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TECHNO-ECONOMIC ANALYSIS OF SOLAR PANEL PRODUCTION FROM RECYCLED PLASTIC WASTE AS A SUSTAINABLE ENERGY SOURCE FOR SUPPORTING DIGITAL LEARNING IN SCHOOLS BASED ON SUSTAINABLE DEVELOPMENT GOALS (SDGS) AND SCIENCE-TECHNOLOGY INTEGRATION

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Abstract

This study aimed to evaluate the techno-economic feasibility of producing solar panels using recycled plastic waste. The method involved analysing key economic indicators such as cumulative net present value, internal rate of return, break-even point, and return on investment, while incorporating science and technology concepts in materials processing and renewable energy systems. The results showed that although the CNPV was negative initially, the project started generating positive cash flow after the third year. This occurred because the recycling and solar integration processes provided long-term cost efficiency and sustainable value. By the twentieth year, profitability increased significantly, confirming the project's long-term viability. The integration of environmental engineering, polymer science, and photovoltaic technology contributed to the sustainable energy model. This solution offers an innovative pathway toward responsible consumption and production, aligned with Sustainable Development Goals. It also supports electricity needs in digital learning, especially in remote schools lacking stable energy access.

Keywords: Digital learning, Plastic waste, Renewable energy, Science and technology, SDGs.

1. Introduction

Plastic waste continues to be a critical environmental concern worldwide due to its non-biodegradable nature and improper disposal from domestic, industrial, and commercial activities [1-6]. Its accumulation not only threatens ecosystems but also undermines human health through contamination of land and water sources. However, advancements in material science and recycling technology have opened pathways to repurpose plastic waste into high-value products, such as renewable energy devices. This study situates plastic waste management within the context of sustainability by exploring the potential of recycled plastics as components for solar panel production, providing a dual benefit: waste reduction and clean energy generation. The use of low-density polyethylene (LDPE), high-density polyethylene (HDPE), and polyethylene terephthalate (PET) in thin-film photovoltaic applications illustrates how environmental engineering and renewable energy science intersect in addressing global challenges [7, 8].

In addition to solving environmental issues, the energy crisis (especially in under-resourced schools) hinders the implementation of digital learning that depends on stable electricity. Digital transformation in education, encouraged by government policies, requires infrastructure support that many rural areas lack [9, 10]. Solar panels made from recycled materials offer a cost-effective and scalable energy solution. Solar panels have been well-researched [11-16]. Prior research has examined plastic-to-fuel conversion and eco-brick technologies [17], but limited studies address the integration of waste-based photovoltaic systems directly aimed at supporting digital education.

This paper builds upon and expands these efforts by positioning the solution within the framework of Sustainable Development Goals (SDGs), particularly SDG 12 on responsible production and SDG 7 on affordable, clean energy [18-20]. This study aims to evaluate the economic feasibility of producing solar panels from plastic waste by integrating concepts of science and technology in material reuse and photovoltaic innovation. The novelty lies in linking plastic recycling to a techno-economic model that simultaneously addresses environmental sustainability, renewable energy access, and educational equity. Unlike previous works that focused solely on environmental or cost efficiency, this research offers a multidimensional framework supporting the energy needs of digital learning in schools, particularly in underserved regions. By quantifying the viability through indicators such as cumulative net present value (CNPV), internal rate of return (IRR), and return on investment (ROI), the study proposes a replicable and impactful solution within the SDG framework and technological innovation.

2. Literature Review

The process of manufacturing solar panels from recycled plastic waste involves several interrelated scientific and technological domains, including polymer engineering, renewable energy systems, and material sustainability. As illustrated in Fig. 1, the production stages include waste collection, sorting, cleaning, melting, component molding, integration of flexible thin-film solar cells, and final parasol assembly. This modular construction utilizes various types of recycled plastic (LDPE, HDPE, PET) as mechanical supports and encapsulation layers for solar cell integration, demonstrating the interdisciplinary application of waste utilization and solar energy innovation [8].

To assess viability, the integration of financial and environmental evaluation is critical. Prior studies have highlighted techno-economic models for recycled-based products such as eco-bricks, educational tools, and bio-based construction materials [8, 21]. However, most have not directly linked economic modelling to educational energy infrastructure. By incorporating solar cell lamination with repurposed plastic casings, this study bridges a gap in the literature between sustainability technology and applied educational energy needs. The literature further supports that thin-film technologies like CIGS and amorphous silicon are flexible and compatible with lightweight applications such as mobile parasols, making them ideal for semi-permanent school installations [7, 22].

