Waste Heat Utilisation in Automotive Factories

From On-Site Heat Coverage to District Heating Contribution

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Relevance of Research

Motivation

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- Decarbonising **industrial heat** is key to climate-neutral energy systems (Thiel & Stark 2021)

→ Still largely supplied by **fossil fuels**

- **55 %** of final energy demand in **automotive manufacturing** is heat (Rohde 2024)

→ Also relevant **beyond** energy-intensive sectors

- Waste Heat Utilisation is a key strategy to reduce fossil fuel use (Hechelmann et al. 2024)

→ Utilisation depends on **temperature levels** and **temporal matching**

- Automotive processes generate waste heat across **diverse temperatures** and **temporal patterns** (Giampieri et al. 2024)

→ Waste heat quantities, temperature levels and temporal matching conditions are often **unknown**

Waste Heat potentials…

…in automotive manufacturing are substantial, but their practical utilisation at factory level remains challenging.

Relevance of Research

Research Gap

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– **Many studies** assess industrial waste heat potentials at **regional, sectoral or national scales** (e.g. Bianchi et al. 2019)…

…relying on **aggregated data** and **static temperature classifications**

Neglecting **factory-specific demand structures** and **integration feasibility**

…and assuming **average process conditions** (e.g. Manz et al. 2021)

Neglecting **temporal matching** between **waste heat supply** and **heat demand**

– Recent studies emphasise **time-resolved analyses** but often focus on **external heat export** (e.g. Burg et al. 2024, Theisinger et al. 2022)

Limited understanding of **internal waste heat utilisation** prior to **external export**

– Consequently, there is **limited** knowledge of **how temperature levels**, **integration feasibility** and **temporal matching** shape the practical **utilisation of waste heat** at **factory level**

RQ

(1) How can **factory-level** waste heat potentials be assessed considering **temperature levels** and **integration feasibility**?
(2) What share of…
(a) …**factory heat demand** can waste heat realistically cover?
(b) …**district heating demand** can the **remaining** waste heat realistically cover?

Methodology

Overview of General Procedure

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First Step (building on Woolley et al. 2018)

Factory-Level Waste Heat Assessment Framework

1. System Definition and Data Basis

- Monitoring Data
- Waste Heat Sources
- Thermal Energy System Boundary

2. Waste Heat Source Characterisation

- Carrier (Liquid/Gas)
- Temperature Level
- Aggregated Waste Heat Quantity

3. Classification by Integration Feasibility

- Direct Usable
- Indirect Usable

4. Factory-Level Waste Heat Potential

Direct Usable

- Total Waste Heat Potential
- Share of Heat Demand
- Average Temperature Level

Indirect Usable

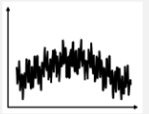
- Total Waste Heat Potential
- Share of Head Demand
- Average Temperature Level

