PIR sensors. By installing PIR motion sensors and smart relays, unnecessary operation of lights and fans can be significantly reduced (e.g., during unoccupied times). A typical saving is approx. 50% for those loads.
Typically, PIR sensor and Smart relays consumes between 0.5W – 1W of energy considering ,1W/sensor and 1W/relay Therefore,
Daily consumption = (208+468) x 1 x 24 = 13.728
Monthly Consumption = 13.728 x 30 = 411.84 units /month
Total Monthly Consumption = 15,576 + 411.84 = 15,988 units
From the bill: Tariff (per unit) = ₹17.70 per unit
So, Monthly Savings = 15,988 units × ₹17.70 = ₹2,82,985
Annual Savings = ₹2,82,985 × 12 = ₹33,95,820

Description	Value
Monthly Electricity Usage	77,877 units
Lights & Fan Share (appx. 40%)	31,151units
Estimated Reduction via sensors	50%
Energy Saved Per month	15,576 units
Tariff Rate	₹17.70/unit
Estimated Monthly Saving	₹2,82,985
Estimated Annual Saving	₹33,95,820
Payback Period	< 3 months

Table No.3: Energy Saving Estimate

Challenges While Implementing this Solution:

1. Wiring Compatibility and Layout: Existing wiring may not support relay integration or sensor placement. Additional civil work, rewiring may be needed.
2.Sensor Placement Optimization sensors need clear lines of sight and must cover key movement zones. Poor placement may lead to false negatives (lights not turning on) or positives (unnecessary switching).
3. Power Supply for Sensors and Relays: Ensuring consistent power (e.g., 5V/12V DC) across multiple floors. Requires stable DC power lines or step-down adapters across zones.
4. Maintenance Access: Ceiling-mounted sensors and relays may be hard to access for repairs. Planning access panels or easy-disconnect modules is crucial.
5. User Acceptance and Behavior Sudden auto-off may annoy users if sensors miss movement. Proper communication and override options are important.

Solutions to overcome these challenges:

1.Wiring Compatibility_and Layout: Conduct a pre-installation wiring audit, use surface-mounted conduits or wireless relays where possible.
2. Sensor Placement Optimization: Use site walkthroughs and 3D layout mapping to position sensors in high-traffic and visible zones.
3. Power Supply for Sensors and Relays: Deploy centralized DC power supplies or mini power adapters for distributed coverage.
4. Maintenance Access: Install removable ceiling panels, use RJ-type connectors for easy sensor replacement.
5. User Behaviour and Acceptance: Educate users, include manual override switches or hybrid modes (auto + manual).

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C. Data and Solution for liquid waste

Our college has water tank between A and B building which supplies water to all college building.
The Capacity of the tank is 1,00,000 L with 5 hp pump which is filled 3 times daily.
Therefore, total water supplied 3,00,000 L/day
The waste generated is 80% of the total capacity i.e. 240,000 L/day
One tank is provided behind boys hostel having capacity of 1,00,000 L with 5hp pump for supplying water to hostel, food court & Cafeteria which is also filled 3 times daily
Therefore, total water supplied 3,00,000 L/day
The waste generated is 80% of the total capacity i.e. 240,000 L/day
Total wastewater generated: 480,000 L/day (0.48 MLD)
Water sources: College buildings, hostel, food court and cafeteria
Current disposal: 10 KL Septic tank → Municipal sewer

