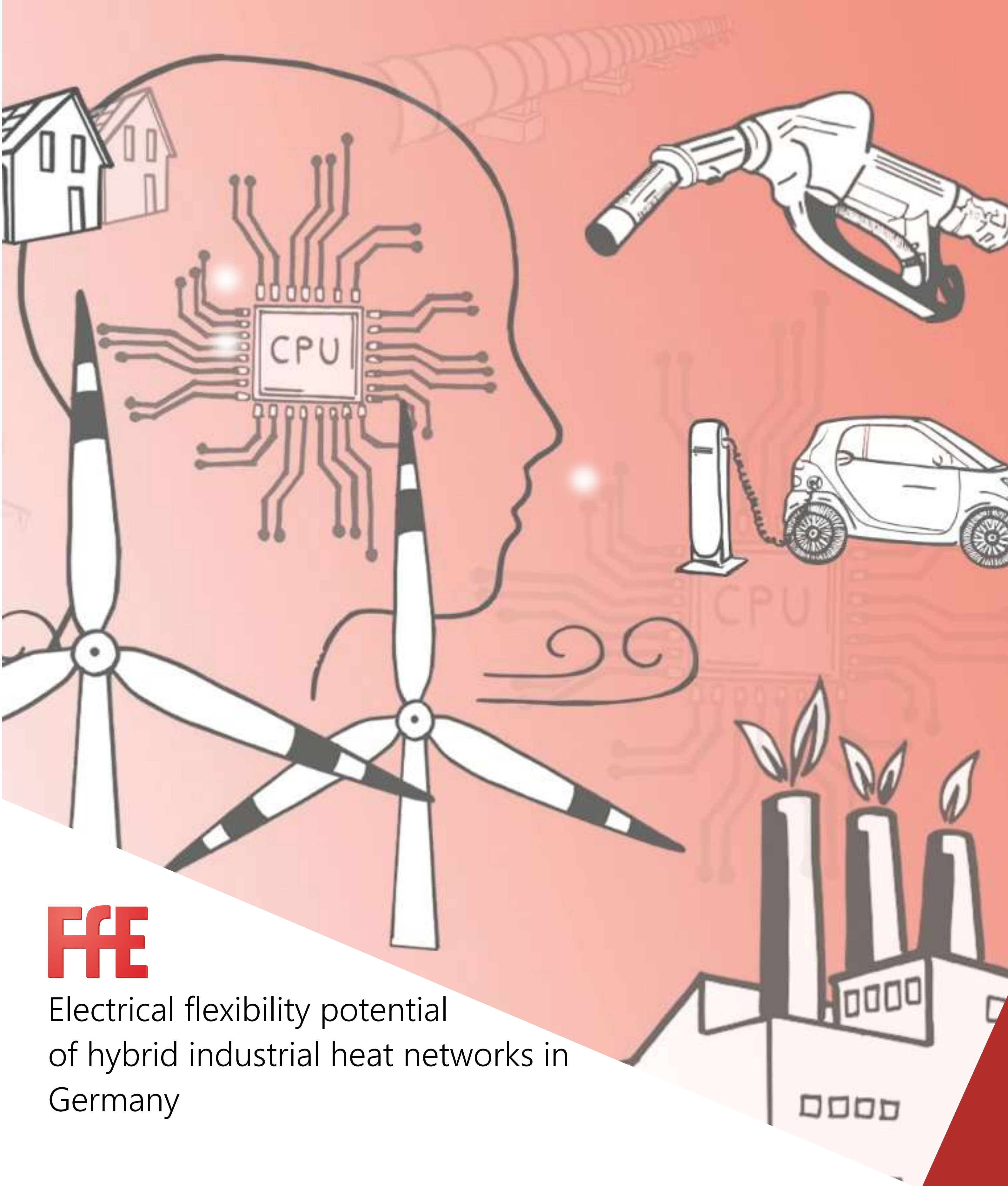

Electrical flexibility potential of hybrid industrial heat networks in Germany

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For a cost-efficient energy supply based on intermittent renewable energies, different flexibility options are needed. In Germany, the industrial thermal energy demand accounts for 22 % of the overall energy demand. If industrial thermal networks were hybridized, they could provide a flexibility of about .4.7 GW (base scenario) to 14.5 GW (maximum flexibility scenario)

Several studies indicate that for the future heat supply based on renewables, the significance of thermal networks will increase. For example, in [1] it is assumed that in 2050 thermal networks will provide about 38 % of overall thermal energy supply.

