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Survey of Industrial Excess Heat Potentials in Austria

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Abstract. In the research and service study for the Energy Transition 2050 program, the technical excess heat potentials for both energy-intensive and energy-extensive Austrian industry were surveyed. A bottom-up approach for most of the energy-intensive industry and a top-down approach for most of the energy-extensive industry were used by the consortium under the leadership of the Chair of Energy Network Technology EVT of Montanuniversität Leoben. The surveyed potentials were classified according to temperature level of excess heat, origin from the process, spatial occurrence and industry sectors. In order to estimate the future industrial excess heat potentials, a database of the innovation network "New Energy for Industry" (NEFI) was used. For the geographical localization, the results were integrated into the existing Austrian Heat Map, which enables a comparison with heat demand densities and existing heating networks. A technical excess heat potential of about 34 TWh could be identified. Thereof, about 300 companies of the energy-intensive industry, which were mainly calculated by the bottom-up method, account for a technical excess heat potential of about 26 TWh. For the energy-extensive industry, an excess heat potential of about 4 TWh was identified for more than 1500 companies using mostly the statistical top-down method. Due to existing know-how in the consortium, the technical excess heat potentials of more than 600 sewage treatment plants could also be estimated at approx. 4 TWh.

Keywords: Excess Heat, Waste Heat, Industry

1. Introduction

In order to achieve a climate-neutral Austria by 2040, the climate-friendly conversion of all sectors, in particular the energy system and infrastructure, is stipulated as a regulatory requirement in the current govern ment program [1]. Expansion targets for renewable energies are defined, which are based on a series of studies regarding the known technical potential. The time frame extends at least until 2050, with implementation timetables up to 2030 are already very well described.

The specific focus of decarbonisation on all sectors relevant to energy consumption is also specified in the government programme (e.g. for 2040 by UBA scenarios) [2].

Further detailing for the industrial sector is also the subject of numerous national and international studies. The NEFI network [3] is also currently working on scenarios for industrial decarbonisation. The government program also stipulates that regulations must be created for the capture and integration of excess heat sources, particularly in the supply for space heating.

The final report of the accompanying research, which was carried out as part of the development of the Austrian heating strategy [4], clearly stated that a comprehensive data basis regarding Austrian excess heat potential is lacking and therefore needs to be developed.

This can also be seen when analysing the surveys available for Austria: The surveys only show sections of the excess heat potentials and heat supply structure in Austria, which are therefore not detailed enough or incomplete as they are obsolete or no longer available (KPC excess heat survey) or only contain local potentials (i.e. AWKST Excess Heat Cadastre III Styria [5], Heat_re_USE.Vienna [6]).

The differentiation of excess heat sources in terms of excess heat temperature, distance between heat source and sink and the time profile of heat availability, or the consideration of future changes in the relevant industrial processes, is not covered structurally anyway.

In terms of GIS representation, the Austrian Heat Map [7] is a very powerful platform for the heating sector, but it does not provide a comprehensive and detailed representation of excess heat data, as this has not yet been collected completely and in detail. This paper shows how and with which methodology this gap was closed for Austria.

2. Methodology

In a simplified form, every industrial plant can be seen as a "black box" into which any type of energy input must also leave in some form, whereby endothermic and exothermic processes must be considered separately.

The challenge arises from the fact that excess heat flows are often diluted or dissipated, i.e. occur at a low temperature level in large and elusive volume flows, and that the excess heat is often bound to products that are difficult to transmit to another heat transfer medium. [8]

In order to better define the methodology, definitions and classifications must be made in advance.

2.1 Definitions and Classifications

The first step is to define the term potential in order to get a clear idea and distinction of what is meant here. There are various definitions of the term "potential" in the literature, whereby these are mainly described for the renewables sector. For the calculation of the excess heat considered here, our own definitions were used.

