RESEARCH ARTICLE OPEN ACCESS

"Comparative Analysis: Biogas-to-Electricity Plants in India"

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Abstract:

Biogas-to-electricity plants offer a dual solution for waste management and decentralized power in India. This paper compares four operational plants across scales: Sivaganga industrial cogeneration (35 MW), Singanpore STP municipal plant (0.60 MW), Varadharajapuram village plant (2 tonne/day), and Ashok Meadows community digester (~10 kW). Technical, financial, and social parameters are analyzed to evaluate replication potential. Results show industrial plants achieve high output but need captive feedstock and long-term PPAs, while STP-based systems like Singanpore provide municipal savings of ₹3-3.5 lakh/month and validate India's first liquid waste-to-power model. Village-scale deployment at Varadharajapuram demonstrates circular economy benefits by powering street lights and supplying manure at ₹60 lakh capex. Community plants prove urban feasibility for bulk waste generators. Feedstock security and byproduct monetization are critical for sub-MW viability. The study provides benchmarks for policymakers to standardize tariffs and support biogas deployment from 5 kW to 35 MW.

Keywords —**Biogas-to-electricity; Waste-to-energy; Decentralized power generation; Anaerobic digestion; Circular economy; Techno-economic analysis; Sewage treatment plant; Biomass cogeneration; Rural electrification; India**

I. INTRODUCTION

India generates 62 million tonnes of municipal solid waste and 500 million tonnes of agricultural residue annually, with <30% scientifically processed. Concurrently, 300 million people face unreliable electricity access. Biogas-to-electricity plants address both challenges by converting organic waste into dispatchable power while mitigating methane emissions. However, deployment spans four orders of magnitude — from 35 MW industrial cogeneration to 5 kW community digesters — with limited comparative data on viability factors. This paper analyzes four representative Indian plants to establish techno-economic benchmarks across scales. Objectives: 1) Document technical and financial parameters, 2) Evaluate replication pathways, 3) Identify policy gaps for sub-MW biogas power.[4],[6],[1],[5].

Methods- This study uses a multiple-case study approach to compare four operational biogas-to-electricity plants across India. Case selection criteria: 1) Operational for >3 years, 2) Distinct scale category: industrial >10 MW, municipal 0.1-1 MW, village 5-100 kW, community <20 kW, 3) Publicaly available technical or financial data.[1],[2],[3],[5] Data Collection: Primary data for Varadharajapuram, Tiruvallur District in Tamil Nadu and Ashok Meadows,Pune was obtained from project implementer Carbon Loops Pvt Ltd and site reports. Secondary data for Kanjirangan Panchyat Sivaganga district Tamilnadu and Singanpore STP was compiled from Global Energy Monitor, Surat Municipal Corporation records, and Ministry of New and Renewable Energy documents. Financial parameters were cross-verified with Central Electricity Authority benchmarks for biomass cogeneration.[3],[5],[1],[2],[4],[6].

Analytical Framework: A 7-parameter comparative matrix was developed covering: 1) Plant Identity & Ownership, 2) Technical Configuration, 3) Energy Output & Utilization, 4) Environmental & Social Impact, 5)Financial Parameters ,Scale & Replicability, 6) Key References. Parameters were selected based on MNRE National Bioenergy Programme evaluation criteria.[4]

Normalization: To enable cross-scale comparison, capital cost was normalized to ₹/kW and energy output to kWh/tonne of feedstock where data permitted. For community/village plants without continuous generation data, output was estimated from connected load and reported operating hours. Industrial and municipal plant data used CEA standard Plant Load Factor reporting.[3],[5],[6].

Limitations: 1) Exact Operation and Maintenance O&M costs and PLF for sub-100 kW plants were unavailable and excluded, 2) Sivaganga capex is estimated from industry average ₹3 Cr/MW as plant-specific cost is not public, 3) Community plant capacity is based on typical digester-gas engine sizing for 2-5 tonne/day waste[1],[5],[6].

II. Comparative Analysis Tables

1. Plant Identity & Ownership

Parameters	Sivaganga District, TN	Ashok Meadows, Pune	Singanpore STP, Surat, Gujarat	Varadharajapuram, TN
Full Name	Sakthi Mill Power Station / Sivagangai Biomass Power Plant	Biogas plant at Ashok Meadows Society	Singanpore Sewage Treatment Plant Biogas Power Plant	Varadharajapuram Biogas Plant, Tiruvallur
Location	Sivaganga, Sivagangai Dist, TN	Pune, Maharashtra	Singanpore, Surat, Gujarat	Varadharajapuram, near Nazarathpet, Tiruvallur Dist, TN
Operator	Sakthi Sugars Ltd	Residents Society / Carbon Loops Pvt Ltd	Surat Municipal Corporation (SMC)	Carbon Loops Private Limited
Commissioned	Feb 2008	~2017-2019	2004-2006	~2019-2021
Ownership Model	Private captive industry	Private society	Municipal Corporation	PPP Panchayat + Private

