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Research Paper

Industrial waste heat: Estimation of the technically available resource in the EU per industrial sector, temperature level and country

Michael Papapetrou[a,b,*], George Kosmadakis[b,c], Andrea Cipollina[a], Umberto La Commare[a], Giorgio Micale[a]

[a] Dipartimento dell'Innovazione Industriale e Digitale, Università degli Studi di Palermo, Viale delle Scienze, Ed.6., 90128 Palermo, Italy
[b] Wirtschaft und Infrastruktur GmbH & Co Planungs-KG (WIP), Sylvensteinstr. 2, 81369 Munich, Germany
[c] Thermal Hydraulics and Multiphase Flows Laboratory, Institute of Nuclear & Radiology Sciences & Technology, Energy & Safety (INRASTES), National Center for Scientific Research "Demokritos", Patr. Gregoriou E' & Neapoleos 27, 15310 Agia Paraskevi, Greece

HIGHLIGHTS

- New methodology for estimation of recoverable waste heat potential.
- Differences between countries and energy efficiency developments considered.
- Estimation of waste heat potential per temperature level and per industrial sector.
- Waste heat potential per EU country.

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ABSTRACT

Industrial waste heat is examined in EU countries, focusing on the amount that can be recovered and exploited, referred to as technical potential of waste heat. An alternative methodology is proposed here, which is based on waste heat fractions derived from a detailed study of the UK industry from the period 2000–2003. These fractions express the part of heat consumption that is wasted and is possible to be recovered. The waste heat fractions have been calculated in this work for each main industrial sector and temperature level. The methodology initially includes the adjustment of waste heat fractions from each industrial sector from the UK industry to the conditions of the different EU countries in the period 2000–2003, in order to account for the different levels of energy efficiency. The second step is to adjust the fractions for the year 2015, using data about the evolution of energy intensity values from 2000 to 2003 to 2015 for each country and sector, resulting to a new set of fractions per country, temperature level and sector.

This methodology has enabled the authors to study in detail the waste heat potential per sector and temperature level, using the most recent data. The main outcome is the estimation of waste heat potential for each main industrial sector in the EU, broken down to the amount of waste heat for each temperature range. A similar analysis is conducted for each EU country as well, in order to identify the magnitude of heat recovery opportunities that could exist for every industrial sector at country level.

The main result of this analysis is the estimation of the total waste heat potential in EU, which is about 300 TWh/year, with one third corresponding to temperature level below 200 °C, which is often referred to as low-temperature waste heat, another 25% in the range 200–500 °C and the rest above 500 °C (mostly in the range 500–1000 °C).

The findings of the current study can be used for assessing the potential of any relevant heat recovery applications, such as heat upgrade and re-use or heat-to-power conversion technologies.

1. Introduction

Industrial waste heat is defined as heat rejected from industrial processes, in which energy (mostly heat and electricity) is used to produce high-added value products (not energy; –power plants are not included in the current analysis). This waste heat is included in a thermal carrier. The most common ones are gaseous streams (e.g. exhaust gas, flaring gas, low-quality steam, cooling air, etc.), liquid

* Corresponding author at: Wirtschaft und Infrastruktur GmbH & Co Planungs-KG (WIP), Sylvensteinstr. 2, 81369 Munich, Germany.
E-mail address: michael@papape.com (M. Papapetrou).

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streams (e.g. hot oil, cooling water, etc.) and solids (e.g. commodities and products, such as hot steel) [1]. Waste heat is calculated as the heat of a carrier, once it is cooled from its initial temperature. Usually we consider cooling up to the ambient temperature unless there are technical limitations; for example flue gases from diesel industrial boilers are not cooled below 120 °C for avoiding condensation of water vapor and the production of sulfuric acid [2].

High temperature heat sources are mostly available in solid carriers. The recovery of heat from solid carriers is very challenging and there is no equipment available for that purpose [3]. According to a report for UK industry [4], the majority of heat sources are below 250 °C, with liquids and gases being the main thermal carriers Different types of heat exchangers are used to collect that heat from the thermal carriers; the pinch point temperature difference depends on the carrier type and quality (e.g. moisture content), and existing technology [5]. The pinch point temperature difference can decrease, leading to a larger percentage of the waste heat being collected, by increasing the effective heat exchanging surface. However, as this drives up the costs, a case-by-case techno-economic analysis is required to determine the optimal size of heat exchangers [6,7].The heat harnessing equipment is outside the scope of the current work, which focuses on estimating the amount of waste heat.