The theoretical (or physical) potential only takes into account physical limitations: The heat must be above 0 °C (reference temperature) and bound to a heat transfer medium (liquid, gas, solid). The technical possibility of extracting or using the heat is not taken into account here. [8], [9]

Starting from the theoretical potential, restrictions such as limitations on heat extraction are taken into account for the technical potential, i.e. depending on the technical possibilities (e.g. state of the art). Technical limitations are, for example, the minimum temperature difference in the heat exchanger, heavy contamination of the heat transfer medium, biological boundary conditions for wastewater or operational safety. What is not taken into account here is whether there is a possibility of direct use (industrial operation with heat demand, existing heating network) or whether the use is economical. [8], [9]

It is important to point out that the results given here represent the technical potential as described above.

In terms of the classification of temperature categories, the following classes were chosen: >100 °C, 50 to 100 °C, 0 to 50 °C. This relatively fine classification in the lower temperature range compared to other studies is due to the expected increasing importance of low-temperature sources and their use in low-temperature or anergy networks in conjunction with heat pumps. [8], [9]

With the aim of universal applicability across all industries, 5 categories were classified as carrier media for excess heat. These are flue gas, condensation, wastewater and cooling water, product heat and exhaust heat/exhaust air for machine cooling. [8], [9]

When determining excess heat potential using the bottom-up method, special attention was paid to energy-intensive industries, whereby a classification according to ÖNACE was chosen. These are, for example, the manufacturing of iron and steel, paper/cardboard and articles thereof, metal production and processing, manufacturing of glass/goods, ceramics, etc.

When classifying the companies, an attempt was also made to record the distribution of excess heat over time. This can be done precisely by evaluating questionnaires, whereas the publication-based bottom-up method and top-down calculations are dependent on information from the company's website or other information from the web concerning production profiles. However, there is usually hardly any information available here. The temporal availability is usually split into seasonal and weekly effects. [8]

2.2 Methods for estimation excess heat

Unlike the input variables of industrial processes (e.g. energy source requirements), for which good statistical data is available, excess heat is often not recorded as an output variable with (direct) costs or benefits [10]. The survey of excess heat potentials is therefore complex and is further complicated by the heterogeneity of excess heat (heat quantity, heat carrier, temperature level and time profile of heat provision).

The literature describes different approaches for determining excess heat potential, which can be divided into top-down and bottom-up methods. **Figure 1** shows a classification of the two approaches including different methods and data sources.

