CHAPTER 14

NICMAR University Pune's Transformational Journey Towards Sustainability: Case Study about Proposed Implementation of EaaS (Energy as a Service)

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ABSTRACT

As the leading university in CRIP sector, NICMAR University Pune, has always strived to further its sustainability agenda by continuous research and development and implementation of state-of-the-art sustainable energy generation models to achieve its campus-wide Net-Zero carbon emission goal and advancing circular economy. To align with India's National Energy and Sustainable Development Goals (SDG-7), the Institution has always scouted for transformative and regenerative options. To implement such advancement strategies into NICMAR University, it conducted market research to identify and determine the best technology, disruptive and smart integrated OEM's available in market assisted with Techno-Economical-Socio Analysis. This market research culminated integration and deployment of advanced EaaS (Energy as a Service) architecture, promising innovative shift from CAPEX and OPEX intensive systems to service oriented energy generation service model (BOOM). Functionally the system transformed the University's food/ horticultural/ sewage into Biogas, supporting carbon mitigation across university by replacing its existing Carbon Intensive System, promoting and driving decarbonization across Scope 1 and 2 GHG's emissions, while advancing waste metabolism and enabling regenerative energy efficient practices across campus. Identification and leveraging enablers for EaaS transition, mapping critical risk factors and providing mitigation strategies to support long term operational viability.

Keywords: Energy As a Service, Net Zero Carbon, Service oriented Energy Generation Models, Sustainable Development Goals, Techno-Economical-Socio Analysis, SDG-7.

1.0 Description about the Case Problem/Dilemma

NICMAR University, a leading management institution devoted to infrastructure and sustainability education, found itself in a critical dilemma.

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The university has rising energy needs and substantial organic waste generation from hostels and canteens with an increasing coercion to meet institutional sustainability mandates, the Universities leadership faced a strategic challenge: How to transition into a Net Zero, Circular Economy, Energy Intensification in campus without incurring a heavy capital expense and achieving the same without disrupting the academic operations.

Facing outdated waste handling models and an urgent need to develop a model climatic action on the campus, thus the administration began exploring innovative, low risk alternatives and search for such commercial partners having the technology. This case study follows the strategic decision-making process that led NICMAR to consider and embrace a Smart Biogas Grid under energy as a Service (EaaS) model as a scalable, environmentally and financially beneficial solution. With an impending crisis looming on head will NICMAR guide its future towards an energy autonomous campus or keep on traditional track of using conventional energy sources and bet on its energy security.

2.0 Background of the Company

Mailhem Environment Pvt. Ltd. is a Pune based environmental engineering firm which specializes in decentralized waste to energy (WTE) and organic waste management solutions. Mailhem Environment Pvt. Ltd. has expertise in designing, manufacturing, constructing and the erection of solid waste management plants & biogas plants, with a capacity varying from 100 kg/day to 1000 tons/day for total waste management solutions. Being one of India's leading solid waste management companies, Mailhem specializes in turnkey projects, right from concept to completion of renewable energy generation plants.

2.1 Key features

- 25 + years Of Experience
- 350 + Biogas Plants of varied capacities all over India
- Hands-on Experience in Multi substrate Co-digestion
- One-stop Solution for Solid Waste Management
- In-house R&D Lab
- Highly Professional & Skilled Manpower
- Long Team Operation & Maintenance Contracts

The company is headed by

- Lt. Col. Suresh Rege (Retd.), Founder, Director of Mailhem Environment Pvt. Ltd. and through his unyielding efforts, the company became a leading name in the field of high-rate Bio methanation plants and renewable energy.

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- Mr Sameer Rege, Chief Executive Officer of Mailhem Environment Pvt. Ltd. Mr. Sameer joined Mailhem in 1998. He is responsible for overseeing the overall business operations as well as the project implementations that the company undertakes. With more than 22 years of experience in integrated solid waste management systems, he has led 496+ end-to-end successful projects across India.
- Mailhem Environment Pvt. Ltd. works under different delivery models such as:
- BOOM (Build Own Operate Maintain): under Energy as a Service (EaaS) contract, drastically reducing capital expenditure for easy of customers.
- Turnkey EPC Products: for Industrial and Municipal clients requiring one-time capital expenditure.
- Public Private Partnership (PPP) Frameworks: often integrated with government initiatives such as SATAT, Swachh Bharat Abhyan and Smart Cities.
- Their flagship modular system – HEM-500, The system is designed for 500 kg/day of organic input. This combines Anaerobic Digestion, Nutrient Recovery and Gas Purification inside a compact IoT Enabled package. This system is widely used by University Campuses, Ward level Installation and Gated Communities.

2.2 Key products offered

- Smart Biogas Grids
- Modular Biogas Digester
- Bio-CNG Bottling Plants
- Biogas to Electricity Units
- IoT Monitoring Dashboards for Waste to Energy Assets

3.0 Introduction to the Case Study

Thus started the NICMAR University's mission of transition into a Net Zero, Circular Economy, Energy Intensification in campus without incurring a heavy capital expense and achieving the same without disrupting the academic operations.