The amount of waste heat as a fraction of energy consumption greatly varies among the various industrial sectors [8]. The temperature at which the heat is available also varies within a very wide range, from about 50 °C up to even 1000 °C or higher, depending on the industrial sector and the process.

Various studies exist that deal with the estimation of this potential. Some are based on regional data [9], which are then extrapolated in other areas or countries [10]. This extrapolation can be reliable in case the input energy is considered per industrial sector [11], since some industries release much higher waste heat amounts than others (e.g. a steel industry compared to a food industry). In addition, the use of up-to-date data is important as the industrial sector develops fast in terms of: (1) energy consumption changes resulting in variations at the level of demand for the end-products [12]; for example the global financial crisis in the 2008–2010 period resulted in a significant reduction of overall industrial energy consumption, (2) structural changes in industry, and (3) energy efficiency measures that are applied in industrial processes, having a large effect on energy consumption per ton of end-product (referred to as specific consumption) or energy consumption per added value of end-product (referred to as energy intensity) [13].

This paper develops an alternative methodology that considers all the above issues with the aim to estimate the technical potential of waste heat in the main industrial sectors in EU countries. The first part of this work describes the methodology using conversion factors of waste heat potential that are both country and industrial sector specific, while the second part applies it for estimating the waste heat in the industrial sectors per EU country and temperature level. The outcome is a complete mapping of this potential, which can be used for investigating the possible applications of different heat recovery technologies, such as heat upgrading and re-use [14], and heat-to-power conversion [15].

2. Overview of methodology and assumptions

2.1. Overview of methodology

The methodology developed and applied in this paper is based on the estimation of waste heat fractions per industry, country and temperature level. The starting point is a study of the UK industry [16] where the technically available waste heat of each industrial sector in the UK was estimated using data from 425 industrial sites from the period 2000–2003. Electricity used for process heat is included in the above study, although it represents a small fraction compared to the total heat consumption. This analysis used data from a large number of industrial sites, bringing confidence that the results are reliable, even though waste heat estimations on a country or continent level are inherently uncertain. In the next sections, the four steps of the methodology that we followed in this paper are explained.

2.1.1. First step

In our methodology, the first step is to calculate the waste heat fractions (WHFs) for the UK industry in the period 2000–2003, according to Eq. (1). We apply Eq. (1) for each temperature band and industrial sector using the data from Ref. [16] about the heat consumption and recoverable waste heat potential. In Ref. [16] cement, ceramics, gypsum, lime and glass have been reported separately; we grouped them together as non-metallic minerals in order to be in line with the classification of the Eurostat, from where we use data in the next steps of the methodology.

$$(WHF_{UK,sector,Temp\ range})_{2000-2003} = \left(\frac{(waste\ heat\ potential)_{UK,sector,Temp\ range}}{(heat\ consumption)_{UK,sector}}\right)_{2000-2003} \quad (1)$$

2.1.2. Second step

The second step of our methodology is to adjust the set of WHF that we calculated for each industrial sector and temperature band in the UK (in the first step), to the realities of each of the other members states of the European Union, by multiplying with a factor that indicates the relative energy intensity of each country compared to the UK (country-specific adjustment) and industrial sector (industrial sector-specific) for the period 2000–2003. The annual energy intensity (EI) values per country and per industrial sector have been taken from the Odyssee-Mure database [17]. The average values of the 2000–2003 period have been used for every country and for each industrial sector. The energy intensity values are given in toe/€2005ppp (purchasing power parities), to eliminate any distortions between currencies and market conditions in the different countries. Then, using Eq. (2) we have calculated a set of WHFs per EU country, industrial sector and temperature band for the period 2000–2003.

$$(WHF_{EU\ country,sector,Temp\ range})_{2000-2003} = (WHF_{UK,sector,Temp\ range})_{2000-2003}\left(\frac{EI_{EU\ country,sector}}{EI_{UK,sector}}\right)_{2000-2003} \quad (2)$$