The aim of this analysis is to estimate the flexibility potential, which industrial thermal networks could currently provide to the electricity supply system through an on-site connection of fuel-based heat supply technologies with electricity-based ones (hybridisation). This hybridisation allows that, at times of lacking electricity in the supply system, the fuel-based technology provides heat, while at times of high electricity generation the electricity-based technologies do. In the distant future, fuel-based technologies can use green fuels, making overall energy supply renewable.

Here firstly, possible interconnections of heat supply technologies to provide flexibility are discussed. Then, a top-down analysis of the German industrial thermal energy demand is presented and relevant data for network-based heat supply is extracted. From this, the yearly thermal energy provided by fossil fuel-based industrial thermal networks is determined as well as their potential flexible electrical load. The step by step reached results are summarized in Figure 1.

A more detailed discussion of the relevant boundary conditions for flexibilisation of industrial thermal networks, the possible technology interconnections and an estimation of the flexibility potential of grid overheating are depicted in [2].

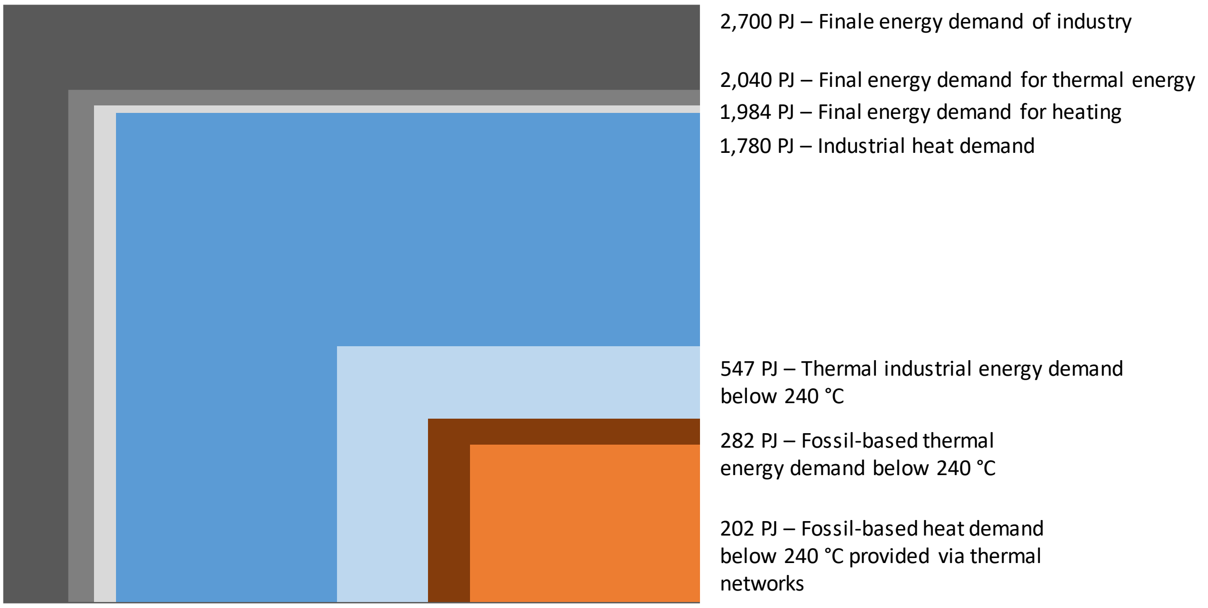

Figure 1: Results for step-by-step determined flexibility potential of industrial thermal networks

Suitable heating unit interconnections for hybridized heat supply

Case studies indicate that, in order to reach an efficient thermal energy supply, an interconnection of several heat sources is suitable. These will be multivalent (operating simultaneously) and multi-energetic (based on several energy sources).

Also when operating several units, the input energy used (e.g. electricity) must be used as efficiently as possible. For example, at low flow temperatures heat pumps are significantly more efficient than electric and electrode boilers. However, they will foreseeably not be able to provide heat at temperatures above 120 °C efficiently. Hence, a temperature-wise interconnection of this low temperature heat source with high temperature heat sources (electric boilers, fuel-based boilers or CHP units) is suitable. An overview on useful hybrid technology combinations depending on the flow temperature is stated in Table 1.