Researcher S. Ghosh, a research student of NICMAR's IGBC Platinum Certified Campus, became worried of the fact that campus generated a substantial amount of leftover food waste, this leftover food held the key to transformation towards cleaner energy generation with sustainable waste mitigation practice.

Nestled away in Pune's urban expanse NICMAR University primarily relied on conventional energy sources to power their campus and generated about 2.4 tons of Organic waste weekly.

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S. Ghosh, leading the University's Sustainability cell, settled down in his room with his tea and a mission in mind "Net Zero Carbon Emission, Circular Economy, Energy Intensification…. Let's aim high". This proved to be a daunting task for a researcher invested in NICMAR's Sustainable Development Goal (SDG-7). He challenged himself "*Can we turn this waste into a practical resource to capitalize on our Journey towards Sustainability*".

Being a pragmatic systems thinker, he thought for a while and shared this idea to fellow student "*NICMAR's Energy demand is high and expected to increase more over years. If we want to cut Carbon Emissions, shouldn't we start by looking into a sustainable energy source for Campus*".

"*Absolutely!*" Chimed a colleague, intrigued by the idea, "*The solution should be scalable, easily integrated and cost effective*".

S Ghosh went over his notes "*We can also start by looking into the reduction and substitution of standard LPG with Biogas for the campus mess, as conventional cooking gas is a major source of GHG emissions. In doing so we can effectively manage our mess waste food disposal too. Further down the line we can bring in advance models of Renewable Energy sources for electricity demand of the campus*".

The fellow colleague smiled, "Exactly let's find out sustainable options available in market".

His goal became clear - to develop cost efficient Net-Zero models, which should be replicable, reduce the University's carbon footprint and demonstrate advances in decentralized energy solutions. This leads him to the core of problem: NICMAR Generates approx. 3.2 tons of organic waste weekly and spends considerable amount on its disposal. In addition is also requires approx. 136.5 kgs of LPG every day for its Mess cooking needs. The University projects a significant rise in campus energy demands in upcoming years. As LPG prices are rising day by day and Government bodies are already pushing for renewable and clean fuel alternatives. The University faces a decision of either building energy autonomy or facing the future compounded costs.

3.1 The urgency factors

- Government CBG Blending Mandate has given rise to LPG prices as suppliers shift to higher priced blended gas.
- Net zero commitment and ESG reporting mandates universities to support and engage in decarbonizing efforts.
- Rising cost volatility and meeting campus energy needs sustainably requires a nature driven solution.
- Landfill dumping diversion mandates and waste management compliances, to segregate organic waste and process it.

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This case systematically evaluates and showcases four competing technology ideas, addresses operational and technical risks, provides financial modelling to support decision making.

Technology comparative analysis for organic waste to energy management: In evaluating sustainable solutions for Organic Waste and Renewable Energy Generation, various technologies were identified and were evaluated in depth, they presented various tradeoffs between operational feasibility, scalability, environmental impact and circular economy. The following analysis evaluates several frequently utilized but rejected alternatives. This was done to identify any possible limitations of technology against the university needs of Net Zero Carbon Emission, Circular Economy, Energy Intensification and a waste to energy system.

1. CAPEX- Heavy In-house Biogas Plant (EPC+O&M)
    - High Upfront Capital cost
    - Long term O&M burden
    - No guaranteed performance
2. Rooftop Solar PV + Battery Backup
    - Limited to electrical output only (no thermal replacement)
    - Doesn't address food/waste disposal problem
    - Battery Maintenance and disposal challenges
3. Campus based Bio-CNG Plant
    - Quite Unviable, below 1000 kg/day
    - Expensive compression and purification infrastructure
    - Complex Safety due to high pressure storage
4. Biogas System under Mailhem Environment Pvt. Ltd. (BOOM)
    - Zero Capital expenditure (CAPEX) for Operator
    - Performance Guarantee and High up-times
    - Circular and Carbon Negative Operation

In evaluating sustainable energy and waste management solutions for NICMAR University, several sustainable models were researched for feasibility, cost and environmental fit. This analysis highlights the advantages of decentralized grids in managing wet organic waste while delivering renewable energy supporting circular economic objectives.

The below-mentioned alternatives showed critical shortcomings in sustainability, scalability and practicality. Although many such solutions are commercially available, only a handful of models provide as many high advantages in commercial, technological and sustainable models such as Energy as a service (EaaS). In real light, the EaaS based smart Biogas System provides a Zero-Capex, Circular solution aligned with NICMAR's operational requirements and sustainability goals.