2.1.3. Third step

The third step of the methodology is to update the calculated sets of WHFs of the second step, accounting for the energy efficiency improvements in each country and industrial sector from the period 2000–2003 to 2015 (year that the most recent heat consumption data are available). For that purpose we calculate the ratio of the energy intensity values in 2015 (per industrial sector and country) using data from the Odyssee-Mure database [17] to the average energy intensity values from the period 2000–2003, which we used in step 2. By multiplying this ratio with the WHF for the same country and industrial sector, we update the WHFs to 2015 values, as shown in Eq. (3).

$$(WHF_{EU\ country,sector,Temp\ range})_{2015} = (WHF_{EU\ country,sector,Temp\ range})_{2000-2003}\frac{(EI_{EU\ country,sector})_{2015}}{(EI_{EU\ country,sector})_{2000-2003}} \quad (3)$$

2.1.4. Fourth step

The final step, consists of multiplying heat consumption derived from 2015 Eurostat data [18] per industrial sector with the WHFs for 2015 for each industry, temperature band and EU country. The result is the estimation of the waste heat potential for 2015, eliminating any major uncertainties related to the differences of energy efficiency levels between countries and years.

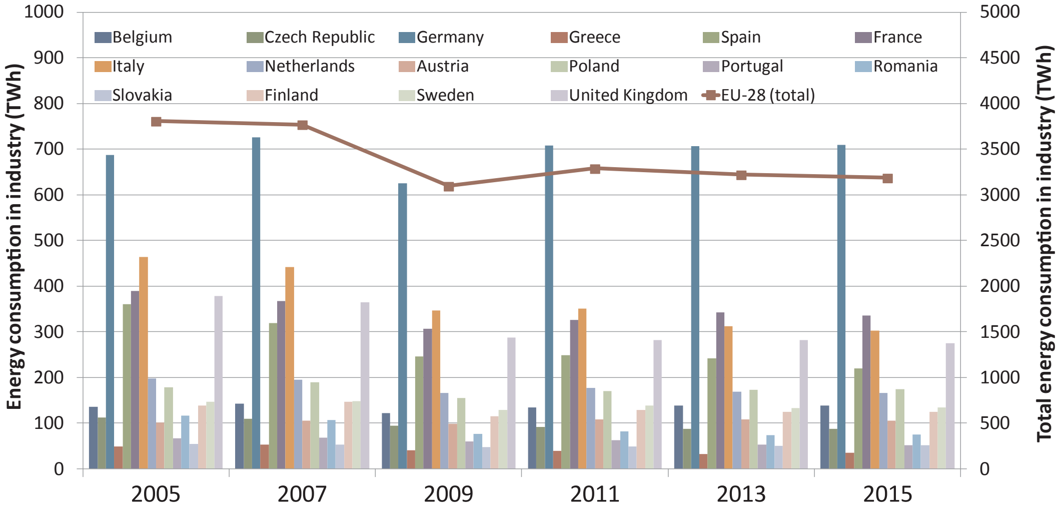

Fig. 1. Annual energy consumption in industry in EU countries (bars – leaft axis) and totals for the EU (red line – right axis) (Eurostat 2005–2015 data).

2.2. Assumptions

Although the above methodology eliminates some major uncertainties, there are several assumptions, which need to be considered when discussing the results. Here, we list the main assumptions:

