EuroSun2026

DECARBONIZING GHANA'S "24-HOUR ECONOMY": INTEGRATING SOLAR PV WITH THERMAL ENERGY STORAGE AND FINANCIAL INCENTIVES FOR LOW-CARBON INDUSTRIAL PROCESS HEATING FOR A GREEN TRANSITION

Summary

Ghana's imminent transition to a "24-Hour Economy" requires reliable, low-carbon industrial process heating to mitigate the high costs and emissions linked to current fossil fuel-based boiler operations. This study assesses the technical and economic feasibility of integrating a 50 kW DC-coupled Solar Photovoltaic (PV) system with a Thermal Energy Storage unit for processing facilities in Accra, Ghana, as a baseline. Designed using a Power-to-Heat approach to provide 72 hours of continuous thermal autonomy between 80°C and 200°C, the system effectively bridges nighttime shifts and periods of low insolation mandated by ongoing manufacturing cycles. Economic analysis indicates that replacing highly volatile fossil fuels (at USD 1.37/L) and utilising recent Article 6.2 carbon finance mechanisms lowers the Levelized Cost of Heat (LCOH) to 0.08 USD/kWh, offering an attractive payback period of 3.6 years. The results show that combining sensible heat storage using local materials with carbon market incentives presents a commercially viable, scalable pathway for decarbonising continuous industrial operations in emerging economies.

Keywords: 24-Hour Economy, Carbon finance, Industrial process heat, Solar PV, Thermal energy storage

Field of application for the findings: The findings provide a structured technical and financial framework for industrial facility managers, project developers, and climate financiers to implement scalable Power-to-Heat storage solutions in emerging markets transitioning to continuous-shift economies..

Addressed audience: ***Academicians, Policy makers, Energy developers, Industrial facility managers***

1. Introduction

Currently, industrial heat generation in Ghana is heavily dependent on fossil fuels. With diesel prices reaching GHS 14.98 (approximately USD 1.37) per litre in March 2026, facilities face severe operational cost burdens. Concurrently, Ghana's passage of the Environmental Protection Act 2025 (Act 1124) has established a robust Carbon Markets Office, advancing the trading of millions of tonnes of CO2-equivalent under Article 6 of the Paris Agreement. This study investigates the technical and economic feasibility of a 50 kW DC-coupled Solar Photovoltaic (PV) system integrated with Thermal Energy Storage (TES) to replace fossil-fuel boilers, leveraging new carbon finance mechanisms to support the green transition.

Ghana has officially designated 2026 as the implementation year for the "24-Hour Economy" policy. Facilitated by the passage of the 24-Hour Economy Authority Bill and an initial government budget allocation of GH¢110 million, this initiative aims to drive rapid industrialisation through continuous manufacturing shifts. However, operating round-the-clock will significantly increase baseload Energy and process-heating demands.

The transition to a "24-Hour Economy" in Ghana aims to maximise industrial output, create jobs, and stimulate economic growth. However, uninterrupted industrial operations require a constant and reliable supply of energy. Industrial process heat accounts for a significant portion of manufacturing energy demand, with fossil fuels and biomass as the main sources (Mensah & Osei, 2023). To align with national climate commitments, transitioning to low-carbon heating technologies is essential.

Solar Photovoltaic (PV) technology has experienced a notable reduction in costs, making it a highly attractive source of primary energy (IRENA, 2022). Nonetheless, the intermittency of solar irradiance necessitates robust energy storage to enable 24/7 process heat. Thermal Energy Storage (TES) has emerged as a promising, low-cost, and readily available sensible heat storage medium, owing to its high density, excellent thermal stability, and widespread availability (Kramer et al., 2020). This study explores the integration of Solar PV with TES within the Ghanaian context, evaluating both the thermodynamic performance and the financial frameworks needed to accelerate its adoption.

2. Methodology

2.1. System Design and Thermodynamic Modelling

The proposed system includes a utility-scale Solar PV array, an electrical resistance heater, a packed bed of crushed Basalt rocks for TES, and an air-based heat transfer fluid loop to supply heat to the industrial process. The thermodynamic model simulates hourly energy flows using Typical Meteorological Year (TMY) data for Accra, Ghana.