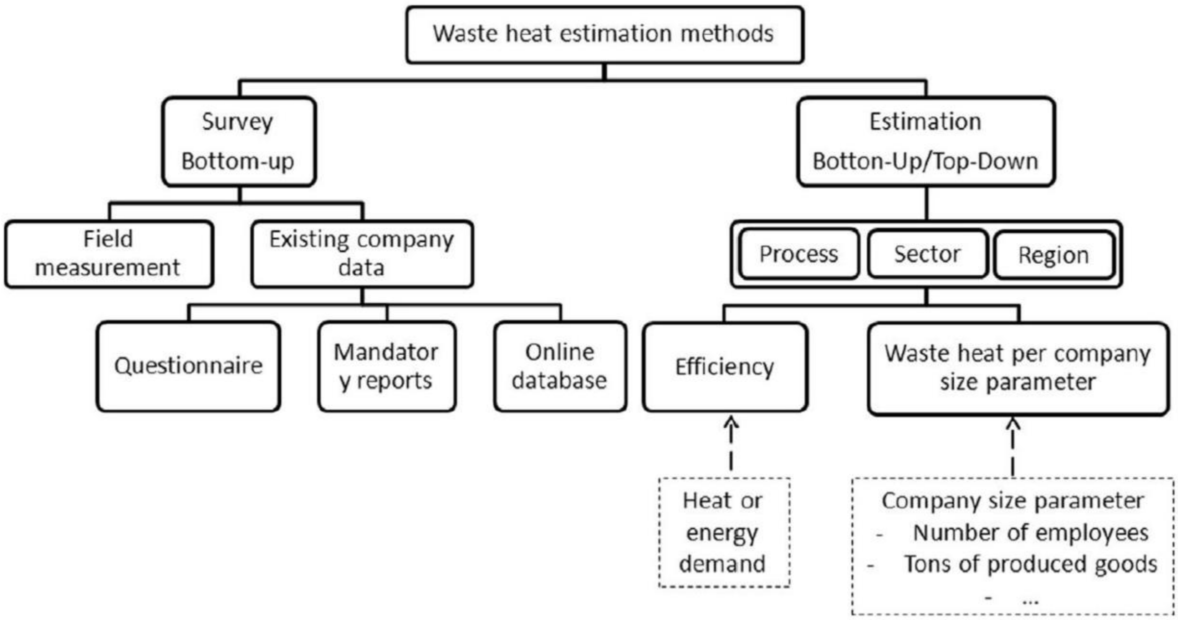

Figure 1. *Classification of methods for determining excess heat potential according to Brückner [10]*

For bottom-up approaches, direct measurements or surveys in which specific data is collected at company level can be used as the data basis. Based on this data, statements can be made about individual companies and, with appropriate data quality, also about entire sectors. Direct access to individual companies makes it possible to fully record the relevant excess heat parameters. [11]

Top-down approaches use general data (statistics, existing databases, etc.) which, when combined with suitable proxies, lead to an estimate of the desired value. Proxies used include the efficiency of individual processes or systems or key figures from specific sectors (e.g. excess heat potential per employee). Corresponding values can come from the literature or, in combination with a bottom-up approach, from surveys. With this approach, excess heat potentials can be determined on all scales. [11]

2.2 Procedure for calculation the excess heat in this study

In contrast to the work published in the literature (e.g. by Brückner [10]), not only excess heat from the flue gas streams but also from wastewater and cooling water, product heat and exhaust heat/exhaust air for machine cooling was taken into account in this study.

Various approaches were used to collect data in order to meet the requirements of both a good data situation at some locations and the large number of companies. In order to determine the excess heat, the primary energy demand, broken down into the individual energy sources, must first be collected in a first step. Only then it is possible to determine the excess heat based on the process analysis or using specific key figures. The energy requirements and excess heat quantities can also be transmitted directly via questionnaires which was also done in this study, but was not taken into account due to the low feedback rate. Figure 2 provides an overview of the methods used here.

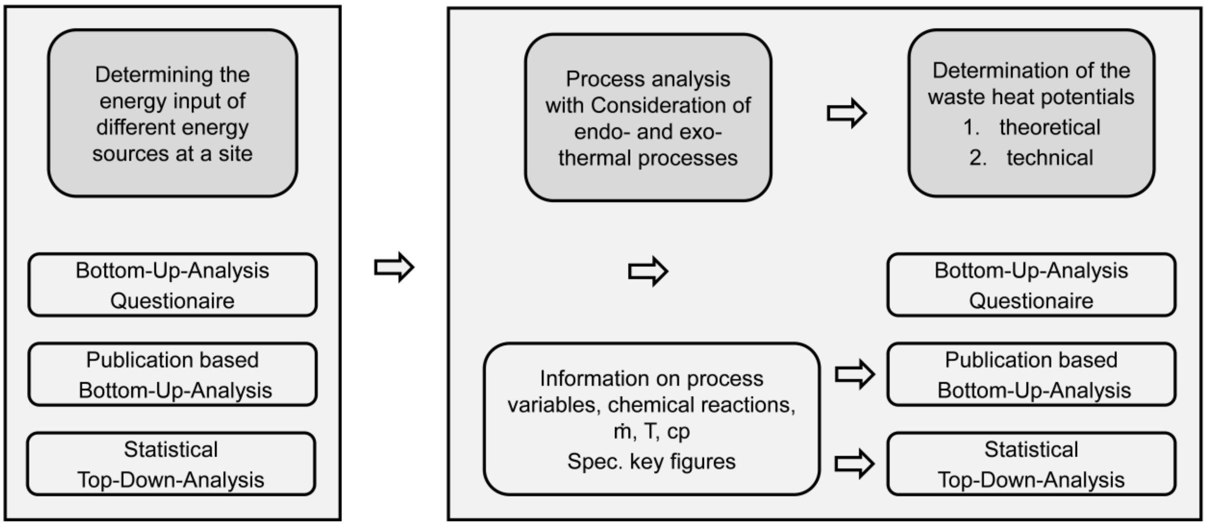

Figure 2. Overview of the general methodological approach used here to determine excess heat potentials [8]