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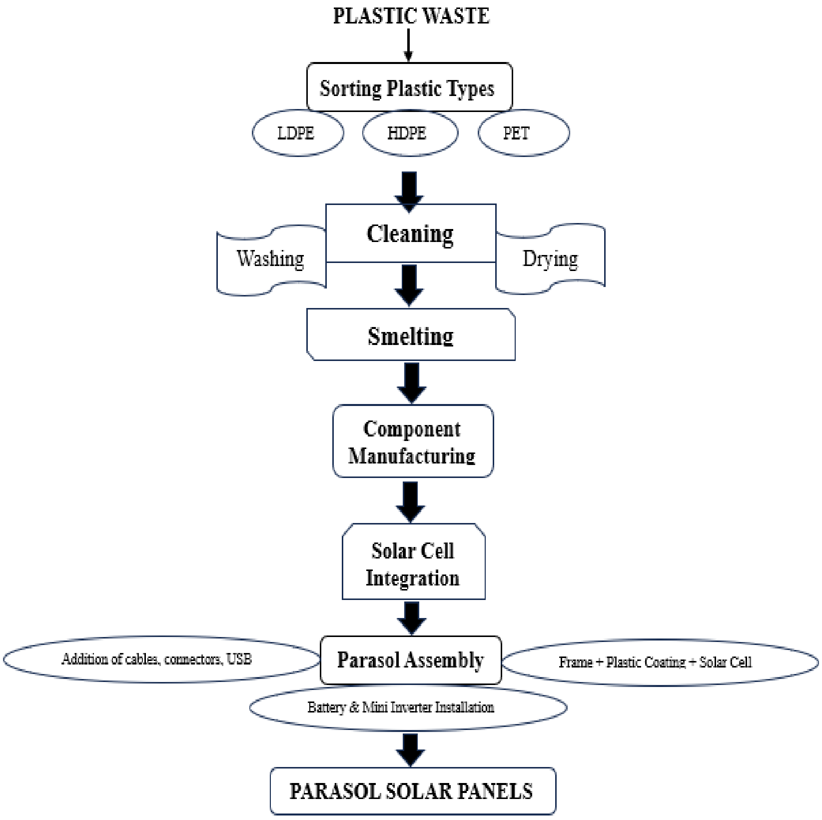

Fig. 1. The process of making solar panels from plastic waste.

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3. Methods

To evaluate the feasibility of producing solar panels from recycled plastic waste, this study applied a techno-economic approach integrating cost modelling with sustainability parameters. Detailed information for understanding the feasibility study is reported elsewhere [23]. The method included material procurement analysis, process equipment cost estimation, and economic indicator computation using real market data.

Table 1 presents the economic breakdown of raw materials used in this process. It includes the types of materials, quantities, unit prices, and annual costs, scaled to industrial production levels.

The materials (ranging from recycled plastics to solar film and lithium batteries) are sourced from local suppliers and environmental service units, reflecting a closed-loop supply chain that emphasizes circular economy principles. This aligns with SDG 12 and supports low-carbon product development in educational and public infrastructures [21, 24].

Additionally, the reliance on locally recycled inputs and modular designs reduces production complexity while enhancing affordability and scalability in rural educational contexts [17, 19].

As shown in Table 2, the economic projection of annual sales was calculated based on a unit price of solar panels derived from marketplace data, scaled to a production capacity of three million units per year. This ensured a realistic financial framework aligned with local market conditions [25].

Material prices were collected from various online Indonesian commercial platforms to reflect updated and accessible cost estimates. The production process was then modelled by scaling laboratory-scale consumption data to industrial-level volume, multiplied by 1000 times for cost simulation.

Calculations covered both fixed and variable costs, including raw materials, utility usage, labor, and sales-related expenditures. Financial indicators such as cumulative net present value (CNPV), internal rate of return (IRR), return on investment (ROI), payback period (PBP), break-even point (BEP), and profitability index (PI) were computed to assess long-term economic viability.

To validate the economic robustness of the model, sensitivity testing was performed by simulating changes in critical variables, such as raw material price fluctuations, production capacity changes, and labor cost adjustments. These simulations followed previous industrial economic analysis methods [21, 23], ensuring that the model could withstand operational and market uncertainties.

Equipment requirements-such as shredders, extruders, lamination machines, and solar testing tools-were listed with prices obtained from engineering suppliers, and depreciation was calculated over an estimated operational life.

The methodology was constructed to serve as a replicable framework for similar sustainable energy projects in educational contexts. This structured model not only informs decision-making at the industrial level but also provides a scientific foundation for integrating renewable energy technologies with educational development goals, especially in regions with limited access to electricity and digital infrastructure.

Table 1. Raw material calculation (Unit in kg).

	Raw material	Production Requirements (kg/hour)	Large Scale (Scale Up 1000x)	Price (USD)	Total (USD)	Source
a	HDPE/LDPE Plastic Waste	5	5.000	0.18	921.94	Environmental Service / Waste Bank
b	Recycled PET (transparent)	2	2.000	0.31	614.63	Local Recycling Supplier
c	Solar film (CIGS/Thin-film)	0.5	500	27.67	13829.13	Solar Panel Distributor
d	Mini lithium-ion battery (12V/20Ah)	0.3	300	21.51	6453.6	Local battery manufacturer
e	Copper wire + connector	0.2	200	5.53	1106.33	Electronic distributor
f	Resin protector + anti UV coating	0.4	400	2.77	1106.33	Industrial chemical supplier
g	Insulation cloth + cover layer	0.6	600	2.15	1290.72	Recycling textile industry
	Price / day				**25322.68**	
	Price / year				**7596803,93**	

Table 2. Sales.

