Evaluating the Potential of Utilising Silica Sand for Thermal Energy Storage Applications: A Case Study of New Luika Gold Mining in Songwe Region, Tanzania

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ABSTRACT

This research investigates the potential application of silica sand from New Luika Gold Mining, Songwe Region, Tanzania, as a thermal energy storage (TES) medium. Through detailed chemical, physical, and thermophysical analysis of three silica sand samples, the sand suitability based on purity, moisture content, porosity, thermal conductivity, and stability under TES operating conditions was evaluated. The coarse silica sand sample TAN-005 demonstrated optimal properties, including high silica content (97.15%), low moisture (0.0198%), and low electrical conductivity (41.6 µS/cm), making it the most promising candidate for high-temperature TES applications. The findings supported the viability of indigenous silica sand as a cost-effective, environmentally friendly TES medium. The significance of the findings aligns with Tanzania's renewable energy goals.

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1.0 Introduction

Tanzania is undergoing a significant transformation in its energy landscape, driven by increasing demand for reliable electricity and the urgent need to transition to cleaner, more sustainable energy systems. The Songwe Region, which is in the southwest of the country, is growing quickly in terms of industry, cities, and rural areas. However, access to stable electricity remains a challenge in many parts of the region, especially in off-grid and rural communities (Ahlborg & Hammar, 2014; Hopcraft *et al*., 2015; Jeuland *et al*., 2020).

Addressing this energy challenge requires innovative and context-specific solutions that leverage local resources while aligning with global sustainability goals (Kourgiozou *et al*., 2021).

Thermal Energy Storage (TES) is one of the promising technologies that support energy system flexibility and enhance the reliability of renewable energy sources. TES enables excess energy, often from intermittent sources like solar or wind, to be stored and used later when demand is high or when production is low (Kourgiozou *et al.,* 2021; Sarbu & Sebarchievici, 2018; Tippayawong *et al.,* 2020). This capability is particularly valuable in areas like Songwe, where solar irradiance is abundant but temporal mismatches between energy generation and consumption persist.

TES systems typically rely on materials that can absorb, store, and release heat efficiently. While commercial TES systems often utilise materials such as molten salts, rocks, or synthetic phase change materials, these options can be expensive, corrosive, or environmentally taxing (Gil *et al.,* 2010; Kougias *et al.,* 2021; Shi *et al.,* 2019; Singal *et al.,* 2020). This requirement has driven research toward identifying more sustainable, cost-effective alternatives. Silica sand has emerged as a promising candidate due to its widespread availability, chemical inertness, high melting point, thermal stability, and low cost (Alva *et al.,* 2017; Davenport *et al.,* 2022; Gifford *et al.,* 2020; Hazra *et al.,* 2021; Ogala, 2022; Ruoso & Ribeiro, 2022).

In Tanzania, New Luika Gold Mining in the Songwe Region provides an accessible and potentially high-quality source of silica sand. However, comprehensive studies evaluating the technical suitability of this silica sand for TES applications are lacking. To fill this knowledge gap, this study investigates the feasibility of using silica sand sourced from New Luika Gold Mining for thermal energy storage, particularly in high-temperature applications such as concentrated solar power (CSP) systems and industrial waste heat recovery.

The main objectives of this research are to characterise the physical, chemical, and thermophysical properties of selected silica sand samples. These insights are intended to inform policymakers, investors, and engineers about the potential of using locally available materials to support sustainable energy infrastructure in Tanzania.

The study supports the national energy development strategies and global decarbonisation efforts while using local silica sand in TES. This aids in limiting fossil fuel use and the importation of technologies. It further develops local industrial capacity and grows the resilience and sustainability of Tanzania's energy system.

Silica sand, an abundantly available and cheap material, has been studied as a TES medium given its high-temperature stability, specific heat capacity, and abundance. With full characterisation of the material, the study investigates the suitability of silica sand from New Luika Gold Mining for TES application.

2.0 Materials and Methods

2.1 Study Area

The research was conducted using silica sand samples from New Luika Gold Mining, located at approximately 8.555° S, 33.343° E in the Songwe Region. The mine is known for high-grade mineral deposits and presents an opportunity for integrating TES into local energy infrastructure, as indicated in Fig. 1.