Second Step

Waste Heat Utilisation Modelling Framework

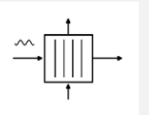
1. Definition of Waste Heat Categories

Directly Usable Waste Heat

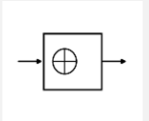


Indirectly Usable Waste Heat

2. Selection of Waste Heat Technology



Exhaust Gas Heat Exchanger



Heat Pump

3. Selection of Waste Heat Prioritisation

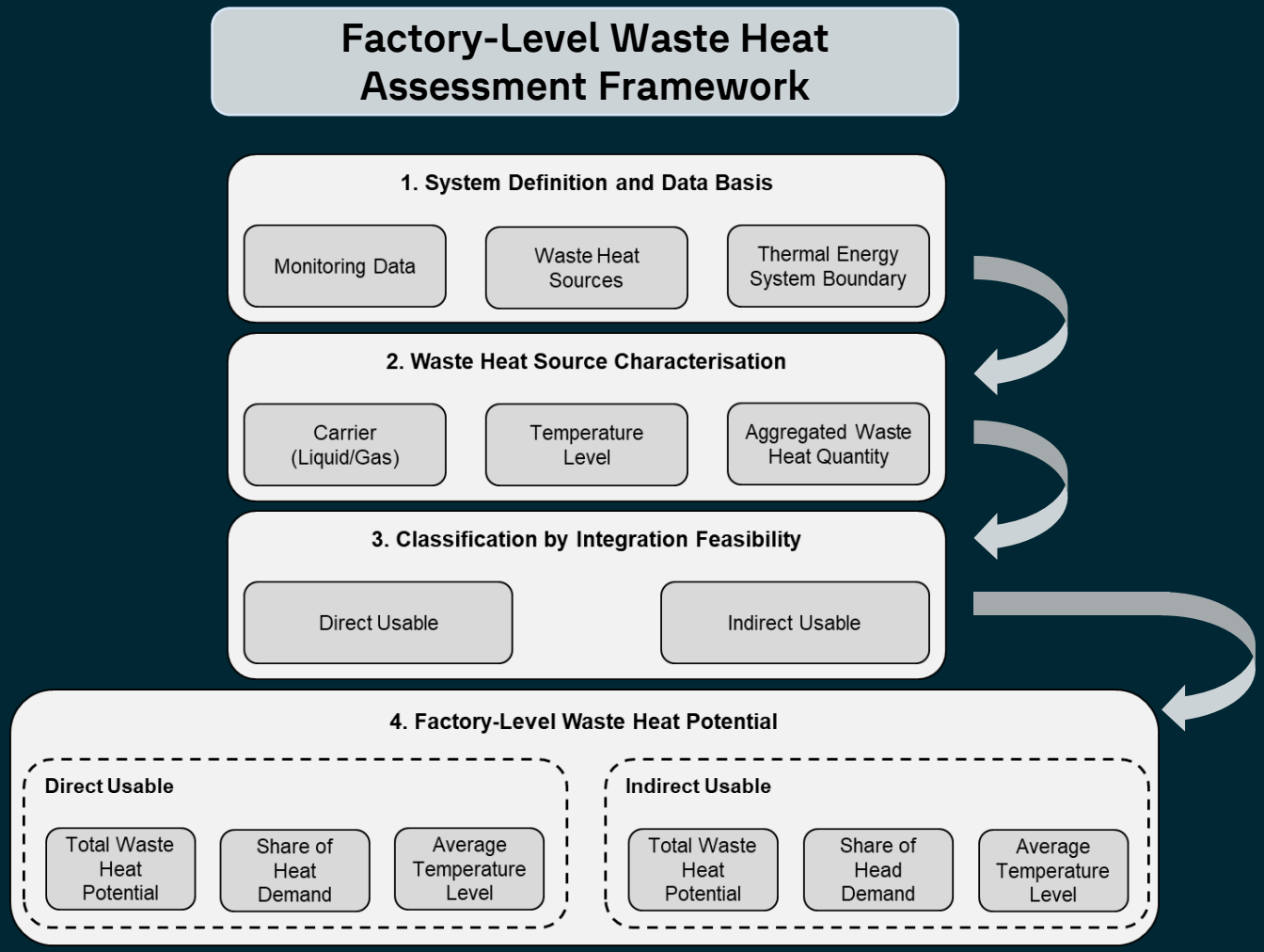
Factory Heat Demand

District Heat Demand

Methodology

Case Study Setup

First Step (building on Woolley et al. 2018)



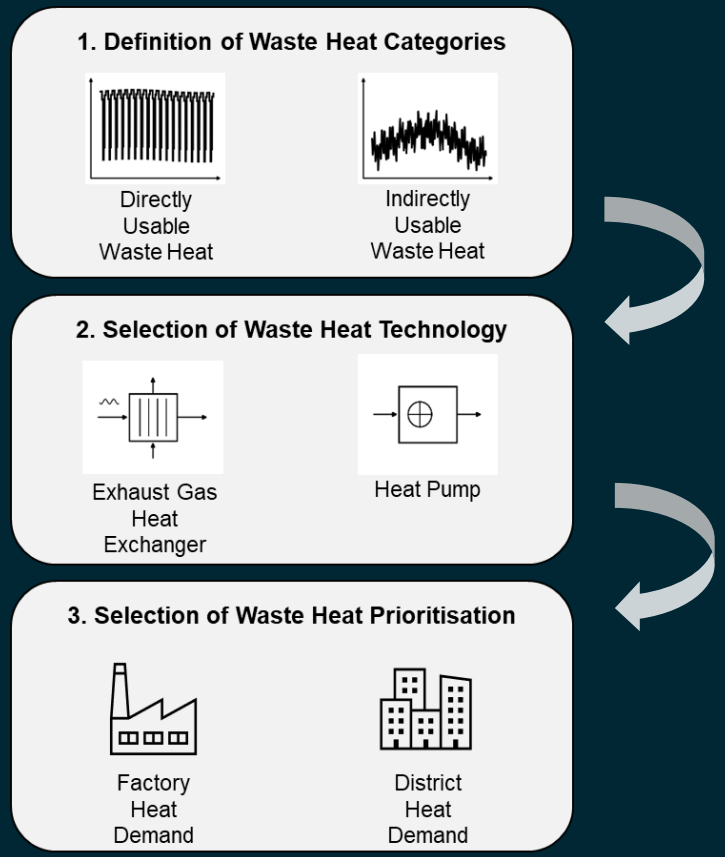
- Based on **real-world data** from **eight automotive factories** in Germany
  - **Four vehicle assembly** factories
  - **Four component manufacturing** factories
- Factory thermal energy system defined by a **central heating network** supplying **space and process heat**
- Waste heat quantities are **aggregated annually** for each source
- Integration feasibility is classified based on **process requirements** in automotive manufacturing
  - **Directly usable: ≥ 100 °C**
  - **Indirectly usable: < 100 °C**
- Total waste heat potential expressed relative to **annual** factory heat demand

