HSLU Lucerne University of Applied Sciences and Arts

Engineering and Architecture
B.Sc.. Energy and Environmental Systems Engineering
Bachelor-Thesis

Cost Drivers of Large Thermal Energy Storage: A Mixed-Methods Analysis

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1. Introduction, Goals and Research Questions

Thermal energy storage (TES) is a key enabler of the energy transition, bridging the temporal mismatch between renewable energy generation and heat demand. Despite growing deployment of borehole (BTES) and tank (TTES) thermal energy storage systems, reliable cost functions for early-stage investment estimation remain limited. Project-level factors driving cost variability are insufficiently understood, making it difficult for investors and planners to assess financial implications early in the planning process.
This thesis aims to derive transparent power-law cost functions for BTES and TTES and to identify the key technical, organizational, and contextual factors that drive investment cost variability across realized projects.
Research questions: What are the primary cost drivers of large BTES and TTES systems? How do investment costs scale with system size? What project-specific factors explain deviations from the modelled cost?

2. Method Overview and Materials

The methodology follows four sequential phases as shown in the workflow figure. An existing dataset of realised BTES and TTES projects was iteratively refined through desk research and direct contact with project developers, adjusting all costs to a Swiss 2025 reference using inflation and purchasing power parity (PPP) corrections. Relevant cost drivers were identified through Pearson correlation analysis in log-log space, and power-law cost functions of the form CAPEX = a · x^b were derived using log-log ordinary least squares (OLS) regression. Outliers were identified using the interquartile range (IQR) method.

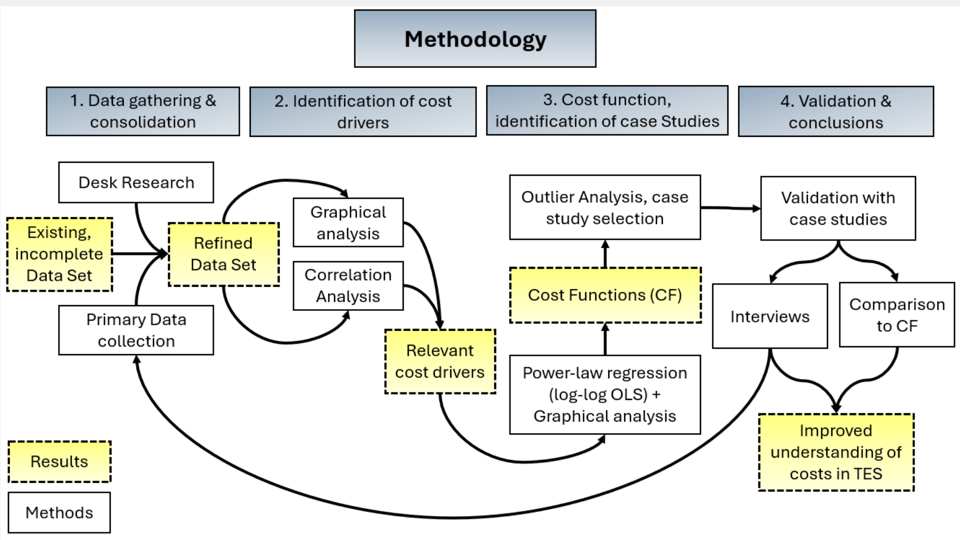

Figure: Illustration of methodology

Semi-structured expert interviews with explorative character were conducted with practitioners from selected projects to contextualize observed cost deviations. Notes taken throughout served as the primary qualitative data source and fed corrected cost figures back into the dataset iteratively.

Industry Partner: Competence Center Thermal Energy Storage, HSLU

3. Results and Discussion

Cost functions (BTES: drilling length, TTES: storage volume)

- BHE: near-linear scaling (b = 1.02, R^2 = 0.99)
- Other BTES: economies of scale (b = 0.59, R^2 = 0.83)
- Both TTES subgroups: b ≈ 2/3, confirming surface-area-dominated costs

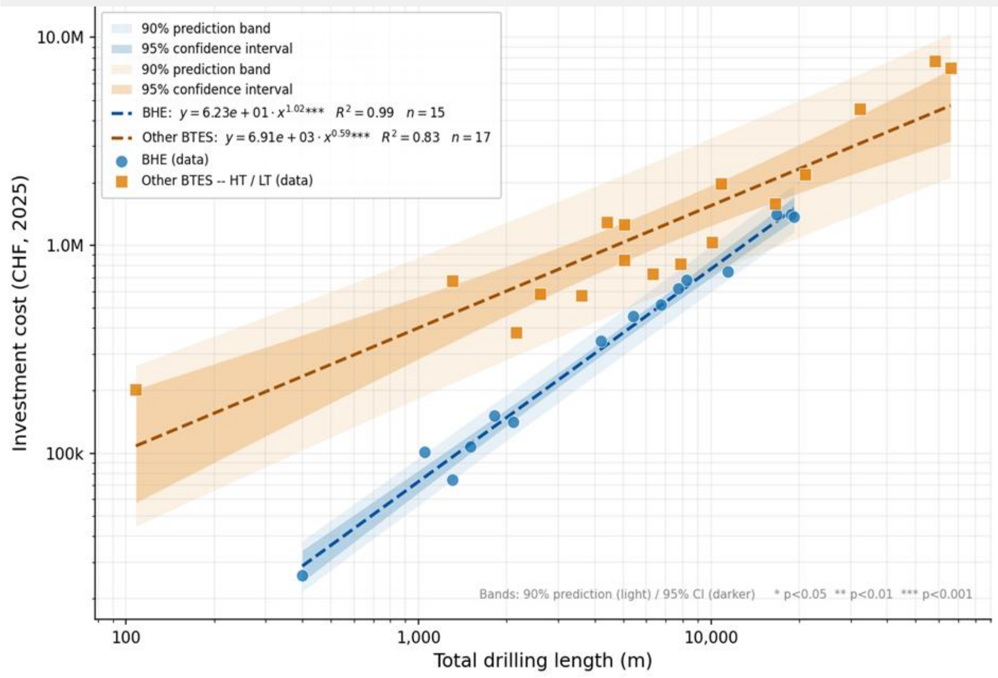

Figure: BTES cost functions derived, $CAPEX = a \cdot X^{\beta}$

Expert interviews revealed that hydrogeological conditions, drilling method, and borehole depth are the dominant cost drivers for BTES, while for TTES, tank wall thickness, district heating integration complexity, multi-tank configurations, and earthquake resistance requirements drive costs beyond what volume alone captures. Direct engagement with practitioners corrected several cost figures and substantially improved dataset accuracy across both technology groups.

4. Conclusion and Recommendations

The TTES scaling exponents confirm the theoretical 2/3 expectation. Expert interviews identified hydrogeological conditions, drilling method, and district heating integration as key cost drivers beyond system size. The PPP correction remains a limitation, as manufacturing and installation often occur in different countries. Future work could introduce project-specific correction factors, explore MWh-Thermal as a unified TTES cost driver, and extend the approach to aquifer and pit storage.

References

- Sarbu, I., & Sebarchievici, C. (2018). A comprehensive review of thermal energy storage. Sustainability, 10(1), Article 191. https://doi.org/10.3390/su10010191
- Lüchinger, R., Hendry, R., Walter, H., Worlitschek, J., & Schuetz, P. (2025). Cost analysis for large thermal energy storage systems. ASME Journal of Engineering for Sustainable Buildings and Cities, 6(2), Article 021006. https://doi.org/10.1115/1.4069122

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