2.2 Sample Collection and Preparation

Samples TAN-001, TAN-005, and TAN-006 were collected and labelled according to ASTM D75 standards. The samples were dried at 105°C (ASTM D2216) to eliminate moisture and sieved to determine particle size distributions using ASTM C136 as indicated on Figs. 2a, b and c.

2.3 Experimental Procedures and Instruments Used

Drying and Moisture Content Determination: Silica sand samples were dried in a laboratory oven (Memmert Model UN110) at 105°C until constant weight to determine moisture content (TZS 2359:2019).

Sieve Analysis for Particle Size Distribution: Samples were sieved using an electric sieve shaker (Endecotts Octagon 2000) with ASTM E11 standard sieves ranging from 6.7 mm to 106 µm. Weight retained on each sieve was recorded to determine d_{90} values.

Bulk Density and Porosity Measurement: Pycnometer bottles and a digital weighing balance (Mettler Toledo) were used to determine bulk density and calculate porosity by comparing the solid volume to total volume.
X-Ray Fluorescence (XRF) for Chemical Composition: A PANalytical Axios mAX XRF spectrometer was used to determine oxide composition (SiO_2, Al_2O_3, Fe_2O_3, etc.).
Calorific Value: A bomb calorimeter (3k-F) was used to determine the calorific value of each sample.
Electrical Conductivity: Measured using a digital conductivity meter (WTW Cond 3110) according to ISO 7888 standards.
Thermal Conductivity Estimation: Calculated from electrical conductivity using the Wiedemann-Franz Law, with an assumed Lorenz number and average absolute temperature.
Thermal Cycling Stability: A programmable muffle furnace (Carbolite Gero) was used to subject samples to heating at 600–800°C, followed by cooling cycles to observe structural integrity.

Simulation Tools: COMSOL Multiphysics was used for Computational Fluid Dynamics (CFD) simulations to model heat transfer and thermal behaviour in packed bed TES systems.

Figure 1
New Luika Gold Mining Location Map

Source: Mapcarta (2025)

Figure 2
Sample Collection

(a) (b) (c)

2.4 Research Hypotheses

The study is guided by the following research hypotheses:

H1: Silica sand from New Luika Gold Mining, particularly the TAN-005 sample, possesses chemical purity and physical properties suitable for efficient and stable thermal energy storage (TES) at high temperatures.

H2: The low moisture content and low electrical conductivity of silica sand samples from New Luika reduce corrosion risk and improve thermal stability under TES operating conditions.

H3: The particle size distribution and porosity of the silica sand samples significantly influence their heat retention capacity and thermal conductivity, with coarse-grained samples performing better in packed bed TES systems outcomes, as illustrated by the hypothesised paths.

H4: Utilising locally sourced silica sand in TES systems is economically viable and environmentally beneficial compared to imported materials.

Figure 3
Research Hypothesis

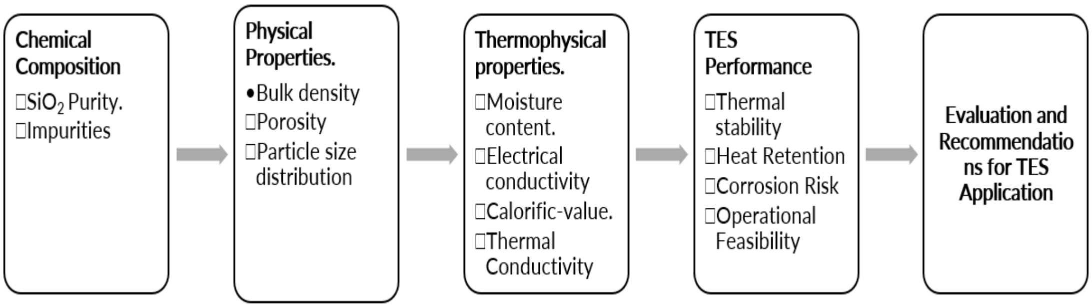
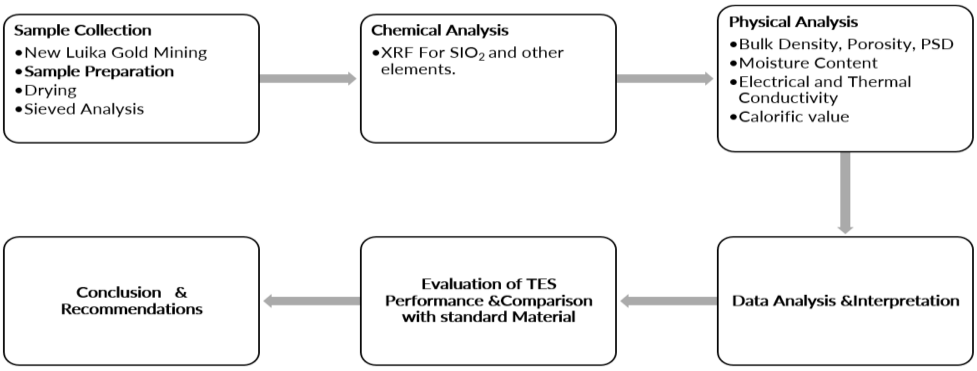


