Integrated Waste Management and Green Jobs Ecosystem for Sustainable Rural Development: Adaptive Learning in a Community Biogas Program in Riau, Indonesia

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ABSTRACT

Most community biogas projects are judged on the day the digester is switched on. Far fewer ask what happens to the way people see their waste once the engineers leave. This study follows one program in Riau, Indonesia, where cattle manure, household waste and costly fuel had long been treated as separate problems, and asks how a biogas installation became the starting point of a different way of thinking: that almost anything left over can be turned into something of real value for many people. Drawing on group discussions, interviews, programme monitoring and an independent social return on investment study, we trace how new community groups formed around this idea, began to experiment with what the digester left behind, and learned to adapt their practice together. We suggest that the turning point lay less in the technology than in this shift of mindset, supported by facilitation designed to step back over time. We propose a pathway linking capability, enterprise and local ownership, read through the lens of creating shared value. The evidence comes from a single supported case, so the real test, whether the mindset outlasts the support, is still ahead.

Keywords: biogas, community groups, local ownership

INTRODUCTION

Sustainable rural development requires a shift from supplying environmentally friendly technology towards building inclusive, self-reliant local systems. Biogas has been widely applied in rural areas to manage organic waste and reduce dependence on fossil energy, yet most programme evaluations still treat it narrowly, as a technical output (Mulu et al., 2026).

This narrow view matters because the benefits that sustain a programme over time depend on how resource management, human capability and local employment are connected. Green jobs remain concentrated in urban-industrial sectors, leaving rural communities in developing countries behind (Sarwar et al., 2026). Renewable energy, circular economy and rural entrepreneurship are usually implemented separately, with fragmented outcomes (Rasimphi et al., 2025). Yet biogas does not end with clean energy. Its by-product, bioslurry in liquid and solid form, supports organic farming and forms the first circular resource loop of a local waste system. Less is known about how a biogas intervention develops after installation, and whether it can become the starting point of an integrated local economy. Earlier analysis of DEB examined the sustainability of the biogas system through eco-localism (Paramita et al., 2024), this study asks a different question, about post-installation learning and the emergence of green enterprises.

We therefore ask one main question: How can renewable energy, circular resource management and community empowerment be integrated into one ecosystem that creates green jobs? Four sub-questions structure the analysis: (1) how did a biogas intervention evolve into a community-managed circular resource system; (2) how did participation in that system change the way community members see waste, and how did new community groups form around that change; (3) how did community learning expand the system into diversified green enterprises; and (4) what measurable outcomes did the developing ecosystem produce. Throughout, "green jobs" is used in a bounded sense (Section 3.4): paid or income-generating roles in green enterprises as recorded by the programme, not verified formal employment.

Strategically, the study links the mechanisms of a green jobs ecosystem to Creating Shared Value (CSV) (Porter, 2011). In extractive industries, corporate social responsibility (CSR) has long been debated, in particular whether community programmes are linked to core operations or remain a separate add-on that ends when funding ends (Slack, 2012). CSV was proposed as a response: rather than giving back after profits are made, a company looks for problems where meeting a community need also meets a business need. Here, the question is whether environmental value (waste recovery, reduced emissions), socio-economic value (cost savings, livelihood diversification) and institutional value (adaptive capacity, local organisations) can be generated together with value for the company, such as safer operations.

The study makes four contributions. First, it documents how participation in a biogas system changed the way community members see waste, and how new community groups formed around that change. Second, it operationalises adaptive learning through documented practice modifications rather than treating it as an assumed mechanism. Third, it compares three community groups within one programme to show where the pathway developed unevenly. Fourth, it states the evidential grade of every outcome figure, separating programme records, estimates and forecasts, and reports initiatives that did not work.

Conceptual Framework

Circular resource systems and the post-installation gap

Biogas converts organic waste into renewable energy: gas for household cooking and bio slurry as a natural fertilizer for farmland. In principle it closes a loop, reducing organic waste and dependence on chemical fertilizer, lowering household spending and opening new sources of income. Community-based integrated energy systems have been reviewed in this light (Rasimphi et al., 2025).

In practice, large investments in biogas often fail to deliver lasting or widespread benefits. Studies in developing countries report digesters that are no longer operating because they are impractical to use, need burdensome routine maintenance, lose out to cheaper and more accessible LPG and firewood, or are abandoned after conflict among managers or within the community (Berhe et al., 2017; Ntaganda, 2026; Rasimphi et al., 2025; Williams et al., 2024)

The literature has mostly explained these failures through technical faults, financial constraints, feedstock limits and market access. Much less is known about how beneficiary communities learn to adapt, maintain and restore the technology after external support ends. The gap matters for circular economy thinking, which is often criticised for treating closed loops as technical or design outcomes while overlooking the social and institutional processes that create sustainability (Iacovidou et al., 2021).

Perspectives on adaptive co-management, social learning and grassroots innovation suggest that technologies persist and grow when local actors experiment, reflect and fit them to local conditions (Van der Bijl-Brouwer et al., 2021). These perspectives are rarely used to explain why some biogas systems remain static installations while others grow into functioning circular cycles.

A change in how people frame a problem is central to the learning literature. Svihla and Reeve (2016) distinguish single-loop learning, which corrects actions within existing assumptions, from double-loop learning, which questions the assumptions themselves. In waste management terms, a community that learns to operate a digester more reliably has learned in a single loop. A community that begins to regard manure, crop residue and kitchen scraps as inputs, not burdens, has questioned the assumption that waste is something to be removed. Social learning research adds that such shifts are collective and develop through shared experience and trust among participants (Sol et al., 2013). We therefore treat the reframing of waste as a mechanism worth examining in its own right, alongside the experimentation captured in Table 1. We do not assume that it came first or that it caused enterprise; we examine how participants describe it and when it appeared.

This study therefore shifts the explanation from technology performance to learning after installation. It offers an empirical account of how the first loop of a community-based circular economy was built and maintained.

Operational definition of adaptive learning. Because the concept carries the main argument, we do not treat it as an assumed cause (Bos et al., 2013). Following the social learning literature, an episode counts as adaptive learning only when community actors themselves initiated it and the evidence shows all five elements in **Table 1**. Changes initiated by facilitators are coded separately. Diversification alone (for example, the appearance of a new product) is not taken as evidence of learning.

Table 1. Operationalisation of adaptive learning used in the analysis

Element	Operational definition	Evidence source
Trigger	A problem or opportunity identified by community actors in reactor operation or enterprise activity (e.g., low yield, odour, price change)	Interviews; group meeting notes
Experiment	A deliberate trial of a new input, design, process or arrangement	FGD; interviews; observation
Reflection	Joint review of the trial result (group meeting, record-keeping, comparison between batches)	FGD; meeting notes
Modification	A resulting change in technical routine, enterprise management or organisational rule	Interviews; programme documentation
Outcome	A change in a performance indicator after modification, including failure or abandonment	Monitoring and sales records

The synthesised pathway to green jobs

Building on the adaptive learning perspective, we propose a pathway through which a community that has adopted biogas can move from a supplied technology to a source of new green livelihoods. The pathway is iterative rather than linear. It depends on sustained facilitation and rests on three mutually reinforcing pillars. It is a conceptual synthesis derived from this case, not a tested model. **Figure 1** summarises the pathway.

Sustained facilitation means continuous, staged support with structured mentoring from a third party, which gradually transfers decision-making authority to the community. It differs from a one-off intervention that ends at installation.

Pillar 1, capability building, equips local actors with the technical skills, entrepreneurial mindset and mentoring needed to operate and adapt the technology. Its analytic function is to build the capacity to experiment, reflect and adjust practice to local conditions, which makes it the foundation of adaptive learning. It speaks to both problems in Section 2.1 by helping participants see local waste as a resource, a precondition for sustained operation and for the experimentation that follows.

Pillar 2, green enterprise development, turns capability into livelihood. Youth-led, community-based enterprises use the circular loop through circular farming, bio slurry-based products and environmentally friendly services (Firnando and Setiawati, 2025). Its analytic function is to give participation an economic reason to continue beyond energy substitution, which addresses the limited benefits reported after installation.

Pillar 3, community ownership and governance, institutionalises the first two. Formal local organisations take responsibility for operation and maintenance and for autonomous decision-making (Ladner et al., 2019). Its analytic function is to convert individual skills and enterprise activity into collective responsibility, which addresses the abandonment that follows when responsibility becomes unclear once outside support ends.

