

Mini-Grids in India: Deployment Trends, Electrification Gaps and Technical Best Practices

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Highlights of Presentation

- Community mini-grids: field work overview and insights
- Causalities in community mini-grid operations
- Where and how to intervene?
- How to assess the operational sustainability?

Community mini-grids: field work overview (May 2022-May 2025)

Total sites 43 India + Namibia	Total interactions 221 213 India · 8 Namibia	Stakeholder workshops 2
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India

41 sites · Jharkhand, Maharashtra, Chhattisgarh

Capacity range 2.88 – 37.7 kW	Stakeholder interactions 213
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Community (32) Private (6) Utility (2) Hybrid (1)

VRLA (35) FLA (3) Li-Ion (2) LFP (1)

Fully operational (31) Daytime only (4)

Out of service (6)

Namibia

2 sites · Otjozondjupa Region ·

Tsumkwe 304 kW	Gam 292 kW	Stakeholder interactions 8
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Utility (2) Flooded Lead Acid (2) Diesel backup (2)

Fully operational (2)

Stakeholder categories engaged

- Community members
- Local operators
- Utility officers
- Community meetings
- Technicians
- NGO and development partners
- Village energy committee heads
- Maintenance officers
- Private sector officers

"Beyond Pilots: Upscaling Distributed Clean Energy in India", a three-day National Roundtable, June 3-5, 2026, CSE's AAETI

Stakeholder Interactions: Some Glimpses

Participatory Workshops (November 2023 and 2024) for BOTGs, Prompts, and Model Validation



Field Interactions in 2024-2025



Loharadera, Gumla, Jharkhand



Phori, Gumla, Jharkhand



Narotoli, Gumla, Jharkhand



CREDA, Raipur, C'garh



Mlinda, Gumla, Jharkhand



Samarbeda, Simdega, Jharkhand
Community



Dumardih, Gumla, Jharkhand
Local Operators



Bar Nayapara, Raipur, C'garh
Field Engineers



CREDA, Raipur, C'garh



TRI, Ranchi, Jharkhand

Officers

Technical

- VRLA and flooded lead-acid batteries dominant across all models
- Battery degradation and replacement delays are universal challenges
- Use of different technologies: bifacial solar panels, PCUs, second-life batteries, inverters with remote monitoring
- **Main grid arrival and free electricity schemes are reducing demand across all business models**

Social

- Productive use increases the utilisation but brings more challenges; ownership of appliances matters.
- Private model serves with a purely financial relationship
- Utility model most affordable but no productive use observed
- **The role of mini-grids in community life is dynamic stop-gap arrangement, primary source, back-up, parallel operation**

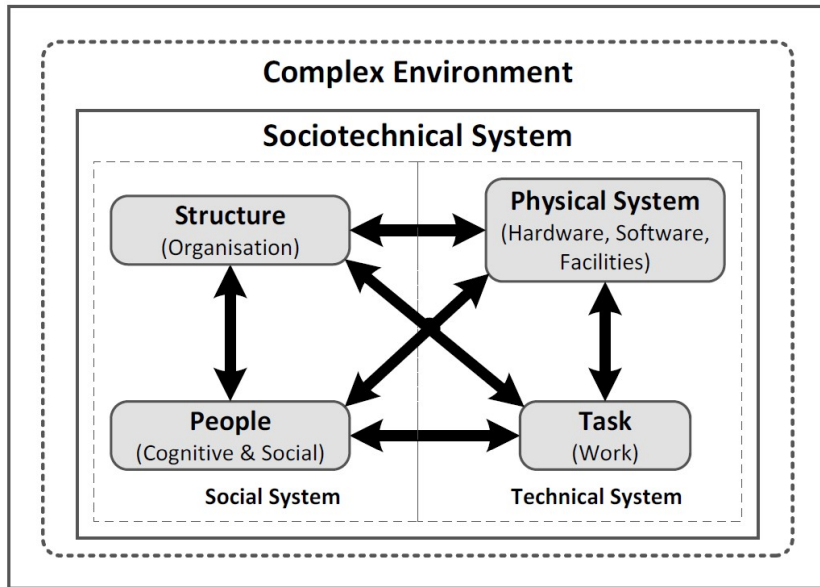
Financial

- Revenue models differ — postpaid, prepaid recharge, and flat monthly bill
- Battery replacement costs strain finances in all models
- The utility model has the lowest tariff, but the supply is for limited hours
- **Financial viability depends on external support: grants, subsidies, or government funding**