[1],[4],[2],[3]

2. Technical Configuration

Parameters	Sivaganga District, TN	Ashok Meadows, Pune	Singanpore STP, Surat, Gujarat	Varadharajapuram, TN
Installed Capacity	35 MW	Small-scale: ~5-15 kW	0.60 MW (600 kW)	2-tonne/day input, ~20 kW equiv
Primary Feedstock	Bagasse, agri waste, wood biomass, coal	Kitchen + food waste from society	Municipal sewage sludge	Cow dung + food waste from 14 hotels in Poonamallee
Feedstock TPD	~1200-1500 tonne/day bagasse	~0.2-0.5 tonne/day	~100 MLD sewage equiv	2 tonne/day
Technology	Biomass cogeneration - boiler + turbine	Anaerobic digester + biogas engine	Anaerobic digestion + GAUSCOR, S.A.,Spain gas engines	Anaerobic Gas Lift Reactor (AGR)
Digester Type	Boiler for direct combustion	Wet anaerobic CSTR type	UASB + Gas holder	AGR batch type
Biogas Process Time	Industrial continuous	~21-30 days batch	Continuous STP process	21 days
Gas Cleaning	ESP + Stack	H2S scrubber, moisture trap	H2S removal, siloxane filter	Basic water scrubber

[1],[4],[2],[3].

3. Energy Output & Utilization

Parameters	Sivaganga District, TN	Ashok Meadows, Pune	Singanpore STP, Surat, Gujarat	Varadharajapuram, TN
Electricity use	Grid export + sugar mill in-house	Powers common lights, STP, lifts	For STP operations, reduces grid use	Powers 140+ street lights
Grid Connection	Yes - 15 year PPA with TNEB	Mostly off-grid	Internal use by SMC	Off-grid for village
Annual Generation	~200,000 MWh/yr at 65% PLF	Variable, ~10-30 MWh/yr estimate	~3,500 MWh/yr estimate	~70 MWh/yr estimate
Other Output	~60-70%	Not metered, ~30-40%	~65-70%	~40-50%

[1],[6],[2],[3],[4]

4. Environmental & Social Impact

Parameters	Sivaganga District, TN	Ashok Meadows, Pune	Singanpore STP, Surat, Gujarat	Varadharajapuram, TN
Problem Addressed	Bagasse disposal from sugar mill	Society wet waste	Sewage treatment + GHG	Cow dung accumulation in village pond
Ben	Industry +	200-300	Surat city sewage system	920 houses,

efici aries	grid	households		4,300 population
COD Reduction %	N/A - solid biomass	~70-80%	~60-70% in sludge	~75-85%
GHG Reduction	~1,50,000 tCO2e/yr est	~15-25 tCO2e/yr est	~4,000 tCO2e/yr est	~50-70 tCO2e/yr est
GHG/ MW	~4,200 tCO2e/MW/yr	~2,000 tCO2e/MW/yr	~6,600 tCO2e/MW/yr	~3,000 tCO2e/MW/yr

[1],[2],[3],[4],[6]

5. Scale & Replicability and Financial Parameters

Parameters	Sivaganga District, TN	Ashok Meadows, Pune	Singanpore STP, Surat, Gujarat	Varadharajapuram, TN
Scale Category	Industrial - 35 MW	Community - Micro	Municipal - 0.6 MW	Village - 2 tonne/day
Replicable For	Sugar mills, paper mills	Housing societies, hostels, campuses	Cities with STPs using anaerobic process	Villages with cattle + hotel waste
Uniqueness	Bagasse + coal co-firing	Urban decentralized model	India's first STP biogas power	Cow dung + hotel waste for street lights
Payback	15-year PPA period	3-5 years	Not disclosed	Village saves ₹1 lakh on ₹1.3 lakh bill
Capital Cost	₹105 Cr total est	₹10-25 lakh society funded	Part of ₹260 lakh SMC project	₹60 lakh
Specific CAPEX	₹30,000/kW	₹1,50,000 - 2,00,000/kW	₹43,000/kW	₹3,00,000/kW
O&M Cost/yr	₹2-3 Cr/yr est	₹1-2 lakh/yr	Part of STP O&M budget	₹3-4 lakh/yr est
O&M Cost/MWh	₹1,200/MWh est	₹5,000-8,000/MWh est	₹1,500-2,000/MWh est	₹4,000-6,000/MWh est
Monthly Savings	Revenue from power sale	Society maintenance reduction	₹3-3.5 lakh/month for SMC	Saves ₹1 lakh/year

[1],[4],[2],[3].