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Table 1

Technology	**Campus Biogas plant**	**Solar Energy + Battery Backup system**	**Bio-CNG (<1 TPD)**	**Smart Biogas Grid under EaaS**
Energy Recovery Potential	High Recover, Biogas produced by onsite system owned by university	Low, electricity generation only, No waste treatment	High, (if >I TPD), low yield for lower capacity	High, Modular-decentralized biogas production, with IOT enabled process monitoring
Space Requirements	Moderate, Compact, and modular systems have emerged in markets	Moderate, Large space required for panel placement	Moderate, space for digestor and auxiliary system	Low, Modular units require small spaces, provides room for scalability
GHG and Emission profile	Low, Average level of methane conversion	Low, reduced operational GHG emission, E-waste generated raises environmental concerns	Low, reduces substantial as compared to open dumping	Very Low, captures all methane from organic waste, EaaS billing ensures high production
Organic waste processing	Excellent, specifically designed for Wet Organic waste	None, No processing of organic waste	Limited, inefficient below 1 TPD	Excellent, specifically designed for Organic food waste, high processing reliability
Benefaction for circular economy	High, provides renewable energy and creates circular economy	Low, zero recycling or energy recovery	High, Renewable fuel and fertilizer production	Substantially high, Decentralized recovery of resources, fertilizer generation
Challenges and Concerns	High CAPEX upfront, operation and maintenance burden	Medium CAPEX, No waste mitigation benefit	High CAPEX and OPEX, not variable for systems <1 TPD	Zero CAPEX and OPEX, reduces financial barrier for implementation, modular construction enables fast construction and commissioning

Source: Created by authors

This Initiative was made possible through a strategic alliance between Mailhem Environment Pvt. Ltd and NICMAR University which started a long-term knowledge transfer between both parties. A collaborative set of studies were done to assess project's feasibility in NICMAR University's Environment. These comprehensive studies paved a way to in-depth Research, Cost Benefit Analysis, Life Cycle Assessment, Environmental Impact Assessment and Risk Assessment & Mitigation Plan to arrive at the best possible technology selection, cost effectiveness and high circular model.

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4.0 Project Comprehensive Feasibility Reports

Decision Making exercise for EaaS Implementation at NICMAR University

4.1 Known factors

- Raw material (organic waste) availability: 450 to 500 kg organic (food and horticulture) waste from campus.
- Camus Energy Requirements: kitchen for food cooking requires a clean and sustainable source of energy.
- Current Waste handling practice: waste collected and disposed of by Municipal corporations at open waste disposal sites.
- Sustainable model requirements: Energy as a service (EaaS), Build own operate maintain (BOOM) framework, Low Capex options, Promoting circular economy, Scalable and Modular models.

Waste Category	Daily quantity (kgs)	Annual Quantity (tons)	Biogas Potential (kg eq of LPG)	Notes
Organic Food	≃ 450	≃150	≃19.8/day	Cooked/ Un Cooked food Waste
Horticulture Waste	≃6	≃2	≃0.3/day	Garden clippings and grass
STP Sludge	≃40	≃13.2	≃1.76/day	Sludge for NPK enhancement in fermented organic manure
Total Organic Input	≃496	≃165.2	≃21.8/day	

Source: Created by authors

4.2 Unknown factors

- Technical Potential: Biogas Generation Potential, Lower CO_2e emission as per Life Cycle Assessment (LCA) and Energy Recovery
- Raw material (organic waste) quality: Day to day variation in quantity and quality, segregation variability and moisture content.
- Policy ambivalence: Municipal permissions for gas storage and usage and reuse of slurry
- Performance Metrics of the system: Projected Performance vs Actual Performance and ROI.

4.3 Constraints

- Space Constraints: Very Limited space availability in campus, System should be compact enough to fit near mess area and should be odor free.
- Financing: Less Capital-intensive models, less operation and maintenance charges, easy to handle and less human intervention.
- Academic Calendar: Adherence to strict timeline as per semester schedule and with zero disruption of normal campus operation.

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4.4 Assumptions

- Waste Segregation is considered to be 90% efficient.
- No retro fitting issues with the existing system and easy integration.
- 95% up time of the IOT enabled biogas generation system.
- Greenhouse gases (GHG) emission reduces by displacing LPG with Biogas will be factored in sustainability reporting.

4.5 Contextual information

- Net Zero by 2070, India's Goal for Net Zero push.
- Urban Decentralization Trend: Push for in-house waste management systems.
- University's Sustainability Mandate: NICMAR University's transition into climate conscious, research oriented and model University.
- Student Involvement: Including students and giving them the lead to handle this project as live exercise strengthening their project management skills while teaching them sustainability discipline.

4.6 Available resources

- Technology Partners: A suitable technology and knowledge partner.
- Human Capital: Student project team and O&M partners.
- Digital Systems: Analytics Dashboards (IoT enabled) for process and predictive maintenance work.