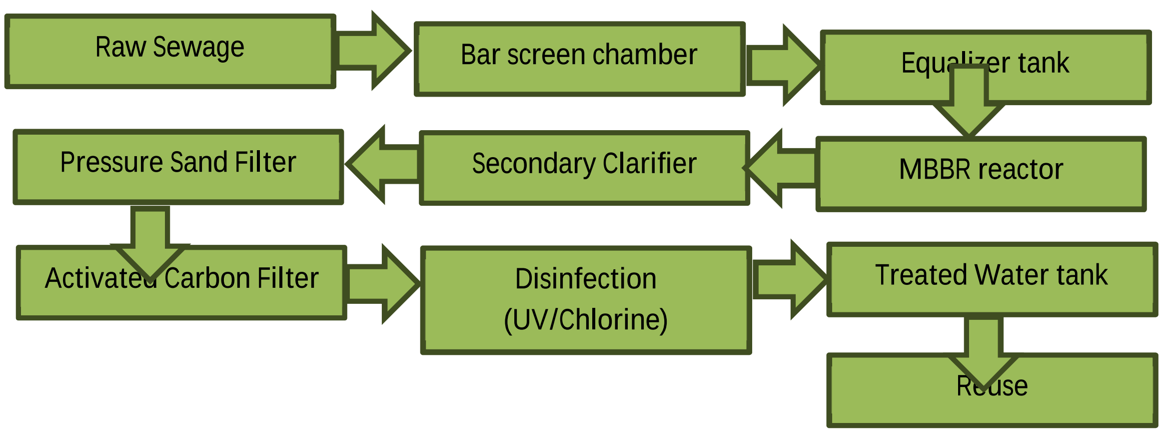
1) Proposed Solution

- Installation of 0.5 MLD MBBR-based STP.
- Reuse of treated water for gardening and flushing.

2) Technology Recommendation:

We recommend MBBR technology for biological treatment because of its

- Compact design
- High Treatment Efficiency (removes 85-95 % BOD/COD)
- Low Sludge Generation (Produces less biological sludge than conventional system)
- Modular and Scalable (Easy to add reactors or increase media if future load increases)
- Energy Efficient



3) Cost Estimate

Item	Approximate
Civil Work	₹12–15 lakh
Electro-Mechanical Equipment	₹10–12 lakh
MBBR media, Filters, Disinfection	₹6–8 lakh
Automation and Electricals	₹2 lakh
Total Estimation	₹30–37 lakh

Table No.4: Materials and cost of components of STP

Operation & Maintenance: ₹4-5 lakh /year

4) *Some STP suppliers in India we can approach*
- VA Tech Wabag
- Ion Exchange India
- Enviro Control Associates
- Thermax Water Solutions
- SFC Environmental Technologies
- Clear Water Enviro Technologies

5) *Power Consumption:*

Components	Power(kW)	Usage(hrs/day)	Daily(kWh)
Raw sewage pump	4	6	24
Blowers for MBBR	10	4	200
Sludge Pump + Clarifier	1.5	6	6
Pressure Sand Filter Pump	2	6	12
Activated Carbon Filter Pump	2	6	12
UV/Chlorination system	0.5	4	2
Total daily Consumption			256

Table No.5: Power Consumption by components of STP

6) *Space Requirement*

Total area 600-800sq.ft. Modular and compact design. Can be partially underground.

Challenges While Implementing this Solution:
- Space Constraints: Limited land availability on campus for STP footprint.
- Power Reliability: Frequent power cuts may affect blowers and pumps.
- Regulatory Approvals: Delay in Consent to Operate / NOC from SPCB.
- Operator Training & AMC: Untrained staff may lead to breakdowns or poor quality
- Effluent Reuse Pipeline: Difficulty in connecting treated water to toilets or garden areas.
- Funding & Budget: Delay in fund release from management or donor.

Solutions to overcome these challenges:
- Space Constraints: Install tanks underground and place control room above to save space. Use MBBR because of its compact footprint (as already selected).
- Power Reliability: Install 15–20 kVA DG set or inverter backup. Use energy-efficient blowers with soft starters.
- Regulatory Approvals: Appoint an environmental consultant to prepare forms and test reports. Maintain good records for faster approval during audits.
- Operator Training & AMC: Sign an Annual Maintenance Contract (AMC) with STP supplier for 3 years. Provide 1-week hands-on training to in-house maintenance staff.
- Effluent Reuse Pipeline: Map plumbing layout early and design dedicated reuse pipelines. Use treated water for gardening initially (easier), and phase flushing later. Add overhead treated water tank near reuse point if gravity flow is not feasible.
- Funding & Budget: Explore Corporate Social Responsibility (CSR) grants from local companies under Swachh Bharat or green campus themes. Companies like Tata Group, L&T CSR, Hindustan Unilever, Infosys foundation are known for supporting STP/green campus project under CSR.