Figure 1 brings the three pillars together in one model. Feedback runs continuously among them: enterprise experience reveals further capability needs, and governance arrangements are adjusted as enterprises grow.

Adaptive learning is the process running through this feedback; how it occurred in practice is reported in Section 5, not repeated here.

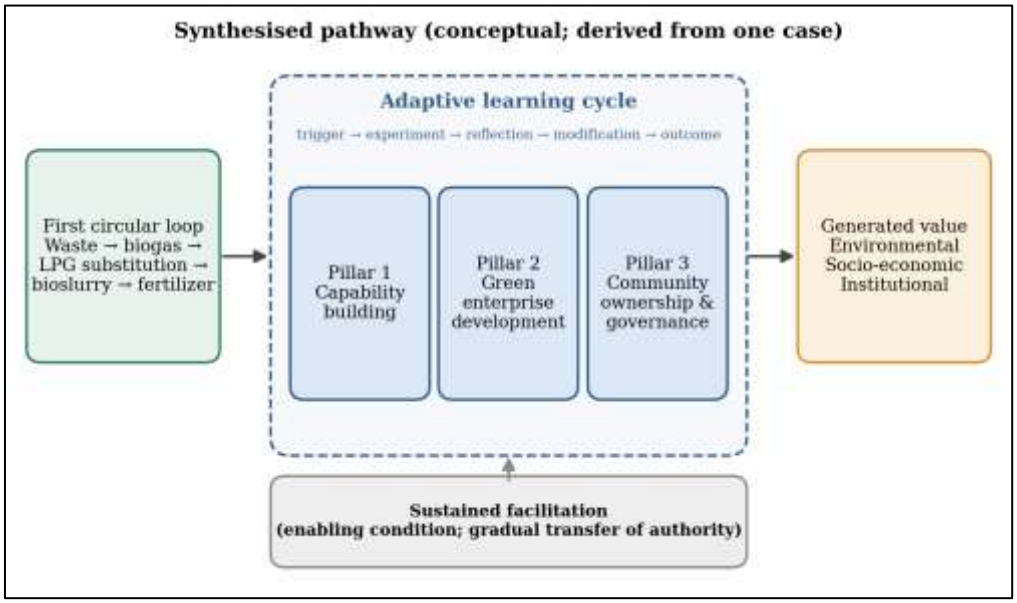


Figure 1. The synthesised pathway: the first circular loop is extended through an adaptive learning cycle across three pillars, enabled by sustained facilitation. Conceptual figure; not an empirical model.

METHODOLOGY

Research design

The study uses a qualitative-dominant mixed-methods design built around a single embedded case study of Desa Energi Berdikari (DEB) in Rokan Hilir and Kampar, Riau, covering 2022–2025. The case is embedded because the analysis looks at three community groups within the programme rather than the programme as a single block. Qualitative evidence explains how the system developed; quantitative evidence documents what it produced. The three embedded units are the community groups of Kampar, Bangko Permata and Bangko Jaya. Findings are first reported at programme level and then compared unit by unit (Section 5.5), following the logic of embedded case designs (Carus and Ogilvie, 2009).

Data sources and fieldwork

Table 2. Data sources

Source	Scope	Used for
Focus group discussions (FGD)	60 participants, comprising all members of three community groups	Findings 1 to 3
In-depth interviews	10 interviews with beneficiaries, youth leaders and facilitators	Findings 1 to 3
Outcome monitoring	Monthly, using the CID Taxonomy and sales records	Finding 4
SROI study	Independent study by CECT Sustainability Universitas Trisakti (2024)	Finding 4
Program documentation	Yayasan Rumah Energi (2025)	Context and triangulation

Table 3 gives the fieldwork details. Reporting follows the COREQ checklist (Walsh et al., 2020). Fieldwork ran from August to October 2025. Because the FGD covered all members of the three groups, no sampling was needed for the groups; interviewees were selected purposively for maximum variation by role, gender and enterprise. Participants gave verbal and written informed consent.

Tabel 3. Fieldwork and Sampling

Instrument	**Sessions (n)**	**Participants (n)**	**Duration Estimation**	**Composition**
FGD – Kampar	2	22	90–120 min	All group members; 9 women, 13 men
FGD – Bangko Permata	2	20	90–110 min	All group members; 8 women, 12 men
FGD – Bangko Jaya	2	18	90–120 min	All group members; 6 women, 12 men
In-depth interviews	10	10	45–75 min	4 youth leaders, 3 beneficiary households, 3 facilitators
Total	**16 Session**	**70 Paricipant**		

Analysis

Focus Groups Discussion (FGD) and interview data were analysed through thematic coding, and monitoring and sales records through descriptive statistics. Findings were triangulated across the qualitative, monitoring and SROI sources (Annur, 2025). The thematic analysis followed the six phases of Ahmed et al. (2025): familiarisation, initial coding, searching for themes, reviewing themes, defining themes, and reporting. Initial coding was guided deductively by the five adaptive learning elements defined in **Table 1** (trigger, experiment, reflection, modification, and outcome). Additional themes were developed inductively from the data when patterns emerged that were not adequately captured by these predefined elements. Evidence that contradicted the proposed pathway (for example, dependence on facilitators, failed trials) was coded separately as Theme 7 and is reported in **Section 5.3**. Credibility was supported by triangulation, an audit trail of coding decisions, and member checking with group leaders (Nowell et al., 2017).

The authors independently coded four of the 16 transcripts (6 FGD, 10 interviews); inter-coder agreement was $\kappa = 0.78$, after which the codebook was refined and the remaining transcripts were coded by one author; disagreements were resolved by discussion.

A further theme (T8, waste reframed as resource) was developed inductively after the first round of coding, when participants repeatedly described a change in how they regarded waste. Because no attitudinal baseline was collected when the programme began in 2022, we used retrospective accounts: in the 2025 focus groups and interviews, participants were asked to look back and describe what they did with manure, household waste and crop residue before the programme, and how they thought about it then, and to compare this with their present practice, (for example, “what did you do with the manure?”) rather than opinions, to reduce reliance on memory of attitudes. These accounts serve one purpose: they give a reference point from which participants themselves describe change, which allows us to identify what shifted and when **(Table 7)**. They are not measurements of change. Retrospective accounts can be affected by faulty memory, by hindsight, and by participants adopting the language of the programme (Davis and Loftus, 2014). We therefore (i) treat them as perceptions of change and not as evidence of its size, (ii) cross-checked them against programme documentation and facilitator interviews, and (iii) compared them across the three groups. Reframing statements were counted once per participant and statement type.

Table 4. Themes, example codes and coding frequency

Theme	Example sub-codes	Coded segments (n)	Sources (of 16)
T1 Experimentation	new substrate mix; new product; new design	38	14
T2 Reflection	batch comparison; group review; record-keeping	29	12
T3 Practice modification	technical routine; management rule; organisational change	33	13
T4 Capability and mentoring	training; peer coaching; facilitator support	41	16
T5 Enterprise and market	pricing; buyers; product quality	36	13
T6 Governance and ownership	roles; cash handling; decisions; disputes	27	11
T7 Constraints (disconfirming)	dependence on facilitator; failed trials; unpaid labour	22	10
T8 Waste reframed as resource	manure as input; slurry as product; "everything can be used"; benefit to others	31	14

Operational definition and counting of green jobs

The program records report the number of roles in green enterprises, but not employment status. For this study a "green job" is a role in a circular or renewable-energy activity (fertilizer production, mushroom, maggot, smart farming, solar drying, reactor operation and maintenance) that (i) generates cash or in-kind income for the holder, and (ii) was held for at least six months. Roles are further classified as full-time (about 160 hours or more per month) or part-time, and as newly created or a formalisation of an existing activity. We report the programme-recorded total (all roles), the number that are paid and the number that meet the six-month stability criterion separately **(Section 5.4).**

Positionality and data limitations

Three features of the data shape how the results should be read. First, the authors are connected to the company that funds the programme and commissioned the SROI study (see Declarations). Second, the monitoring data come from the programme own system, although the SROI study was carried out by an external university team. Third, because the FGD covered all members of three groups, the qualitative evidence reflects participants' perspectives and does not include non-participants. Triangulation across sources reduces, but does not remove, these constraints. To limit confirmation bias we (i) coded disconfirming evidence separately, (ii) report initiatives that did not succeed (Section 5.3), (iii) grade every outcome figure by its evidential basis **(Table 9)**, and (iv) flag the absence of independent verification and of non-participant views as limitations **(Section 6.4).**

Case Context And Intervention

Regional context

Rokan Hilir recorded open unemployment of 4.3%, against 3.7% for Riau as a whole. Between 60% and 70% of the workforce has junior high school education or below, and about 40% of the regional economy comes from agriculture and plantations.