In the case of methods using publicly available data, there is also a distinction between the publication-based bottom-up and the statistical top-down analysis. This division is based on Brückner [10], but Brückner only considers excess heat from the flue gas of combustion processes, which has already been mentioned above. In general, it should be noted that the distinction between bottom-up and top-down is not a sharp one, but a smooth transition.

The bottom-up approach used here (mostly for the energy-intensive sectors) is based on publicly available data such as environmental reports, EMAS environmental declarations [12] or company reports, broken down into the individual energy carrier.

If this information is not available, CO_2 emissions from the European Union Emission Trading System (EU ETS) database [13] are used and the energy input is recalculated via the energy carrier. For industries with process-related CO_2 (e.g. steel industry, cement production), this must be taken into account appropriately. Exothermic and endothermic processes must also be taken into consideration accordingly. Once the energy input is known, the next step is to research the processes and reproduce them as accurately as possible. This enables excess heat flows and temperatures to be determined via flue gas, condensation, wastewater or products. [8]

The top-down method was used at a few sites in energy-intensive industries and for evaluations most of energy-extensive industries for which neither environmental reports nor EMAS certificates nor production volumes or CO_2 emissions were available. In this approach key figures are formed from statistical data (e.g. energy per employee), and then used to determine the energy demand of the companies. Key figures from the literature (for example from [10], [14], [15], [16], [17]) or from our own calculations of similar industrial sectors are used to determine excess heat. A combination of bottom-up and top-down calculations is also possible (energy demand by top-down, excess heat by bottom-up and vice versa). [8]

It is important to note here once again that the results always represent the technical potential and do not take into account economic feasibility or the possibility of immediate use.

2.3 Future heat potentials for the years 2030 and 2040

In addition to the surveys of current excess heat potentials, which were based on the "pre-pandemic" year 2019, the excess heat potentials for the years 2030 and 2040 were also calculated.

In the study "Pathway to industrial decarbonisation" [18], NEFI has developed the industrial demand scenarios outlined as a visionary guide for stakeholders in the manufacturing industry, for political decision-makers and for technology providers. The three scenarios are "Business as usual" (BAU), "Pathway of Industry" (POI) and "Zero Emission" (ZEM) and based on the NEFI objectives (I) decarbonisation of the industrial energy system, (II) value creation through technology made in Austria, (III) securing production sites and jobs through user integration.

The scenario used in this study for the 2030 and 2040 forecast is the POI which is comparable to the "With Existing Measures" (WEM) scenario, but also takes into account the industry's perspective with its own measures.

However, only the energy input was extrapolated, while the excess heat factors were used from the current values.

The future excess heat potentials of the sewage treatment plants were extrapolated on the basis of the forecast population development.

3. Results

A total technical excess heat potential of around 34 TWh was identified for all sectors evaluated, including gas compressor stations and sewage treatment plants. Around 300 companies in the energy-intensive industry, which were mainly calculated using the bottom-up approach, account for a total potential of around 22 TWh (**Figure 3**). Gas transport in pipelines (bottom-up method) account for about 2 TWh. In 1500 companies in the energy-intensive industry (more than 50 employees), which were mostly calculated using the statistical top-down method and for some larger companies using the bottom-up approach, account for around 6 TWh. In addition, the excess heat potential of more than 600 sewage treatment plants was estimated at around 4 TWh.

It is obvious to see that excess heat in the lower temperature range up to 50 °C accounts for by far the largest share, at almost 28 TWh. It can also be seen that excess heat potential above 100 °C is mainly available in the energy-intensive industry and from gas pipeline compressor stations.