Figure 4
Research Design Approach



3.0 Results and Discussion

3.1 Chemical Composition Analysis

The chemical composition of the three silica sand samples (TAN-001, TAN-005, and TAN-006) shows significant differences in purity and impurity levels, which directly influence their potential for thermal energy storage (TES), as indicated in Table 1 and Fig. 5.

TAN-005 has the highest silica content of 97.15%, signifying high purity, which is essential for ensuring thermal stability and minimising corrosion risks during high-temperature TES operation.

TAN-001 exhibited the lowest silica content at 76.00%, with a notably high aluminium oxide (Al_2O_3) content of 10.06%, which could impair thermal stability.

Iron oxide (Fe_2O_3), a key indicator of corrosion potential, was below 1% in TAN-005 and TAN-006 and highest in TAN-001 at 1.81%. The variations suggest that TAN-005 would be the prime candidate for TES applications due to its very high silica purity and very low levels of all impurities, although in the case of TAN-001, it could show some drawbacks related to thermal stability and corrosion resistance and, therefore, would be less suited for long-term high-temperature storage use. TAN-006, having an intermediate purity, may be suitable as a second choice, although this material might have to be pretreated or blended for maximum performance.

Table 2
Chemical Composition

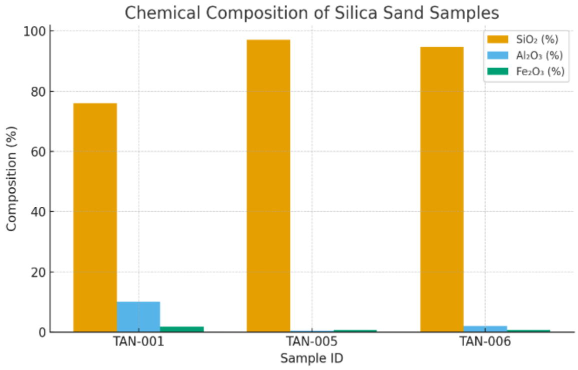
Sample ID	SiO_2 (%)	Al_2O_2 (%)	Fe_2O_3(%)	Observations
TAN-001	76	10.06	1.81	Lower silica, higher impurities
TAN-005	97.15	0.55	0.67	Highest purity, ideal for TES
TAN-006	94.69	2.08	0.67	Moderate purity

High silica content in TAN-005 implies superior thermal stability and low corrosion risk for TES applications.

Source: African Minerals and Geosciences Centre Mineral Processing Laboratory

Figure 5

High Silica Content in TAN-005 Implies Superior Thermal Stability and Low Corrosion Risk for TES Applications



Source: African Minerals and Geosciences Centre Mineral Processing Laboratory

3.2 Physical Properties

Physical characterisation measured the bulk density and porosity of the silica sand samples, parameters important for thermal storage efficiency and heat transfer effectiveness, as indicated in Fig. 6 and table 2.

Bulk density was uniform around 1.09 to 1.11 g/cm³ across all samples, indicating consistent material compaction capability.

Porosity was lowest in TAN-005 at roughly 30%, compared to 33-35% in others. Lower porosity enhances heat retention and improves TES efficiency by reducing void spaces for heat loss.

This combination of properties suggests TAN-005's physical form supports better thermal performance, particularly for packed bed TES systems.