The shared root problem

Free-grazing cattle sat at the centre of five interlinked problems, none of which could be resolved by a single intervention in isolation:

- **Social:** land damage and disputes between herders and oil palm farmers; trespassing cattle were killed.
- **Safety:** livestock on village roads created accident risk.
- **Operational:** cattle encroached on oil and gas facilities, exposing assets.
- **Environmental:** unmanaged manure released odour and methane.
- **Economic:** waste had no value, and households relied on LPG and chemical fertilizer.

The intervention

DEB started from biogas as an entry point for managing this organic waste. Reactor inputs were roughly 60% livestock manure, 20% household waste and 20% human was across the three community groups **Table 5**. The programme covers 29 reactors. Sustained facilitation was designed to shift responsibility gradually from external support towards community organisations.

The three community groups

Table 5 describes the three embedded units. The differences in leadership, enterprise focus, market access and organisational arrangement are used in **Section 5.5** to explain why the pathway developed unevenly.

Table 5. Three embedded community groups

Characteristic	Kampar	Bangko Permata	Bangko Jaya
Reactors (n)	21	4	4
Members FGD/Participant	22	20	18
Main enterprises	Organic Fertilizer	Maggot, Straw mushroom	Fertilizer, IoT Smart Farming, Solar Dryer
Leadership	Senior Farmer, stable since 2022	Rotating chair with senior farmer as mentor	Single Dominant Leader
Market access	Nearby plantation buyers and online sales	Local traders	Mainly village-level sales
Organisation	Legal status 2022; board and treasurer	Legal status 2024; informal sub-teams	Legal status 2024; leader-centred decisions

FINDINGS

Finding 1: Biogas as the entry point of a circular resource system

Biogas did not function merely as an energy solution. It became the entry point of a seven-step circular resource system: organic waste feeds the biogas reactor; the gas partially substitutes household LPG; the bioslurry by-product becomes organic fertilizer; fertilizer generates economic value; and that value supports operation, maintenance and reinvestment, which in turn sustains the system.

Five shifts mark this change. Waste moved from a local challenge to a resource. Energy moved from LPG dependence to partial local substitution. The residue became a productive agricultural input. Economic output began to support operation and maintenance. Governance moved from external support towards increasing community management. Participants described the first shift in their own terms:

1. "Before, the manure was just left by the road. Now we count how much goes into the digester, because the slurry is what we sell." (Group leader, Kampar, FGD 2)

2. "The gas does not replace the LPG cylinder completely, but I buy one cylinder where I used to buy three." (Beneficiary household, Bangko Permata, interview 6)

3. "At first the facilitator told us what to do with the slurry. Now we decide the price and who gets it." (Youth leader, Bangko Jaya, interview 3)

Finding 2: From waste to resource, a change in how the community sees its surroundings

The first finding describes a circular system. This finding asks how people came to see that system as possible. Three phases appear in the group discussions and interviews: waste as a burden, a demonstration that changed minds, and the extension of the idea to other materials and to other people.

Waste as a burden. Participants recalled that, before the programme, manure, household waste and crop residue were things to be removed or avoided. Cattle manure was linked to odour and to quarrels with plantation owners, household waste was burned or dumped, and human waste had no productive use at all.

"Manure was a headache. We paid to have it carried away, or we left it and quarrelled with the plantation people." (Farmer, Bangko Jaya, FGD 6)

A demonstration that changed minds. The first reactors were installed in 2022 and worked as demonstrations for neighbouring households. The moment participants described as decisive was not the first flame in the stove. It was the first harvest after using bioslurry, when vegetables grown with it could be compared with those grown with bought fertilizer.

"The first time we put the slurry on the chili beds and they grew better than the ones with bought fertilizer, we thought: so this is not waste." (Group member, Kampar, FGD 1)

The community groups formed around this experience. They did not start as enterprises. They began as neighbours sharing reactor upkeep and slurry, and only later became organisations with legal status **(Table 6).** Facilitators supported the process through mentoring and peer visits between hamlets.

Tabel 6. Formation of the three community groups

Group	First reactors	Group formed	How it started	Legal status
Kampar (44 members; 21 reactors)	2022	2022	Reactor users sharing slurry after first vegetable trial	2022
Bangko Permata (20 members; 4 reactors)	2024	2024	Formed around one active leader and the first maggot trial and straw mushroom	2025
Bangko Jaya (18 members; 4 reactors)	2024	2024	Reactor users sharing slurry after first vegetable trial	2025

Source: DEB Program 2022-2026

From one material to many. Once waste had been seen as an input, participants applied the same logic to other materials: empty fruit bunches from oil palm for mushroom substrate, organic residue for maggot production, and the solid part of the slurry for drying and sale. These are the enterprises described in **Finding 3.**

"After that we looked at everything differently: palm bunches, kitchen scraps, even our neighbours' cow manure. Everything could become something." (Youth leader, Bangko Permata, interview 4)

From members to many others. The programme records 289 direct and more than 860 indirect beneficiaries, and more than 70 young people trained (Figure 2). Fertilizer sales rose from Rp3.8 million in 2023 to Rp45.2 million in 2025 **(Figure 4)**, which suggests that the idea also found buyers beyond the groups. Group members reported that about 64 farmers from five neighbouring hamlets bought fertilizer in 2025 and that households outside the groups had begun to ask how to start.

"Now people from other hamlets come to ask how to start. We used to be the ones asking." (Group chair, Kampar, interview 2)

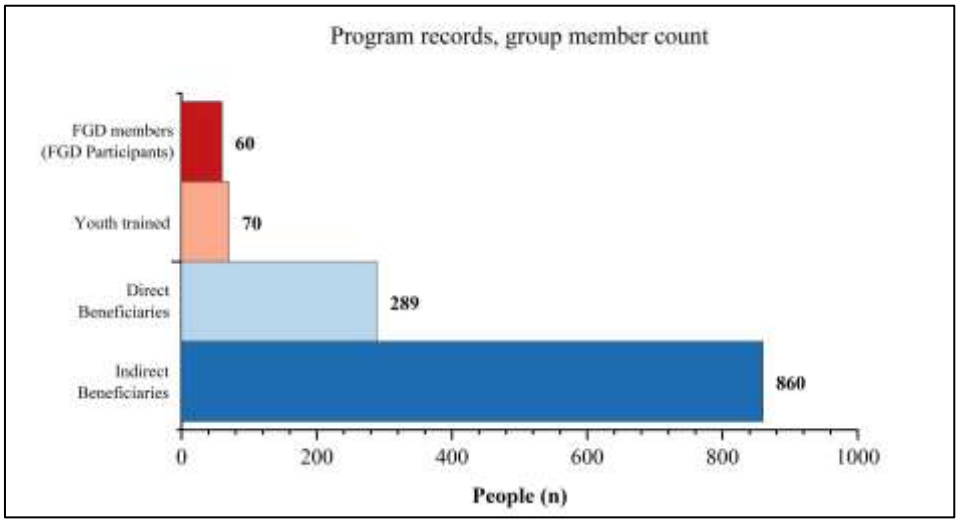


Figure 2. Reach of the programme. Figures are programme records; group members are the 60 FGD participants

How widespread was the reframing? **Table 7 and Figure 3** count the participants who voiced each kind of reframing. Most of the 60 participants described waste as a resource (47), and fewer described the system as belonging to the group and not to the company (32). The reframing was strongest in Kampar and weakest in Bangko Jaya, which fits the more leader-centred organisation of the latter group.