1. The starting point of this work [16] already includes some uncertainties (waste heat is estimated with a ± 33% accuracy). The reported available waste heat in UK is within the range of 37–73 PJ/year and in the current work its average value has been used.
2. When using the Eurostat 2015 data for heat consumption per industry and country, the derived heat and energy from renewables (mostly biomass in wood industry) is not taken into account. We did that in order to be consistent with Ref. [16], which also did not consider these heat consumption sources based on their methodology; if we took these sources into account the adaptation of WHFs for other countries and years would not have been correct. In any case, these heat sources account for about 13% of EU industrial energy consumption, most of it being in the pulp and paper sector. Therefore, the result would not change significantly at least for all other industrial sectors.
3. Electricity consumption that is used for process heat is also considered in the calculations and included in the heat consumption, following a similar methodology as in Ref. [16].
4. The use of energy intensity values at purchasing power parities for adjusting the WHFs for the different countries and the different periods does not consider different possible forms of the end-product within an industrial sector. For example, the paper and pulp industry in Sweden and Finland have much higher energy intensities than these industries in other European countries. This is because Sweden and Finland produce mainly pulp, a low value product which requires an energy intensive process. Other European countries might just import pulp and produce paper (less intensive process), a higher value product. We could avoid this by using the specific energy consumption (energy input per volume of industrial production) rather than the energy intensity, however the available data do not allow for a full calculation between all countries, industrial sectors and periods (data are partly available only for steel, cement, glass and paper industries). In any case, a comparison in a small sample of sectors and countries has been made when using specific energy consumption and energy intensity data, with the results being similar and following the same trend.
5. It is assumed that the relative difference of energy intensity in each country and sector and any improvement over time is distributed equally between heat/fuels and electricity.
6. This methodology does not consider the detailed circumstances that might be present at specific industrial sites (e.g. use of combined heat and power – CHP, or industrial symbiosis). The results consider the average energy values of the industrial sector of each country and as such cannot be derived with high accuracy. More accurate estimations of the waste heat potential would require to restrict the study to the industries of a region or even better to a specific site.

3. Estimation of waste heat potential

3.1. Energy consumption in industry

A brief introduction is provided here about industrial energy consumption in the EU, which mainly includes process heat, space heating, and electricity.

Energy consumption in the industrial sector is about 3200 TWh per year, representing about 26% of the total consumption in EU, according to Eurostat, 2015 [19]. This share varies among the EU countries, according to historical data of the Odyssee-Mure project [13], ranging from about 15% in Cyprus, Luxembourg and Denmark to over 40% in Finland and Slovakia.

The industrial energy consumption as a share of the total energy consumption has declined since 2000 as the result of the following three reasons: (1) energy efficiency measures have been implemented in the industry, (2) changes in the type of industries that operate within the EU, and (3) increasing energy consumption in other sectors, mainly in buildings, services and transportation.

Fig. 1 shows the industrial energy consumption (Eurostat data [12] in TWh per year) in some of the EU countries with at least moderate industrial activity. In the same graph is given the total industrial energy consumption in the EU. .

The countries with the higher industrial energy consumption are Germany, Italy, France, UK, and Spain, as expected. These five countries represent about 60% of the total industrial energy consumption in EU.

Industrial energy consumption has decreased in 2009, mainly because of the economic recession. The recovery has been very slow, with the energy consumption remaining almost constant since then at about 3200 TWh/year.

The decrease in industrial energy consumption as a percentage of the total energy consumption since 2000 is a general trend, but with different intensity in each industrial sector [13]. Chemicals, steel and non-metallic minerals show the largest decrease of about 20–25%, but despite the fast decline, chemical and steel industries remain the largest consumers (with about 580 TWh/year each), followed by paper, non-metallic minerals and food (with about 350 TWh/year each) [13]. These five sectors represent about two thirds of the total energy consumption in industry.

Most industrial sectors require all ranges of heat [20], with food, tobacco, textiles and leather industries having heat demand mostly up to 100 °C, pulp and paper industries up to 500 °C, while industries for manufacturing metals, iron and steel, and non-metallic minerals requiring mostly heat with temperature over 500 °C [21].

For the calculation of the waste heat in this paper we use the most recent heat consumption data available (2015 Eurostat data [18]). Primary energy sources in industry (solid fuels, oil, gas, etc.) have been processed, in order to calculate (process) heat consumption in each sector and EU country. The fraction of electricity used for process heating is also added in this consumption (mostly in iron and steel industries). According to this analysis, heat consumption in all EU industries is 1820.73 TWh/year, with the contribution of each industrial sector depicted in Fig. 2. The remaining energy consumption of about 1400 TWh/year corresponds to space heating and cooling and electricity for pumps, motors, cooling/refrigeration, office equipment, and lighting [22].

Even though Eurostat gives separate data for sectors such as transport equipment, machinery, mining, wood, construction and textiles, the paper that we used as a starting point [16] as well as many other sources we used for our calculation [17,18] do not break down the data for these sectors, therefore we grouped them all here under the heading "other industrial sectors".