Table 2

Physical Properties

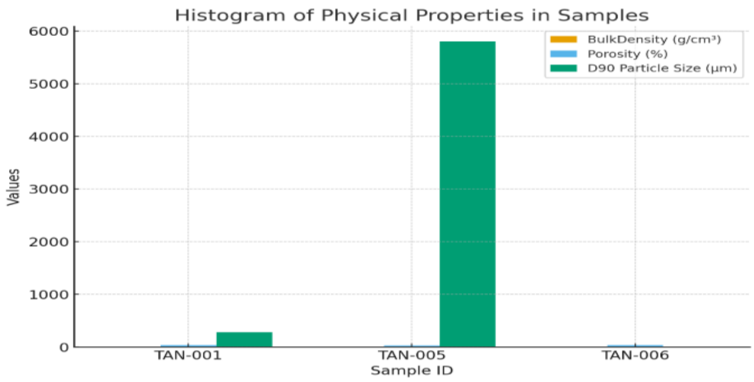
Sample ID	BulkDensity (g/cm³)	Porosity (%)	D_{90} Particle Size
TAN-001	1.09	34.67	280 µm
TAN-005	1.11	30	5.8 mm
TAN-006	1.11	33.33	Not specified

TAN-005's lower porosity enhances heat retention, and coarse grain size is favorable for packed bed TES systems.

Source: African Minerals and Geosciences Centre Mineral Processing Laboratory.

Figure 6

TAN-005's Lower Porosity Enhances Heat Retention, and Coarse Grain Size is Favorable for Packed Bed TES Systems



Source: African Minerals and Geosciences Centre Mineral Processing Laboratory.

Table 3

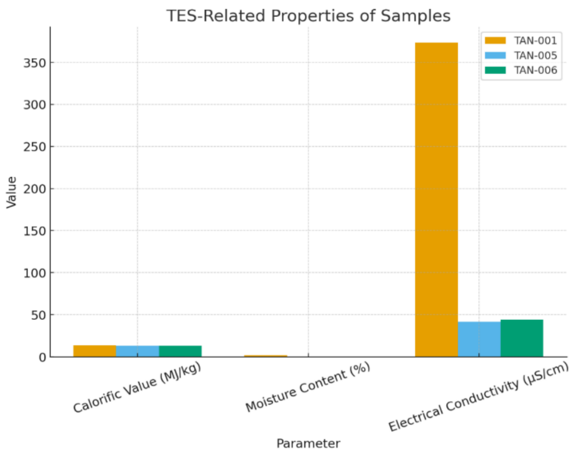
Thermophysical Properties

Parameter	TAN-001	TAN-005	TAN-006	TES Implication
Calorific Value (MJ/kg)	13.61	13.21	13	Comparable energy potential
Moisture Content (%)	1.6261	0.0198	0.0415	TAN-005 lowest moisture, higher stability
Electrical Conductivity (µS/cm)	373.3	41.6	44.25	TAN-005 lowest, less corrosion risk

Electrical conductivity converted to S/m and thermal conductivity calculated confirmed adequate conductivity for heat transfer with low corrosion potential.

Source: Tanzania Bureau of Standards

Figure 7
Electrical Conductivity Converted to S/m and Thermal Conductivity Calculated Confirmed Adequate Conductivity for Heat Transfer with Low Corrosion Potential



Source: Tanzania Bureau of Standards

3.3 Thermophysical Properties

Key thermophysical properties, including moisture content, electrical conductivity, and calorific value, were evaluated to understand TES performance implications as indicated in Table 3 and Fig. 7.

Moisture content was significantly lower in TAN-005 (0.0198%) compared to TAN-001 (1.6261%), meaning less steam generation during heating and higher thermal stability.

Electrical conductivity was lowest in TAN-005 (41.6 µS/cm), indicating decreased ionic activity and corrosion risk, beneficial for TES longevity. TAN-001 had much higher conductivity (373.3 µS/cm), potentially leading to higher corrosion.

Calorific values were comparable across samples (~13 MJ/kg), showing moderate but consistent thermal energy storage capacity.

What these results collectively suggest is that, thermophilically speaking, TAN-005 is a better fit for TES use, mainly because its cheap price comes with low moisture and conductivity, factors that put thermal stability and material durability high on the priority list. TAN-001 is high in moisture and conductivity, so it could be a problem operationally, while TAN-006 sits somewhere in the middle and might still be considered with adequate handling and design considerations.

