



ECONOMICS OF RECYCLING IN THE EPDM RUBBER PRODUCTS MANUFACTURING INDUSTRIES

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Article History

Received: 03 March 2026; Revised: 13 March 2026; Accepted: 07 April 2026;

Published: 27 April 2026

Abstract: This study presents a comprehensive techno-economic and environmental assessment of recycling practices in the ethylene propylene diene monomer (EPDM) rubber manufacturing industry in India. With the Indian EPDM market valued at approximately USD 279.4 million in 2024 and projected to grow steadily, the generation of 5 to 15% manufacturing waste represents a significant opportunity for resource recovery. Using a mixed-methods approach integrating primary industrial data, cost-benefit analysis, energy evaluation, carbon footprint assessment, and return on investment (ROI) modelling, the study quantifies the advantages of incorporating recycled EPDM into production systems.

The results demonstrate that partial substitution of virgin rubber with recycled rubber yields substantial economic benefits without compromising industrial feasibility. A 40% replacement level alone can generate national cost savings of approximately ₹874 crore annually, while full replacement scenarios significantly minimize raw material costs. Energy analysis indicates a reduction of 361 kWh per ton, translating to annual savings of over 11.57 million kWh and cost savings of approximately ₹104 million for a medium-scale plant. Environmental assessment reveals a marked decrease in carbon emissions, with reductions reaching up to 716 kg CO₂ per ton of compound and large-scale annual mitigation potential exceeding 200,000 tons of CO₂ in India. Financial analysis further confirms the strong viability of recycling investments, with ROI values ranging from 82% to 179% and short payback periods.

To cite this paper:

Amaira Anand (2026). Economics of Recycling in the EPDM Rubber Products Manufacturing Industries. *Indian Journal of Applied Economics and Business*. 8(1), 1-14. [https://DOI:10.47509/IJAEB.2026.v08i01.01](https://doi.org/10.47509/IJAEB.2026.v08i01.01)

Overall, the findings establish EPDM recycling as a highly effective strategy for improving cost efficiency, reducing energy consumption, and lowering carbon intensity in the rubber manufacturing sector. The study highlights that even moderate levels of recycled content can deliver significant economic and environmental gains, supporting circular economy principles and sustainable industrial development.

Keywords: Economics, Recycling, EPDM, Waste Rubber, Sustainability

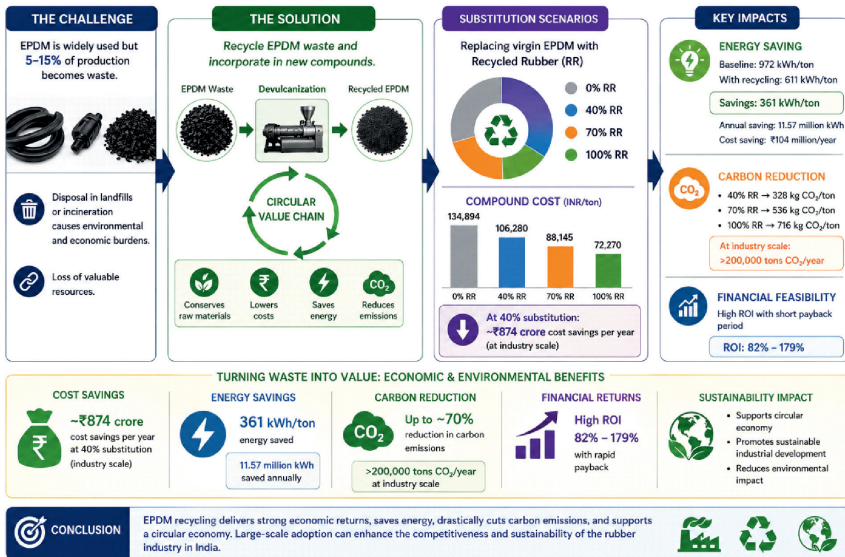


Figure: Graphical Abstract

1. INTRODUCTION

Rubber is a durable engineering material valued for its resistance to temperature variations, weathering, and chemically aggressive environments, enabling long service life across diverse applications. However, these same properties create significant challenges at the end of the rubber life cycle. The continuous growth in rubber production and consumption has led to a corresponding increase in post-industrial and in-process manufacturing scrap, making rubber waste disposal a critical environmental and economic concern^[1]. Inadequate handling and processing of this waste results in resource loss, ecological degradation, and barriers to achieving United Nations Sustainable Development Goal 12 (SDG 12), which emphasizes responsible consumption and production through reduce, reuse, and recycle (3R) strategies^[2]. Unlike thermoplastics, vulcanized rubber cannot be readily remelted or reshaped due to sulphur-based