Table 1: Overview on suitable technology interconnection by target temperature level (electrode and electric boilers are summarized as electric boiler)

Target temperature	Suitable technology combination for hybrid systems
Flow < 120 °C	alternating: heat pump, CHP, fuel-based boiler
Flow > 120 °C	interconnected: heat pump + electric boiler / CHP / steam boiler alternative: CHP, electric boiler, steam boiler
Flow > 120 °C and Return > 120 °C	alternating: CHP, steam boiler and or electric boiler

The most cost efficient operation of the hybrid systems depends on the difference in heat generation costs from electricity and from fuels. In order to provide support to the energy system, furthermore, it has to be differentiated between times of need for an increase or decrease in electricity demand. Details on system operation are discussed in [2].

Network-suitable industrial thermal energy demand

In 2017, the German industry consumed 2,700 PJ of final energy out of which 2,040 PJ was used to provide thermal energy (22% of German energy demand) [3]. This demand is divided into 89 % process heat, 7 % space heating, 1 % domestic hot water, 1 % air conditioning and 2 % process cooling (2%) [4]. The final energy demand per final energy type (breakdown see [4] resp. [2]) in combination with energy conversion efficiency factors per final energy[1], indicates that the industrial heat demand lay at 1,780 PJ.

Thermal energy demand at temperatures of over 240 °C is not relevant for network based thermal energy supply. Therefore, the industrial process heat demand by temperature level is determined, see Figure 2. About 24 % or 396 PJ of the overall process heat supply are provided at temperatures below 240 °C and are included in the theoretical potential for network based heat supply. This potential can be significantly increased by including surface heating (136 PJ) and domestic hot water (15 PJ). Thus, the potential for network-based thermal heat supply lies at 547 PJ or respectively 31% of industrial heat demand

[1] Renewable energies, fuels, waste and waste heat 88 %; district heating 98 %, electricity 99 %

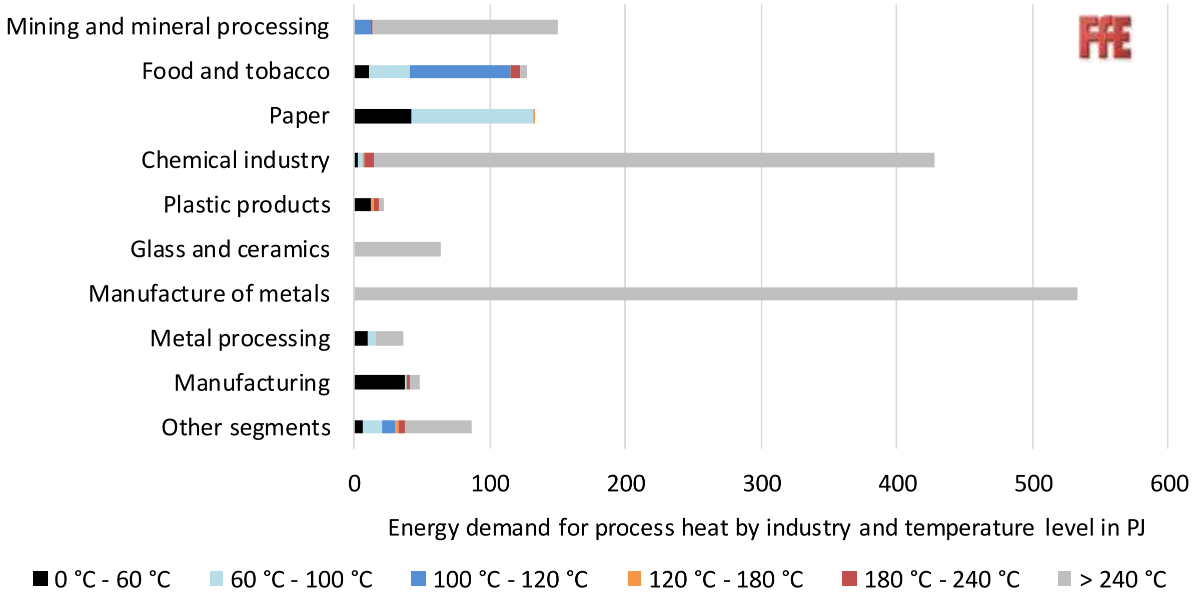

Figure 2: Energy demand for process heat by industrial branch and temperature level, based on data from [4] and [5]

Hybridization of currently fossil fuel-based heat supply

As only fossil fuel-based heat generation units shall become part of a hybrid system, the industrial heat demand supplied by electricity, district heating, renewable heat generation or waste and waste heat units must be subtracted from the potential of 547 PJ.