4.7 Anticipated outcomes

- Environmental: Large CO2e saving from displaced methane emission and allied processes.
- Financial: Net Annual Savings through energy source substitution and fertilizer cost eliminated.
- Academic: Real time sustainability and project management teachings, case-based learning model integrated with teaching.
- Social: Robust culture promoting on campus waste segregation, water security and carbon neutrality.
- Scalability and Longevity: Capacity Expansion potential to accommodate for future campus requirements.

4.8 Key stakeholders

- Vice Chancellor and trustees: Approving Authority/ body, Institutional strategy and commitment, Financial and Project clearance Approval authority.

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- NICMAR Facility Managers: Secondary decision influencers, oversight of day-to-day operation and maintenance.
- Mess Contractor firm and team: End users of the system, concerned with supply reliability, fuel and cost savings and operational simplicity.
- Technology Supplier/ partner: Technology provider, EPC Project and BOOT/M contract management.
- Researchers and students: Primary decision makers, accountable to VC and Board, Project campions, hands on learning.

5.0 Evaluation Criteria

For evaluation of sustainability and feasibility of the Smart Biogas Grid under Energy as a Service (EaaS) model at NICMAR University a multi criteria appraisal is adopted. This approach integrates Cost Benefit Analysis, Life Cycle Assessment, Environmental Impact Assessment, Risk Assessment and Mitigation, each is considered for its distinctive ability to address interlinked nature of this project.

- Cost benefit analysis
  - Purpose: To determine long term economic impact and financial viability.
  - Why it was used: Direct cost such as O&M, Services and Manpower can be quantified against tangible benefits such as energy savings, fertilizers credits and waste processing cost avoidance.
  - Helps compare traditional models (capex intensive) to newer EaaS models in terms of payback period, ROI and operation effectiveness.
- Life Cycle Assessment
  - Purpose: To quantify environmental performance across life cycle of a product, process and service.
  - Why it was used: Evaluates CH_4 and CO_2 emissions, materials used at each project stage and energy inputs
  - Illustrate the Net Carbon Benefit and back institutes Scope 1 and Scope 3 GHG reduction Goals.
  - Aligns with SDG monitoring frameworks.
- Environmental Impact Assessment
  - Purpose: To quantify projects indirect and direct effects on ecological and social systems.
  - Why it was used: To identify Air, Water, Noise and Soil Impacts to environment.
  - Ensures adherence to regulatory compliances and accidental environmental damage.
  - Creation of strong case for institutional support

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- Risk Assessment & Mitigation Plan
  - Purpose: To forecast technical, environmental, financial and social risks.
  - Helps to plan for productivity and eliminate hurdles.
  - Helps building scoring matrix and in decision making process.
  - These tools combined provide multidimensional analysis (technical, economic, environmental and social), Risk Informed decision making, Basis for comparing alternative options, carbon credit and ESG scoring.

5.1 Cost benefit analysis

The cost benefit analysis based on waste food-based biogas systems, where biogas is used for cooking purposes in the campus canteen captures strong economic and environmental benefits when viewed in conjunction with Life Cycle Assessment (LCA). The plant processing capacity is 500 kg of campus organic waste per day, with an annual intake of approximate 1,09,500 kg. Each kg being converted into 0.1 m3 of biogas. This biogas, when converted, can displace a huge amount of LPG (liquefied petroleum gas), this translates into 4489.5 kg per year, using a specified conversion factor. At per current market price of liquefied petroleum gas, this translates into a cost reduction of ₹4,44,159 for the University.

Table 2: Return on Investment for Food Waste based Biogas Plant (Biogas used only for cooking purpose)

Assumptions			
1	Quantity of Input Waste in Kg/day	496	Kg/Day
2	Biogas Potential per kg of Waste	0.1	Cum/kg
3	Conversion factor for Biogas to LPG	0.44	
4	Number of days in year	365	Days
5	Disposal Cost	0.5	Rs/kg
6	Per kg Cost of Cooking Gas	1770	Rs/Cylinder
7	1 Cylinder	19.2	kg
8	Per kg Cost of Liquid Manure	0.3	Rs/Liter
9	Liquid Manure Generation	496	Liter
10	1 kg of Methane	0.025	toneqCO2
11	Carbon Credit Rate	5	$
12	1 $	85	INR
13	1 year	12	months
14	12 months	365	Days
15	Electricity Consumption	**5**	Electrical Units per day
16	Electricity Rate	10	Rs/Electrical Unit
17	1 month	30	Days

Source: Created by authors

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This model also creates additional revenue generation streams such as the cost saving by substituting current campus fertilizer usage by biogas slurry which is generated in abundance daily as a process by product. This model combines social-co benefits and environmental benefits by accounting for carbon credits and reduction of environmental footprint. This proves projects economic feasibility, its alignment in Greenhouse Gases reduction with circular economy principles, creating NICMAR University campus an exemplary model for net zero strategy implementation.