3.2. Waste heat fractions per sector and temperature level

3.2.1. Introduction on industrial waste heat

The scope of this paper is to estimate the amount of waste heat that can be recovered from industrial processes. The industrial processes will not be described here in detail, but the reader can find more information in other studies. For example a detailed description of the main industrial sectors and their waste heat sources are provided in "Best Available Techniques" (BAT) and their "Reference Documents" (BREFs) [23].

There are many differences between the industrial sectors in terms of both energy consumption and waste heat potential An overview of energy losses compared to the energy utilized has been presented in the SPIRE Roadmap [24] for the US industries. The main conclusion was that 20–30% of the total energy consumption was lost in the form of waste heat, but also in the form of energy losses in pumps/motors and other electromechanical equipment.

Similar studies for EU have been conducted focusing on waste heat and have led to a large variation of results. This is partly attributed to the use of data from different years with large differences of energy consumption, industrial activity, and energy efficiency, as well as to the confusion to some extent between the total waste heat availability and its technical potential. Total waste heat usually refers to the total amount of heat once the thermal carrier is cooled down to the ambient temperature (in some cases a different reference temperature is considered, introducing additional inconsistencies between the results, especially for very low temperature levels). Only a part of this heat can be recovered; this is called technical potential of waste heat and is the main focus of the current work.

In addition to the total waste heat and the technical waste heat potential, in the literature we see also references to the economically recoverable fraction of waste heat [11]. An extra step would be required in our methodology for calculating this, but new assumptions would have to be made about the technologies to be used and the minimum acceptable return on investment, which is a subjective criterion. This kind of assessments is more suitable to be made on a case-by-case basis, rather than on a European level analysis.

3.2.2. Waste heat fractions

In the ECOHEATCOOL project [25] waste heat recovery fractions have been assessed for some energy-intensive industries, following the findings of a relevant Swedish study [26]. These results have been further processed in Ref. [11], where the waste heat potential has been estimated at country/region level. They stated that with waste heat recovery fractions per temperature level and per industrial sector, it is possible to estimate the total technically recoverable waste heat in Europe. They reached waste heat recovery fractions of about 2–4% in all industrial sectors, except from chemicals with a fraction of 12% and basic metals with a fraction of around 17%.

Moreover, waste heat potential has been studied in Norway, where a bottom-up study was performed, based on questionnaires [9], showing that more than 60% of the waste heat is at temperatures below 140 °C. These findings from the industrial sector in Norway have been extrapolated in German industry in Ref. [10], who directly used the recovery fractions from the Norwegian study for metal production, chemicals and processing of stone and earth (30%, 8%, and 40% respectively), while they used a flat 3% for the other sectors. These fractions have been used for temperature levels of over 140 °C, while the potential below that temperature has been estimated to be the half.

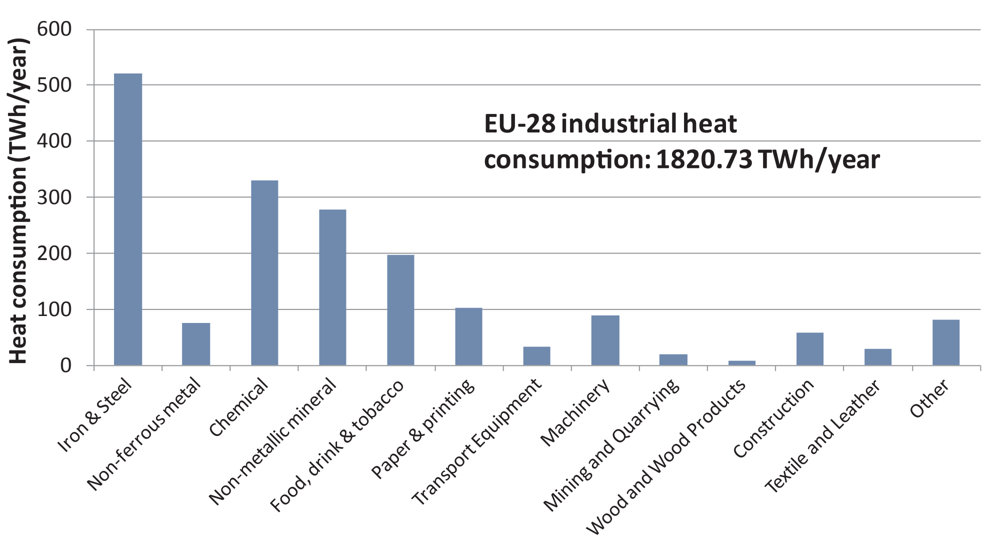

Fig. 2. Industrial heat consumption in the EU classified by industrial section (Eurostat, 2015 data).

