



## Solar-Powered Waste Compactor for Sustainable Environmental Application

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*This study presents the design, development, and field evaluation of a compact solar-powered waste compactor aimed at improving municipal solid-waste (MSW) collection efficiency. The system uses 9-V rechargeable batteries charged via a 6-V solar panel mounted on the bin lid. An embedded sensor triggers automatic compaction upon each waste deposit, supplemented by manual control. A fill-level monitoring circuit with light-emitting display indicators and a buzzer signal when capacity is reached. The compaction mechanism increases effective bin capacity by over four times compared to nominal volume, thereby extending collection intervals. A 64-day field trial in New Delhi compared four solar compactors (0.013 m<sup>3</sup>) with four conventional bins (0.015 m<sup>3</sup>). Conventional bins required 80 collection trips at a cost of ₹5220.80, whereas solar compactors required only 16 trips costing ₹1044.16. This represents an 80% reduction in transport expenses and an average saving of ₹261.04 per bin per cycle. Projected over one year, a single solar compactor could save approximately ₹47,000 in collection costs, excluding labor and vehicle wear. Considering these savings, the system offers a potential payback period of less than eight years, which can be further reduced with bulk municipal deployment and indirect benefits such as lower greenhouse gas emissions. The Operational advantages included reduced waste spillage, odor suppression, and emission reductions of up to 70–80% due to the enclosed automated design. The results confirm that solar-powered compactors offer a robust, eco-friendly, and economically viable alternative for sustainable urban waste management. [DOI: 10.1115/1.4072035]*

*Keywords: renewable energy, waste compactor, NX solar panel, solid-waste management, eco-friendly, environment, sustainability*

### 1 Introduction

In modern times, the generation of solid waste is inevitable. Its characteristics vary considerably among communities and nations, influenced by population density, consumption patterns, economic activities, and cultural practices [1,2]. In India, the annual population growth rate is approximately 3–3.5%, accompanied by an increase in the rate of solid-waste generation of up to 1.3% per year [3]. Rapid population growth, inadequate urban planning, limited infrastructure, and low public awareness have intensified the challenges of waste management in many cities [4]. Municipal solid waste (MSW) refers to non-hazardous solid waste generated by communities that requires collection and transport to a processing or disposal site [5]. It includes garbage—organic waste with high moisture content that is largely decomposable—and rubbish, paper, cloth, or wood that decompose very slowly [6]. Solid-waste collection forms the primary stage of a complex management process and is vital for protecting public health, safety, and environmental quality [7]. Historical data from the Indian Energy Portal indicates that MSW generation in India showed an uninterrupted increasing trend between 1971 and 1997. By the end of 2025, it is expected to double compared to 1997 levels [3]. The per capita waste generation increased from 375 g/day (14.9 Mt/year) in 1971 to 490 g/day (48.5 Mt/year) in 1997 and is projected to reach 700 g/day (97 Mt/year) by the end of 2025 [3,4]. Over the past decades, MSW generation in India has risen steadily due to rapid urbanization, industrialization, and changing consumption patterns [1,2]. According to the Central

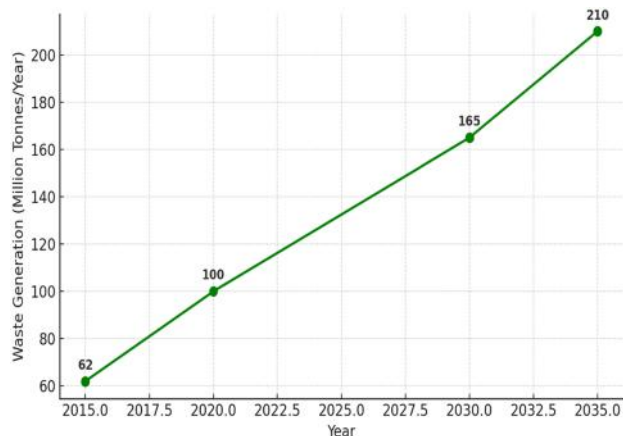
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Pollution Control Board (CPCB) of India, approximately 62 million tons (Mt) of municipal solid waste (MSW) were generated in 2015 [3]. This quantity is increasing at an estimated annual rate of 4–5%, placing significant strain on existing waste management systems [4]. CPCB projections estimate that annual MSW generation will reach 165 Mt by 2030, nearly three times the 2015 level [3]. Extrapolation under a “business-as-usual” (BAU) scenario suggests further growth up to 200–220 Mt/year by 2035, assuming no substantial changes in per capita generation rates or waste reduction measures [5]. An intermediate estimate for 2020 stands at around 100 Mt/year (CPCB 2021) [6]. A graphical projection of these values is shown in Fig. 1, which illustrates the steep upward trajectory in waste generation from 2015 to 2035 [3,6].