crosslinks formed during vulcanization, which enhance mechanical strength and stability but severely limit biodegradation [3]. The presence of additives such as antioxidants, processing aids, vulcanizing agents, and reinforcing fillers further increases resistance to environmental breakdown, causing rubber waste to be predominantly landfilled or incinerated, raising sustainability, regulatory, and cost concerns [4].

EPDM (ethylene propylene diene monomer) rubber is one of the most widely used synthetic elastomers owing to its excellent resistance to weathering, ozone, heat, and aging, along with good flexibility, electrical insulation, and chemical stability. These properties make EPDM suitable for applications in automotive weatherstrips, roofing membranes, hoses, seals, gaskets, and cable insulation across the automotive, construction, and electrical sectors. In 2024, the Indian EPDM market was valued at approximately USD 279.4 million and is projected to grow at a CAGR of about 7.3% through 2030, driven by expanding domestic manufacturing and industrial demand [5]. Despite this growth, post-industrial EPDM scrap remains largely underutilized, with studies indicating that 5–15% of total EPDM production is lost as manufacturing waste, resulting in tens of thousands of tonnes of potentially recyclable material generated annually in India [6].

Recycling EPDM manufacturing and end-of-life waste offers significant environmental and economic benefits by converting production losses into valuable secondary resources. Partial substitution of virgin EPDM with recycled material reduces raw material consumption, production costs, and waste disposal expenses, while also lowering energy use and greenhouse gas emissions associated with virgin polymer production. From a broader perspective, EPDM recycling supports circular economy principles, improves resource efficiency, enhances corporate sustainability performance, and aligns rubber manufacturing practices with SDG 12. Globally, the use of recycled rubber in non-tyre rubber products is now common practice, and Indian automotive rubber manufacturers have also increasingly adopted recycled rubber in commercial production [1].

Advanced recycling technologies such as various devulcanization techniques have expanded the applicability of recycled rubber in automotive, construction, and footwear sectors [7].

Over the past three decades, extensive research has focused on rubber recycling, primarily targeting waste tyre reuse through partial replacement

of virgin rubber. Optimization of replacement ratios has been studied based on mechanical, rheological, dynamic, and morphological performance [8]. Additional studies have examined recycling technologies for end-of-life rubber products and manufacturing scrap. Life cycle and economic assessments have demonstrated that cleaning and compacting end-of-life tyre fibres enables their reuse as reinforcing materials in bituminous mixes and plastic compounds, eliminating disposal while delivering economic and environmental benefits. Similarly, reclaimed asphalt rubber pavement (RARP) studies show that recycling up to 40% RARP can reduce greenhouse gas emissions by 24.5% and costs by 35%, while improving cracking and aging resistance [9]. Cleaner production practices in rubber manufacturing have also been shown to achieve a return on investment within 17 months while delivering significant environmental improvements through waste recycling ^[10]. Furthermore, feasibility studies on waste tyre pyrolysis confirm that tire recycling plants are economically viable and environmentally beneficial by reducing environmental fees, preventing soil damage, and mitigating accumulated waste impacts ^[11].

Despite these extensive studies, relatively few investigations have addressed detailed cost benefit analyses from an economic perspective, particularly for EPDM rubber manufacturing waste. Comprehensive economic evaluations quantifying the recycling and reuse potential of EPDM scrap in alternative rubber products remain a significant research gap, highlighting the need for focused studies in this area.

2. METHODOLOGY

This study adopts a mixed-methods quantitative approach combining primary industry data, secondary published data, questionnaires and observations to quantify the economic, energy, and environmental benefits of rubber recycling in EPDM manufacturing in India. The framework integrates; 1) Data Collection; 2) Economic Cost-Benefit Analysis; 3) Energy Consumption Analysis; 4) Carbon Footprint Analysis; and 5) Return on Investment (ROI) Analysis.

