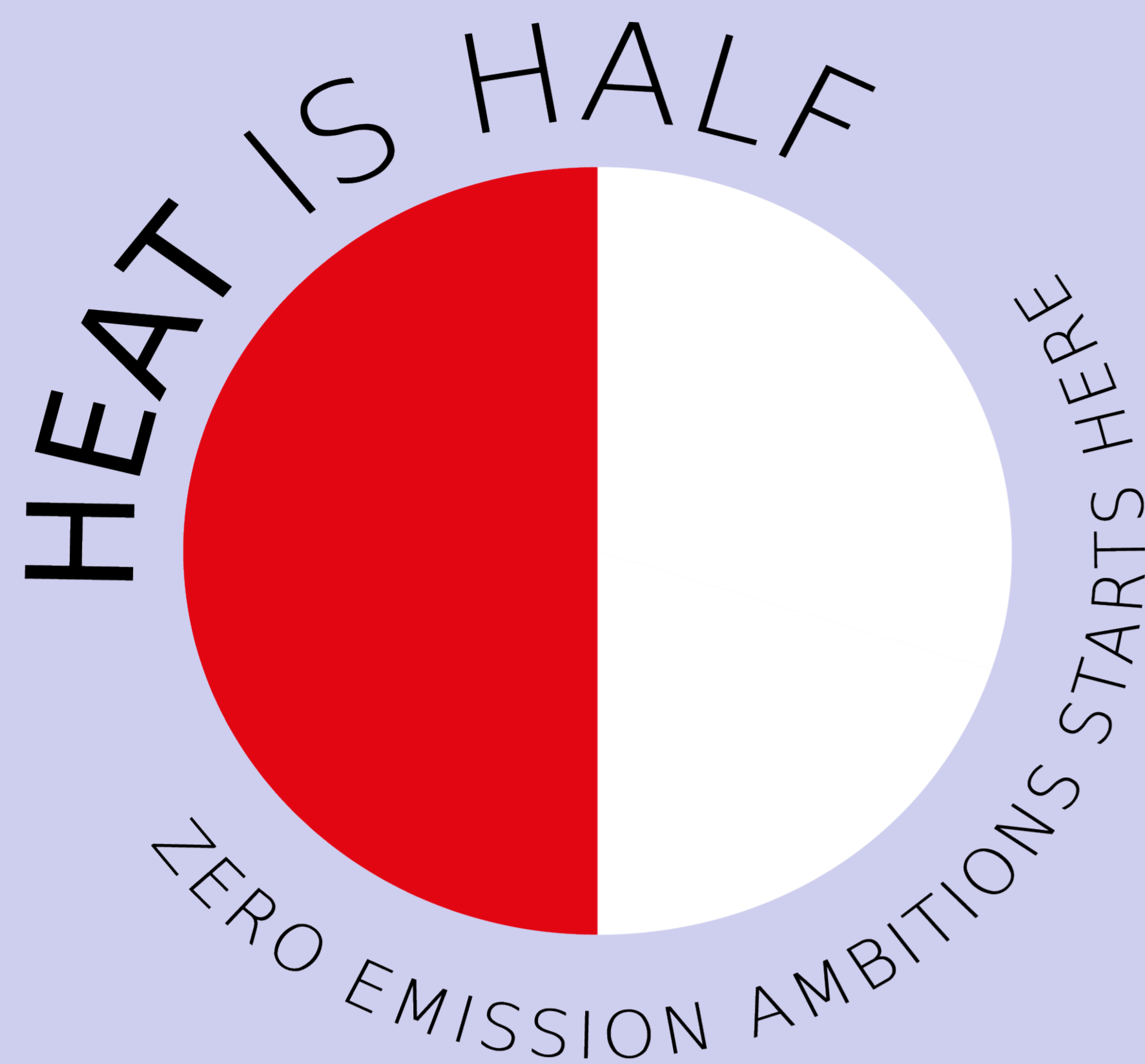


A novel hybrid system for medium-temperature industrial steam: Techno-economic performance across three European climates

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“Heat is half” of the Global final energy consumption, and need significant attention from policymaker to prioritise the decarbonisation efforts