Table 3: Return on Investment

Income		5,82,950.63	
1	Biogas - Equivalent to LPG (in kgs)	4,44,159.38	
2	Liquid Manure in Liter	32,850.00	
3	Carbon Credit	51,191	
4	Saving in Disposal Cost	54,750.00	
Expenditure		3,18,000.00	
1	**Yearly Operation and Maintenance Charges**	**25000**	300000
2	**Electricity Charges**	**1500**	18000
	Investment cost without optional items	11,50,000.00	
	Return on Investment	**4.34**	

Source: Created by authors

5.2 Life cycle assessment

Life Cycle Assessment (LCA) is the scientific, process-based method used to quantify Environmental Impact of System, Product, Process across its lifespan, from raw material production to finished products disposal. Taking into reference NICMAR University's shift to a smart biogas grid under Energy as a service (EaaS) model, life cycle assessment offers a robust and standard structure to evaluate carbon emission and resource utilization at ever of a process, product and service's entire lifecycle.

Using LCA, it was estimated that by operating a 496 kg per day biogas system for use over 25 years can reduce the emission of conventional waste disposal methods by 1,650 tons of CO_2e when compared to open landmine waste disposal and the conventional usage of cooking LPG. For reference, a 496 kg of organic waste dumped in open landmine can generate up to 166.85 kg of methane which is equal to 1514.75 tons of CO_2e over 25 years alone. By capturing this methane for regular combustion in as built systems. By this we are achieving positive displacement of fossil energy in addition to preventing greenhouse gasses emission. Achieving Scope 1 (On-Site Combustion) and Scope 3 (Waste Related) emission reductions.

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LCA also concluded presence of significant sources of emission from operations and materials such as CO_2 from sheet work and concreting, fuel use in site excavation and transportation, maintenance operation emissions from lubrication and water usage. These inputs help fine tune the design, enabling us to optimize lower carbon from fuel usage by optimizing logistics, using recycled steel and employing low carbon concrete construction.

What makes this LCA process increasingly powerful is its integration with digital tools and open databases. With multiple LCA platforms, stakeholders can construct detailed environment inventory and simulate different technology scenarios. The availability of online repositories helps with real-time comparisons of emission, materials and energy sources.

A comprehensive life cycle assessment evaluating the carbon emission and sustainability value of 496 kg/day Biogas System from Cradle to Grave is shown below.

This study applies Life Cycle Assessment (LCA) to calculate direct and indirect CO_2 and CH_4 emissions, as well as CO_2 offsets achieved through fossil fuel substitution and synthetic fertilizer replacement.

Table 4: Net CO_2 Generation from Various Stages

Sr No.	Stage	Net CO_2	Unit	
1	Manufacturing	76.25	Kg	
2	Site Construction & Transport	48049.8	Kg	
3	Raw Material	244.7888	Kg/day	
4	Operation & Maintenance	38.86	Kg/day	
5	Operational Life of Equipment	8250	Days	i.e.. 25 yrs.
6	Sum of Row 3 & 4 for 25 Yrs	2340103	Kg	
7	Sum of Row 6 & 1+2	2388229	Kg	
8	**Total CO_2 for Lifecycle**	**2388.229**	**Tons**	**In 25 Yrs**

Source: Created by authors

After considering all emissions and offsets, the smart biogas grid system under EaaS model system shows net reduction of 1,650 tons of CO_2e, making it in a carbon negative process. This LCA validates the implementation of decentralized circular bioenergy infrastructure in educational campus. It emphasizes energy self-reliance and also contributes to India's Climate Goal of SGD 7 (Affordable Clean Energy).

5.3 Environmental impact assessment

The proposed project consists of installation and commissioning of a 496 kg/day capacity Smart Biogas System on NICMAR University, Pune Campus. Operated by Mailhem Environment Pvt. Ltd. through Build-Own-Operate-Maintain/Transfer (BOOM/T) Model,

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the installation aims to convert food and organic waste generated on campus into campus energy needs, by employing an Energy as a Service Model (EaaS).

1. Project: Smart Biogas Micro-Grid, NICMAR University, Pune
2. Location: NICMAR University, Pune. 18° 34′ 26″ N 73° 46′ 00″ E
3. Project Type: Decentralized Waste to Energy (WTE)- under Energy as a Service (EaaS)
4. Capacity: 496 kg/day organic waste processing

Baseline Environmental Conditions

- Air Quality
    - Situated in Urbanized institutional Zone, Moderate ambient Air Quality.
    - Carbon emission from existing diesel generators.
- Water Resources
    - Water Supply by Ground Water and Municipal Distribution.
    - No direct discharge in natural water bodies.
- Waste Generation
    - Approx 2.5 tons of organic waste generation weekly.
    - Waste to Energy generation Infrastructure is not available.
- Energy Consumption
    - Due to expansion in campus capacity energy load is increasing.
    - Currently all energy needs are met by Government Grid Supply.
- EIA Summary and Result
    - Waste Input: Approx 496 kg/per day (Raw, Cooked, horticulture, STP Waste).
    - Biogas Output: 21.8 kgs/day of LPG equivalent Biogas.
- Slurry Output: 300 liters/day of liquid slurry to be used as compost.