Methodology

Case Study Setup

Second Step

Waste Heat Utilisation Modelling Framework



- **One representative vehicle assembly factory** selected
- Definition of waste heat categories based on **Step 1**
- Exhaust gas heat exchangers are modelled using a pinch temperature difference of **5 K**
- Heat pump performance is modelled using a constant COP based on **50 %** of the theoretical Carnot efficiency (Ahrendts et al. 2023)
- Selection of Waste Heat Prioritisation:
  - **First Prioritisation: Factory Heat Demand**
  - **Second Prioritisation: District Heat Demand**
- The model is run at an **hourly resolution** over a **one-year period**

Results First Step

Waste Heat Sources in Automotive Factories

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Low-Temperature → Indirectly Usable

- Generated by **cooling and conditioning of processes** and **equipment**
- Predominantly from **electrically driven systems**
- **Continuous and widely** distributed across factory systems
- Includes:
  - Cooling of machinery, welding and process equipment
  - Refrigeration and air-conditioning systems
  - Data centres and wastewater streams

→ Typically requires **heat pump integration**

High-Temperature → Directly Usable

Vehicle Assembly

- Mainly located in the **paint shop**
- Generated by **coating** and **curing processes**
- Released via **exhaust air from drying ovens**

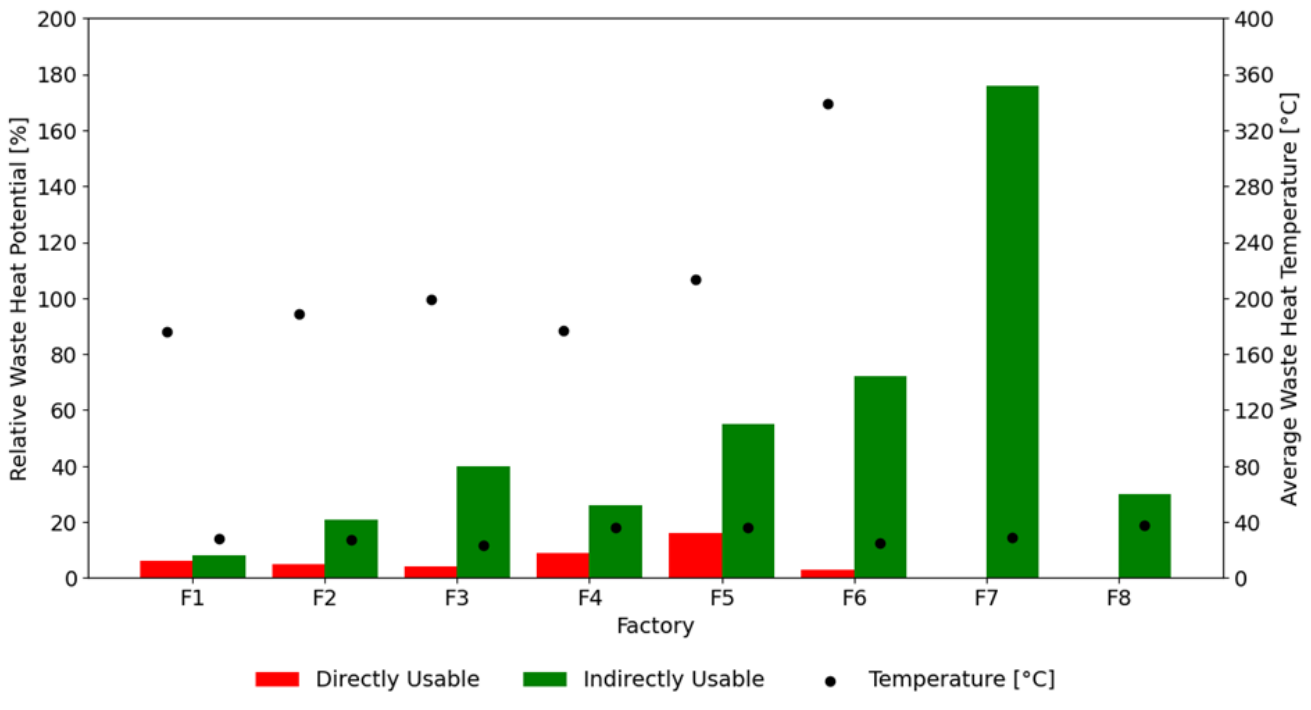
Component Manufacturing