2.1. Data Collection

Primary data were collected from EPDM rubber product manufacturers operating in India, particularly from automotive weatherstrip, sealing, and

profile manufacturing units. Secondary data were obtained from industry reports, government publications, and peer-reviewed studies. Key variables collected include annual production volume measured in tons; the quantity of EPDM waste generated during production expressed as grams per ton of output; the recycling rate of in-process and post-consumer EPDM waste expressed as a percentage; the market cost of virgin EPDM rubber and recycled EPDM rubber measured in INR per kilogram; energy consumption expressed in kilowatt-hours per ton of production; and carbon emission factors associated with amount of CO₂ in ton produced per ton of virgin EPDM rubber polymerization and compared it with amount of CO₂ in ton produced per ton of recycled EPDM.

2.2. Economic Assessment Methodology

The economic benefit of recycling EPDM rubber waste is evaluated by estimating material cost savings, waste disposal cost reduction, and energy cost savings.

Material Cost Savings Equation:

$$\text{Net Material Cost Savings} = C_v - C_r$$

Where:

C_v = Cost of fully virgin EPDM rubber compound (INR/kg)

C_r = Cost of recycled EPDM rubber (INR/kg)

Energy Saving Assessment

Energy savings are calculated by comparing baseline EPDM compounding with recycling-integrated production.

Energy Saving Equation

$$\Delta E = E_b - E_r$$

Where E_b represents baseline energy consumption (kWh/kg) and E_r represents energy consumption after incorporating recycled EPDM.

Energy Cost Savings Equation:

$$\text{Energy Cost Savings} = Q \times \Delta E \times P_e$$

Where P_e is the average industrial electricity tariff in India (INR/kWh).

2.3. Carbon Footprint Reduction Assessment

Carbon emissions are estimated by using a simplified life-cycle approach based on emission factors.

Carbon Emission Equations

$$CO_{2 \text{ virgin}} = Q_{\text{virgin}} \times EF_{\text{virgin}}$$

$$CO_{2 \text{ Recycled}} = (Q_{\text{virgin(used)}} \times EF_{\text{virgin}}) - (Q_{\text{Recycled(used)}} \times EF_{\text{Recycled}})$$

$$\text{Carbon Reduction } (\Delta CO_2) = CO_{2 \text{ virgin}} - CO_{2 \text{ Recycled}}$$

Where:

Q_{virgin} = Total annual use of virgin EPDM (Kg)

$Q_{\text{virgin(used)}}$ = Total annual use of virgin EPDM (Kg) in a particular formulation

$Q_{\text{Recycled(used)}}$ = Total annual use of Recycled EPDM (Kg) in a particular formulation

EF is the emission factor for India (ton CO₂/per Kg).

2.4. Return on Investment (ROI)

ROI is calculated to assess the financial feasibility of recycling investments.

ROI Equation: ROI (%) = [(Annual Economic Benefit - Annual Operating Cost) / Initial Investment] × 100

3. RESULTS AND DISCUSSION

Based on our previous study ^[12] the cost calculation is done by varying the percentage of virgin rubber (VR) and recycled rubber (RR), and displayed in the Table 1. The percentage indicates the percentage of virgin rubber replaced by the recycled rubber.

Table 1: Formulation and costing of the rubber compounds.

Raw material name	Cost	0% RR			40% RR			70% RR			100% RR		
	INR/kg	T1 (pbr)	1 Ton	INR	T2 (pbr)	1 Ton	INR	T3 (pbr)	1 Ton	INR	T4 (pbr)	1 Ton	INR
EPDM 6405H	231	100	262	60495	60	142	32853.8	30	66	15335.9	0	0	0
Recycled Rubber (RR)	32	0	0	0	80	190	6084	140	310	9940	200	415	13316
Active ZnO	209	5	13	2737	5	12	2477	5	11	2313	5	10	2169

