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A framework for waste heat recovery utilizing machine learning, knowledge graphs, and large language models

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Extended Abstract

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Abstract Summary

This paper presents a novel, AI-driven framework to identify and evaluate industrial waste heat recovery potentials, addressing the challenge of highly heterogeneous and unstructured industrial data. The proposed methodology utilizes a hybrid data analysis pipeline that integrates machine learning, knowledge graphs, and large language models (LLMs).

First, unsupervised machine learning techniques—including natural language processing, dimensionality reduction, and density-based clustering—are applied to discover distinct thermal archetypes from unstructured site descriptions. Supervised learning models are then used to predictively categorize new, unseen companies into these established archetypes. Second, the extracted archetypes, alongside equipment and processes, are structured into a dynamically queryable knowledge graph to systematically map complex operational relationships.

Finally, the framework implements a hybrid Graph Retrieval-Augmented Generation (GraphRAG) architecture, enabling a locally hosted LLM to interact with the structured data. By dynamically combining exact structural graph queries with semantic vector retrieval, the system effectively synthesizes contextual information to answer complex analytical queries regarding waste heat recovery.

The results demonstrate that this integrated approach offers a resilient, highly scalable decision-support tool for industry stakeholders. Future research will focus on incorporating real-time operational time-series data and exploring larger reasoning models to deepen the analysis of thermal recovery potentials across broader geographic networks.

Presenting Author Biography

Amine Aamoume is a researcher at the Institute of Energy Systems (INES) at Offenburg University of Applied Sciences, Germany. He holds a background in electrical engineering and renewable energies, focusing his work on the optimization of modern power systems. His research experience includes developing energy management strategies for industrial applications and microgrids. Currently, his work centers on the intersection of power systems and artificial intelligence, specifically leveraging machine learning for advanced data analysis in energy contexts.