In Figure 3, the network-suitable process heat demand by industrial branch and temperature level is depicted as well as the energy provision from several energy sources [3]. The graph shows that, according to the data available, in several branches the energy provision from the four "not displaceable energy sources" is higher than the relevant heat demand at network suitable temperature levels, e.g. chemical industry. These branches are excluded from further analysis. For the remaining branches, the energy provided by renewable energies and district heating is assumed to cover an energy demand at temperatures below 240 °C, the heat supply by electrical energy and waste, however, is subtracted from all temperature levels.

The remaining potential for hybridized industrial thermal heat supply, expanded by the fossil fuel-based heat demand for surface heating and domestic hot water, lies at 282 PJ and therefore at 16 % of overall heat demand in the industry.

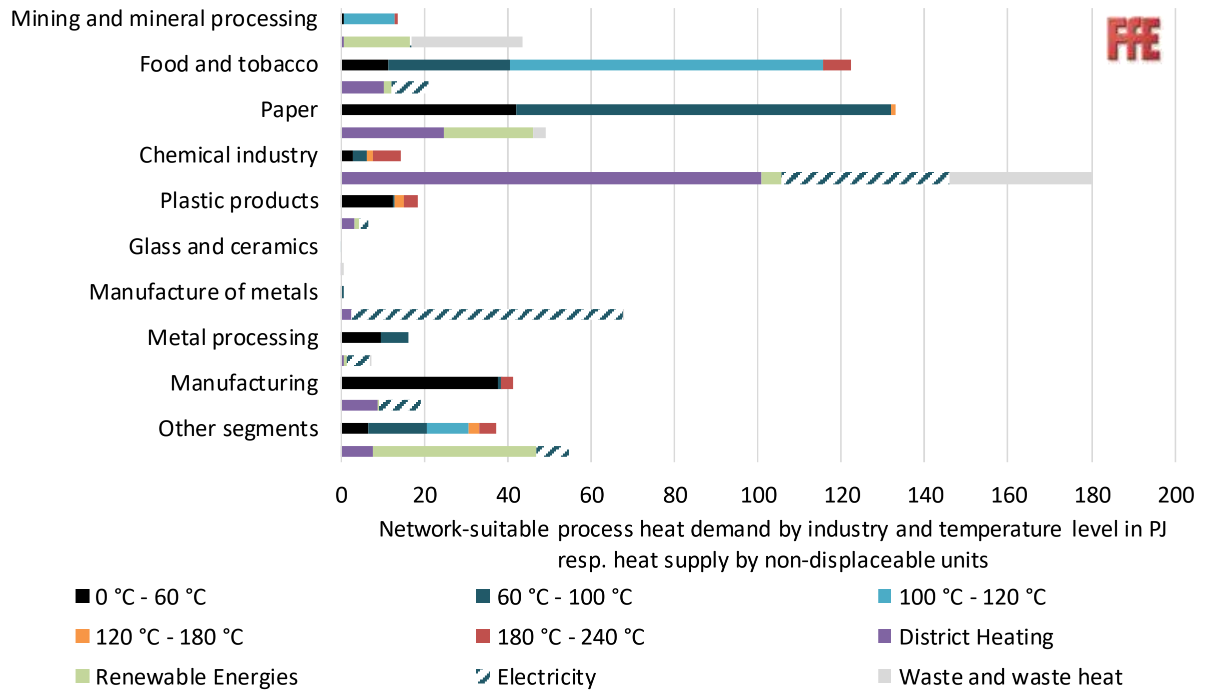

Figure 3: Energy demand for process heat by industrial branch regarding temperature level and energy provision from renewable energies, electricity and district heating, derived from [3], [4] and [5].

