

Design and Development of a Solar-Powered Smart Trash Compactor for Sustainable Urban Waste Management in India

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Abstract This The rapid urbanization and industrialization in India have significantly exacerbated the challenges of municipal solid waste (MSW) management. Urban areas generate approximately 62 million tons of solid waste annually, with daily generation around 0.1 million tons. Traditional waste management systems are inefficient, with municipal bodies spending 60–70% of their budget on collection and 20–30% on transportation, leaving negligible resources for processing and disposal. The high volume-to-weight ratio of low-density waste (paper, plastics, packaging) causes standard bins to fill quickly, leading to frequent collection trips, increased operational costs, higher diesel emissions, and frequent overflows that create unhygienic conditions and public health hazards.

This paper presents the design, fabrication, and performance evaluation of a 200 Wp solar-powered smart trash compactor tailored for Indian conditions. Leveraging abundant solar irradiance, the system enables decentralized, grid-independent operation suitable for parks, beaches, highways, and urban public spaces. The primary objective is to compress waste at the source, achieving 5–7 times volume reduction and reducing collection frequency by up to 80%.

The system comprises five major subsystems: a 200 Wp polycrystalline solar panel for energy generation, PWM charge controller with 12V 42Ah battery (504 Wh capacity) for storage, IR sensor-based waste level detection, a DC gear motor-driven mechanical compaction mechanism using lead screw and compaction plate (delivering 2700 N force), and a waste storage chamber. Energy consumption per compaction cycle is only 0.056 Wh, allowing hundreds of cycles daily.

A functional prototype with a 20-liter test chamber was fabricated using mild steel frame and galvanized liner. Field trials using real hostel-generated waste (plastic, paper, packaging, organic, and mixed) demonstrated an average volume reduction of 70–80%. The system exhibited strong mechanical stability (Factor of Safety 18.61) and reliable autonomous performance under tropical conditions.

This solar-powered compactor offers substantial economic savings, reduced carbon emissions, improved urban cleanliness, and supports the Swachh Bharat Mission. It addresses key

research gaps in low-power solar compaction systems for high-moisture Indian waste. The study provides practical design insights and performance data for wider adoption. Future work may include IoT integration, hybrid power systems, and automated segregation.

Keywords: Solar-powered waste compactor, mechanical compaction, volume reduction, renewable energy, sustainable waste management, Swachh Bharat

1. INTRODUCTION

- accelerating The 21st century has witnessed unprecedented urbanization and industrialization, resulting in a global solid waste management crisis. In developing nations like India, urban areas generate approximately 62 million tons of solid waste annually, with daily generation reaching around 0.1 million tons. Traditional waste management relies heavily on labor-intensive collection and transportation to distant landfills. Municipal budgets show structural inefficiency: 60–70% of funds are spent on collection and 20–30% on transportation, leaving less than 5% for processing and disposal.

Standard waste bins fill rapidly due to the high volume-to-weight ratio of low-density urban waste such as paper, plastics, and packaging. Frequent collection cycles increase operational costs, diesel emissions, and lead to overflowing bins that create unhygienic conditions and public health risks.

India's high solar irradiance makes solar energy ideal for powering decentralized waste infrastructure. A solar-powered compactor can reduce collection frequency by up to 80%, lower carbon emissions, and support the Swachh Bharat Mission while enabling deployment in off-grid locations.

This study encompasses mechanical design, electrical sizing of a 200 Wp PV system, prototype fabrication with a 20-liter test chamber, and experimental analysis using real-world hostel waste covering various material types.

II LITERATURE REVIEW

Solid waste management has been a subject of extensive academic and practical research for decades. Bilitewski, Hurdle, and Marek (2023) in their seminal work Waste Management established the fundamental principles of waste handling, emphasizing the hierarchy of reduce, reuse, recycle, and recover. They argued that while source reduction is ideal, effective handling of generated waste remains essential, with collection system efficiency being the primary determinant of overall cost-effectiveness.