4.0 Conclusion and Recommendations

4.1 Conclusion

The study has brought out significant evidence that the silica sands, obtained from New Luika Gold Mining in the Songwe Region, have the potential to act as a thermal energy storage (TES) medium. Out of all the samples studied, TAN-005 showed the highest silica purity of 97.15%, with a moisture content of 0.0198% and 41.6 µS/cm of electrical conductivity, which made it fit for TES applications at high temperatures. Its other physical properties – low porosity and coarser particle size – also boost its ability to store heat and retain it. This kind of sand is thus capable of facilitating a cost-effective and environmentally friendly TES system, which falls in line with the larger goals of renewable energy and energy transition set by Tanzania.

In the Songwe Region, the use of indigenous silica sand presents great opportunities for energy system flexibility and reliability, while also supporting Tanzania's media decarbonisation strategies to drop reliance on imported materials and fossil fuels. In summary, the findings significantly contribute to the advancement and incorporation of silica sand-based TES technologies into Tanzania's energy infrastructure, particularly for the provision of reliable electricity access in rapidlyenlightened and off-grid areas.

4.2 Recommendations

Pilot Testing and Scale-Up: It is recommended to initiate pilot TES systems using the identified optimum silica sand (TAN-005) under real operational conditions to validate laboratory findings and address potential engineering challenges in large-scale applications.

Integration with Renewable Energy Projects: Policymakers and energy developers should explore the integration of silica sand-based TES with solar power plants and other intermittent renewable energy sources in the Songwe Region to enhance energy availability and grid stability.

Further Material Optimisation: Additional studies should focus on optimising particle size distribution, packing density, and thermal cycling durability to maximise TES performance and lifecycle.

Economic and Environmental Assessments: Comprehensive techno-economic analyses and life cycle assessments are necessary to quantify cost benefits, environmental impacts, and sustainability advantages relative to conventional TES materials.

Capacity Building and Local Industry Development: Capacity building through training and partnerships with local industries can promote the manufacture, deployment, and maintenance of TES systems utilising local silica sand, fostering regional economic growth.

Policy Support and Incentives: Government and regulatory bodies should provide supportive policies, incentives, and frameworks that encourage research, investment, and adoption of TES technologies as part of Tanzania's energy transition and rural electrification initiatives.

Following these recommendations, mineral resources can be tapped to allow Tanzania to develop backstopping sustainable energy storage solutions to usher in reliable clean energy access and industrialisation in the Songwe Region and beyond.

4.2.1 Advantages

Cost-Effectiveness: The abundant availability and low cost of silica sand can lower the overall TES system costs, making renewable energy more accessible.

High-Temperature Stability: The high silica content and low impurities imply high thermal stability, making silica sand suitable for high-temperature TES applications such as concentrated solar power (CSP).

Technical Flexibility: Silica sand's physical properties, like porosity and particle size, can be optimised for various TES system designs, enhancing heat retention and system efficiency.

Environmental Benefits: Using indigenous silica sand reduces environmental impacts linked to transportation and mining of imported materials, aligning with Tanzania's decarbonisation and sustainability goals.

Local Resource Utilisation: The silica sand is sourced locally from New Luika Gold Mining in the Songwe Region, which supports local industry development and reduces dependence on imported TES materials.

4.2.2 Limitations

Engineering Challenges at Scale: While laboratory tests show promising properties, scaling up TES systems with silica sand might encounter technical and engineering challenges that require field validation.

Material Handling and Processing: The need for drying, sieving, and possibly pre-treatment or blending silica sand to optimise particle size distribution adds complexity to material preparation.

Durability under Thermal Cycling: Long-term durability and structural integrity under repeated thermal cycles may require further study beyond initial stability tests to ensure lifecycle reliability.

Integration Complexity: Integrating silica sand-based TES with existing renewable energy infrastructure could require significant system design adaptations and operational adjustments.

Economic and Environmental Assessments Needed: Comprehensive techno-economic analyses and lifecycle environmental impact assessments are necessary to confirm cost-benefit and sustainability advantages over conventional materials.

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8.0 Declaration of Conflicting of Interests

The authors declare no conflict of interest.

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