Raw material name	Cost	0% RR			40% RR			70% RR			100% RR		
	INR/kg	T1 (pbr)	1 Ton	INR	T2 (pbr)	1 Ton	INR	T3 (pbr)	1 Ton	INR	T4 (pbr)	1 Ton	INR
Stearic Acid	126	1	3	331	1	2	300	1	2	280	1	2	263
CB (N-550)	106	158	414	43998	158	375	39824	158	350	37179	158	328	34864
PEG-4000	153	3	8	1203	3	7	1089	3	7	1016	3	6	953
White filler	12	30	79	936	30	71	847	30	66	791	30	62	742
CaO	56	9	24	1318	9	21	1193	9	20	1114	9	19	1044
Rubber process oil	114	72	189	21432	72	171	19399	72	159	18111	72	149	16983
Sulphur	128	1.5	4	504	1.5	4	456	1.5	3	426	1.5	3	399
Primary accelerator	344	1.5	4	1350	1.5	4	1222	1.5	3	1141	1.5	3	1070
Secondary accelerator	322	0.7	2	590	0.7	2	534	0.7	2	498	0.7	1	467
Total =	-	381.7	1000	134894	421.7	1000	106280	451.7	1000	88145	481.7	1000	72270

The waste generates during production of EPDM rubber products was recycled and then the recycled rubber was used to replace the virgin rubber 0 %, 40 %, 70 %, and 100 %. Hence the respective cost is displayed in the table, and it is very obvious that the 100 % replacement of the virgin EPDM rubber will show the minimum cost. However, the cost of the EPDM compound has gradually increased with the enhancement of recycled rubber (RR) content.

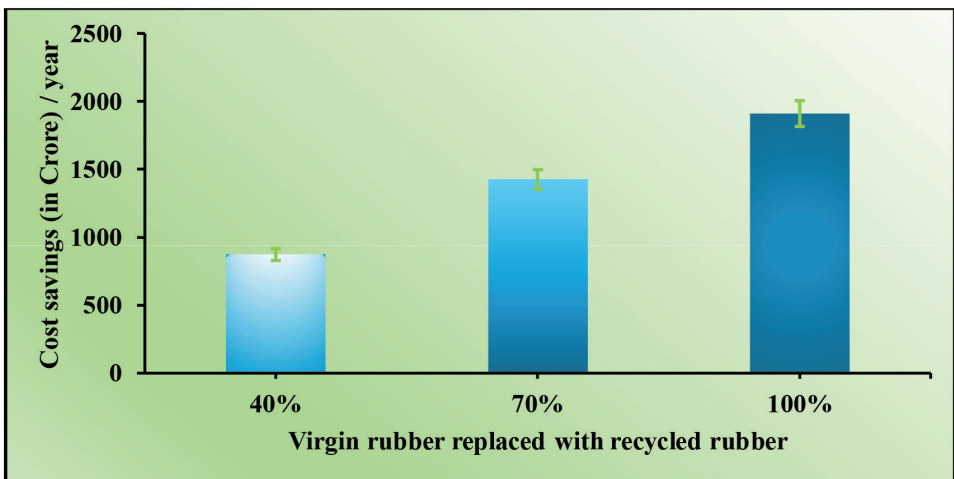


Figure 1: Cost savings per year by replacing virgin rubber with recycled rubber in all over India.

On the other hand, based on the cost saving data the economics of cost saving calculation is carried out for the whole India and accordingly the projected value of cost savings is monitored in the Figure 1. In case of the minimum replacement of the virgin rubber i.e., 40% could be a game changer for the EPDM product manufacturing industries in India or globally, as the cost saving amount (874 crores/ year) is a significant cost saving number irrespective of compromising the mechanical properties of the rubber products.

The annual revenue based on the annual rubber consumption is displayed in Figure 2, where the revenue is gradually increased with the rubber consumption. Based on the previous and present data trend and statistics the prediction of annual revenue is done from the present year to 2030.