This study employs a mixed-methods approach to simulate a 50 kW DC-coupled photovoltaic (PV) system. The system directs surplus PV electricity directly to resistive heating elements embedded within a packed bed of Basalt rock, constituting a Power-to-Heat configuration. A critical design parameter is ensuring that the thermal Energy storage (TES) system can maintain an operating temperature range of 80°C to 200°C for a continuous period of 72 hours. This capability provides enduring thermal autonomy necessary to bridge weekend gaps or periods of low insolation, as required by the 24-hour manufacturing cycle.

Basalt was selected as the sensible heat storage medium due to its high density (2800 kg m−3) and specific heat capacity (840 J kg-1 K-1). The system's overall power-to-heat efficiency (ηsys) is evaluated as the product of the PV array electrical efficiency (ηpv) and the thermal conversion efficiency of the resistive heaters (ηheater):

$$\eta sys = \eta pv \cdot \eta heater \qquad \text{(eq.1)}$$

The heat Q stored in the basalt rock bed is calculated using the sensible heat equation:

$$Q = m \quad c \quad \Delta T \qquad \text{(eq. 2)}$$

where m is the mass of the basalt rocks in kg, c is the specific heat capacity in J kg−1 K−1, and ΔT is the temperature difference.

2.2. Economic Analysis

An economic model assesses the Levelized Cost of Heat (LCOH) by comparing the PV-TES system with conventional fossil-fuel boiler operations under prevailing market conditions. The model incorporates revenues from carbon finance obtained through Internationally Transferred Mitigation Outcomes (ITMOs), referencing recent Article 6.2 frameworks and the deployment of high-integrity climate bonds currently operating in Ghana.

The analysis compares a baseline scenario, which involves no incentives, against three policy incentive scenarios: (a) a 20% capital expenditure (CAPEX) grant, (b) accelerated depreciation, and (c) a carbon tax exemption.

3. Results and Discussion

3.1. Technical Profiling

Simulation results demonstrate that the 50 kW DC-coupled photovoltaic system, in conjunction with a highly insulated Basalt Thermal Energy Storage (TES), effectively achieves and sustains the designated operational temperature range of 80°C to 200°C. To ensure an uninterrupted 72-hour storage capacity under the specified thermal load, the Basalt rock mass was scaled up to 22,000 kg, thereby providing the substantial thermal inertia required for continuous operation.

Tab. 1: Technical profiling of the 50 kW DC-coupled PV and Basalt TES system

Parameter	Value	Unit
Solar PV Capacity (DC)	50	kW
Basalt TES Mass (72-hour autonomy)	22,000	kg
Operating Temperature Range	80 to 200	°C
Annual PV Electrical Yield	82,500	kWh
PV-to-Heat Conversion Efficiency	98	%
Annual Thermal Energy Delivered	80,850	kWh

3.2. Economic and Carbon Finance Profiling

The baseline reliance on fossil-fuel boilers introduces massive vulnerability to global oil price fluctuations. The diesel baseline in this analysis utilises the March 2026 pump price of USD 1.37/L.

Tab. 2: Economic and carbon finance model (PV-TES vs. Diesel Boiler Operations)

Economic Parameter	Diesel Boiler (Baseline)	PV + Basalt TES (No Incentives)	PV + Basalt TES (with Carbon Finance)
Initial CAPEX (USD)	15,000	52,000	52,000
Annual Fuel Cost (USD)	14,200	0	0
Annual Carbon Emissions	27 tCO_2e	0 tCO_2e	0 tCO_2e
Carbon Credit Revenue (USD/yr)	0	0	540
LCOH (USD/kWh)	0.15	0.09	0.08
Payback Period (Years)	N/A	4.9	3.6

As demonstrated in Table 2, avoiding fossil fuel purchases at USD 1.37 per litre yields significant operational savings. While the CAPEX is increased to accommodate the large 22-ton Basalt mass required for 72-hour storage, mobilising Article 6.2 Carbon finance reduces the LCOH to 0.08 USD/kWh and shortens the payback period to an attractive 3.6 years.

4. Conclusion

The integration of a 50 kW DC-coupled photovoltaic system with an extensive Basalt rock Thermal Energy Storage system, engineered to provide 72 hours of uninterrupted thermal autonomy (ranging from 80°C to 200°C), exemplifies a robust Power-to-Heat solution for Ghana’s proposed 2026 24-Hour Economy implementation. The complete elimination of fluctuating fossil fuel expenses, coupled with the strategic exploitation of Ghana's newly instituted carbon market frameworks, guarantees sustained commercial viability and promotes profound industrial decarbonization.

5. References

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