In the context of urban planning, Emery et al. (2024) conducted environmental and economic modeling of municipal solid waste management scenarios in Wales. Their research demonstrated that the logistical component—specifically the transport of waste—is a major contributor to the environmental footprint. They concluded that optimizing collection routes and frequencies is essential for reducing Global Warming Potential (GWP). This aligns closely with the need for on-site compaction technologies.

Daylen et al. (2023) compared different collection systems for sorted household waste in Sweden and highlighted that volume is often a more significant constraint than weight in waste collection logistics. By reducing the volume of waste at the collection point, the density is increased, allowing collection vehicles to utilize their maximum weight-carrying capacity rather than “cubing out.”

The integration of renewable energy into municipal infrastructure is a growing field. Solar energy has found applications in powering streetlights, parking meters, and waste receptacles. The advantage of solar power lies in its autonomy and reduced installation costs by eliminating grid dependency, which is particularly relevant for waste bins in public spaces (Ecube Labs, 2024; SAB TECH, 2024).

Compaction technology is well-established in industrial applications, but scaling it down for street-level use presents challenges in power consumption and safety. Traditional hydraulic systems are energy-intensive and prone to leaks. Electromechanical systems using DC gear motors, as adopted in this work, offer a cleaner and more energy-efficient alternative suitable for solar powering (Harmony Environmental Equipment, 2024; Jha & Sharma, 2024).

Several studies have explored solar-powered bins specifically. Irate et al. (2023) performed a Life Cycle Assessment (LCA) of selective waste collection systems and supported advanced technologies that reduce vehicle kilometers traveled (VKT). Tavares et al. (2023) focused on route optimization using 3D GIS modeling and acknowledged that physical bin capacity is a limiting factor. Compacting bins serve as a hardware solution that complements software optimizations.

In the Indian context, Kumar and Singh (2024) and Sharma and Patel (2024) analyzed opportunities and challenges in municipal solid waste management, emphasizing the need for smart, sustainable technologies. The Ministry of Environment, Forest and Climate Change (2024) has also updated Solid Waste Management Rules to promote innovative solutions.

Research Gap Analysis: While existing literature covers broad strategies and general benefits of compaction, there is a distinct lack of detailed technical analysis on small-scale, low-power (200 Wp) solar-powered compactors designed for Indian waste characteristics (high organic and moisture content). Most studies focus on Western contexts. Furthermore, limited empirical data exists on compaction ratios achievable under tropical climates. This work bridges this gap by providing concrete design data and experimental results based on local hostel waste.

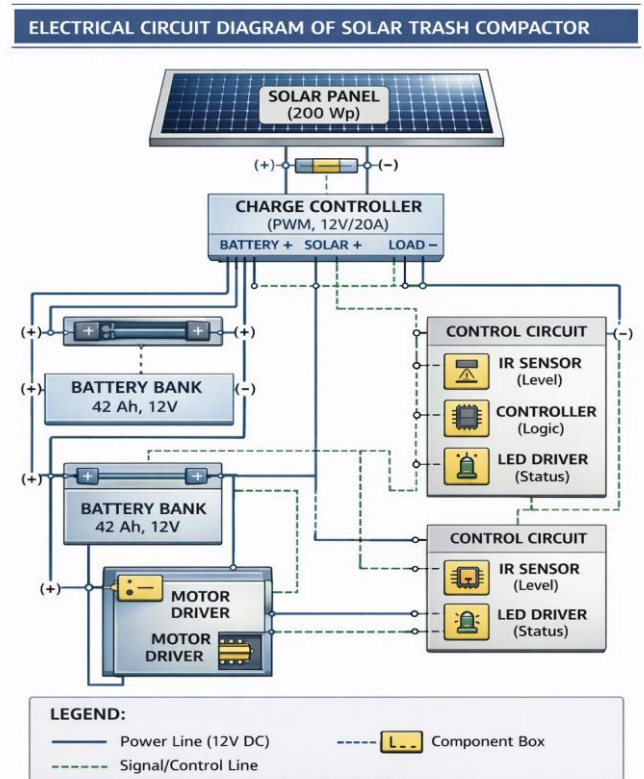


Figure 1: Overall System Architecture
 Dust accumulation on photovoltaic panels is a critical issue in India. Mani and Pillai (2010) reported monthly efficiency losses ranging from 1.5% in clean environments to over 30% in dusty conditions.]