Subtraction of decentral heat supply - Analysis of heat supply in real factories

In many industrial applications, decentral units provide heat at network-suitable temperatures and must therefore be subtracted from the potential. FfE holds a vast dataset on energy supply in real industrial sites, which was analysed for this investigation. Table 2 gives an overview on the share of network-based heat supply in the companies analysed.

Table 2: Overview on share of central based heat supply at adequate temperatures in the analysed dataset

Industry	Number of companies	Companies with heat demand < 240 °C	Share of network based process heat demand	Share of network based surface heating demand
Rubber and plastics	3	3	65 %	90 %
Glass, ceramics, mining	3	2	90 %	0%
Paper	4	4	69 %	100 %
Metal processing, manufacture of metals	8	5	38 %	83 %
Chemical industry	5	5	98 %	98 %
Manufacturing	13	8	62 %	95 %
Food and tobacco	11	11	99 %	96 %

Excluding this decentral heat supply a potential of 202 PJ or a share of 11 % of overall industrial heat demand remains as suitable for hybridized thermal network-based heat supply (see Figure 4).

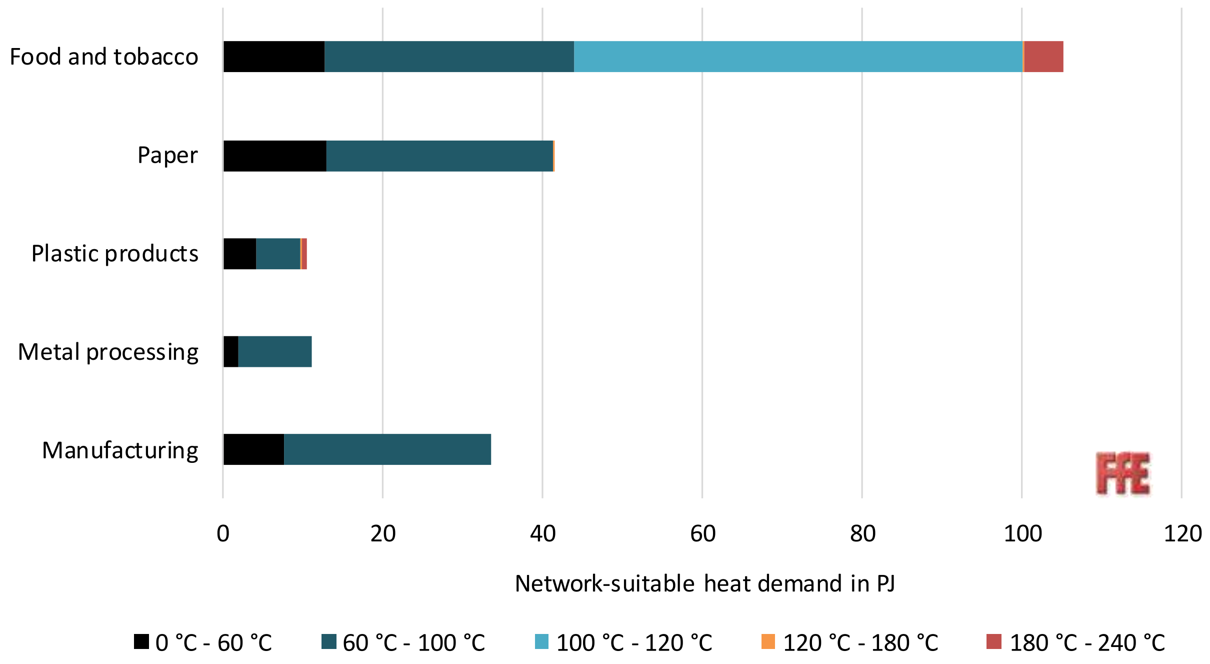

Figure 4 Energy demand for heating purposes centrally provided by fossil fuels, potentially to be provided by hybridized industrial thermal networks

Installed network connected heat load

In Table 3 the potentials calculated are aggregated to suitable network temperatures and combined with the electric heating unit for the base scenario. In the base scenario, heat pumps are applied for a temperature lift up to 120 °C and the further temperature spread is provided by electrode boilers. In the maximum flexibility scenario, a maximization of installed electricity consumption is assumed, hence all heat is provided by electric boilers.