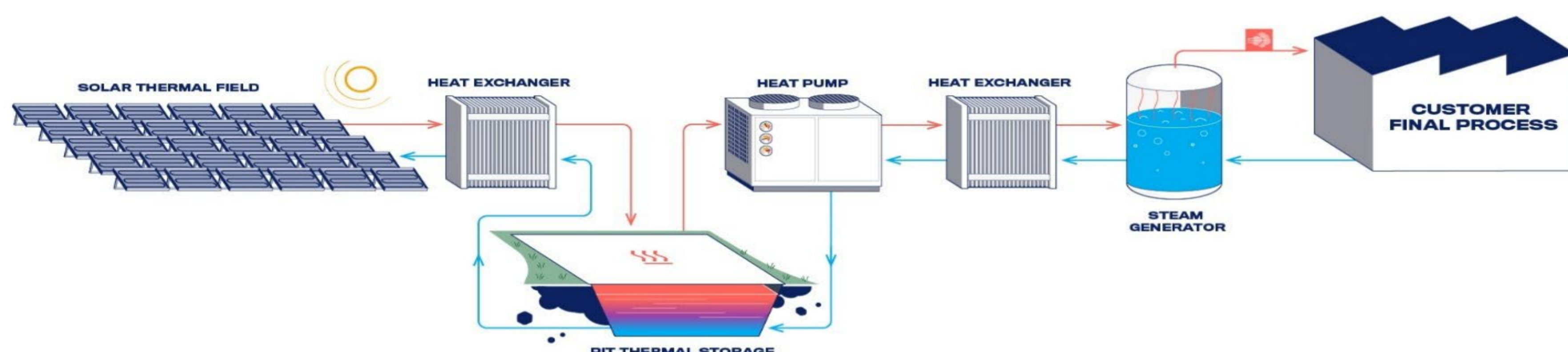
Synthesis of the work

The study presents a novel system combining solar thermal collector, pit thermal energy storage and heat pump for steam generation in food & beverage industry to generate steam at 150 °C.

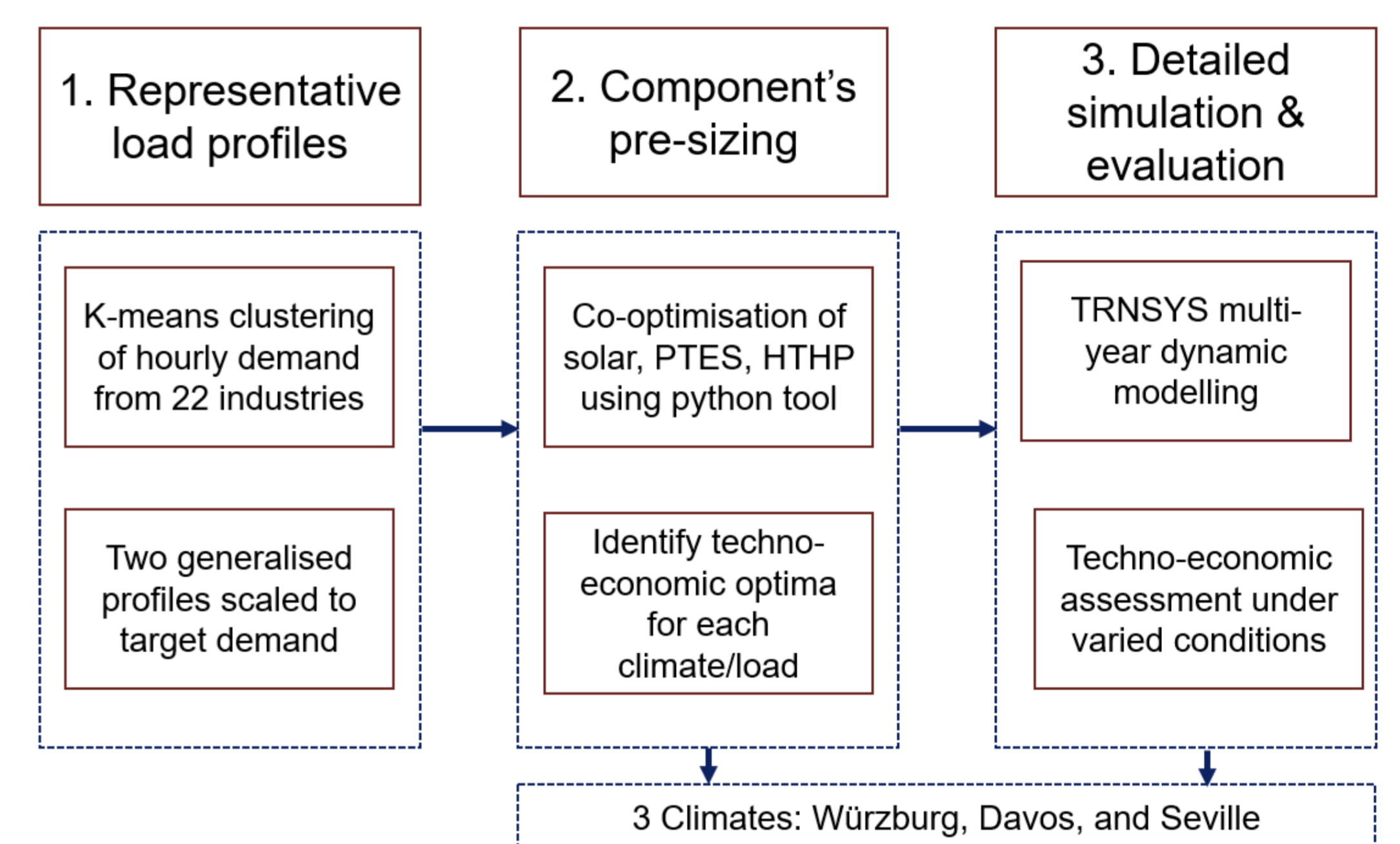
- ✓ The proposed hybrid system supplied 83–99% of annual steam demand across all climates and load profiles, showing strong potential for deep decarbonisation in industrial heating.
- ✓ Levelised Heating cost (LCOH) reaches 71–75 €/MWh in Seville at current electricity prices, with payback in 7–9 years compared to Fossil Gas.
- ✓ Technology collaboration is key to achieve high renewable heating fraction in industries and represent significant opportunities.