The projected rise in MSW generation has considerable implications for environmental quality, public health, and municipal governance, as shown in Table 1. Solar energy technologies can be applied in waste management to power processes such as waste treatment, recycling, and waste-to-energy conversion, enabling cleaner and more sustainable handling of municipal and industrial waste [7]. Parabolic trough solar technology can be effectively integrated with waste management systems by using solar thermal energy to capture and convert carbon dioxide from industrial waste emissions into useful products, thereby linking renewable energy generation with sustainable waste utilization [8]. Without significant improvements in segregation at source, recycling, and treatment capacity, the country may face (a) increased demand for landfill space; (b) elevated greenhouse gas emissions from decomposing organic waste; (c) greater risks of water and soil contamination; and (d) higher incidence of public health hazards. To address these challenges, India must implement integrated solid-waste management strategies, promote circular economy principles, and expand infrastructure for waste-to-energy, composting, and material recovery facilities. The acceleration of urbanization and heightened public awareness of environmental degradation have underscored the urgency for smarter—and greener—waste management solutions. Solar energy can be utilized to accelerate the drying and volume reduction of drinking water treatment sludge through solar evaporation systems, making its management more efficient and environmentally sustainable [9].

**1.1 Context and Motivation.** In India, inefficient waste management has emerged as a major environmental and public health challenge. Improper disposal of MSW leads to severe air, soil, and water pollution, and significantly increases the prevalence of vector-borne and infectious diseases in urban areas [4,10]. The objective of this project is to compact, manage, and dispose of waste efficiently without relying on conventional power sources,



**Fig. 1** Projected trends in municipal waste generation in India [3,6]

thereby minimizing environmental hazards and operational costs. Despite the enactment of the Municipal Solid Waste Management and Handling Rules, 2000, municipal authorities in many Indian cities have been unable to meet mandated standards [11]. This shortfall is largely attributed to inadequate waste collection, inefficient transportation systems, unscientific disposal methods, and poor segregation at the source [1]. Furthermore, insufficient financial resources and a lack of technical infrastructure have hindered the effective implementation of sustainable waste management practices. The accumulation of untreated waste in open dumpsites, such as Ghazipur in Delhi and Pirana in Ahmedabad, has led to repeated landfill fires, groundwater contamination, and hazardous gas emissions, posing serious health risks to nearby populations [11,12]. Given these systemic issues, there is an urgent need to adopt decentralized, energy-independent waste management systems such as solar-powered compactors and community-level waste processing units to reduce dependency on conventional electricity, improve operational efficiency, and promote environmental sustainability in the Indian context [13].

**1.2 Real-World Deployment.** Commercially, solar-powered waste compactors such as the BigBelly system have been widely deployed in smart cities worldwide [14]. These units use solar energy to drive mechanical compactors, increasing bin capacity by up to five–eight times, reducing collection frequency and costs, improving hygiene, and integrating real-time analytics for route optimization. Poor waste management can lead to serious public health issues, including the spread of several vector-borne diseases. Proper solid-waste collection is therefore crucial for protecting public health, safety, and environmental quality. One of the effective approaches to improving solid-waste management is the use of trash compaction technology, which offers multiple benefits from economic, environmental, and technical perspectives. Importantly, compaction minimizes the risk of creating unhygienic and unsanitary conditions in the surrounding area. Since collection accounts for approximately three-quarters of the total cost of solid-waste management, reducing collection frequency through compaction can significantly lower operational expenses. A solar-powered waste compactor is equipped with embedded sensors that measure the bin fill level in real time and trigger automatic waste compaction [15]. This mechanism can increase bin capacity by up to six–eight times. The compaction unit is powered by a battery charged via a solar panel, enabling operation for approximately 3–4 days on a full charge, depending on compaction frequency and usage patterns. Typically, the design includes a 6-V solar panel mounted on top of the bin, supplying power to four 9-V batteries, which in turn power the motor for compaction [7]. By compressing waste, the unit increases storage capacity and reduces the need for frequent emptying. This reduction in collection frequency results in savings on labor, fuel, and maintenance costs, while also lowering greenhouse gas emissions [4,16]. Being solar-powered, these eco-friendly waste compactors can operate in diverse weather conditions, including rainy, snowy, or sunny environments. They are available with or without companion recycling kiosks and can be customized with various exterior designs. Wireless communication modules can connect the bin directly to the municipal office for real-time data sharing. Solid-waste characteristics vary considerably among communities, influenced by geographic location, economic conditions, and seasonal