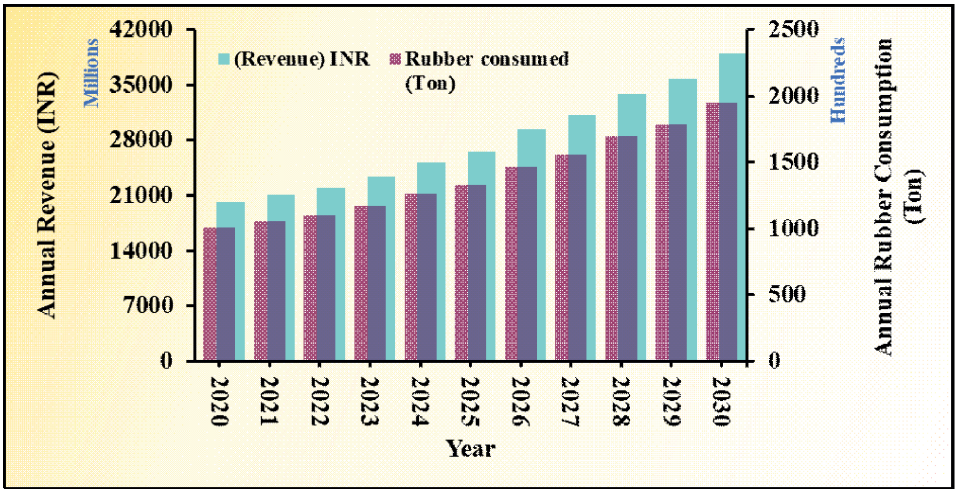


Figure 2: Annual revenue & rubber consumption per year data in India.

Table 2: Carbon emissions calculation per year in India

Q_{virgin} (in kg)	$CO_2_{virgin} = Q_{virgin} \times EF_{virgin}$ (in kg)	$Q_{Recycled}$ (in kg)	$CO_2_{Recycled} = Q_{Recycled} \times EF_{Recycled}$ (in kg)	Carbon Reduction (in kg) / per Ton of compound	Carbon Reduction / year in India (in ton)
262	1048	0	0	0	0
142	568	190	152	328	100153
66	264	310	248	536	163664
0	0	415	332	716	218626

*Note: EF_{virgin} (in kg CO₂-equivalent per Kg of virgin rubber) = 4, $EF_{Recycled}$ (in kg CO₂-equivalent per Kg of virgin rubber) = 0.8

The Table 2 presents a comparative evaluation of carbon emissions from virgin and recycled rubber in compounded materials, demonstrating the emission reduction potential achieved through material substitution. Carbon emissions are calculated using standard emission factor based relationships, where emissions from virgin rubber are obtained as the product of its quantity and an emission factor of 4 kg CO₂ per kg, while recycled rubber emissions are calculated using a significantly lower emission factor of 0.8 kg CO₂ per kg, reflecting reduced energy consumption and avoidance of raw material extraction^[13]. Four scenarios are analysed to illustrate the progressive impact of increasing recycled rubber content. In the baseline case, consisting entirely of virgin rubber (262 kg), total emissions amount to 1048 kg CO₂ with no reduction benefit. With partial substitution (190 kg i.e. 40% recycled rubber), emissions from the recycled fraction are reduced to 152 kg CO₂, resulting in a net carbon reduction of 328 kg per ton of compound. Further increasing the recycled content to 310 kg (i.e. 70%) enhances the reduction to 536 kg CO₂ per ton, indicating a strong linear improvement trend. In the extreme case of full substitution (415 kg i.e. 100% recycled rubber), virgin rubber usage is eliminated, leading to the maximum achievable carbon reduction of 716 kg CO₂ per ton of compound. When extrapolated to an industrial scale in India, these reductions correspond to annual savings ranging from approximately 100,153