III. Results and Discussion

The comparative analysis across four scales reveals distinct viability drivers for biogas-to-electricity deployment in India.

3.1 Scale and Economy: A clear inverse relationship exists between plant capacity and specific capital cost. Industrial cogeneration at Sivaganga operates at ~₹30,000/kW, while village-scale Varadharajapuram is 10x higher at ₹3,00,000/kW. Community plants like Ashok Meadows fall in between at ₹1,75,000/kW. This economy of scale explains why sub-100 kW projects require grants or CSR funding, as commercial IRR remains poor without standardized feed-in tariffs [1], [3], [5], [4], [6].

3.2 Feedstock-Technology Linkage: Feedstock dictates technology choice and utilization model. Sivaganga's bagasse availability enables boiler-turbine cogeneration with coal co-firing for baseload stability. Singanpore STP uses anaerobic digestion of sewage sludge paired with GAUSCOR gas engines, optimized for continuous municipal waste streams. Varadharajapuram's AGR process handles high-solids cow dung + food waste in 21-day cycles, suitable for rural batch operation. Community plants adapt similar wet-waste digesters but at lower gas volumes. Feedstock security, not digester efficiency, emerges as the primary constraint across all scales [1],[2],[3],[5].

3.3 Utilization and Grid Interface: Only Sivaganga and Singanpore interface with the grid. Sivaganga exports via a 15-year PPA with TNEB, while Singanpore uses power internally to offset STP demand. Varadharajapuram and Ashok Meadows operate off-grid, powering street lights and common utilities. This avoids grid-evacuation costs and regulatory hurdles for sub-MW plants but limits revenue to avoided electricity bills. MNRE guidelines note that captive use improves viability for <1 MW biogas power [1],[2],[3],[5],[4].

3.4 Byproduct Monetization: Manure is critical for sub-MW economics. Varadharajapuram distributes free organic manure to 100 farmers, solving waste disposal while building social acceptance. Ashok Meadows societies use digestate for landscaping, reducing external fertilizer costs. In contrast, industrial and municipal plants focus on energy output, with manure as a secondary benefit. Formalizing digestate under FCO standards could unlock revenue for small plants [3],[5],[4].

3.5 Replicability: Singanpore proves STP-based biogas is replicable across 500+ Indian cities with anaerobic STPs, as validated by SMC's 4.75 MW total from 5 plants. Varadharajapuram demonstrates a model for 6.4 lakh Indian villages with cattle populations. Sivaganga is replicable only for sugar/paper mills with captive biomass. The 35 MW to 5 kW spectrum confirms technology maturity, but policy support must target the 10 kW-1 MW gap where ₹/kW is highest and tariffs are absent [2], [3], [1], [6], [4].

IV. Conclusion

The four cases confirm biogas-to-electricity is technically proven across India's industrial, municipal, village, and community contexts. Industrial plants like Sivaganga deliver baseload power but depend on captive feedstock and long-term Power Purchase Agreements(PPAs),Municipal STPs, exemplified by Singanpore, achieve operational savings and GHG reduction, making them ideal for AMRUT/Smart Cities Mission integration. Village-scale plants like Varadharajapuram create circular economies — waste to power to manure — with high social acceptance when addressing local issues like pond pollution. Community models suit urban bulk waste generators. Common success factors: feedstock security, in-house/nearby power use to avoid grid-evacuation hurdles, and monetizing byproducts. The primary barrier remains financial viability below 1 MW due to lack of standardized tariffs and high per-kW capex[1],[2],[3],[5],[4],[6].

V. Future Scope

Parameter Expansion: Add 24-parameter technical study covering PLF, COD reduction %, O&M

cost/MWh, and GHG/MW to enable LCOE comparison. Hybrid Models: Assess solar-biogas hybrids to improve plant PLF and provide 24x7 power. Carbon Finance: Quantify CER potential under Article 6.2 for sub-MW plants to improve Internal Rate of Return (IRR). Digestate Standards: Develop Fertilizer Control Order (FCO) certification pathways for biogas slurry to formalize manure revenue.AI for Operations: Deploy predictive maintenance for small gas engines to reduce downtime, critical for sub-100 kW systems [6],[4].In future these plants will be beneficial to improve Rural Electrification(RE) in India.

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ACKNOWLEDGMENTS

The author acknowledge data support from Carbon Loops Pvt Ltd for Varadharajapuram and Ashok Meadows case studies. Technical specifications for Singanpore STP were verified using public records from Surat Municipal Corporation. Financial benchmarks were derived from Central Electricity Authority and Ministry of New and Renewable Energy reports. The authors thank the operators of all four plants for maintaining operational data that enabled this comparative study [5], [2], [6], [4].