**Table 1** Estimated and projected MSW generation in India

Sl. No	Year	Estimated/Projected MSW (Mt/year)	Reference
1.	2015	62	[3]
2.	2020 (est.)	100	[6]
3.	2030	165	[3]
4.	2035 (proj.)	200–220	[5]

variations. As per the reported data, the statistical data for the top five Municipal Solid-Waste (MSW) generators estimated and projected annually is shown in Fig. 2 [17–21]. Waste collection techniques vary widely from country to country. In many European nations, the Envac system—essentially an underground waste collection process using vacuum pipes to transport waste to landfills or transfer stations—is widely implemented [22,23]. In countries such as Australia, Canada, and certain parts of the United States, waste collection is predominantly carried out by vehicles [24]. Conventional municipal waste collectors can store only a limited amount of waste and usually become full in a short span of time. Once full, they cannot accommodate additional garbage, leading to overflow and subsequent pollution in nearby areas. This indicates shortcomings in both space utilization and cost efficiency [24,25].

The renewable energy-based solar-powered waste compactor addresses these challenges by increasing bin capacity nearly six–eight times through compacting the garbage inside it, thereby offering greater space utilization for the same bin volume. It also enables immediate cost savings by sending a signal to the municipality once it becomes full. Infrared (IR) sensors enhance functionality by opening the bin mouth only when garbage is being deposited. The efficiency of solar-powered waste compactors has been proven in practice. For example, Philadelphia replaced 700 traditional garbage bins with 500 waste compactors, each with a base capacity of 32 gallons capable of holding 150–200 gallons of waste after compaction. This reduced garbage handling costs by approximately 75%, saving around \$875,000 per year [26]. Similarly, in Central London, the Westminster City Council installed solar-powered trash bins, claiming a 70% reduction in waste collection frequency and an 80% reduction in greenhouse gas emissions [27]. In India, waste management has become an escalating problem due to poor collection and disposal techniques, posing both environmental and economic threats [24]. The proposed project aims to reduce these challenges by efficiently utilizing solar energy for waste compaction and sending real-time fill-level signals directly to municipal control centers. A Global Positioning System (GPS) system enables easy tracking and timely collection of compacted waste. In this way, both space and cost efficiency can be optimized using solar-powered trash compactors. Inspired by advancements in solid-waste management (SWM), this work proposes the design of a solar-powered, compact, and portable waste compactor suitable for tropical countries like India. MSW is often collected in a loose or uncompacted form, resulting in large volumes that are costly to handle. Waste compaction significantly reduces this volume, improving collection efficiency, reducing costs, and lowering greenhouse gas emissions [1,5]. Such solar-powered waste compactors are well-suited for high-traffic locations, including city centers, community spaces, parks, beaches, and other public areas.