No.	**SALES**		
1	capacity per day	10.000	Item/day
2	capacity per year	3.000.000	Item/year
3	selling price per item ($)	3,69	Unit
4	annual income ($)	11.063.306,70	Total

4. Results and Discussion

The core findings of this study are based on a comprehensive evaluation of production costs, equipment investment, and economic profitability in manufacturing solar panels from plastic waste. As detailed in Table 3, the feasibility analysis summarizes fixed and variable costs, estimated sales, return on investment, and break-even point. Fixed costs such as equipment depreciation and capital interest were calculated at $183,095.98, while variable costs including materials, labor, and utilities totaled $8,011,974.16 annually. With an annual revenue of $12,907,191.15, the estimated profit margin reached 30.74%, with an ROI of 32.96%. The break-even point was achieved at 1,122,910 units, equivalent to 37.4% of the total production capacity. These results confirm that the project is financially viable and efficient in resource utilization [8, 24].

Table 3. Feasibility analysis.

Component	Parameter	Cost (USD)
Fixed Cost	Loan Interest	
	Capital Related Cost	168.752,31
	Fixed cost + depreciation	
	Depreciation	14.343,67
	Fixed Cost less depreciation	
	Total Fixed Cost	183.095,98
Variable Cost	Raw material	7.067.609,10
	Utilities	4.426,52
	Operating Labor (OL)	28.027,04
	Labor Related Cost	8.408,11
	Sales Related Cost	903.503,38
	Total Variable Cost	8.011.974,16
% Profit Estimated	Sales	12.907.191,15
	Manufacturing Cost	8.180.726,46
	Investment	153.744,53
	Profit	0,37
	Profit to Sales	30,74
BEP	Unit	3000000
	Fixed Cost	183.095,98
	Variable cost	8.011.974,16
	Variable cost	0,00
	Sales	12.907.191,15
	Sales	0,00
	BEP	112209,1107
	Percent Profit on Sales	0,366188478
	Return on Investment	32,95156145
	Pay Out Time	0,030255757

Figure 2 illustrates the relationship between cumulative net present value (CNPV) and time over a 20-year investment horizon. At the initial stages, CNPV is negative due to upfront capital costs. However, from the third year onward, the project begins generating positive cash flows. By the twentieth year, CNPV approaches approximately $43,023.97, indicating strong long-term profitability. This steady financial gain is primarily driven by low-cost raw materials and stable solar panel demand for digital learning support in schools. The integration of photovoltaic technology with waste materials also aligns with previous research that emphasizes material reuse for economic gain [17].

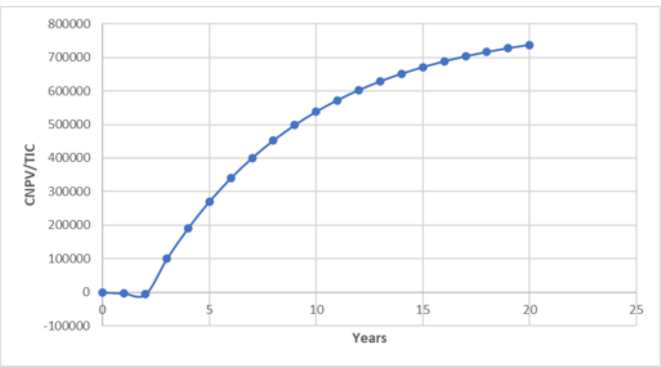

Fig. 2. CNPV/TIC calculation.

From a technological standpoint, this study confirms the compatibility of thin-film solar cells with plastic-based components, such as casings and covers, derived from HDPE, LDPE, and PET. The modular umbrella-based solar panel concept reduces installation complexity and enhances portability, making it ideal for schools in remote or disaster-prone areas [7, 22]. Moreover, this innovation supports digital education programs that require reliable electricity for online learning, computing devices, and network routers. Through an SDG-based lens, the project contributes to SDG 7 (affordable and clean energy), SDG 12 (responsible consumption and production), and indirectly to SDG 4 (quality education) by ensuring infrastructure readiness. This adds new information regarding SDGs as reported elsewhere [26-31].

The findings validate the feasibility and impact of solar panel production from plastic waste. The approach not only reduces environmental burden but also supports socio-technological transformation through cost-effective energy access in education. The integration of scientific modelling, real-market data, and sustainability indicators strengthens the relevance of this study for both policymakers and practitioners.

5. Conclusions

This study confirms the techno-economic feasibility of producing solar panels from recycled plastic waste to support digital learning in schools. The integration of waste management, photovoltaic technology, and education infrastructure resulted in a profitable, scalable, and sustainable model. Financial indicators such as CNPV, ROI, and BEP demonstrated long-term viability, with positive cash flow beginning in the third year. This innovation aligns with multiple Sustainable Development Goals, offering a practical solution for energy access in remote areas. The model presents a replicable framework for green technology implementation within the socio-educational landscape.

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