- Originates from **forming** and **heat treatment processes**
- Driven by **furnace-based operations**
- Released via **exhaust gases and hot air streams**

→ Typically enables **direct heat recovery**

Results First Step

Factory-Level Waste Heat Potentials



- F1-F4: Vehicle Assembly Factories
- F5-F8: Component Manufacturing Factories
- Waste heat covers a **significant share** of heat demand
- Majority of potential is **indirectly usable**
- Directly usable potential is **limited**
- **Structural heterogeneity** across factories

Vehicle Assembly

- Directly usable: **4-9 %**
- Indirectly usable: **8-40 %**
- **Relatively consistent** across factories
- Driven by **similar process structures**

Component Manufacturing

- Directly usable: **3-16 %** (in process-intensive plants)
- **No direct** usable potential in assembly-oriented sites
- Indirectly usable: **30–176 %**
- **Strong heterogeneity** across component factories

Results Second Step

Utilisation of Waste Heat within the Factory

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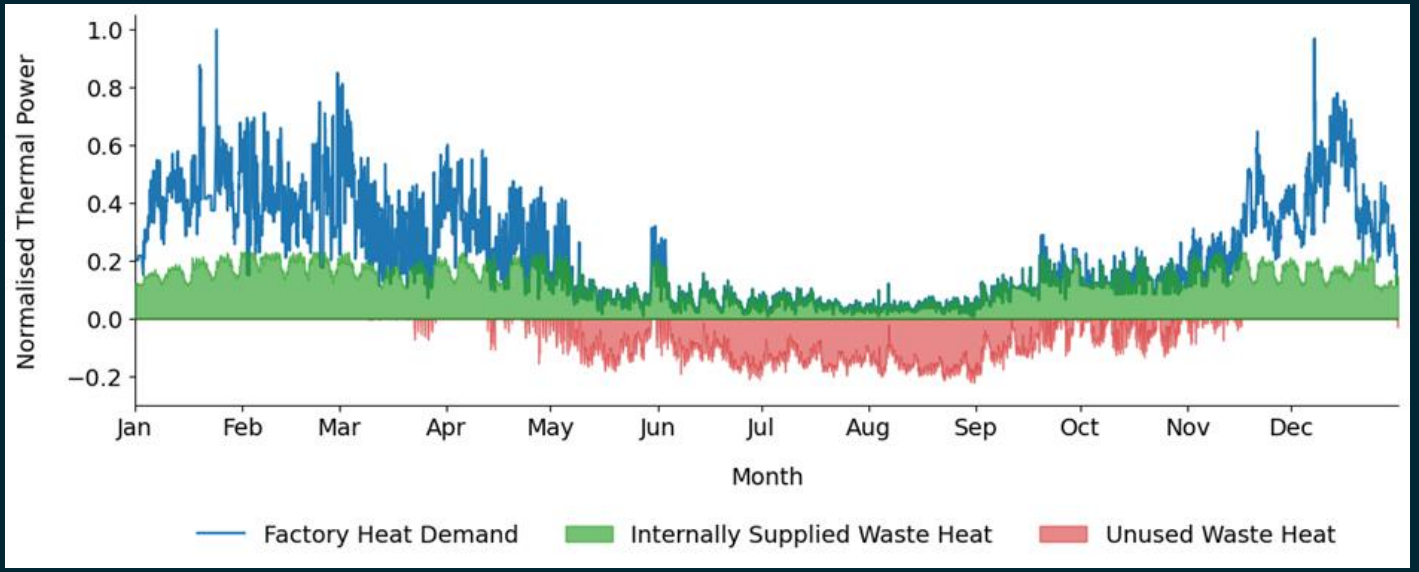


- Internal utilisation is **prioritised over external use**
- Waste heat supply and heat demand **show distinct seasonal patterns**
- During summer, waste heat can **fully cover factory heat demand**
- During winter, waste heat can **cover only part of the demand**
- Results highlight the importance of **time-resolved analysis**

