Short communication:
NIPES-Journal of Science and Technology Research 1(10) 2024 pp 30-33. ISSN-2682-5821

NIPES

Journal of Science and Technology Research

Journal homepage: www.nipesjournals.org.ng

Environmental Impact and Sustainability of Thermal Energy Storage in Concentrated Solar Power Systems

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Abstract
This short communication examines the environmental impact and sustainability of Thermal Energy Storage (TES) in Concentrated Solar Power (CSP) systems. We analyze the life cycle impacts, including greenhouse gas emissions, water usage, and land use, comparing TES to alternative backup systems. The study highlights the potential of TES to enhance CSP sustainability while identifying areas for further improvement in environmental performance.

Keywords: Concentrated Solar Power (CSP), Heat Transfer Fluids, Cost Analysis of Thermal Energy Storage, Environmental Impact and Sustainability

https://doi.org/10.5281/zenodo.14020637

Introduction
Concentrated Solar Power (CSP) with Thermal Energy Storage (TES) offers a promising solution for dispatchable renewable energy generation. However, the environmental implications of integrating TES into CSP systems warrant careful consideration [1-5]. This communication aims to synthesize current understanding of TES environmental impacts and sustainability in CSP applications.

Life Cycle Impacts:

Life Cycle Assessment (LCA) studies reveal that TES can significantly reduce the overall environmental footprint of CSP plants:

Greenhouse Gas (GHG) Emissions:

TES can reduce life cycle GHG emissions by up to 7% compared to CSP without storage and up to 210% compared to natural gas backup systems. This reduction is primarily due to increased plant capacity factors and reduced reliance on fossil fuel-based grid electricity.

Water Usage:

Life cycle water consumption decreases with increasing TES capacity, although on-site water use may increase slightly. TES systems generally have similar water use profiles to natural gas backup systems.

Land Use:

The life cycle land use is comparable across CSP configurations with and without TES. However, TES allows for more efficient use of the solar field by enabling energy production beyond sunlight hours.

Material Considerations:

The choice of TES materials significantly influences environmental impact:

Molten Salts: Commonly used in TES, molten salts like Solar Salt (60% $NaNO_3$, 40% KNO_3) show lower environmental impacts compared to synthetic oils used in some CSP systems. However, the production and disposal of these salts still contribute to the overall environmental footprint.

Recycling Potential:

Over 90% of materials used in CSP plants, including TES components, are recyclable at the end of the plant's life4. This high recyclability enhances the long-term sustainability of TES systems.

Economic and Environmental Trade-offs:

The integration of TES in CSP plants presents a complex interplay between economic and environmental factors:

Levelized Cost of Electricity (LCOE):

TES can potentially lower the LCOE of CSP plants compared to no-storage alternatives, enhancing economic viability (14-16).

Carbon Pricing:

A carbon price of $150-$240/tonne CO2eq would be required for CSP with TES to be competitive with coal-fired generation, depending on the TES configuration.

Sustainability Considerations:

Resource Efficiency: TES enhances the overall efficiency of CSP plants by increasing capacity factors and enabling better grid integration of solar energy.

Toxic Material Mitigation: Ongoing research focuses on developing new salt mixtures with reduced toxicity and improved performance, further enhancing the sustainability of TES systems.

Life Cycle Optimization: Opportunities exist for multi-variable optimization, incorporating variations in heat transfer fluid properties alongside storage capacities and solar field areas to minimize environmental impacts.

Conclusion:

Thermal Energy Storage significantly enhances the sustainability of Concentrated Solar Power systems by reducing life cycle greenhouse gas emissions, optimizing water and land use, and improving overall system efficiency. While challenges remain, particularly in terms of material impacts and economic competitiveness, ongoing research and development in TES technologies promise to further improve the environmental performance of CSP systems. Future work should focus on advanced materials with lower environmental impacts, improved system designs, and policy frameworks that recognize the full value of dispatchable renewable energy with storage.

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