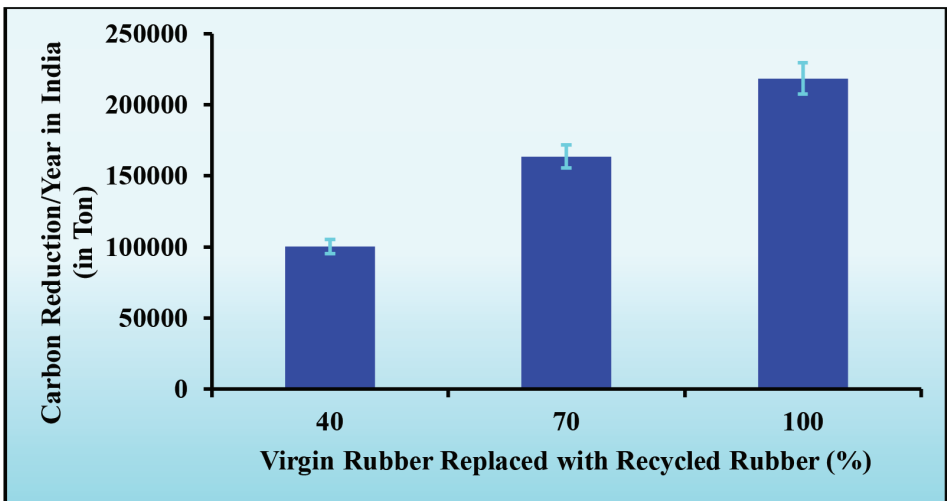


Figure 3: Carbon emission reduction per year by replacing virgin rubber with recycled rubber in all over India

tons to 218,626 tons of CO₂, depending on the level of substitution shown in Figure 3. Overall, the results clearly demonstrate that increasing recycled rubber content significantly lowers the carbon footprint of rubber products, with up to 70% lower emission intensity compared to virgin materials, thereby supporting circular economy practices and offering a highly effective pathway for large-scale decarbonization in the rubber industry ^[13].

Table 3: Energy Saving calculation per year in a medium scale industry.

<i>Parameter</i>	<i>Symbol</i>	<i>Value (Annual)</i>	<i>Unit</i>	<i>Notes / Source</i>
Annual Production	Q	32,061	tons/year	Indian medium-sized EPDM plant
Baseline Energy Consumption	E _b	972	kWh/ton	From plant energy audits
Recycled Content Energy Consumption	E _r	611	kWh/ton	% reduction from baseline due to recycling
Energy Saving per Ton	$\Delta E = E_b - E_r$	361	kWh/ton	Calculated
Average Industrial Electricity Tariff	P _e	9	INR/kWh	Indian industrial tariff
Total Annual Energy Savings =	$Q \times \Delta E$	11,574,046	kWh/year	Calculated
Annual Energy Cost Savings =	$Q \times \Delta E \times P_e$	104,166,412	INR/year	Calculated

The Table 3 presents the energy and cost savings achieved in a medium-scale EPDM rubber products manufacturing industry by incorporating recycled material into the production process. With an annual production of 32,061 tons, the baseline energy consumption of the plant is 972 kWh per ton, which reduces significantly to 611 kWh per ton when recycled content is used, resulting in an energy saving of 361 kWh per ton. This reduction is substantial at an industrial scale, leading to a total annual energy saving of 11,574,046 kWh. Considering an average industrial electricity tariff of 9 INR per kWh, the plant achieves an annual cost saving of approximately ₹104.17 million. Overall, the data clearly demonstrates that integrating recycled materials not only improves energy efficiency but also delivers

significant economic benefits for medium-scale rubber industries, enhancing both sustainability and profitability^[13].

Table 4: ROI (%) calculation per year in a medium scale industry

<i>Annual Economic Benefit (INR)</i>	<i>Annual Operating Cost</i>	<i>Initial Investment</i>	<i>ROI (%)</i>
92,00,00,000	15,08,000	1,12,00,000	82
1,50,00,00,000	15,08,000	1,12,00,000	134
2,01,00,00,000	15,08,000	1,12,00,000	179