Aims

- To develop and evaluate a hybrid system combining flat-plate solar collectors, pit thermal energy storage, and a high-temperature heat pump for continuous 150 ° C industrial steam.
- To determine optimal component sizing and assess the techno-economic performance across different climates and industrial load profiles.



Method



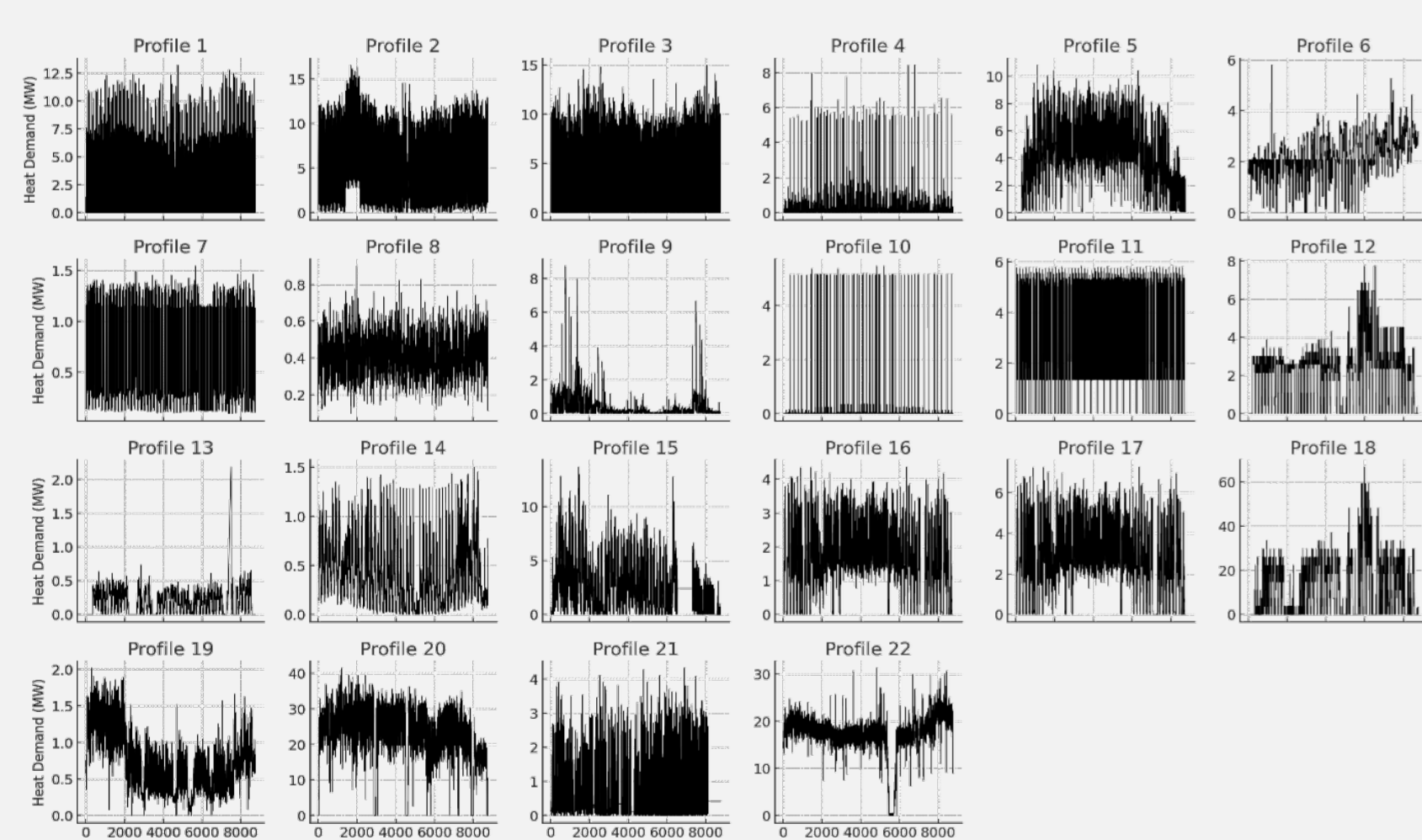
Step 1 – Load Profiles Derivation of representative industrial steam-demand profiles using k-means clustering of hourly data from 22 facilities.