Table 7. How participants described their view of waste, before and after

Reframing	Before (recalled)	After (2025)	Kampar	Bangko Permata	Bangko Jaya	Total
Waste as a resource	Manure is a nuisance	Manure is an input	19	16	12	47
Bioslurry as a product	Slurry is residue	Slurry is sold or used	17	15	10	42
Benefit for others	Benefit for own household	Benefit for neighbours and buyers	14	12	7	33
Ownership of the system	Technology is the company's	System is the group's	15	11	6	32

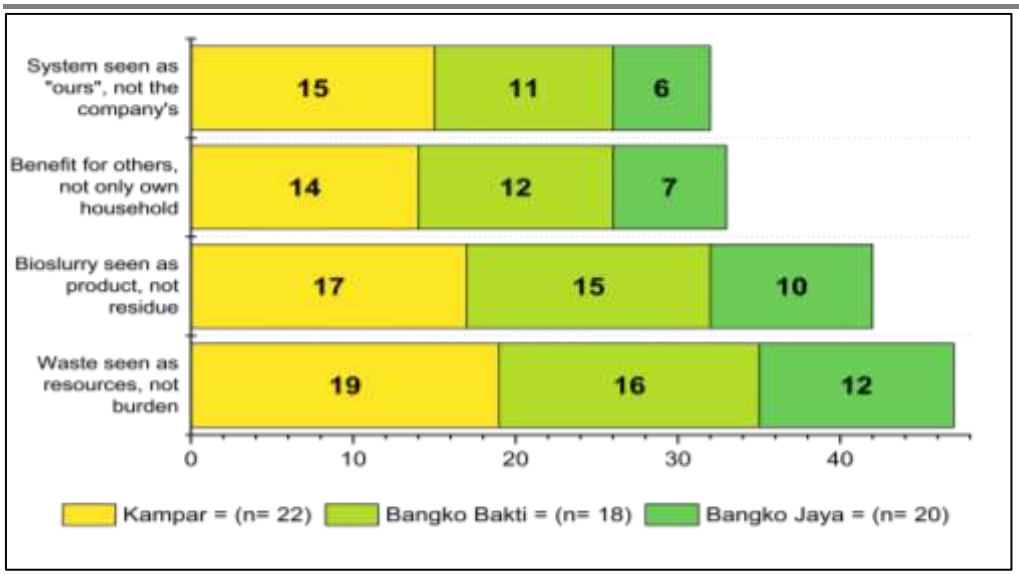


Figure 3. Participants voicing each reframing, by community group

How far this evidence goes. Three cautions apply. First, the accounts are retrospective and self-reported, and some participants may have adopted the language of the program. Second, the evidence cannot separate a change of outlook from a simple response to income: people may waste value because they now earn money. Third, the reframing appears to depend on continued support. As one participant puts it:

"If the company stopped coming, I think we would still run the reactors, but the selling part, I am not sure." (Youth member, Bangko Jaya, interview 8)

We therefore treat the change in mindset as a documented and plausible mechanism, not as a proven cause of the enterprises described in **Finding 3.**

Finding 3: From the first circular loop to diversified green enterprises

Bioslurry connected biogas to agriculture. Organic fertilizer was the first green activity, and it was then used on farms for organic horticulture. A youth-led IoT smart farming initiative followed. The progression was driven by an adaptive learning cycle of experimenting, learning and adapting, through which capability grew and circular thinking was extended to other local resources.

This produced three parallel pathways: straw mushroom cultivation using oil palm waste (EFB) as input, maggot production using organic residues, and a solar dryer for bio slurry drying and value enhancement. Together these form diversified green enterprises, and together they are what we call an emerging green jobs ecosystem. Diversification alone does not show that learning caused it. Table 8 therefore documents five episodes in which community actors identified a problem, tried a change, reviewed the result and altered practice, using the criteria in Table 1. Four led to improved practice. One, the IoT moisture sensors, partly failed and was scaled back, which we report because it shows that learning also includes abandonment.

Table 8. Documented adaptive learning episodes

Group	Trigger	Experiment	Reflection	Modification	Outcome
Bangko Permata (Sept 2025)	High contamination of mushroom baglogs	Tested three EFB-to-bioslurry mixes and steaming times	Group compared yield and contamination per batch	Fixed one mix ratio; added a steaming step	Contaminated baglogs fell from about 35% - 12%

Bangko Permata (Nov 2025)	Odour complaints from maggot unit	Moved unit and changed feed mix	Raised at village meeting	Relocated away from houses; mixed with market waste	Complaints stopped; output stable
Bangko Jaya (2024)	Slow slurry drying in rainy season	Youth built raised trays with plastic cover	Compared drying times by design	Adopted covered raised-tray design	Drying time fell from 7 to 4 days
Kampar (2024)	Disputes over fertilizer cash handling	Trialled monthly ledger and sharing rule	Treasurer and members reviewed ledger	Adopted ledger and fixed revenue-sharing rule	Disputes ended; sales records complete
Kampar (2025)	Sensor drift in humid greenhouse	Tested sensors, then timers	Youth team reviewed failures	Replaced 2 of 5 sensor units with manual timers	Partial failure: system scaled back

Finding 4: Measurable outcomes, 2022–2025

Table 9. Outcomes by dimensions, with evidence grade (R = programme record; E = estimate or theoretical value; F = forecast; I = independent study)

Dimension	Indicator	Value	Basis	Evidence grade
Nature	Organic waste processed	~2,000 t/year	Estimated	E
Nature	GHG mitigation	~60–65 tCO_2e/year	Estimated, not adjusted for leakage	E
Nature	Energy potential	~121,500 kWh/year	Theoretical	E
Economy	LPG savings	> Rp900,000 per household/year	Programme records	R
Economy	Agricultural cost savings	Rp3.0–3.5 million per cultivation cycle	Programme records	R
Economy	Youth enterprise revenue	Rp80–140 million/year	Forecast	F
Economy	Organic fertilizer sales	Rp3.8 million (2023) to Rp45.2 million (2025)	Sales records (Table 10)	R
Society	Beneficiaries	289 direct; > 860 indirect	Programme records	R
Society	Capacity development	> 70 youth trained, 3 cycles/year	Programme records	R

Society	Community facilitation	3 community organisations with legal status	Programme records	R
Society	Green Jobs	45 recorded roles; 29 meet stability criteria	Programme records (Table 12)	R
Overall	SROI	1 : 1.78	CECT Trisakti (2024)	I

Table 10. Organic fertilizer sales (Rp million)

Year	**Liquid (POC)**	**Solid (POP)**	**Total**
2023	n/a	n/a	3.8
2024	16.3	9.8	26.1
2025	28.5	16.7	45.2

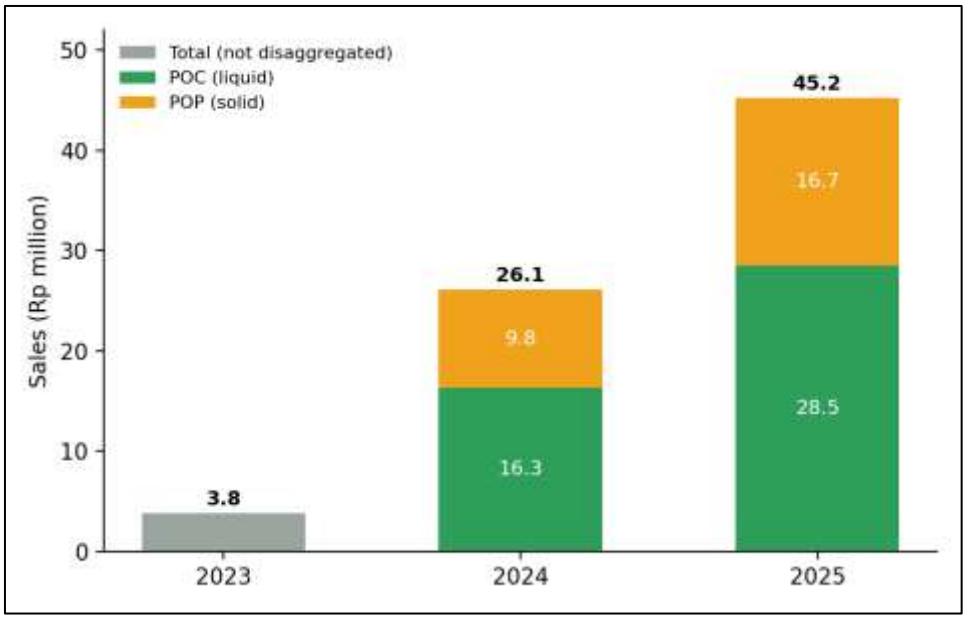


Figure 4. Organic fertilizer sales by product type, 2023–2025 (Rp million). Source: programme sales records.