VII. MAJOR FINDINGS

A. *Energy Consumption Reduction*

The existing energy usage of ~310 kWh/year can be drastically reduced using PIR motion sensors and automated control systems. Estimated savings from automation total ₹33 lakh/year.

B. Solid Waste Management.

Implementation of a 3,000 L capacity biogas plant processes 50 kg of kitchen waste/day, producing ~150 kWh energy/day.
Garden waste of 60 kg/day can be composted with bio-culture, yielding ~1350 kg of compost every 45 days, worth ₹40,500 per cycle.

C. Liquid Waste Recycling

The combined wastewater output is 0.48 MLD/day. A 0.5 MLD capacity MBBR-based STP (Moving Bed Biofilm Reactor) has been proposed. Treated water will be reused for gardening and toilet flushing, reducing freshwater demand and costs.

VIII. COST-BENEFIT ANALYSIS

1) Energy: Annual savings of ₹33 lakh from automation.
2) Biogas: Replacing LPG with biogas in the cafeteria.
3) Composting: Revenue of ₹40,500 per composting cycle.
4) STP: Long-term water savings; initial cost offset through CSR funding.

IX. EXPECTED OUTCOMES

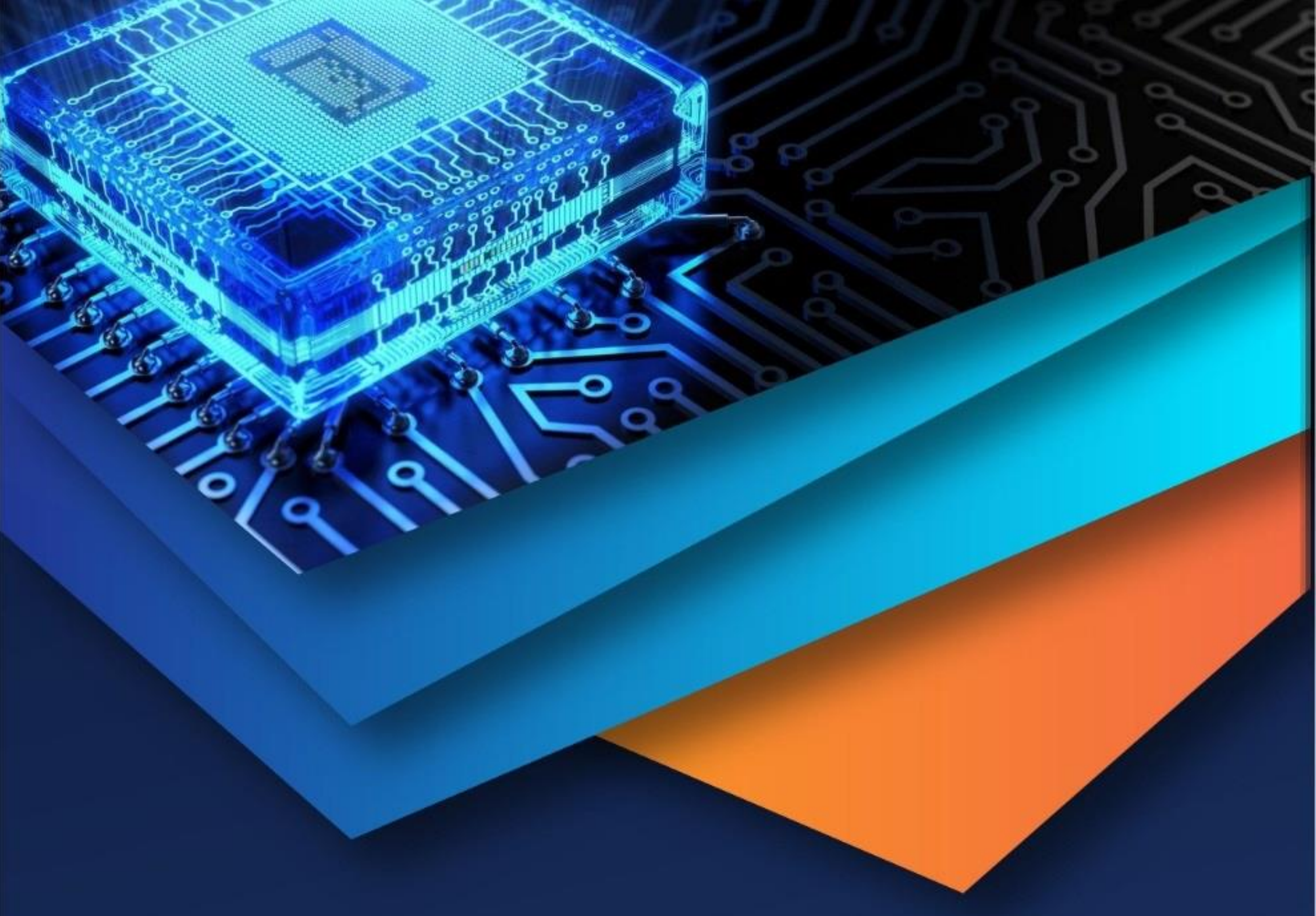
1) Environmental Impact: Net-zero transformation would significantly reduce greenhouse gas emissions, water wastage, and landfill burden. It supports circular economy practices in a campus setting.
2) Social and Educational Impact: Provides real-time, hands-on sustainability education for students. Promotes community awareness and behavioral change through participation and demonstration.
3) Replicability and Scalability: The strategies are modular, cost-effective, and adaptable to different campus sizes and contexts.