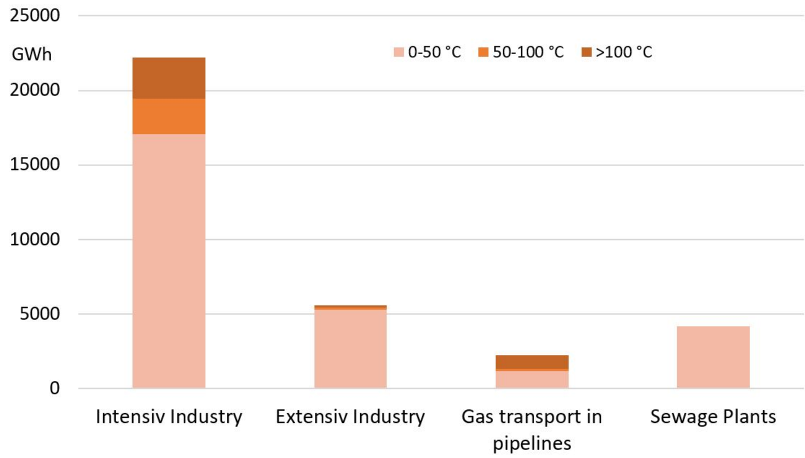

***Figure 3.** Results for different categories with temperature distribution*

If we classify the excess heat into temperature categories only, it becomes clear that the majority of excess heat (81 %) is available at a temperature below 50 °C (**Figure 4**).

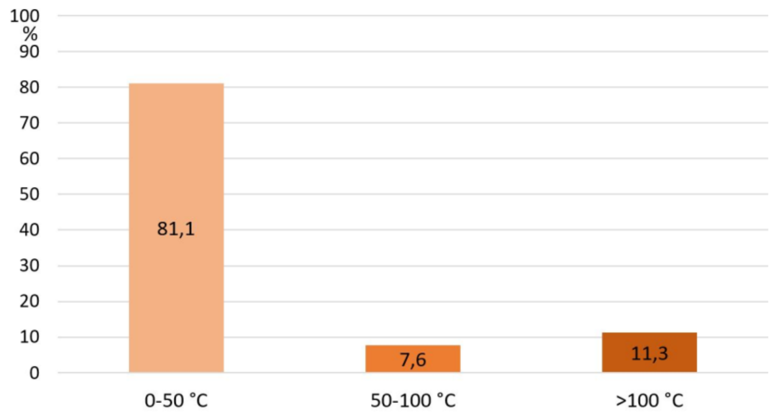

Figure 4. *Temperature distribution for all industries, inclusive Gas transport in pipelines and sewage plants.*

Figure 5 shows the temperature distribution of excess heat from all sectors considered (including gas transport in pipelines and sewage treatment plants) with classification into 3 temperature categories <50°C, 50-100°C and >100°C.

The huge potential of the iron and steel industry is remarkable here, also with a large share in the higher temperature range. A similarly high proportion in the upper temperature range can be seen in the production of chemicals, non-metallic minerals products and in gas transportation in pipelines.

Other large amounts of excess heat were found in the pulp and paper division, but only in the medium and lower temperature range. In sewage treatment plants and in the entire field of extensive industry, the big potentials are due to the large number of sites and here only in the lower temperature range.

