



REVIEWER'S REPORT

Manuscript No.: IJAR-56116

Title: Life-Cycle Environmental Impact of Thin-Film Silicon Solar Cells.

Recommendation:

Accept as it

Rating	Excel.	Good	Fair	Poor
Originality		√		
Techn. Quality			√	
Clarity			√	
Significance		√		

Reviewer Name: Dr. Manju M

Detailed Reviewer's Report

1. Emergence and Global Importance of Photovoltaic Technology

Photovoltaic (PV) technology has emerged as a central pillar of global renewable energy strategies due to its ability to generate electricity without direct emissions. Escalating energy demand and climate change concerns have accelerated its worldwide adoption. Governments increasingly integrate solar energy into long-term energy policies. The scalability of PV systems enhances their applicability across diverse settings. Sustained global expansion reflects growing confidence in solar power.

2. Rapid Technological Progress and Economic Viability

Continuous advancements in PV cell design, materials, and manufacturing processes have significantly improved system efficiency and durability. Large-scale production and automation have reduced overall costs. As a result, solar electricity has become competitive with conventional energy sources. Enhanced performance increases energy output per unit area. Cost reductions have expanded accessibility across residential and institutional sectors.

3. Life-Cycle Perspective in Photovoltaic Assessment

A comprehensive evaluation of PV systems requires a cradle-to-grave life-cycle perspective. This framework encompasses raw material extraction, manufacturing, operation, and end-of-life management. Exclusive focus on emission-free operation provides an incomplete sustainability picture. Life-cycle assessment (LCA) enables transparent evaluation of environmental impacts. It supports balanced and evidence-based sustainability claims.

4. Energy Demand during Raw Material Extraction

Raw material extraction, particularly silicon purification, is energy-intensive. Chemical refining processes may generate hazardous intermediates if improperly managed. Environmental impacts at this stage are process-dependent rather than intrinsic to PV technology. With appropriate controls, associated risks can be significantly reduced. This stage remains critical for overall footprint minimization.

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5. Chemical Intensity of Silicon Refining Processes

The conversion of silica to high-purity polysilicon involves energy-intensive chemical reactions and distillation processes. By-products such as chlorosilanes pose potential occupational and environmental hazards. Improper handling may affect both workers and surrounding ecosystems. Regulatory oversight is therefore essential. Ongoing technological improvements continue to reduce refining-related impacts.

6. Manufacturing and Assembly Phase Impacts

PV module manufacturing involves high-temperature processes and the use of various chemicals. Acids, solvents, and dopants present localized occupational risks. In some modules, lead-containing solders raise environmental concerns. These impacts are largely confined to controlled industrial environments. Effective pollution control systems mitigate emissions and waste.

7. Health and Safety Considerations in Manufacturing

Health and safety risks during PV manufacturing mainly arise from toxic or explosive gases. Under standard industrial safety practices, these hazards are well controlled. Proper containment, continuous monitoring, and worker training are essential. Such risks are manageable rather than prohibitive. This underscores the feasibility of responsible PV production.

8. Use of Hazardous and Toxic Materials

Certain PV technologies utilize materials that may pose risks if improperly handled. Thin-film technologies can involve cadmium or selenium compounds. Strict exposure controls and waste management are therefore required. Cleaner alternatives and safer materials are increasingly adopted. Responsible material management enhances environmental credibility.

9. Environmental Concerns in Thin-Film Technologies

Thin-film PV technologies offer material efficiency advantages but introduce specific chemical risks. Toxic by-products may arise during fabrication. Without safeguards, these could affect ecosystems. Life-cycle assessment helps identify and balance such trade-offs. Regulatory frameworks ensure responsible deployment.

10. Environmental Footprint of the Installation Phase

The installation phase of PV systems has a relatively minor environmental footprint. Temporary land disturbance is the primary concern. Emissions are limited to transportation-related activities. Appropriate site selection minimizes localized impacts. Overall, installation contributes minimally to total life-cycle burdens.

11. Operational Phase and Zero-Emission Advantage

During operation, PV systems generate electricity without combustion or pollutant emissions. Maintenance requirements are minimal. Independent studies confirm negligible environmental and health

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risks during this phase. Electrical safety during servicing remains the main concern. This phase represents PV technology's strongest sustainability advantage.