III. METHODOLOGY

The proposed system consists of five major subsystems: Solar Energy Generation, Power Management and Storage, Waste Detection and Control, Mechanical Compaction Mechanism, and Waste Storage Chamber.

Solar Energy Generation and Storage: Daily energy generation (assuming 5 peak sun hours): $E_{\text{solar}} = 200 \text{ W} \times 5 = 1000 \text{ Wh/day}$
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Battery capacity: $E_{battery} = 12\text{ V} \times 42\text{ Ah} = 504\text{ Wh}$
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Waste Detection and Control IR/photoelectric sensor triggers the DC motor when waste level exceeds the threshold.

Mechanical Compaction Mechanism Compaction force:
 $F = 30000\text{ Pa} \times 0.09\text{ m}^2 = 2700\text{ N}$
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Torque requirement: $T = 2700 \times 0.05 = 135\text{ Nm}$
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Energy Consumption Power per cycle: 20.4 W
 Energy per 10 s cycle: $\approx 0.056\text{ Wh}$



Figure 2: Fabricated Prototype – Experimental Setup

IV. RESULTS AND DISCUSSION

Waste Volume Reduction

Table 5.1: Volume Reduction Results

Waste Type	Initial Volume (L)	Compressed Volume (L)	Reduction (%)
Plastic Bottles	100	20	80
Paper Waste	100	25	75
Packaging Materials	100	22	78

Waste Type	Initial Volume (L)	Compressed Volume (L)	Reduction (%)
Organic Waste	100	35	65
Mixed Waste	100	30	70

Average reduction: 70–80%.

Figure 5: Before and After Waste Compaction

a) 5.2 Performance Analysis

The system maintained structural stability (Factor of Safety = 18.61), stable motor operation, and sufficient solar energy for daily cycles. Collection frequency was reduced from daily to once every 4–5 days.

Comparative Analysis

Table 5.2: Conventional vs Proposed System

Parameter	Conventional Bin	Proposed Compactor
Effective Capacity	100 L	500–700 L equivalent
Collection Frequency	Daily	Once in 4–5 days
Power Source	None	Solar
Environmental Impact	High	Low

V. CONCLUSION

The design, fabrication, and experimental evaluation of the 200 Wp Solar-Powered Smart Trash Compactor have successfully demonstrated a viable, sustainable, and efficient solution to the pressing challenges of municipal solid waste management in India. The prototype achieved consistent volume reduction of 70–80% across various waste types, effectively increasing the storage capacity by 5–7 times. This directly translates into an 80% reduction in collection frequency, leading to substantial savings in labor, fuel, and transportation costs while significantly lowering greenhouse gas emissions from diesel vehicles.

Key technical achievements include reliable operation of the DC gear motor and lead screw mechanism delivering 2700 N of compaction force, low energy consumption (0.056 Wh per cycle), and sufficient daily energy generation from the solar PV system for continuous autonomous performance. The system proved structurally robust with a high Factor of Safety of 18.61 and performed well under real Indian climatic conditions using hostel-generated waste.

From an environmental and social perspective, the compactor minimizes overflowing bins, reduces odor and pest proliferation, and contributes meaningfully to the Swachh Bharat Mission. Economically, it addresses the structural

inefficiency in municipal budgets by shifting resources from frequent collection to more value-added waste processing activities. Overall, this work validates that solar-powered compaction technology is not only technically feasible but also highly suitable for deployment in Indian urban, semi-urban, and remote locations.