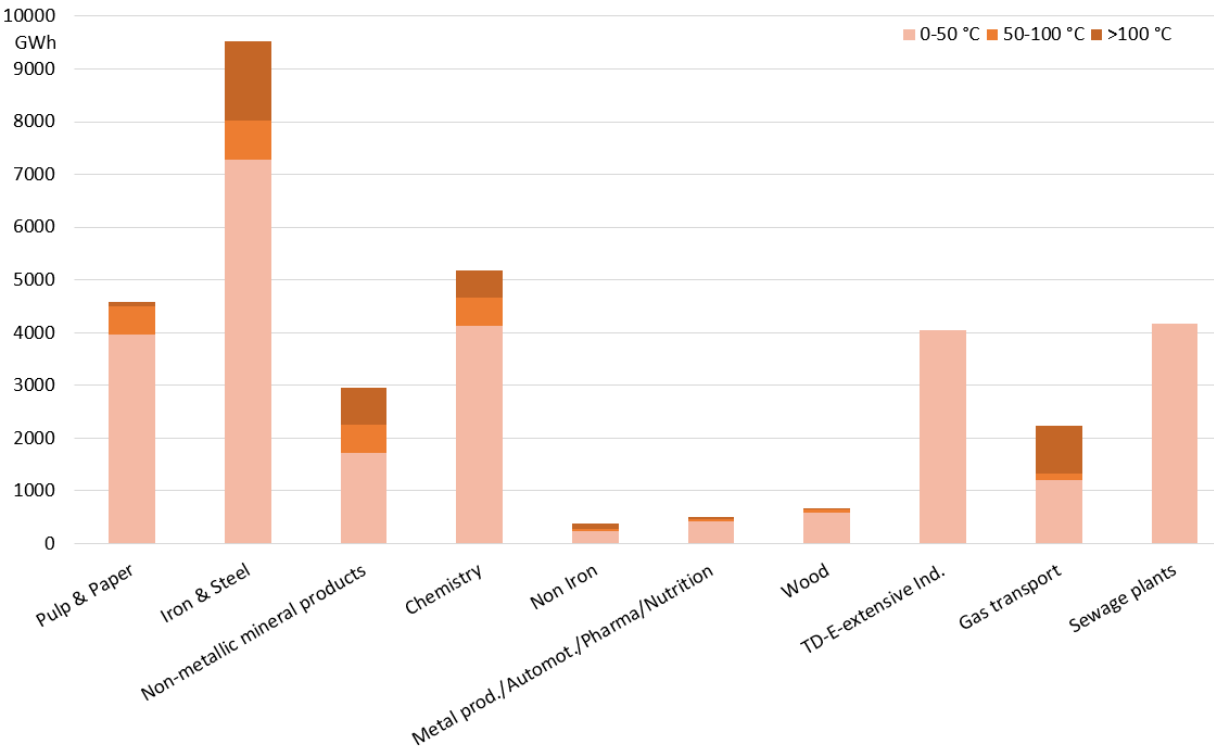

Figure 5. *Results of the excess heat survey by various ÖNACE categories and temperature ranges*

According to this estimation, the future total excess heat potential will be 32 TWh for 2030 and 34 TWh for 2040, compared to 34 TWh for 2019. **Figure 6** shows an increase in excess heat potential for almost all sectors, stagnation for pulp and paper and a decrease for iron and steel. In the latter case, the strong influence of technological changes can be seen.