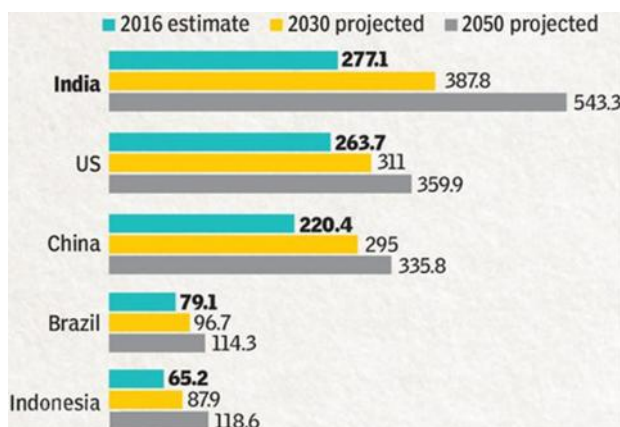


Fig. 2 Trends top five countries: annual municipal solid waste generators MTs [10–13]

## 2 Designing the Prototype of Solar Compactor

An economically efficient prototype was developed to evaluate and analyze the benefits of deploying a renewable energy-based compacting waste compactor. The system integrates embedded sensors Navghane et al. to measure the bin's fill level in real time and automatically trigger the compaction process, effectively increasing bin capacity by up to six–eight times [24]. The compaction mechanism is powered by a rechargeable battery, which is charged through a 6-V solar panel mounted at the top of the bin. The solar panel charges a 9-V battery bank (four units), enabling the motor to drive the trash compactor [25]. Once fully charged, the battery can operate the unit for approximately 3–4 days, depending on compaction frequency and waste load. By compressing its contents, the bin's filling capacity is significantly increased, reducing the need for frequent emptying. This results in fewer collection trips, which directly translates into savings in labor, fuel, and maintenance costs, as well as a reduction in greenhouse gas emissions. The compaction technology allows for optimized collection frequency, offering advantages from economic, environmental, and technical perspectives [24,25]. Powered entirely by solar energy, the system operates reliably in various weather conditions—including sunny, rainy, and snowy climates. Units can be supplied with or without companion recycling kiosks, and their exterior can be customized for esthetic integration into public spaces. In addition to waste compaction efficiency, the system is cost-effective and integrates a GPS tracking module for bin location monitoring. This ensures transparency in municipal operations by preventing false service reports. Furthermore, its wireless communication system enables direct connectivity with the municipal control office for timely and efficient waste collection. The solar-waste compactor is a solar-powered trash compactor equipped with sensors to automatically trigger waste compaction, thereby increasing the effective bin capacity. A simple prototype of the setup is shown in Fig. 3. The compactor operates on energy supplied by a battery charged via a solar panel.

The proposed design includes two key features: Compactor mechanism—a rack-and-pinion arrangement in the vertical plane, driven by a motor, will compress the waste. The motor selection will be based on the bin's dimensions and the type of waste to be processed. Level indicator system—an IR sensor—will detect the presence of waste inside the bin and send a signal to initiate compaction. A separate circuit will monitor the bin's fill level, activating LEDs sequentially to indicate the progressive fill status. This arrangement ensures efficient waste management by optimizing bin capacity while operating entirely on renewable energy.

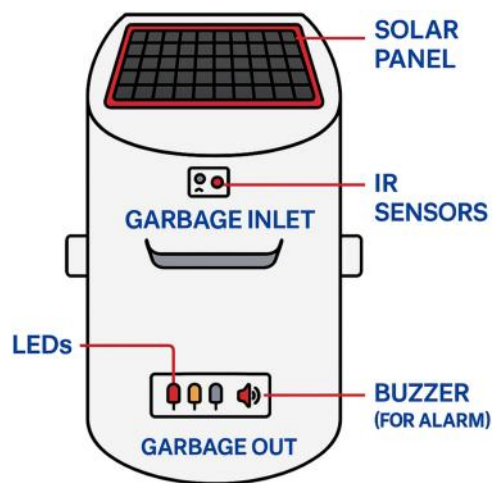


Fig. 3 A schematic diagram of solar-powered waste compactors

### 3 Fabrication and Experimentation of Solar Compactor

For laboratory testing, a solar compactor was fabricated using a low-cost bin made up of a plastic bin, shown in Fig. 4. A lidless bin was fabricated with a diameter of 20 cm and a height of 42 cm. A rack-and-pinion assembly was mounted externally along the bin wall.