Institutional

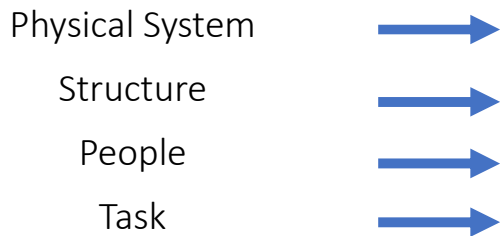
- All models rely on local operators: institutional capacity and support structures differ
- Community model benefits from VEC governance and NGO support (clustered approach, insurance schemes)
- Private model moving toward RESCO with replication model
- **Institutional arrangements, not purely technically reliable and economically viable design, determine long-run sustainability**

Analytical Lens



(Oosthuizen & Pretorius, 2016)

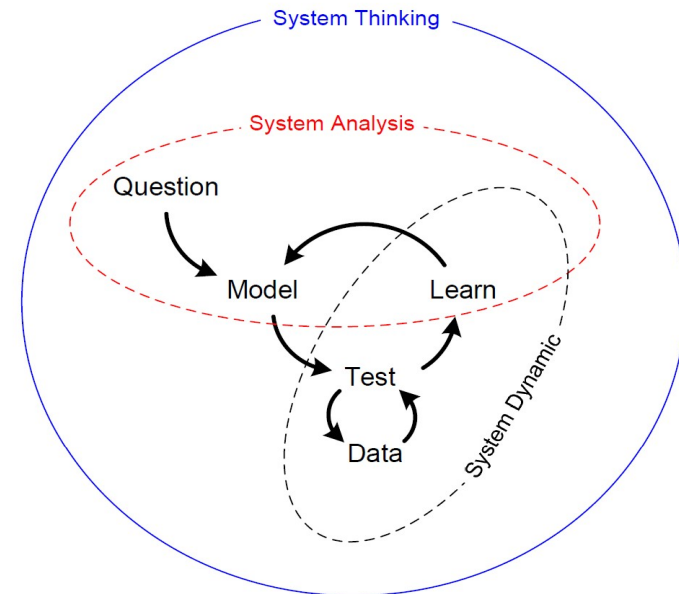
Socio-technical Element



Sustainability Dimension

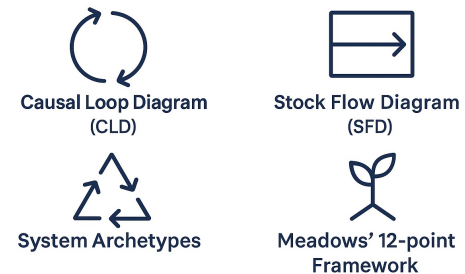
Physical System → Technical
 Structure → Institutional
 People → Socio-economic
 Task → Techno-economic

Analytical Method



(Haraldsson, 2004)

Systems Thinking Tools Used



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Where and how to intervene?

Increasing effectiveness

Parameters	12	Constants, parameters, numbers
	11	The sizes of buffers and stocks
	10	The structure of material flows
Feedback	9	The lengths of delays
	8	The strength of negative feedback loops
	7	The gain around positive feedback loops
Design	6	The structure of information flows
	5	The rules of the system
	4	The power to add, change or evolve system structure
Mindset	3	The goals of the system
	2	The mindset or paradigm
	1	The power to transcend paradigms

Meadow's 12 (Leverage) Points Framework
(Angheloiu & Tennant, 2020).

12. Constants:

Boost solar efficiency; adjust tariffs

11. Buffers:

Expand battery capacity; add fuel reserves

10. Material flows:

Optimise grid layout; streamline distribution

9. Delays:

Faster maintenance; shorter billing cycles

8. Negative feedback:

Load-shedding; peak-demand tariffs

7. Positive feedback:

Referral incentives; reinvest in the community

6. Information flows:

Real-time dashboards; customer feedback

5. Rules:

Off-peak tariffs; grid connection rules

4. System structure:

Hybrid grids; new storage tech

3. Goals:

100% renewable; community priorities

2. Mindset:

Community ownership; renewable-first

1. Transcend paradigms:

Decentralised mini-grids; new planning models

How to assess operational sustainability?

Temporal Orientation of Assessment

		Temporal Orientation of Assessment	
		Cross-sectional	Longitudinal
Analytical Logic of Assessment	Static	Snapshot Assessment	Trend-based Assessment
	Dynamic	Relational Diagnosis	Trejectory-oriented Assessment

References

- Angheloiu, C., & Tennant, M. (2020). Urban futures: Systemic or system-changing interventions? A literature review using Meadows' leverage points as analytical framework. *Cities*, 104, 102808.
- Haraldsson, H. V. (2004). Introduction to system thinking and causal loop diagrams. Department of Chemical Engineering, Lund University.
- Oosthuizen, R., & Pretorius, L. (2016). Assessing the impact of new technology on complex sociotechnical systems. *South African Journal of Industrial Engineering*, 27(2), 15–29.