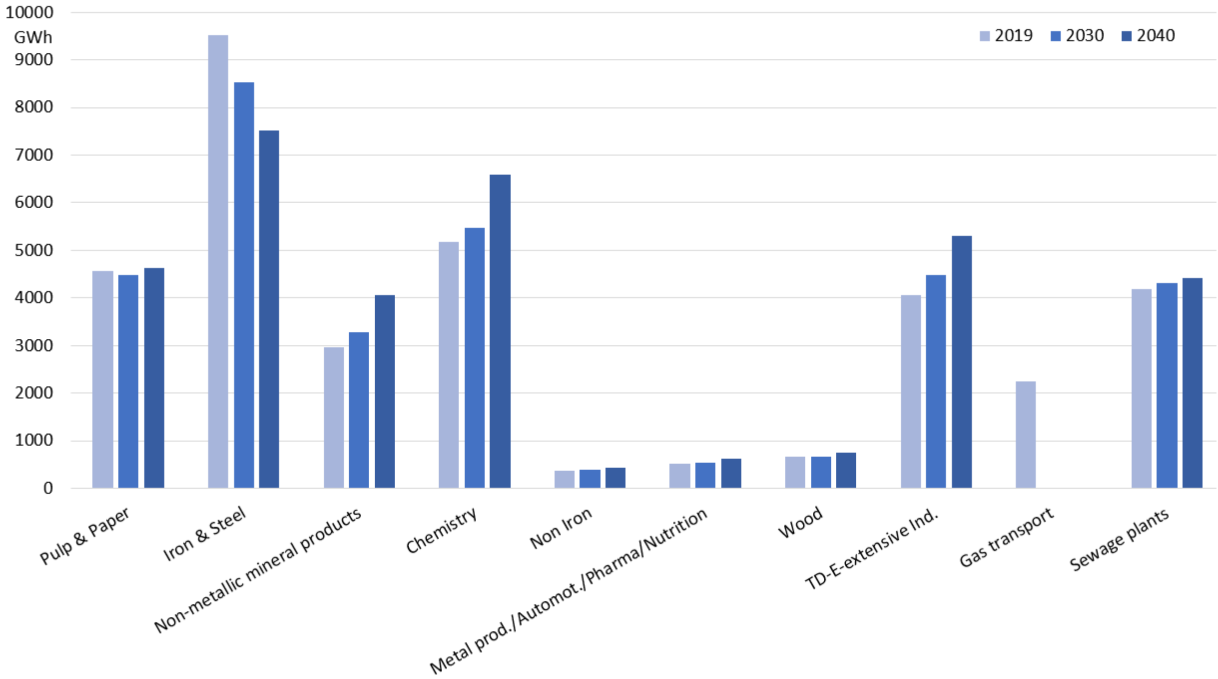

Figure 6. *Development of excess heat potential for 2030 and 2040*

The next step was the integration of the calculated data into the existing Austrian Heat Map [7], which massively increased the amount of data and at the same time provided a higher level of detail on the type of information.

The available information was expanded to include the technical potential of the various categories of excess heat (flue gas, wastewater, etc.) and their temperature levels (see **Figure 7**). In addition to the massive increase in the number of companies represented, previously unrepresented sectors such as pharmaceuticals, food and beverages, wood processing of gas transportation in pipelines have been included. Sewage treatment plants were newly included, for which a separate added layer was defined so that the large number of these low-temperature sources does not cover up industrial excess heat.

The more than 1500 companies in the energy-extensive industry, which were calculated using the top-down analyses, were aggregated per district. This was necessary to ensure visibility in the map and can also be switched on and off via a separate layer.