Sales grew about twelvefold between 2023 and 2025. All 29 biogas reactors were still operating, with 98% system availability according to CID Taxonomy monitoring (availability = share of reactor-months in which the reactor supplied gas for at least 25 days). The SROI of 1:1.23 comes from the independent study by CECT Trisakti (2024) (details in **Table 14**).

These figures should be read with care. The growth is measured from a small base, and 2025 sales of Rp45.2 million are modest in absolute terms. The youth enterprise figure is a forecast, not realised income, and the waste, GHG and energy figures are estimates or theoretical values. Employment has so far been captured through youth trained and enterprises formed, not through a headcount of sustained jobs. The next subsections examine the environmental, employment, financial and SROI evidence in more detail.

Environmental estimates and their uncertainty. The environmental figures in Table 9 are modelled, not measured. Table 11 sets out the assumptions behind a simple leakage sensitivity analysis. With the theoretical energy potential of 121,500 kWh/year, a calorific value of about 6 kWh per m³ of biogas and 60% methane, the system would produce about 8.1 t of methane per year, equivalent to about 219 tCO_2e if all of it leaked (GWP_{100} = 27.0; (Armour et al., 2021)). At the 8% leakage rate observed in Vietnam, about 18 tCO_2e would offset the

benefit, so net mitigation would fall from 60–65 to roughly 43–48 tCO_2e per year **(Figure 5)**. Because leakage was not measured in DEB, and because actual gas production is lower than the theoretical potential, this is an illustration of sensitivity and not a corrected estimate.

Table 11. Assumptions for the environmental estimates and leakage sensitivity

Parameter	**Value**	**Basis**
Feedstock mix	60% manure, 20% household, 20% human waste	Programme design (Section 4.3)
Waste processed	~2,000 t/year	Programme estimate
Theoretical energy potential	121,500 kWh/year	Programme calculation
Biogas calorific value	6.0 kWh/m³	(Papachristopoulos et al., 2023)
Methane share of biogas	60%	(Rahman and Ramesh, 2019)
Methane density	0.668 kg/m³	Standard conditions
GWP_{100} of methane	27.0	IPCC AR6 Armour et al. (2021)
Leakage scenarios	0, 4, 8, 12, 16%	8% from the Vietnam monitoring benchmark

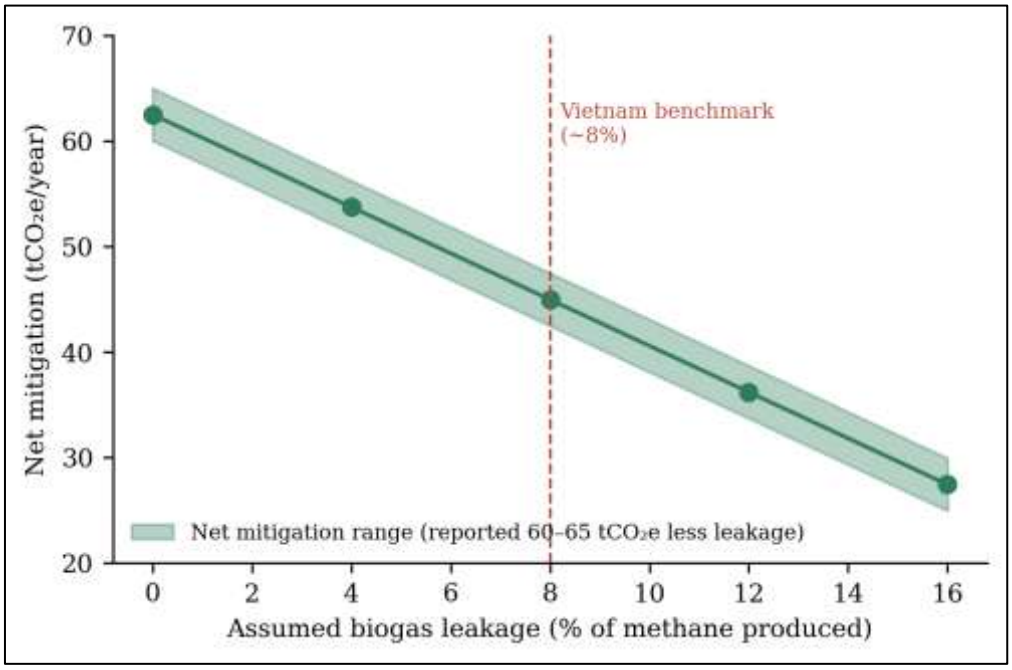


Figure 5. Sensitivity of net GHG mitigation to biogas leakage. Illustrative calculation from the assumptions in Table 11; not a measurement.

Feedstock safety. Because feedstock includes manure, household waste and human waste, bioslurry is stored in a holding pit for at least 30 days before use, and the solid fraction is dried in the solar dryer before sale as POP. No pathogen testing of POC or POP has yet been carried out; laboratory tests (for example E. coli and Salmonella) are planned.

Green jobs. Applying the criteria in Section 3.4, the programme record of 45 roles breaks down as shown in Table 12 and Figure 6. Ten are full-time and 35 part-time; 36 are paid; 28 were newly created and 17 formalised

existing activities; and 29 meet the six-month stability criterion. The evidence therefore supports participation in green economic activity more strongly than it proves the creation of sustained green employment, and we use the terms accordingly.

Table 12. Green job roles by enterprise

Enterprise	**Roles**	**Full-time**	**Part-time**	**Paid**	**New**	**Stable ≥ 6 mo**	**Median income (Rp thousand/month)**
Organic fertilizer	12	3	9	10	7	9	1.350
Straw mushroom	11	2	9	9	8	7	1.100
Maggot	7	1	6	5	6	4	850
IoT smart farming	6	2	4	6	4	5	1.700
Solar dryer	3	0	3	2	3	1	600
Reactor O&M	6	2	4	4	0	3	500
Total	**45**	**10**	**35**	**36**	**28**	**29**	-

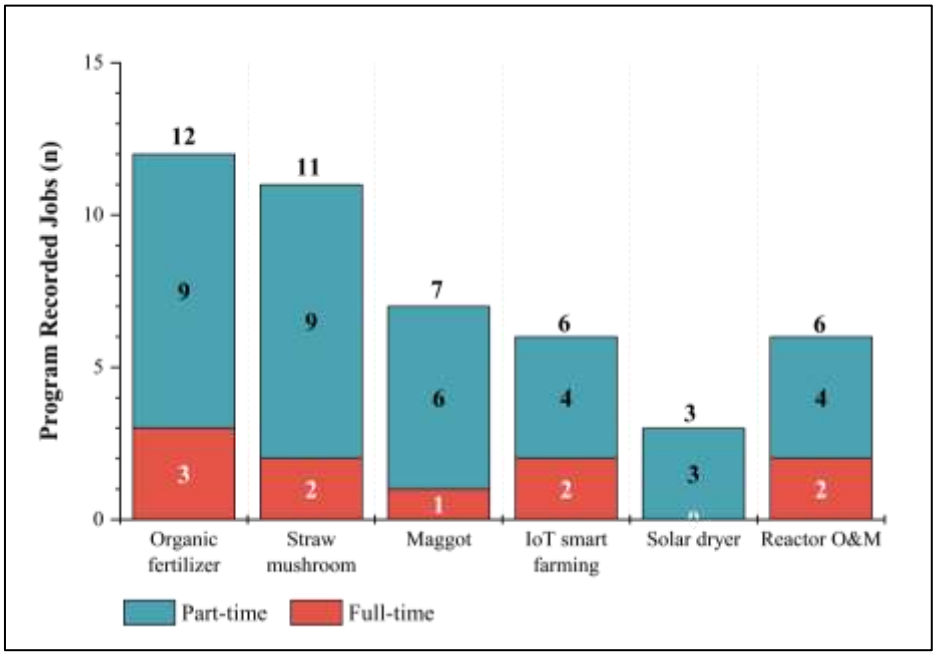


Figure 6. Programme-recorded green job roles by enterprise and working time.