12. Energy Payback Time as a Sustainability Indicator

Energy payback time (EPBT) indicates how quickly a PV system offsets its embodied energy. Modern systems typically achieve EPBT within a few years. This is short relative to their operational lifespan. Continued efficiency improvements further reduce payback durations. PV systems are thus confirmed as net energy producers.

13. Factors Influencing Energy Payback Performance

Manufacturing efficiency significantly affects embodied energy. Geographic location influences solar irradiation and electricity output. Installation design and balance-of-system components also play roles. These factors explain variations in reported EPBT values. Optimization enhances overall energy performance.

14. Potential for Reduced Energy Input in Silicon PV

Silicon-based PV technologies exhibit strong potential for further energy reduction. Process optimization can substantially lower manufacturing energy demand. Near-term EPBT values approaching one year are achievable. Reduced energy input improves environmental performance. Continued innovation strengthens long-term viability.

15. Importance of End-of-Life Management

Although PV panels have long service lives, end-of-life planning is essential. Decommissioned modules contain both recyclable and hazardous components. Improper disposal may lead to environmental contamination. Early planning prevents waste accumulation. End-of-life management is integral to sustainability.

16. Recycling and Material Recovery Opportunities

Most PV module mass consists of recoverable materials such as glass and aluminum. Recycling reduces reliance on virgin resources. Energy requirements for recycled materials are significantly lower. Recycling pathways are advancing globally. Material recovery transforms waste into sustainability gains.

17. Regulatory Frameworks and Emission Control

PV manufacturing emissions are regulated under industrial environmental standards. Air and wastewater controls limit hazardous releases. Regulatory compliance ensures impacts remain within permissible limits. These frameworks demonstrate that risks are manageable. Regulation enhances industry accountability.

REVIEWER'S REPORT**18. Role of Safer Technologies and Industrial Practices**

Adoption of safer materials and cleaner processes reduces environmental and health risks. Efficient material use minimizes waste generation. Worker training and quality assurance are essential. Integrated management strategies improve sustainability outcomes. Proactive practices yield measurable benefits.

19. Need for Comprehensive Life-Cycle Optimization

Sustainability gains require optimization across all life-cycle stages. Isolated improvements are insufficient. Systematic evaluation enhances energy performance and reduces impacts. Regional conditions should guide optimization strategies. Life-cycle thinking remains central to PV advancement.

20. Research Implications and Future Assessment Needs

Further research should refine EPBT and LCA metrics under region-specific conditions. Indian climatic and industrial contexts warrant focused analysis. Improved data enhances policy relevance. Future studies support evidence-based deployment. Continuous assessment strengthens decision-making.

21. Overall Life-Cycle Environmental Performance of PV Systems

Holistic life-cycle assessment demonstrates clear environmental benefits of PV systems. Early-stage impacts are offset by long-term clean energy generation. Short EPBT confirms favorable energy returns. Recycling further reduces future burdens. PV systems emerge as low-risk, high-benefit technologies.

22. Concluding Perspective on Photovoltaic Sustainability

Photovoltaic technology represents a reliable and responsible renewable energy pathway. Environmental and health risks are manageable under appropriate controls. Ongoing technological progress enhances efficiency and performance. Life-cycle optimization ensures long-term sustainability. PV remains integral to clean energy transitions.

23. Objectives of the Study

This study aims to analyze energy consumption across the complete life cycle of photovoltaic systems. It examines materials used and by-products generated at each stage. Health, safety, and environmental concerns during manufacturing are assessed. The study evaluates opportunities for reducing energy input, particularly in silicon-based PV. A comprehensive life-cycle approach underpins the analysis.

24. Significance of the Study

The study provides an integrated life-cycle understanding of photovoltaic systems by linking energy use with material and environmental impacts. It demonstrates that manufacturing-related health and safety risks are manageable. The work highlights opportunities for reducing energy input in silicon-based technologies. Overall, it supports sustainable solar energy development.

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25. Recommendations

Adoption of safer materials, cleaner technologies, and efficient processes in PV manufacturing is recommended. Energy consumption across all life-cycle stages should be optimized. Stronger recycling systems and life-cycle assessments are essential. Region-specific research should be expanded. These measures will enhance long-term photovoltaic sustainability.