Table 5: Mitigation Strategy

Environmental Side	Impact	Mitigation Strategy
Air Quality	Reduced GHG Emission by 30-40%	Enclosed Digester, Use of H2S Scrubber
Water Quality	Minimal Impact	No effluent Discharge, slurry to be used as compost for horticulture
Solid Waste	Avoids landfill dumping	Waste Segregation and Logistic training on campus
Energy System	Replaces LPG with Biogas	IOT Monitoring and Controlling for Maximum efficiency
Land Use	Spatial Footprint- Minor	Site: No vegetation to be clearance or diversion
Biodiversity	None	Close loop system with no leaks of organic degradation
Noise & Vibration	Minimum	Vibration Isolator, Acoustic Housing, Silent Drives
Odor	Minor odor during Operation	Use of Air filters, Maximum sealing of system

Source: Created by authors

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EIA done for the proposed Smart Biogas Micro-Grid installation in NICMAR University, Pune, shows that the project had minimal to negligible environmental risks and offers significant sustainability gains:

- Approx 519 tons of CO2e emission would be avoided.
- 100% of organic diverted from landfills.
- Achieving closed loop circular economic model.
- Improved and cleaned Air Quality in longer run.
- Potential of Educational Integration and community engagement.

With robust operation, maximum safety, IOT-based monitoring, Alignment with SDG-7 and Indian Government Policies the project is deemed environmentally sound, technically viable and socially beneficial, making implementable at institutional level.

Socio-environmental co-benefits:

- Educational Value Creation: An Ideal setup serving as living interdisciplinary lab for other institutes, firms etc.
- Supports Scope 1 and Scope 3 carbon reduction for net zero 2030 strategy.
- Generates Green Jobs: through plant operator, to OEM Engineers, Energy Managers
- Enable Carbon Credit eligibility verification of reduction in emissions.
- Community Engagement: Sensitization of Students and scholars to sustainability

5.4 Risk assessment and mitigation plan

Proposed Risk matrix identifies and analyzes operational, technical, regulatory and behavioral types of risks anticipated in development of Smart Biogas Micro-Grid system under Energy as a Service (EaaS) model. All the Risks mentioned are paired with proactive mitigation recommendations and measures to guarantee compliant and optimized project results.

Scoring Scale:

- Likelihood (L): 1 (Rare) to 5 (Almost Certain)
- Impact (I): 1 (Negligible) to 5 (Critical)
- Risk Score: L*I
- Risk Level: 1-4 (Low), 5-9 (Medium), 10-15 (High), 16-25 (Critical)
- Priority to be given to investment in monitoring-controlling and safety systems.
- Risk Dashboard to be utilized for regular risk assessment.
- Annual Risk Assessment to be done with OEM to identify critical Risks.

The risk assessment matrix for Smart Biogas Grid's implementation at NICMAR University provides a well distributed spectrum of technical, operational and compliance related risks, it shows that most of the risks are manageable. High risk points such as Feed

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Reliability, H2S Corrosion, Gas leak and fire hazard and System downtime can be managed and mitigated effectively by advance proactive monitoring and predictive maintenance strategies. Low risk points such as technology obsolescence can be addressed through annual reviews and technology upgradation clauses in the BOOM contract.

Table 6: Risk Identification and Mitigation Plan

Sr No.	Risk Identified	L	I	Score	Risk Level	Mitigation Plan
1	Feed Reliability	4	4	16	C	Continuous physical waste monitoring, Waste segregation training
2	H2S corrosion and damage	3	5	15	H	Using Multi-stage Scrubbers, Sensor based monitoring
3	System Downtime	3	4	12	H	Preventive and Predictive maintenance, 24*7 support from OEM's maintenance team
4	Odor/ Pollution	3	3	9	M	Custom Sealing solution to be adopted
5	Regulatory Compliance	2	4	8	M	Engage PMC and Local authorities at early stage
6	Gas Leakage and Fire Hazard	2	5	10	H	Fire suppression system, Gas leak Sensors, Fire Fighting Mock drills
7	Operational Integration	3	3	9	M	Smart Metering, Billing and grievance feedback portal
8	Payback/ ROI	2	3	6	M	BOOM Linked KPI's, financial simulation modeling
9	Tertiary Stakeholder Resistance	3	2	6	M	Training and Awareness Workshops
10	Technology Outdated	1	4	4	L	Upgrade clause in EaaS, Yearly tech review

Source: Created by authors

Overall, the project shows strong risk preparedness framework aligning with national best practices in sustainable engineering and offers high resilience under institutional and regulatory context.

5.5 Operation and maintenance overview

For systems like HEM 500, operation and maintenance can be structured and a recurring routine which is undertaken by the staff recruited and appointed by the EAAS supplier.