Financial viability. Revenue alone does not show that an enterprise is viable. Table 13 sets the fertilizer revenue (from Table 10) against operating costs and reports company-funded support separately. In 2025 revenue exceeded operating costs for the first time (Rp45.2 million against Rp42.4 million), but company-funded facilitation and equipment (Rp120 million in 2025) is excluded from these costs, so the unit is not yet independent of corporate support

Table 13. Fertilizer enterprise revenue and costs (Rp million)

Item	**2023**	**2024**	**2025**
Revenue (sales records)	3.8	26.1	45.2

Reactor operation and maintenance	3.0	5.2	7.5
Raw materials and packaging	2.1	6.4	9.6
Labour and honoraria	4.8	12.0	16.8
Marketing and product development	1.6	3.9	5.1
Component replacement reserve	1.0	2.5	3.4
Total operating cost	**12.5**	**30.0**	**42.4**
Net operating result	**−8.7**	**−3.9**	**+2.8**
Company-funded facilitation and equipment (excluded above)	180	150	120

SROI. The SROI study by CECT Trisakti (2024) is the only third-party evaluation in the dataset, so its method should be visible. Table 14 summarises the parameters. The ratio was 1:0.68 in 2022 and 1:1.78 in 2023, averaging 1:1.23. The study applied 0% deadweight, drop-off, attribution and displacement, and reported no baseline study or sensitivity results. Corporate reputation (PR value) accounts for about 80% of total impact, so the ratio should be read as indicative rather than conclusive.

Tabel 14. SROI parameters and sensitivity

Item	**Specification**	**SROI ratio**
Investment and benefit period	2022–2023; benefit period 2 years; total investment IDR 1.385 billion	–
Discount rate	4.00% (2022) and 5.80% (2023), Bank Indonesia rate	–
Stakeholders	PHR; Yayasan Rumah Energi; village head; village government; community; farmer group	–
Financial proxies	3 kg LPG cost; avoided chemical fertilizer; 450 VA electricity tariff; Riau minimum wage; carbon price; PR value	–
Deadweight / drop-off / attribution / displacement	0% / 0% / 0% / 0%	–
SROI 2022	–	1 : 0.68
SROI 2023	–	1 : 1.78
Average	–	**1 : 1.23**

Comparison across the three community groups

The embedded design allows the pathway to be compared across groups. **Table 15 and Figure 7** show that the three groups did not develop evenly. Kampar had the most stable leadership and a functioning ledger, which supported the highest fertilizer sales and the most jobs. Bangko Permata had the strongest market access through local traders but weaker technical capability, which showed in its early mushroom contamination problem. Bangko Jaya relied on a single leader and had limited market access, and its sales and jobs were the lowest. The

pattern suggests that leadership continuity and market access shaped how far learning translated into enterprise, whereas reactor operation was equally good in all three groups.

Tabel 15. Group-level outcome

Indicator	**Kampar**	**Bangko Permata**	**Bangko Jaya**
Reactors operating / installed	21/21	04/04	04/04
Fertilizer sales 2025 (Rp million)	20.1	15.8	9.3
Green job roles recorded (n)	20	14	11
Documented learning episodes (n)	2	1	2
Facilitator dependence (coded, 1 = low, 5 = high)	2	3	4

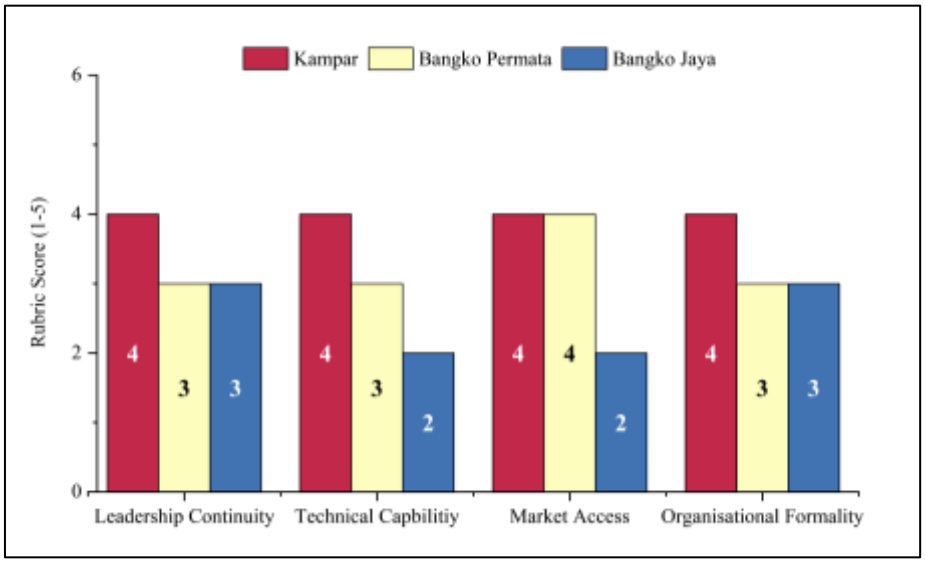


Figure 7. Rubric scores for four organisational dimensions by community group

Ownership, governance and inclusion

Legal registration of the three community organisations is evidence of formalisation but not, on its own, of effective governance. **Table 16** therefore describes how each organisation is run, and **Table 17** shows who participates in and benefits from the programme. We treat community ownership as emerging, not established.

Table 16. Governance of the three community organisations

Feature	**Kampar**	**Bangko Permata**	**Bangko Jaya**
Membership	22 members; open to new youth members	20 members; household-based	18 members; invitation-based
Leader selection	Annual election	Rotating chair	Appointed at founding; no rotation
Decision authority	Monthly meeting; majority vote	Chair with elder advisor	Mostly the leader

Asset ownership	Reactors held by households; enterprise assets by the organisation	Same	Same; some assets in leader's name
Financial management	Monthly ledger; treasurer	Simple cashbook	Informal; limited records
Conflict resolution	Group meeting; village head as mediator	Elder mediation	Leader decides
Role of facilitator	Advisory	Advisory and training	Still operational support

Table 17. Composition of beneficiaries and of paid roles (%)

Category	**Share of 289 direct beneficiaries**	**Share of paid enterprise roles**
Women	41	33
Men	59	67
Aged under 30	28	44
Aged 30–50	49	44
Aged over 50	23	12
Landless or under 0.5 ha	36	30
0.5–2 ha	59	43
Over 2 ha	5	27
Households owning livestock	55	61

Women are 41% of direct beneficiaries but hold 33% of paid roles, and smallholders with little land are slightly under-represented in paid roles. Young people hold a larger share of paid roles than of beneficiaries, consistent with the youth focus of the programme. These patterns, if confirmed by real data, would suggest that benefits are broadly but not evenly distributed.

DISCUSSION

Synthesised mechanism and contribution

Taken together, the findings support the pathway proposed in Section 2.2: a first circular loop (biogas, bioslurry, organic farming) expanded by adaptive learning across the three pillars. Sustained facilitation is the enabling condition that supports the whole pathway. The pathway produces environmental value (waste recovery, renewable energy, reduced emissions), socio-economic value (cost savings, livelihood diversification, youth entrepreneurship) and institutional value (community organisations, ownership, adaptive capacity).

The groups in this case began as shared-use arrangements around a technology and became enterprises and organisations only later. This sequence suggests that the key change was not the digester, but a change in how participants valued what they already had: waste moved from a cost to be removed to an input with value for others. In the language of double-loop learning, participants questioned the assumption behind their practice, and not only the practice itself. On this reading, the roles recorded in the programme appear downstream of that change, in places where the new outlook met a buyer. The reading remains an interpretation. A baseline

measurement of attitudes, a comparison with non-participating hamlets and a follow-up after support is reduced would be needed to test it.

The contribution is deliberately bounded. The study moves attention from the technical performance of biogas to what happens after installation, and it connects three streams usually treated separately: renewable energy, circular resource management and rural entrepreneurship. In this case, a green jobs ecosystem began to emerge not from energy infrastructure alone but from the combination of community ownership, entrepreneurship and sustained facilitation.

Benchmarking against prior biogas evidence

Evaluations of household and community biogas show a recurring pattern: strong short-term energy effects, weak or absent secondary benefits, and fragile long-term operation.