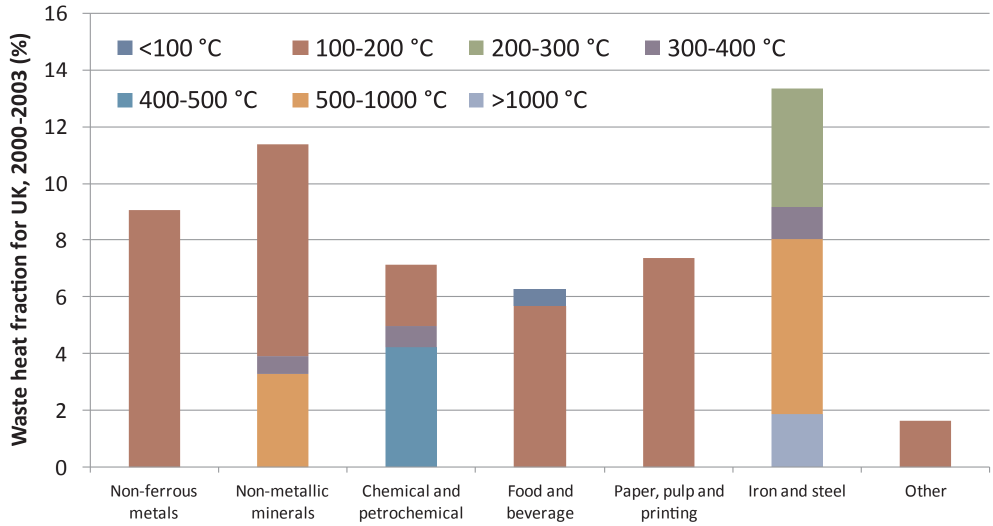

Fig. 3. Waste heat fraction per industrial sector and temperature level for UK industry for the period 2000–2003.

3.2.3. Calculation of waste heat fractions per industrial sector and temperature level

Following the methodology presented in Section 2.1, the data from the UK industry have been processed, resulting to waste heat recovery fractions for the period 2000–2003 per sector and temperature level for UK, as shown in Fig. 3.

The waste heat potential over 1000 °C is limited and observed only in the iron and steel industries. Even within the 500–1000 °C temperature range, not much waste heat is available, with the potential being restricted in the cement, iron and steel sectors. Within the 200–500 °C range the potential increases, mainly in pulp and paper and iron and steel industries. The majority of waste heat lies in the temperature range of 100–200 °C, spread over most industrial sectors, while below 100 °C the potential is rather limited, concentrated in the food and drink sector, mostly from drying and preheating processes.

The waste heat fractions calculated lie mostly within the 6–9% range, of heat consumption. Only the non-metallic minerals and iron and steel sectors have a higher waste heat fraction (about 11 and 13% respectively), due to the high temperatures at which they require their process heat, resulting to larger heat losses. This result is in-line to a Swedish and a German study [10,25].

In order to extrapolate the waste heat fractions from the UK industry to the industries of other countries, energy intensity values are used, as explained in Section 2. Energy intensity values correlate the energy input in each country and industry with the added value end product. Their ratios (energy intensities for each EU country divided by UK industries) provide an estimation of relative energy efficiency of that EU country compared to UK for the specific industrial sector. The outcome is a set of WHFs for each EU country per industry and temperature band for the period 2000–2003, similar to the one shown in Fig. 3.