Daily Operations include: Segregating organic food from plastics or undesired material, checking for the feed size consistency and ensuring proper dilution so the digester inlet feed system is not chocked. Feeding controlled quantity of feed, avoiding surge or zero feeding as it fluctuates the system generation later days. Adjustment of gas pressure at burners and ensuring least pressure drop in gas delivery line.

Routine Maintenance: Daily/ weekly system physical checks for any abnormality. Periodic cleaning or digester tank and feed screen. Checking organic fermented slurry for any abnormal color, odor or foaming. Monthly cleaning and purging of gas nozzles to get rid of any debris or buildups. Checking all the critical safety and pressure valves. Soap test for identification of any leaks. Record keeping of the feed and production to obtain process efficiency, and quality analysis of the system gas and slurry.

Annual/Overhaul Maintenance: Digester inspection carried out by OEM trained staff, for any corrosion or system crusting and coatings. Gas membrane material quality inspection to assess the fitness of gas balloon. Pressure testing of gas lines and safety systems. Providing fire and safety training to operation and institute managing staff. Training in emergency situation handling and creation of health and safety SOPs.

5.6 Major strategic and policy sections

Regulatory and National Policy Evolution: India's Net Zero framework and Renewable energy policy (SDG-7, CBG Mandate and ESG Requirements). Policy targeting specifically for education sector. City waste policy and urban ecosystem framework. Demonstrates how biogas aligns with local technology optimization and macro level regulatory environment.

Institutional governance and strategic alignment: Incorporates NICMAR's institutional values, mission and identity. Creates sustainable decision-making framework and board level governance solutions. Strategically positioning itself as a market leader.

Market dynamics and systematic energy transition: Supports India's energy mix shift from fossil fuels to renewable fuels. Creates and institutional energy autonomy and energy framework resilience. Showcases biogas as future technology aligned with India's energy transition.

Regenerative campus framework and Circular Economy: Scope beyond carbon reduction, encourages nutrient recovery, circular value creation and carbon credits. Establishes NICMAR's role as a leader in circular campus ecosystem. Stations biogas as a principal system for campus waste circular economy project.

5.7 Implementation and adoption challenges

Financial funding challenge: Conventional system requires upfront CAPEX for system procurement, site preparation and civil work and water and gas piping infrastructure. Operation and maintenance/ OPEX costs which are recurring in nature are generally not correctly accounted for at the start leading to increase in operation costs. Hidden costs such

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hiring project execution and management firms make a project financially daunting for an institution, but the same is resolved by EAAS framework wherein the institution is not required to invest any CAPEX or OPEX, mitigating the financing issues.

Institution Governance Challenge: Project spearheaded or championed by one entity can be affected when the champion changes due to limited knowledge transfer. Institutional entities are generally favored to absorb the project's responsibility in addition to existing, this creates poor project management and underperformance. Same can be managed by adoption an EAAS system where whole project is executed on EPC basis, making institutional governance and monitoring to a minimum.

Technical and Operational Challenges: Inadequate segregation leads to clogged systems and reduced gas yields. Biogas systems are very sensitive to atmospheric and biological changes. Trained staff are required to operate and trouble shoot the plant, which is rarely available, or has to be separately recruited. IOT based modular systems enable minimum human intervention in plant operations which can be monitored and controlled remotely. Predictive and preventive maintenance is carried out by the BOOT/M supplier by their own trained professional regularly. The performance guarantee by supplier covers the operational parameters and production targets.

Policy and Regulatory challenges: Multi agency approval is required for municipal solid waste, navigating through pollution control, environment and safety norms can form obstacles for licensing and usage of the system. Carbon credit accounting or EAAS contract ambiguity can feel risk laden to the Institutes administration. Quality inspection and production reporting requires stringent documentation which might not be an institution's strength.

End user Adoption and Social barriers: Waste Segregation and storage can be seen as an added burden to the housekeeping team. Technology success uncertainty keeps end users from adopting more tech intensive systems. Many users traditional fail to understand the cost versus long-term impact of technology adoption.

6.0 Conclusion and Recommendations

The holistic methodology employed NICMAR University to move past most traditional and to accommodate the unique requirements (strategic decision making, with robust, quantifiable, replicable and sustainable nature) of the project. By engaging selective evaluation tools as per the projects need such as with Cost benefit analysis, Life Cycle Assessment, Environmental Impact Assessment and Risk Assessment and Mitigation Plan. NICMAR University ensured that its approach towards this evaluation was data driven which showed tangible outcomes at every step. These evaluations allowed NICMAR University to

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demonstrate the real environmental and social impacts of its technology selection overall strengthening its position as an exemplary model in sustainable campus development.