Key Results

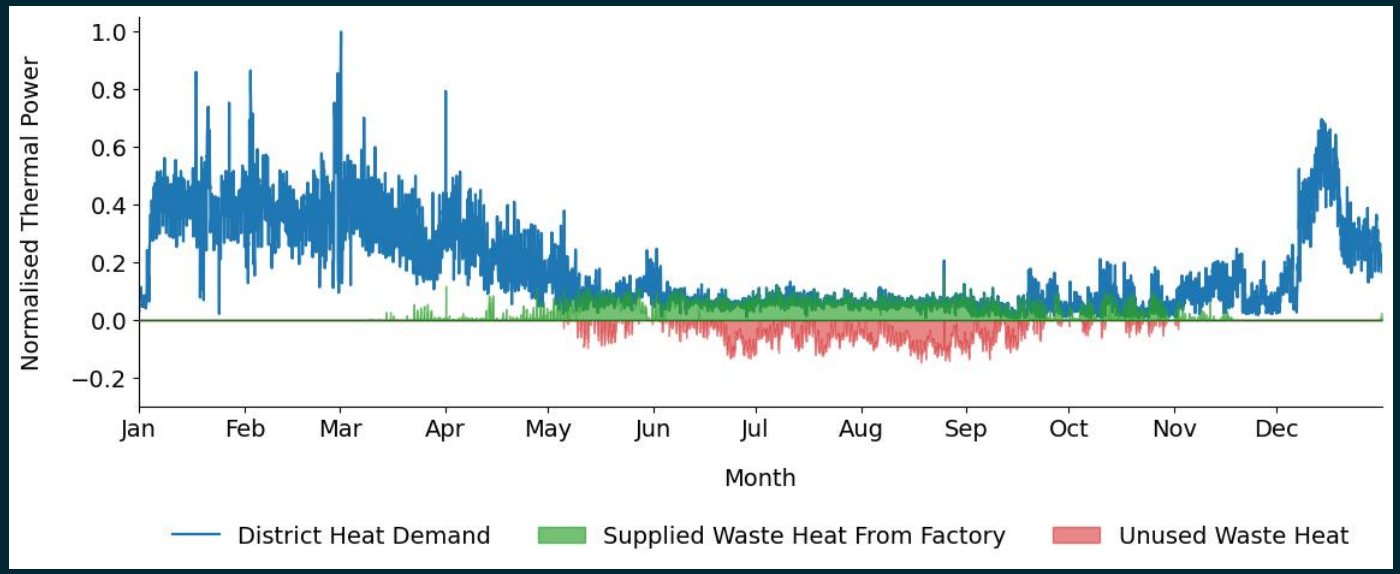
- **57 %** of annual heat demand covered by waste heat
- **70 %** of waste heat effectively utilised
- **30 % remains** unused due to temporal mismatch
- Surplus occurs mainly from May till October

Technology Insight

- Directly usable waste heat is utilisable **year-round**
- Surplus originates **from indirectly usable waste heat**
- Indirectly usable waste heat enabled by a **central heat pump system (SPF = 2.6)**

Results Second Step

External Utilisation of Waste Heat in a District Heating System



- Surplus waste heat is **only available after internal demand is satisfied**
- Waste heat supply and district heat demand **show opposite seasonal patterns**
- External utilisation occurs mainly during **summer months**
- In winter, surplus waste heat **is nearly absent** due to high factory heat demand

Key Results

- **18 %** of waste heat is exported to district heating
- Waste heat covers **14 %** of district heating demand
- **12 %** of total waste heat remains unused due to the lack of coincident demand and thermal energy storage capacity

Conclusion

Implications & Future Research

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Our study provides **several important contributions…**

1

…revealing that waste heat in **automotive manufacturing** originates from **structurally different sources**
…distinguishing between **directly usable** and **indirectly usable** waste heat

2

…showing that **waste heat potential** does not necessarily translate into practical utilisation
…quantifying realistic utilisation under **time-resolved operating conditions**
…identifying **temporal mismatch** as key constraint

3

…demonstrating that waste heat utilisation is a **key lever** for decarbonising factory heat supply in non-energy intensive manufacturing sectors such as automotive
…showing that external utilisation is **limited and seasonally concentrated**

Future Research should …

…develop **integrated energy and material flow models** that allow for a holistic and system-level assessment of **waste heat integration pathways**.

Thank you for listening and contributing to our research

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