After that, the ratio of energy intensity between the 2000–2003 period and the one for 2015 are calculated per industry and country, in order to adapt the results to the energy efficiency situation of 2015, as described in Section 2.1. The final result is an updated set of fractions per industry and country for 2015. These calculated waste heat fractions are made available through Mendeley data. These fractions will be used in the next section for estimating the waste heat potential of all industrial sectors in the EU.

4. Results and discussion

4.1. Waste heat potential per industrial sector and temperature level

Heat consumption data have been processed from Eurostat for 2015 per industry and EU country. Some industrial sectors with low consumption, such as textiles, machinery have been grouped under the heading “other industries” for consistency with the other data sources. The waste heat potential per industrial sector and temperature level was calculated for each EU country, using the 2015 waste heat fractions from the Annex, that have been calculated as described in Section 3.2.3. Fig. 4 gives the waste heat potential per industrial sector and per

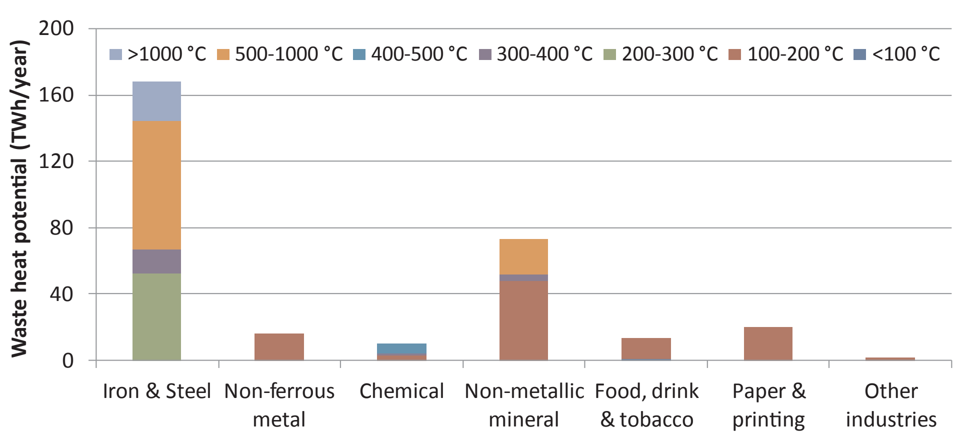

Fig. 4. Waste heat potential per industrial sector and temperature level for EU industry in 2015.

temperature range for all EU countries together; the country level analysis is provided in the next section.

The waste heat potential at temperature level of 100–200 °C is high (about 100 TWh/year), and represents one third of the total one. It is available in a large variety of industries, such as chemical, non-metallic minerals, food, and paper industries. For higher temperature levels, the amount of waste heat decreases with a waste heat potential over the temperature level of 200–500 °C of about 78 TWh/year. For waste heat with temperatures over 500 °C only industries that use high temperature process heat, like the steel industry, feature, with the total potential being quite high at 124 TWh/year.

What is interesting is the very low waste heat potential with temperature below 100 °C, equal to 1.25 TWh/year, when compared to the other temperature levels. One reason for this is the very low temperature difference compared to the reference temperature (ambient temperature), the very low heat consumption within this range, and the very low heat losses (low waste heat fractions).

The sum of waste heat potential in EU is 304.13 TWh/year, which is 16.7% of the industrial consumption for process heat, and represents 9.5% of the total industrial energy consumption.

4.2. Waste heat potential per EU country

Each EU country has a different mix of industries operating within its borders. According to Ref. [13], in all EU countries there are food, paper, non-metallic, machinery, and chemical industries. Often, the smaller countries are dominated by a single sector; for example in Malta 40% of industrial energy consumption is at the machinery sector, in Cyprus 60% is at the non-metallic minerals sector, and in Luxembourg 60% in the steel industry. In larger countries (e.g. France, Germany) there is more balance between industries, showing that their industrial sector is highly diversified.

Following the methodology presented previously, using appropriate waste heat recovery fractions for each industry and temperature level, the waste heat potential in each EU country has been calculated. Heat consumption data for each country were available from Eurostat, which have been further processed, as described in Section 3.1.

The results are presented for each industrial sector separately and per EU country, since the amount of data is large. These results are shown in Figs. 5–11 for iron and steel, non-ferrous metal, chemical, non-metallic mineral, food, paper and pulp, and other industries respectively.