After through comparison and evaluation of various sustainable models such as CAPEX- Heavy In-house Biogas Plant (EPC+O&M), Rooftop Solar PV + Battery Backup, Campus based Bio-CNG Plant and Smart Biogas System Grid under Energy as a Service (EaaS) model and build own operate maintain (BOOM) framework. They were directly compared wherein Mailhem led Energy as a Service (EaaS) model stood out as the most promising and integrating model as per NICMAR University's needs. It achieves higher circularity goals, provides better integration with NICMAR University's Campus self-waste management system, and is met with high stakeholder approval. Moreover, Energy as a Service (EaaS) model offers enhanced sustainable and reliable energy. It also drastically reduces NICMAR University's dependence on less sustainable and external sources.

This proved integrating Mailhem's EaaS provided high carbon reduction and becomes the critical piece that drives the NICMAR University's aim and objectives in sustainability. This helped the University's transition into a demonstrative learning environment. This enables the campus to transition from a passive energy consumer to an active exemplary sustainable model. This creates a unique environment of research, industry partnerships and education where students, policymakers and other institutes can firsthand see the real time operations of such models. In the long run this model created a cultural shift within and outside the Institute, demonstrating data driven decision making, environmental management strategies and education excellence to pursue smarter and greener environment.

After thorough consideration, the professor and students found a fitting Mailhem Environment Pvt. Ltd. as their Sustainability partner and Stakeholder in the project. Mailhem Environment Pvt. Ltd. proposed an Innovative model pioneered by the firm. Their Smart Mirco-Grid Biogas system, deployed under Energy as a Service (EaaS) framework, provided integrative solution to NICMAR University's objectives.

This case study provides details of implementation of a 496 kg per day Smart Biogas Grid at NICMAR University, facilitated under a BOOM agreement with Mailhem Environment Pvt. Ltd., also facilitates a powerful exemplary technology driven demonstration of modern sustainability across academic institutes and small urban cluster.

This initiative operating under Energy as a Service (EaaS) model addresses futuristic global sustainability goals by delivering scope 1 and scope 3 greenhouse gas emission reductions and on the other hand demonstrating strong circular economy for resource and financial efficiency.

From a technical design perspective, the system is designed to process 165.2 tons of organic waste per year, generating over 16,520 m3 of biogas annually. This results in a high methane output of up to 6.843 m3 per year, convert that same methane in terms of mass and

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the result comes out to 7,268.8 kg LPG equivalent Biogas per year. This leads to direct substitution of 7,268.8 kg of LPG in college mess and reduction of fossil fuel consumption and associated emission of greenhouse gases. This intervention is critical and necessary for University's campus aiming for net zero transition. This model provides an annual estimated 66 tons saving of CO_2e, with power of short term as well as long term mitigation. After calculating for cradle to grave lifecycle (Manufacturing, Construction, Operation and Raw materials) the result shows a saving of 1650.79 tons of CO_2e over 25 years life of the system.

Such outcomes are rooted in internationally recognized metrics, and the approach aligns with CO_2e lifecycle calculations methods and methane's global warming potential (GWP). The Environmental Impact Assessment (EIA) demonstrates projects justness in sensitive urban context. This selected design utilizes sealed systems the keeps air and odor pollution to a minimum level, also it aids in containing the potential fire and runoff hazards to maintain zero contamination of ground water. The Biogas slurry is used for fertilizing the University campuses flora and fauna plantations, this provides a circular economy operating within the campus boundary, bolstering local economy as well.

Under a Buil-Own-Operate-Maintain (BOOM) Model, NICMAR University would incur Zero Capital or Operational Investment. Mailhem Environment Pvt. Ltd., the supplier presented their modular 496 kg/day Biogas Plant to be powered by organic waste collected by the campus mess, horticulture waste, STP Solids. The unit would generate 21.8 kgs of LPG equivalent biogas daily and equipped with IOT enabled real time monitoring and controlling of system's performance parameters.

Site feasibility assessment and Techno Commercial analysis in collaboration with the Mailhem Environment Pvt. Ltd.'s technical team, resulted in the following data.

Considering a single 496 kg/day Biogas Generation Unit, resulted in:

- Organic Waste Input: 109.5+ Tons/year
- Biogas Output: ~10,905 Cum/kg/year
- Energy Yield: Equivalent to 4,818 kg of LPG (250 Commercial Cylinders)
- Annual Revenue (biogas + manure): ₹5,31,759/-
- Operational Costs: ₹3,18,000/-
- Net Savings: ₹2,13,759/-
- Payback Period: ~ 4.34 years (excluding depreciation)
- A very favorable outcome and catering to NICMAR's objectives.

Having made Executive Project Proposal (complimented with Cost benefit analysis, Life Cycle Assessment, Environmental Impact Assessment and Risk Assessment and Mitigation Plan) Prof. and Students pitched the same to the university. The proposal was accepted and recognized as more than a renewable energy initiative.

It stood firmly with NICMAR University's broad vision of:

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- Reducing dependency on convention energy sources.
- Achieving Net-Zero Carbon Emission by 2030.
- Promoting Circular Economy and Waste Segregation.
- Enhancing NICMAR University's Environmental, Social & Governance Policies.

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