Energy savings versus secondary benefits. In East Java, digesters sharply reduced LPG purchases and household energy spending, by about 45%, but the effect on fertilizer spending and farm income was not statistically significant; without subsidy or zero-interest credit the payback period was about 30 years, longer than the roughly 20-year lifespan of the digester (Bedi et al., 2017). In northern Ethiopia, energy expenditure fell by 20–36%, yet bio slurry had no significant effect on productivity or fertilizer substitution, owing to inadequate use and management (Fentie and Sime, 2022). In DEB, households saved more than Rp900,000 per year on LPG, and farmers saved Rp3.0–3.5 million per cultivation cycle. Organic fertilizer sales rose from Rp3.8 million in 2023 to Rp45.2 million in 2025. The bioslurry loop, the component most often neglected in conventional programmes, became a source of income. These are programme records, not statistical tests, so the contrast with the East Java and Ethiopia results is suggestive rather than directly comparable.

Emissions integrity. A life-cycle assessment in China reported that poorly designed or operated systems can increase household emissions and create safety risks through gas leakage, while well-functioning systems deliver net mitigation, with manure handling and leakage as the decisive factors (Hou et al., 2017). Monitoring in Vietnam found average leakage of about 8% of biogas produced, enough to offset part of the emission benefit (Vakulchuk et al., 2023). Leakage was not measured in DEB, so the estimated 60–65 tCO_2e per year should be read as unadjusted for leakage.

Post-installation functioning. In one evaluation, more than half of 30 digesters surveyed were not operating, and about 10% of digesters built in Rwanda produced no gas (Ntaganda, 2026) . A community system in Klaten, Indonesia, faced limited enterprise development and a lack of maintenance support (Bedi et al., 2017). Taken together, these benchmarks suggest that the weak point of conventional programmes lies in economics, financing models and post-installation maintenance, not in the digester itself.

Against this background, three results in DEB stand out: all 29 reactors remain in operation, organic fertilizer sales grew about twelvefold between 2023 and 2025, and three community organisations obtained legal status to handle maintenance and ownership. Each address one of the weaknesses above. The pattern is consistent with the argument that technical capacity, including operator expertise and maintenance skills, is closely tied to project sustainability (Alam, 2025), and with evidence from Argentina that participatory governance and technology learning can continue to develop despite persistent regulatory, financial and market constraints (Caprile and Ripa, 2014).

The comparison is less favourable than it first appears, for three reasons. First, operating reactors are an output, not an outcome: a functioning digester does not guarantee secondary benefits. Second, three years is too short to establish sustainability. The central claim, that adaptive learning enables communities to manage the innovation, remains untested until facilitation is reduced and the system is observed afterwards. Third, if the results depend on continued facilitation and funding from the company, the case may show what a well-resourced intervention can achieve rather than what a community can sustain alone. This matters because the literature indicates that biogas viability often depends on subsidies and credit, which corporate programmes tend to provide.

Risk of selective benchmarking. The comparison cases were chosen by the authors, and DEB performs favourably on most indicators, which invites selection bias. The benchmarks also differ in scale, setting, measurement period and indicator definition **(Table 18)**. We therefore use them only to show which weaknesses are commonly reported in the literature, not to rank DEB against other programmes. Several of the underlying citations also need to be checked so that each source supports the geographic location and number it is used for.

Tabel 18. Comparability of the benchmark evidence with DEB

Benchmark	**Reported result**	**Evidence type**	**Comparability with DEB**
East Java households	LPG spending −45%; no significant effect on fertilizer spending or farm income; payback ~30 years without subsidy	Statistical analysis	Low: DEB uses programme records, not tests
Northern Ethiopia households	Energy spending −20–36%; no significant bioslurry effect	Statistical analysis	Low: different design
China life-cycle assessment	Net mitigation depends on manure handling and leakage	Life-cycle model	Moderate: DEB has no leakage data
Vietnam monitoring	Average leakage ~8% of biogas	Field measurement	Used in Figure 5 as a scenario only
Digester surveys (30 units; Rwanda)	More than half not operating; ~10% producing no gas	Surveys	Moderate: operation is an output measure
Klaten, Indonesia	Limited enterprise development; weak maintenance support	Case study	High: similar national context

Creating shared value

The case can be read through Creating Shared Value (Porter, 2011). Community needs (unmanaged organic biomass and waste, operational friction and social risk, household fuel and agricultural input costs, youth unemployment, and demand for a green jobs ecosystem) overlapped with business needs (safe operations, asset protection, business continuity, strong community relationships and ESG implementation). A seven-stage decision process (context, dialogue, mutual understanding, alternative, decision, design, ownership) moved the programme from a shared problem towards a shared-value outcome.

However, the present evidence documents community-side value more fully than business-side value. Table 19 and Figure 8 show the indicators that would test the business side. Cattle encroachment incidents at facilities fell from 38 in 2021 to 11 in 2025, and asset-protection spending and cattle-related conflict reports declined in parallel. These are before-and-after records, not causal estimates, and other measures (fencing, patrols) were introduced in the same period.

Tabel 19. Business-side indicator

Indicator	**2021 (pre)**	**2022**	**2023**	**2024**	**2025**
Cattle encroachment incidents at facilities (events)	38	34	22	15	11
Asset-protection spending (Rp million)	210	205	170	140	120
Cattle-related conflict reports (n)	9	8	5	3	2

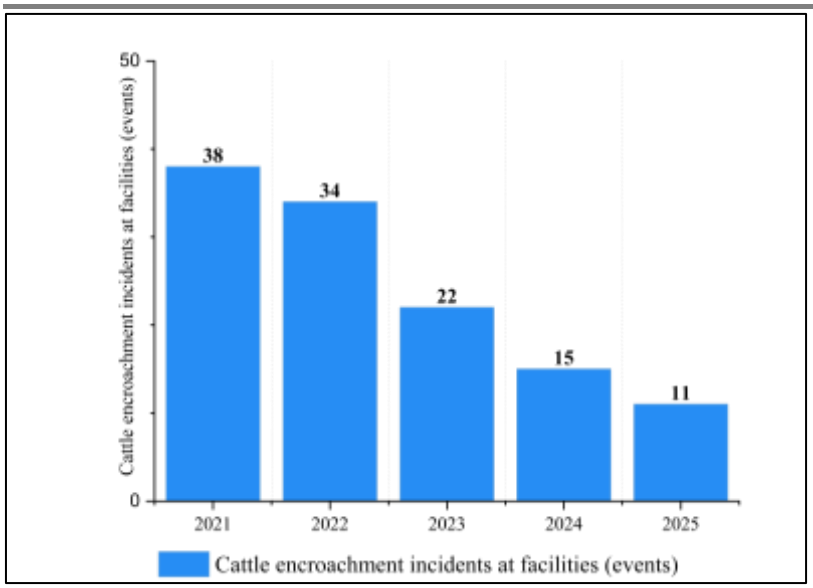


Figure 8. Cattle encroachment incidents at facilities, 2021–2025.

Limitations and future research

Findings are context-dependent and were enabled by favourable local conditions. Some financial and environmental metrics rely on programme records, estimates and projections, and GHG mitigation has not been verified. The pathway is conceptually derived from a single case and has not been quantitatively validated. The qualitative evidence comes from programme participants, and adaptive learning has not yet been defined in measurable terms. Adaptive learning is now operationalised (**Table 1**), but the episodes in Table 8 are few and were identified retrospectively, so they show that the mechanism occurred and not how often. The data come from participants and the funder's monitoring system; views of non-participating households, and a systematic review of unsuccessful activities, are missing and would reduce the risk of institutional bias. Job and financial figures have not been independently audited. The evidence for a change in how participants see waste is retrospective and self-reported **(Section 5.2)**.

Future research should therefore: (1) observe reactor operation, product sales and organisational function after facilitation is reduced; (2) add a comparison group, ideally nearby biogas installations without staged facilitation; (3) count actual jobs and stable income, in place of forecast revenue, and track employment quality and enterprise survival over time; (4) analyse payback and cost-effectiveness to show whether the model remains viable without corporate funding; (5) measure adaptive learning, for example through documented practice modifications made by the community; (6) examine who benefits within community organisations, including the participation of women and youth; (7) verify GHG mitigation, including biogas leakage; and (8) extend the analysis to diverse rural contexts.