The compactor consists of a flat circular disc (10 cm diameter) that moves vertically downward to compress the waste to a predefined extent. The bin is equipped with a 6 V NX-rated solar panel, four 9-V solar-rechargeable batteries, an IR sensor with transmitter and receiver, five 1.5-V LEDs, a 555 timer IC (I, J, K, L, M), and a 741 operational amplifier (IR-based). A 4007 rectifier diode serves as a one-way check valve, while a 1 k $\Omega$  resistor is used to limit current and adjust signal levels. Four additional LEDs and a buzzer are included for indication and alarm purposes. The power supply is arranged as follows: The four 9-V rechargeable batteries (C, D, E, F) are charged by the 6-V solar panel [A] mounted on the bin top. A 1.5-V light emitting display (LED) indicator, directly connected to the solar panel circuit, is mounted on the bin cover. One battery powers the relay circuit controlling the motor's clockwise and counterclockwise motion, which drives the compactor. Another battery powers the IR sensors [G]. The level indication circuit is located at the bin's base and consists of copper wires [H] fixed to the inner wall at different heights. This circuit, powered by the fourth battery, operates the 1.5-V LEDs and buzzer [M]. The buzzer was triggered by the final LED in the sequence, sounding an alert when the bin is full and further compaction is not possible, indicating that the bin must be emptied immediately.

**3.1 Experimental Methods.** The waste compactor was first tested indoors, where the NX-based solar panel successfully charged the batteries, and the system operated as intended. It was then installed outdoors for further evaluation. During outdoor testing, the solar panel consistently charged all four batteries, keeping the bin fully operational. In terms of power performance, the batteries required approximately 12 h to discharge during operation and about 8 h to recharge fully. This setup proved suitable for both summer and winter conditions, as the NX-based solar panel was able to generate power even under low sunlight. However,

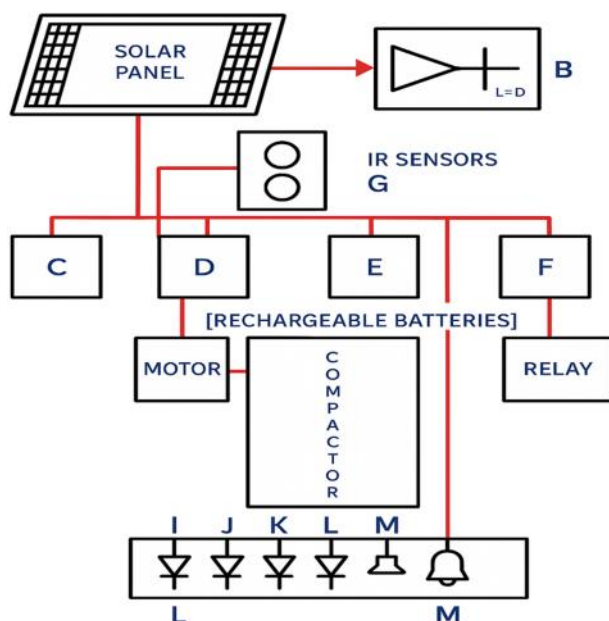


Fig. 4 Circuit arrangement in the waste compactor

charging efficiency was higher in summer compared to winter. The bin effectively compacts waste such as paper, plastics, and other lightweight materials. Once the bin reached full capacity, the buzzer activated to signal that it needed to be emptied.

**3.2 Experimental Procedure.** Experiments were conducted in two modes (a) batch mode and (b) continuous mode.

#### (a) Case I: Non-charging/Batch mode

In this non-charging batch mode process (Fig. 5(a)), four 9-V batteries served as the primary power supply. The bin operated continuously for approximately 12 h, until the batteries were completely drained, at which point the operation ceased. Throughout the batch operation, the compaction force remained consistent until the batteries were exhausted. The bin effectively compacted lightweight waste such as plastics and paper. The total volume of garbage that could be placed in the solar-powered waste compactor was 0.0132 m<sup>3</sup>, which was reduced to roughly one-third to one-fourth of its original volume during operation. Once the maximum compaction limit was reached, the bin was considered full, and the buzzer automatically activated, indicating that no additional waste could be deposited. During each batch process, all four