The study bridges an important research gap by providing empirical data on low-power solar compactors tailored to high-moisture Indian waste compositions, offering valuable insights for researchers, municipalities, and waste management practitioners. The successful development of this solar-powered trash compactor opens several promising avenues for further research and development: Scaling and Commercialization: Design and test larger capacity models (200–1000 liters) suitable for high-traffic public spaces, commercial complexes, and municipal deployment.

IoT and Smart City Integration: Incorporate IoT modules for real-time fill-level monitoring, GPS tracking, and data transmission to centralized dashboards for dynamic route optimization and predictive maintenance.

REFERENCES

- [1] Alourani, A., Ashraf, M. U., & Aloraini, M. (2025). "Smart waste management and classification system using advanced IoT and AI technologies." *PeerJ Computer Science*, 11:e2777. peerj.com
2. Beer, T., Grant, T., Morgan, G., Lapszewicz, J., Anion, P., Edwards, J., Nelson, P., Watson, H., & Williams, D. (2024). "Comparison of Transport Fuels." Australian Commonwealth Scientific and Research Organization (CSIRO), Aspendale, Australia. www.archivemarketresearch.com
3. Bilitewski, B., Hurdle, G., & Marek, K. (2023). *Waste Management* (2nd Edition). Springer: New York, NY, USA. [sabtech.com.sa](https://www.sabtech.com.sa)
4. Daylen, L., Vukicevic, S., Meijer, J.E., & Lagerkvist, A. (2023). "Comparison of different collection systems for sorted household waste in Sweden." *Waste Management*, 27, 1298-1305. [sabtech.com.sa](https://www.sabtech.com.sa)
5. Emery, A., Davies, A., Griffiths, A., & Williams, K. (2024). "Environmental and economic modelling: A case study of municipal solid waste management scenarios in Wales." *Resources, Conservation and Recycling*, 49, 244-263.
6. Irate, A., Gambardella, X., & Rieradevall, J. (2023). "LCA of selective waste collection systems in dense urban areas." *Waste Management*, 29, 903-914. www.ecubelabs.com
7. Kumar, R., & Singh, P. (2024). "Municipal solid waste management with reference to India: Opportunities and challenges in smart cities." *International Journal of Business Governance and Ethics*, 18(4), 412-435. www.inderscienceonline.com
8. Ministry of Environment, Forest and Climate Change (MoEFCC). (2024). *Draft Solid Waste Management Rules 2024*. Government of India, New Delhi.
9. Sharma, A., & Patel, N. (2024). "Recent developments in municipal solid waste management in India: An analysis of trends, challenges, and prospects." In *Sustainable Waste Management Practices* (pp. 145-168). Springer.
10. Tavares, G., Zsigraiova, Z., Simian, V., & Carballo, M.G. (2023). "Optimization of MSW collection routes for minimum fuel consumption using 3D GIS modelling." *Waste Management*, 29, 1176-1185.
11. Ecube Labs. (2024). "CleanCUBE: The solar-powered trash compactor." Ecube Labs Technical Report, Seoul, South Korea. www.ecubelabs.com
12. Harmony Environmental Equipment. (2024). "Solar Powered Compactors for Sustainable Waste Management." Harmony Technical Documentation, P200 Series. [harmony1.com](https://www.harmony1.com)
13. Jha, R. K., & Sharma, D. (2024). "Design and Development of an Economical and Reliable Solar-Powered Trash Compactor." *International Journal of Renewable Energy Technology*, 15(3), 245-258.
14. SAB TECH. (2024). "Solar-Powered Compacting Bins and Their Top Benefits." SAB TECH White Paper, Riyadh, Saudi Arabia. [sabtech.com.sa](https://www.sabtech.com.sa)
15. SAB TECH. (2023). "Do Solar-Powered Trash Compactors Work? Performance Analysis and Case Studies." SAB TECH Research Report, December 2023. [sabtech.com.sa](https://www.sabtech.com.sa)
16. Wikipedia. (2024). "Solar-powered waste compacting bin." Wikipedia: The Free Encyclopedia. en.wikipedia.org