X. CONCLUSION

A Net Zero transformation is not merely an infrastructure upgrade but a shift in campus culture. Through strategic planning, stakeholder involvement, and continuous monitoring, educational institutions can become pioneers of sustainable development. The outcomes from this project indicate that a comprehensive, data-driven approach is both feasible and impactful.

REFERENCES

[1] D. McCollum (2021), Net-zero emissions energy systems
[2] Bifeng Zhu et al. (2020), Development of green campuses
[3] Van Den Broek (2019), University campuses as small-scale city models
[4] Balaji Kalluri 1, Vishnupriya 2, Pandarasamy Arjunan 3 1 and Jay Dhariwal, Net-Zero Energy Campuses in India: Blending Education and Governance for Sustainable and Just Transition, (2023)
[5] Ciara O'Flynn 1, Valentine Seymour 1, James Crawshaw 2, Thomas Parrott 3, Catriona Reeby 1 and S. Ravi P. Silva 2, The Road to Net Zero: A Case Study of Innovative Technologies and Policy Changes Used at a Medium-Sized University to Achieve Czero by 2030, 2021
[6] Nikhat Parvez, Avlokita Agrawal and Akhilesh Kumar, Solid Waste Management on a Campus in a Developing Country: A Study of the Indian Institute of Technology Roorkee, 2019
[7] Mr. I. Dhenkar, Mr.'s. Y. Burondkar, Mr. J. J. Kadam, Mr. S. Ranim, Mr. N. S. Dole, Design and Fabrication of Compost Machine: Proposal Model, Dec 2018,
[8] Prof. R.B. Gunale, Shreyas Bugad, Dhiraj Wagh, DESIGN AND FABRICATION OF ORGANIC WASTE COMPOST MACHINE, May 2022, Volume 9, Issue 2
[9] Government of India (CPHEEO, BEE), Waste and energy standards
[10] Case studies from IIT Bombay, Infosys Bengaluru, and NIT Trichy



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