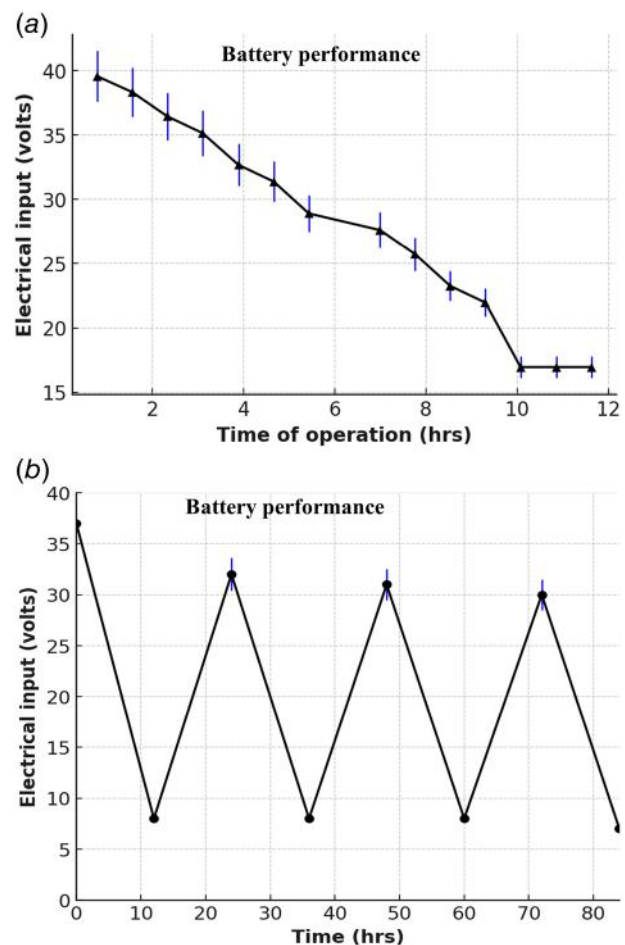


Fig. 5 (a) Non-charging/batch mode and constants are initial battery voltage = 40 V, battery capacity = 100 Ah, load resistance = 10  $\Omega$ , ambient temperature = 298 K, discharge mode = continuous, internal resistance of battery = 0.05  $\Omega$  (b) charging/continuous mode and constants are charging voltage = 32 V (peak values observed), minimum cutoff voltage = 8 V, cycle duration = 12 h, battery capacity = 100 Ah, charging current = constant, ambient temperature = 298 K, and number of cycles shown = 4

**Table 2 Comparison of conventional garbage bins and solar-powered trash compactors**

Sl. No.	Current garbage bins	Solar-powered trash compactor	Technology yet	References
1.	Fixed bin capacity limits waste storage	Compaction mechanism multiplies capacity by ~5–8 ×	Smart systems expand storage within the same footprint	[22,29]
2.	Requires frequent emptying, increasing operational costs	Less frequent emptying improves economic efficiency	Proven cost-effective in deployed locations	[28]
3.	Open bin mouth leads to litter, vermin, and pollution	Automated covered mouth protects surroundings	Traditional bins require manual opening	[22]
4.	No energy utilization in conventional bins	Runs entirely on solar energy via integrated panels	Solar-powered compaction is now viable	[22]
5.	Susceptible to rust and wear	Constructed from durable materials (e.g., powder-coated steel or UV-stabilized plastic)	Enhanced longevity over traditional bins	[22]
6.	Traditional/manual	Smart bin with solar power used Sensors + microcontroller	Intelligent waste removal system	[30]
7.	traditional waste system	solar energy and sensors to improve waste capacity and enable alert-based collection	smart waste collection system with vehicle routing optimization (VRP)	[31]
8.	Not viewed as a “smart” infrastructure component	Fully qualifies as a smart-city asset with IoT integration	Represents innovation in waste management	[22]
9.	Generates no valuable environmental data	Offers real-time analytics for route optimization and maintenance	Data-driven operations are emerging	[22]

9-V batteries were fully utilized, sustaining the compaction mechanism for the entire 12-hour cycle.

### (b) Case II: Charging/Continuous mode

In this process, four 9-V batteries were used as the primary power source, with a 6-V NX-based solar panel serving as the charging medium for all four solar-rechargeable batteries. The bin mechanism operated in continuous mode over a 72-hour test period reported in Fig. 5(b). During operation, the batteries discharged after approximately 12 h of continuous use and were then recharged by the solar panel. The charging process took around 8 h to fully replenish the batteries, after which the system operated for another 12-hour cycle. Importantly, the waste compactor continued to function normally during the charging phase.