Table 3: Overview on relevant temperature levels for grid based thermal energy supply, adequate technologies and flexibility potential

Network temperature level	Theoretical potential for network based thermal energy supply PJ	Applied technologies in base scenario
240 °C	5 PJ	Electric boiler
180 °C	1 PJ	Heat pump (COP = 3) + electric boiler
120 °C	156 PJ	Heat pump (COP = 3)
60 °C	40 PJ	Heat pump (COP = 4)

From the available data no valid estimation of the installed load per energy demand (also called full load hours of generation units) can be derived. Hence, the maximum flexible load for both scenarios is presented in Figure 5 for a variation in full load hours. An order of magnitude of 4.000 full load or less is plausible.

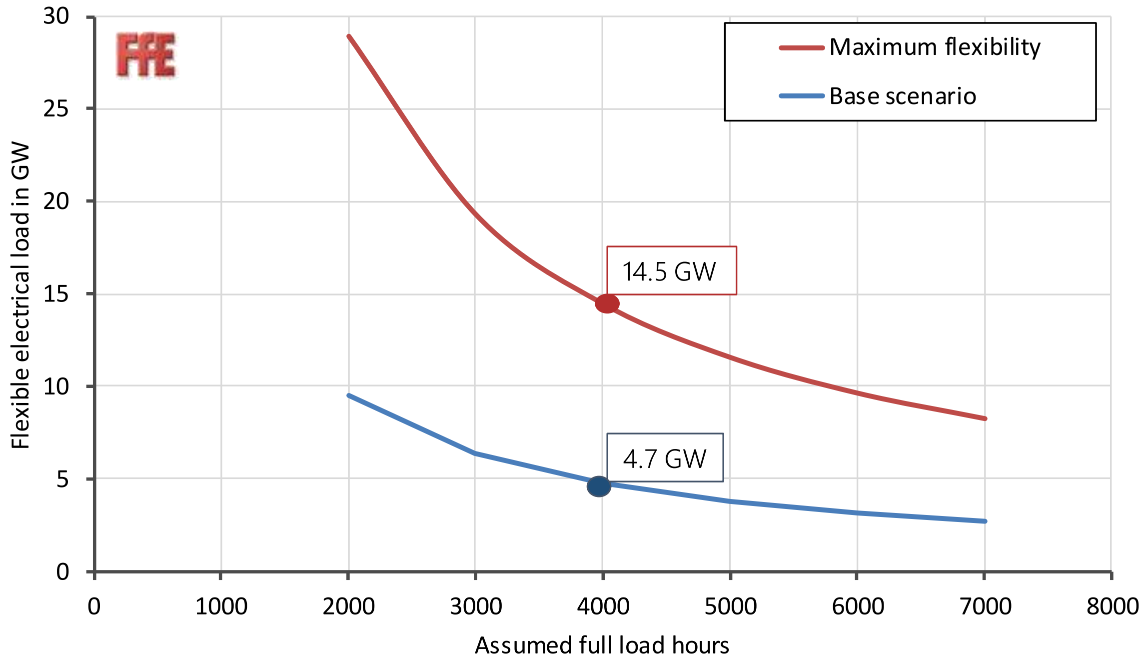

Figure 5: Visualization of flexible electrical load possibly provided from hybridized of industrial thermal networks

At 4,000 full-load hours, in the base scenario a flexible capacity of 4.7 GW is reached and 14.5 GW in the scenario with maximum flexibility. Compared to an average electricity demand in Germany of 59 GW, this makes up approx. 8 % (baseline scenario) or even 25 % (maximum flexibility scenario).

Limitation of research, conclusion and outlook

The main limitations of this research is data availability. Here future investigations on the flexibility potential should focus on a validation of the input data, especially the heat demand by temperature level and the assumed efficiency factors. In addition, the results shown in Figure 3 contradict the real-life experience that e.g. in the chemical industry fossil fuels provide a vast share of network-based heat.

In this investigation, the flexibility potential was only determined for the status quo. An analysis of several possible future scenarios could support the derivation and evaluation of a thermal network strategy. Overall, the vast cross-sectoral and countrywide potential of this flexibility option is worth further theoretical and practical investigations.

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