The economic feasibility of the proposed recycling system was evaluated through a detailed Return on Investment (ROI) analysis, considering both capital expenditure and recurring operational costs. Table 4 shown the total initial investment required for establishing the facility is estimated at ₹1.12 crore, which includes major equipment such as a 300 HP force crusher (₹50,00,000), a 10 HP sieving machine (₹32,00,000), and plant setup and infrastructure costs (₹30,00,000). The annual operating cost is calculated to be ₹15.08 lakh, comprising manpower expenses for four personnel (₹10.08 lakh), maintenance costs (₹3.00 lakh), and utilities including power and other consumables (₹2.00 lakh) ^[14]. All the three scenarios were analysed to evaluate how increasing recycled rubber content progressively enhances economic performance, demonstrating that higher recycling levels significantly improve overall profitability and ROI while keeping investment and operating costs constant with annual economic benefits of ₹92.0 crore, ₹150.0 crore, and ₹201.0 crore, respectively. After accounting for the operating expenses, the net annual returns remain significantly high in all cases, leading to ROI values of approximately 82%, 134%, and 179% shown in Figure 4. The results highlight that even under conservative assumptions, the system generates substantial surplus over operational costs, ensuring efficient utilization of invested capital. The relatively low operating expenditure compared to the high revenue potential enables rapid recovery of the initial investment, indicating a short payback period and strong financial viability. Furthermore, such high returns reinforce the attractiveness of the proposed model for industrial-scale adoption, particularly in the context of waste recycling and resource recovery, where economic gains are complemented by environmental benefits such as reduced landfill disposal and lower carbon emissions ^[14].

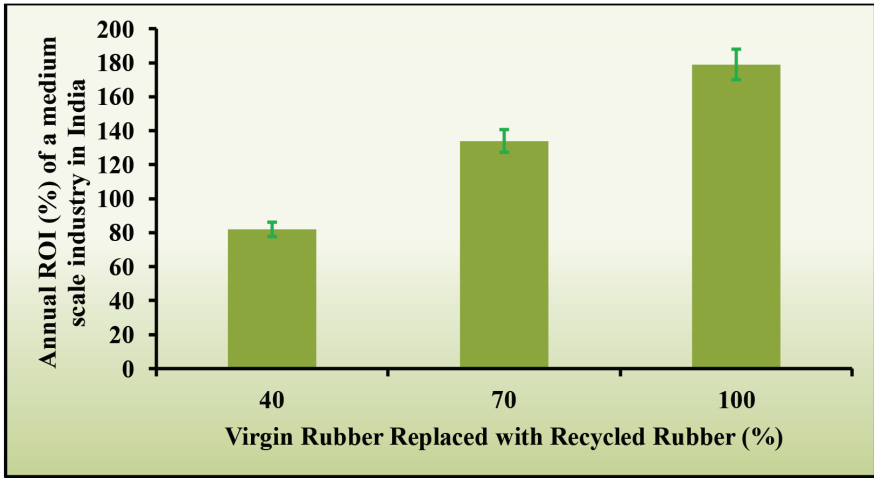


Figure 4: Annual ROI (%) of a medium scale industry in India per year by replacing virgin rubber with recycled rubber.

4. CONCLUSION

This study comprehensively demonstrates that recycling of EPDM rubber waste in India presents a compelling convergence of economic viability, environmental sustainability, and industrial efficiency. With a substantial proportion of EPDM production (5–15%) currently lost as manufacturing waste, the recovery and reuse of this material offer a significant opportunity to convert waste streams into valuable economic resources. The analysis confirms that integrating recycled EPDM into rubber formulations leads to considerable cost advantages, including reductions in raw material expenditure, energy consumption, and waste management costs. Notably, even partial substitution levels (around 40%) yield substantial national-scale savings, highlighting a practical and immediately implementable strategy for industry stakeholders without compromising product performance. From an environmental standpoint, the findings clearly establish that increasing recycled content significantly lowers carbon emissions, with potential reductions of up to ~70% per ton of compound. This positions EPDM recycling as an effective pathway for decarbonizing the rubber industry while aligning with circular economy principles and sustainable development goals. The strong financial feasibility is further validated through ROI analysis, which indicates high returns (up to 179%) and short payback periods, making recycling

infrastructure investments highly attractive for both medium- and large-scale industries. Additionally, the observed energy savings reinforce the dual benefit of cost reduction and improved process efficiency. Despite these promising outcomes, the study also underscores the need for further research focused on optimizing recycling technologies, improving material performance at higher substitution levels, and developing comprehensive economic models specific to EPDM recycling systems. In conclusion, EPDM rubber recycling is not merely a waste management solution but a strategic industrial approach that enhances profitability, reduces environmental impact, and strengthens long-term sustainability. Its large-scale adoption can play a transformative role in advancing a resource-efficient, low-carbon, and economically resilient rubber manufacturing sector in India and beyond.

Conflicts of interest: The author have no conflicts of interest to declare.

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