The application of the compaction mechanism demonstrated significant advantages over conventional bins. The fully automatic solar-powered trash compactor reduces manpower requirements, lowers operational costs, and requires minimal maintenance. The well-covered design prevents insect and rodent infestations. The bin can handle approximately 0.013 m<sup>3</sup> of solid waste after compaction in a single cycle, making it both cost- and fuel-efficient. Without compaction, a conventional bin would need to be emptied four–five times to accommodate the same volume of waste. An inner lining layer allows the bin to safely handle

hazardous waste. By integrating automation and solar energy, the solar-powered waste compactor supports the next-generation municipal waste management system—delivering a fully automated, controlled, and transparent process for waste collection and disposal, while conserving manpower, fuel, and operational resources.

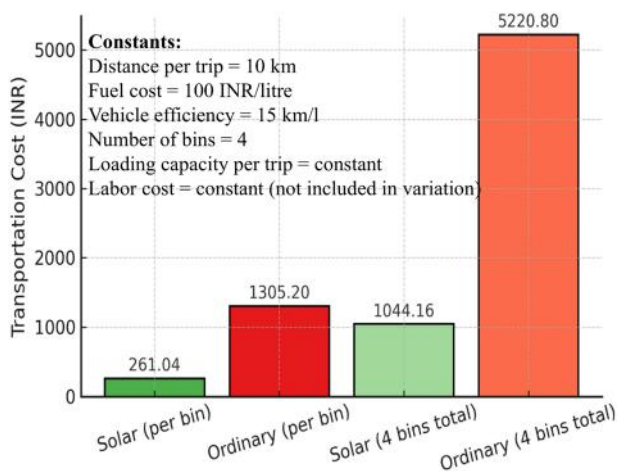
## 4 Results and Discussion

The prototype was deployed at Swarn Jayanti Park at Rohini, New Delhi, for the study of its performance analysis, and the following observations were obtained. The comparison table reported in Table 2 highlights the significant operational, environmental, and economic benefits of adopting solar-powered trash compactors over conventional bins. Key advantages include extended waste storage capacity through compaction, reduced collection frequency, integration of GPS and sensors for optimized routes, and a measurable decrease in greenhouse gas emissions. These features align with smart-city initiatives and contribute to sustainable urban waste management practices.

**4.1 Studied Areas: Economic Evaluation.** Previously, waste was managed using ordinary garbage bins with a capacity of 0.015 m<sup>3</sup>, which required frequent emptying. After deploying a solar-powered trash compactor with a capacity of 0.013 m<sup>3</sup>, the effective waste-handling capacity increased nearly fivefold due to compaction. This significantly reduced both the cost of emptying and fuel consumption for transportation, making the solar compactor an efficient and sustainable choice.

Unlike conventional bins, which lacked an alarm system and often led to waste overflow and the spread of waste-borne diseases, the solar compactor features a pre-loaded alarm for fill-level control, preventing spillage and maintaining hygiene. Waste collection hours were extended, reducing garbage accumulation in surrounding areas. In the deployed case at Mukarba Chowk landfill (6.7 km from the park), the transportation cost for an ordinary bin was 326.3 INR, while the solar-powered compactor costs only 65.26 INR per cycle. These results reported in Fig. 6, demonstrate the solar compactor’s clear advantages from both environmental protection and economic perspectives given in Table 3.

**4.2 Economic Evaluation and Payback Period.** The deployment of solar-powered trash compactors offers a substantial improvement over conventional garbage bins in terms of waste-handling capacity, operational efficiency, environmental