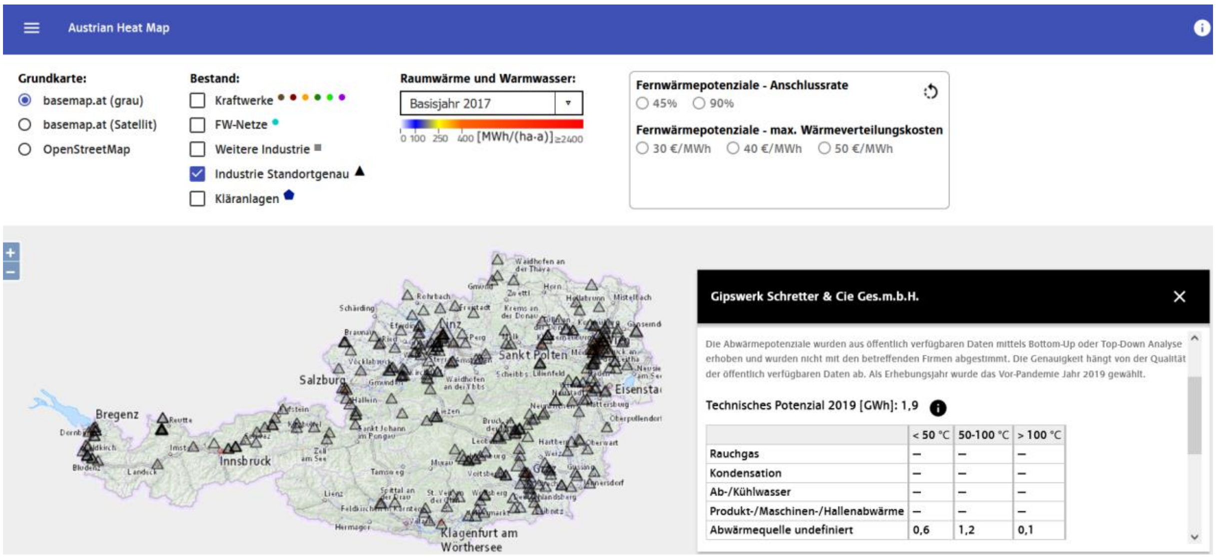

Figure 7. *Illustration of excess heat potentials in the heat map [7]*

4. Summary and conclusion

The identified excess heat potential of 34 TWh can only be properly assessed if this is related to the consumption values. If we compare the energy demand for space heating and hot water in all sectors (approx. 100 TWh, data from Statistics Austria's useful energy analysis), excess heat could cover around a third of this. When compared with the demand for space heating in the private sector (approx. 54 TWh), as much as 62 % could be covered by excess heat. Compared to the demand for process heat below 200 °C with around 19 TWh, excess heat exceeds this demand by far [19]. The use of heat pumps increases these percentages again by the electrical drive energy of the heat pump.

The influence of the processes used on the available temperatures is also clearly evident.

Processes at high temperatures, such as the melting of iron and steel, glass or the production of cement clinker, lead to excess heat at higher temperatures. If drying processes dominate, such as in the paper or wood sectors, the proportion of excess heat at low temperatures is significantly higher. Most processes in the energy-extensive industry, as well as sewage treatment plants, are also usually operated at low temperatures and therefore offer little to no excess heat in the high-temperature range.

Therefore the majority (about 28 TWh, 81 %) of the excess heat found can be allocated to the temperature class below 50 °C. Except for drying purposes or air preheating, this low-quality excess heat can hardly be used directly and needs a temperature rise via heat pump. If the excess heat is decoupled into heating networks, only 5th generation heating networks [20], also known as ultra-low temperature district heating ULTDH [21] or Anergy Networks, can be considered at this low temperature level. In order to achieve the turnaround in the heating sector, it is absolutely necessary to take this currently rarely used technologies into account.

For the forecast of energy demand in 2030 and 2040, the economic development for energy-intensive branches was combined with technical developments in the corresponding branch. Economic growth and technological progress such as efficiency improvements show opposing trends, which weaken each other in their influence on excess heat utilization.

An increase in excess heat can be seen in almost all sectors, which can be explained by the fact that, according to the scenario, few breakthrough technologies are expected and therefore the expected economic growth will dominate. Stagnation is expected in the paper industry, as technological progress and economic growth are expected to neutralise each other.

The situation is completely different in the iron and steel sector. The introduction of new technologies for steel production is expected to lead to a massive reduction in energy consumption in the NEFI scenarios.

The accuracy of the results depends on the publicly available data - the more that is published, the better the company or process can be analysed. In comparable companies with almost identical products, the vertical range of manufacture is usually not known, i.e. to what extent the materials or semi-finished products used in production have already been prefabricated. Electrical energy demand can only be taken into account if environmental reports are available, otherwise key figures must be used here. If there are hot products streams, an estimation can only be made on the basis of literature data with the consideration of generous efficiency losses of the technology capturing an excess heat flow. The same applies to hall exhaust air or excess heat from hot surfaces such as the rotary kiln.

If measures for heat recovery have already been implemented, especially internal measures, these are often not known, so it is not possible to reduce the calculated values by these energy amounts.

Due to the unknown real or measured excess heat quantities, the models cannot be verified and therefore the accuracy of the results cannot be determined.

It should be noted once again that the results do not provide exact values. Rather, the aim here is to provide an overview with scales for strategic spatial planning and preliminary projects.

For more precise planning and techno-economic analyses, a precise analysis of the processes with evaluation of time-resolved data must be carried out at the companies concerned. Only with this information a project for the decoupling of excess heat can be implemented.

Data availability statement

As described in the "Methodology" section, the data used comes from publicly available sources. These are statistics on energy and employees in the various sectors, EU ETS database and EMAS register, sector reports, environmental reports, company homepages and newspaper articles. The most important sources are listed in this paper, but it is not possible to go into detail on the sources for the hundreds of companies analysed.

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