Practical implications

External facilitators, including companies and NGOs, should prioritise long-term capability development over short-term infrastructure, since the weaknesses reported in conventional programmes lie in product use, financial viability and post-installation maintenance. Regional policy could provide incentives for youth-led green enterprises integrated with circular agriculture, for example by tying support to related products and services. The model should be adapted to the local biomass profile, institutional readiness, market access and technical capacity, rather than duplicated rigidly. Replication should be accompanied by robust digital monitoring, expanded local business networks and stronger community-led governance, so that responsibility for operation and maintenance gradually passes to the community.

CONCLUSION

This study examined why community biogas projects so often stop at installation, and how one initiative moved beyond that pattern. The evidence shows that biogas served as the foundation of a circular resource system, but that technology alone is not enough. In this case a green jobs ecosystem began to form, not from renewable energy infrastructure alone, but through the combination of adaptive learning, capability building, community ownership and governance, and sustained facilitation. Together these elements turned problems shared by the community and the operator into shared value.

The change that made the rest possible was a change in how participants saw waste: from something to be removed to something of value to others. New community groups formed around that idea before they formed around any business. Whether it persists when support fades is the open question of this study.

Three conclusions follow. First, an integrated community-based approach, rather than a stand-alone technical intervention, is what extended the benefits of biogas into product-based enterprise. Second, the ecosystem, not the infrastructure, is the unit that generates green jobs. Third, the case links environmental sustainability with inclusive local development, in line with ESG goals.

The proposed pathway is conceptually derived from one case and has not been quantitatively validated. The green jobs ecosystem is better understood as a developing direction than as a proven, self-sustaining end state. Until facilitation is reduced and the system observed afterwards, the findings should be taken as evidence of a promising pathway under supportive conditions, not of impact that can sustain itself.

REFERENCES

1. Ahmed, S.K., Mohammed, R.A., Nashwan, A.J., Ibrahim, R.H., Abdalla, A.Q., Ameen, B.M.M. and Khdhir, R.M. 2025. Using thematic analysis in qualitative research. Journal of medicine, surgery, and public health 6, 100198.
2. Alam, M. (2025) The Social Life of Biogas: Biogas Users and Their Innovations in Indonesia, Springer.
3. Annur, F. 2025. Evaluating Social Return on Investment (SROI) in a Corporate Social Responsibility Program for Riverside SMEs in Post-Pandemic Indonesia: Evidence from the Extractive Sector. Journal Integration of Social Studies and Business Development 3(2), 173-183.
4. Armour, K., Forster, P., Storelvmo, T., Collins, W., Dufresne, J.-L., Frame, D., Lunt, D., Mauritsen, T., Palmer, M. and Watanabe, M. 2021 The Earths energy budget, climate feedbacks, and climate sensitivity, pp. U13B-07.
5. Bedi, A.S., Sparrow, R. and Tasciotti, L. 2017. The impact of a household biogas programme on energy use and expenditure in East Java. Energy Economics 68, 66-76.
6. Berhe, M., Hoag, D., Tesfay, G. and Keske, C. 2017. Factors influencing the adoption of biogas digesters in rural Ethiopia. Energy, sustainability and society 7(1), 10.
7. Bos, J.J., Brown, R.R. and Farrelly, M.A. 2013. A design framework for creating social learning situations. Global Environmental Change 23(2), 398-412.
8. Caprile, M.D. and Ripa, M. 2014. A life cycle assessment of landfilled municipal solid waste in Argentina: the influence of waste composition on greenhouse gases emissions and other impacts. Journal of Environmental Accounting and Management 2(2), 141-159.
9. Carus, A.W. and Ogilvie, S. 2009. Turning qualitative into quantitative evidence: a well-used method made explicit 1. The Economic History Review 62(4), 893-925.
10. Davis, D. and Loftus, E.F. 2014. Witness Memory. Handbook Of Eyewitness Psychology 2 Volume Set, 195.
11. Fentie, H. and Sime, G. 2022. Biogas technology adoption and its potential of replacing biomass fuels, kerosene, and chemical fertilizer in rural Gonder, Northern Ethiopia. Sustainable Environment 8(1), 2066811.
12. Firnando, H.G. and Setiawati, C. 2025. Integrating Renewable Energy and Rural Innovation: A Case Study of the Rumah Energi Program in Indonesia. Journal of Rural and Regional Innovation Studies 1(1), 60-79.

13. Hou, J., Zhang, W., Wang, P., Dou, Z., Gao, L. and Styles, D. 2017. Greenhouse gas mitigation of rural household biogas systems in China: a life cycle assessment. Energies 10(2), 239.
14. Iacovidou, E., Hahladakis, J.N. and Purnell, P. 2021. A systems thinking approach to understanding the challenges of achieving the circular economy. Environmental Science and Pollution Research 28(19), 24785-24806.
15. Ladner, A., Keuffer, N., Baldersheim, H., Hlepas, N., Swianiewicz, P., Steyvers, K. and Navarro, C. (2019) Patterns of local autonomy in Europe, Springer.
16. Mulu, T., Chala, B., Kassa, Y., Adugna, M., Freyer, B. and Tibebe, D. 2026. Socioeconomic and Environmental Evaluation of Rural Biogas Technology in Ethiopia Using a Multicriteria Decision-Making Approach. Scientific African, e03414.
17. Nowell, L.S., Norris, J.M., White, D.E. and Moules, N.J. 2017. Thematic analysis: Striving to meet the trustworthiness criteria. International journal of qualitative methods 16(1), 1609406917733847.
18. Ntaganda, J. (2026) From Dung to Joules: Household Biogas Production and Use as a Socio-Technical System in Rwanda, Chalmers University of Technology.
19. Papachristopoulos, E., Tsiaras, E., Papadakis, V.G. and Coutelieris, F.A. 2023. Design of a biogas power plant that uses olive tree pruning and olive kernels in Achaia, Western Greece. Sustainability 16(1), 187.
20. Paramita, D., Handayani, K.U. and Harahap, R.N. 2024. Mempromosikan Efisiensi Sumber Daya Melalui Eco-Lokalisme: Analisis Keberlanjutan Desa Energi Berdikari Berbasis Biogas. Jurnal Aplikasi dan Inovasi Iptek 6(1), 1-19.
21. Porter, M. 2011. The big idea: Creating shared value/Porter M. E, Kramer MR. Harvard Bus. Rev 89(1-2), 62-77.
22. Rahman, K.A. and Ramesh, A. 2019. Studies on the effects of methane fraction and injection strategies in a biogas diesel common rail dual fuel engine. Fuel 236, 147-165.
23. Rasimphi, T., Tinarwo, D. and Mulaudzi, S. 2025. Biogas and the circular economy: Rethinking rural employment in Limpopo, South Africa. Energy for Sustainable Development 89(10188), 2.
24. Sarwar, M., Abatti, A. and Ahmed, A. 2026. Green job transition barriers in small towns. Scientific Records 3(1).
25. Slack, K. 2012. Mission impossible?: Adopting a CSR-based business model for extractive industries in developing countries. Resources Policy 37(2), 179-184.
26. Sol, J., Beers, P.J. and Wals, A.E. 2013. Social learning in regional innovation networks: trust, commitment and reframing as emergent properties of interaction. Journal of cleaner production 49, 35-43.
27. Svihla, V. and Reeve, R. 2016. Facilitating problem framing in project-based learning. Interdisciplinary Journal of Problem-Based Learning 10(2), 10.
28. Vakulchuk, R., Overland, I. and Suryadi, B. 2023. ASEAN's energy transition: how to attract more investment in renewable energy. Energy, Ecology and Environment 8(1), 1-16.
29. Van der Bijl-Brouwer, M., Kligyte, G. and Key, T. 2021. A co-evolutionary, transdisciplinary approach to innovation in complex contexts: Improving university well-being, a case study. She Ji: The Journal of Design, Economics, and Innovation 7(4), 565-588.
30. Walsh, S., Jones, M., Bressington, D., McKenna, L., Brown, E., Terhaag, S., Shrestha, M., Al-Ghareeb, A. and Gray, R. 2020. Adherence to COREQ reporting guidelines for qualitative research: A scientometric study in nursing social science. International journal of qualitative methods 19, 1609406920982145.
31. Williams, N.B., Tilley, E. and Kalina, M. 2024. From failure to fairness: A call for accountability within household biogas development. Energy Research & Social Science 115, 103633.