Step 2 – System Pre-Sizing Python-based co-optimization tool to identify near-optimal sizes for solar collectors, Pit storage and heat pump.

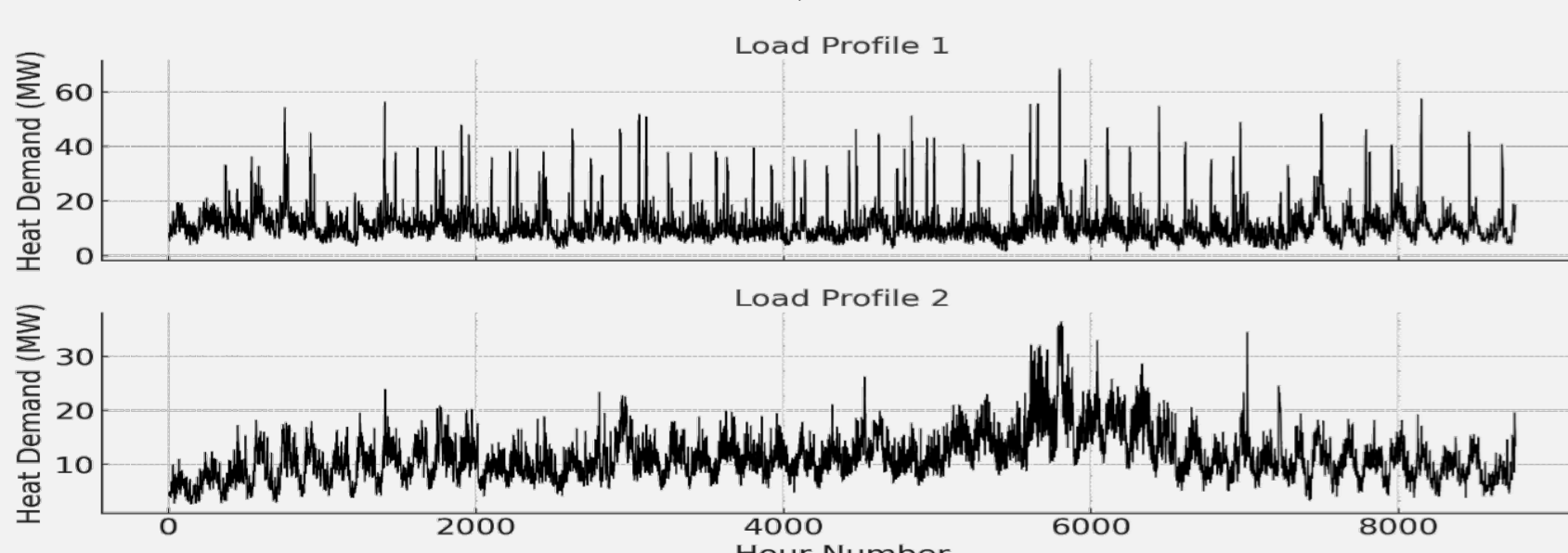
Step 3 – Detailed Simulation: Model the selected configuration in TRNSYS over multi-year operation to evaluate dynamics, storage behaviour, costs, and final LCOH.