**Fig. 6 Cost analysis solar versus ordinary bins (64-day run)**

**Table 3 Waste collection analysis—Swarn Jayanti Park**

Sl No.	Parameter	Solar (per bin)	Ordinary (per bin)	Solar (four bins total)	Ordinary (four bins total)
1.	Runtime	64 Days	64 Days	64 Days	64 Days
2.	Bin volume	0.013 m <sup>3</sup>	0.015 m <sup>3</sup>	0.052 m <sup>3</sup>	0.060 m <sup>3</sup>
3.	Time to full (per cycle)	16 days	3 days (approx.)	—	—
4.	Empties/trips	4	20	16	80
5.	Waste collection hours	1536.00 h	1532.68 h	6144.00 h	6130.72 h
6.	Empty time	0.00 h	3.32 h	0.00 h	13.28 h
7.	Trips (assumed 1 per empty)	4	20	16	80
8.	Truck rate (INR/trip)	65.26	65.26	65.26	65.26
9.	Transport cost (INR)	261.04	1305.20	1044.16	5220.80

sustainability, and cost-effectiveness. While ordinary bins in this study had a nominal capacity of 0.015 m<sup>3</sup>, the solar-powered compactors, with a nominal capacity of 0.013 m<sup>3</sup>, achieved an effective capacity increase of approximately five times through mechanical compaction. This allowed for extended collection intervals—from every 3 days for ordinary bins to every 16 days for compactors—reducing operational strain on waste management systems [22,28]. From an environmental standpoint, the solar compactors' enclosed structure, automated lid operation, and alarm-based fill-level control reduced litter spread, odor, and vermin attraction. These improvements, coupled with fewer collection trips, resulted in green house gas (GHG) emission reductions of up to 70–80% compared to conventional bins [27]. The integration of GPS tracking and wireless communication provided route optimization and operational transparency, directly aligning with smart-city initiatives [24]. The economic evaluation, scaled to a 64-day operation with four solar and four ordinary bins, shows clear cost benefits. Ordinary bins required 80 trips over the period, costing ₹5220.80 in transportation at ₹65.26 per trip. Solar-powered compactors required only 16 trips, costing ₹1044.16, representing an 80% reduction in transport costs, as shown in Fig. 6 and data reported in Table 3. On a per-bin basis, the savings per cycle were ₹261.04, translating to approximately ₹1565 per bin per year (assuming ~six cycles/year). Assuming an installed cost of ₹1,00,000 per solar-powered compactor, annual transportation

**Fig. 8 Waste management at the field: solar-powered waste compactor**

savings alone would yield a simple payback period of ~16 years. The prototype of the solar power model shown in Fig. 7. However, when factoring in additional savings from reduced labor, lower fuel usage, decreased maintenance frequency, and avoided public health costs from improved sanitation, the effective payback period could be shortened to under 8 years. Over a 10-year lifespan, net savings per unit could exceed ₹2–3 lakh in operational cost reductions and environmental benefits. In the current scenario, waste management in the field with a waste compactor and wireless system is shown in Fig. 8. Whereas the field deployment example at Mukarba Chowk landfill, New Delhi, validates these findings: ordinary bins cost ₹326.3 per trip in transportation, while solar-powered compactors cost only ₹65.26 for the same route. The extended waste collection hours also minimized waste spillage and improved public space cleanliness.

## 5 Conclusions

Solar-powered waste compactors merge renewable energy with sensor-driven automation to create intelligent and efficient waste management systems. They promised improved public hygiene, operational cost savings, environmental sustainability, and readiness for integration into smart-city infrastructures. Ongoing research focused on enhancing these systems with autonomous waste segregation, compacting, artificial intelligence-driven analytics, and adaptability for rural contexts. In conclusion, the integration of solar-powered trash compactors presents a technically robust, environmentally beneficial, and economically viable waste management solution. Scaled deployment across urban environments could yield significant municipal savings, reduce environmental footprint, and improve urban hygiene. Future work should focus on comprehensive life-cycle cost analysis, user acceptance studies, and integration with existing municipal infrastructure to maximize adoption potential.

**Fig. 7 Prototype of the solar-powered waste compactor**

## Conflict of Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this article.

## Data Availability Statement

The datasets generated and supporting the findings of this article are obtainable from the corresponding author upon reasonable request.

## Nomenclature

V = volt  
₹ = rupees  
Ω = ohm

## Abbreviations

BAU = business-as-usual  
CPCB = Central Pollution Control Board  
[C, D, E, F] = 9-V rechargeable batteries  
[G] = IR Sensor  
GPS = Global Positioning System  
[H] = copper wire  
[I, J, K, L] = 1.5-V LED  
IoT = internet of things  
IR = infrared  
LED = light-emitting display  
[M] = buzzer  
MSW = municipal solid waste  
SWM = solid-waste management

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