Results: k-mean clustering



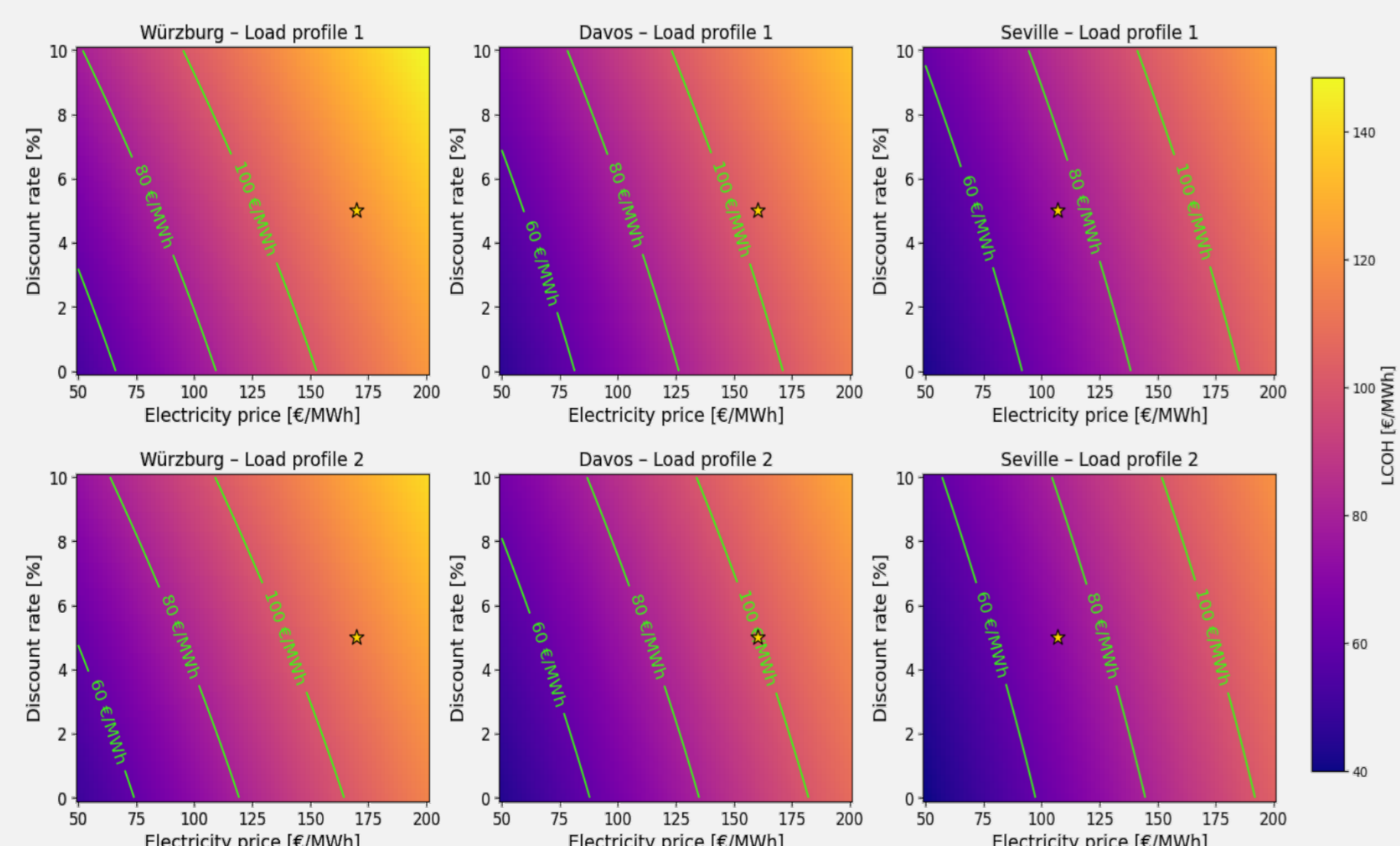
K-mean clustering



Upper: Annual hourly heat demand profiles for 22 industrial facilities, used as input for clustering analysis.

Lower: Scaled annual load profiles for Cluster 1 and Cluster 2, each representing 100 GWh/year of heating demand.

Results: LCOH



Sensitivity of LCOH to electricity price and discount rate for each climate–load profile pair. Green contour lines indicate constant LCOH values of 60, 80, and 100 €/MWh. Star markers denote LCOH at baseline conditions (country-specific electricity price and at a 5 % discount rate for 15 years economic lifetime).

In Summary, integrating solar collectors, Pit storage and an steam heat pump offers a practical, scalable path to deep decarbonisation of medium-temperature steam. However, ultimate competitiveness hinges on access to lower-cost, low-carbon electricity and supportive policy

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