In most sectors the highest potential exists in Germany, which is expected as it is the largest EU Member State and has intensive industrial activity. However, in food industry the leading country in waste heat potential is France followed by Germany, and in other industries the leading country is UK.

Moreover, the waste heat of most sectors is within the temperature level of 100–200 °C, which matches the temperature of the exhaust gases of boilers and standard heating equipment. The temperature of the waste heat is increased to more than 500 °C in only three industrial sectors: chemical, iron and steel and non-metallic mineral.

Finally, the sum of waste heat potential in each EU country from all industrial sectors per temperature level is shown in Fig. 12.

The highest waste heat potential exists in the industrial sectors of Germany, Italy, France, Spain and UK, and if summed it represents about 60% of the total one.

4.3. Comparison of results

The results of this methodology compare well with results from similar previous studies. In the UK we calculated a waste heat potential of 24 TWh/year, which is within the range of 10–40 TWh/year estimated by various studies for UK industry [27]. We estimated the waste heat potential in Sweden to be 7.09 TWh/year, while in Ref. [28] the waste heat potential in Sweden was estimated to about 9 TWh/year (using 2002 data). But the energy efficiency index has decreased since 2002 by about 16% in Sweden (1.24%/year for the period 2000–2015, according to Odyssee-Mure database); taking that into account, we come to 7.56 TWh/year for 2015 which is very close to the 7.09 TWh/year calculated in the current study.

There are also cases where differences with previous studies are observed. Pehnt et al. [10] calculated a waste heat potential for Germany of about 132 TWh/year, which is about 43% higher than the 74.85 TWh/year we calculated here. Considering energy efficiency improvement in Germany (0.87%/year over the period 2000–2015) the resulting waste heat potential is 117 TWh/year, reducing this difference to 36%. When exploring the reasons for this difference, we notice that while there are no significant differences in the average fractions used in the two studies, we apply the waste heat fraction only on the heat consumption of each industry (since this is how the waste heat fractions were calculated), while Pehnt et al. apply it on the total energy consumption including both heat and electricity.

In terms of studies covering the whole of Europe, an estimation of waste heat potential has been conducted within the framework of the I-Therm EC-funded project [29], which calculated a potential of 370.42 TWh/year using 2012 data. In their study, there was no differentiation between energy efficiency levels among the different countries. Also in terms of temperature ranges, they grouped the waste heat to temperatures below 100 °C, from 100 to 300 °C and over 300 °C for calculating the waste heat fractions, but the reported waste heat potential is not divided into any temperature levels. The potential they

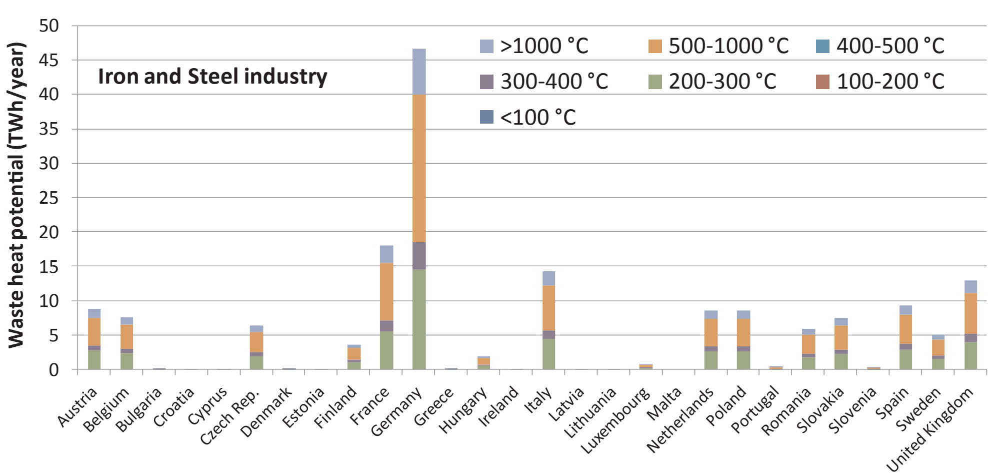

Fig. 5. Waste heat potential in each EU country per temperature level in iron and steel industry.

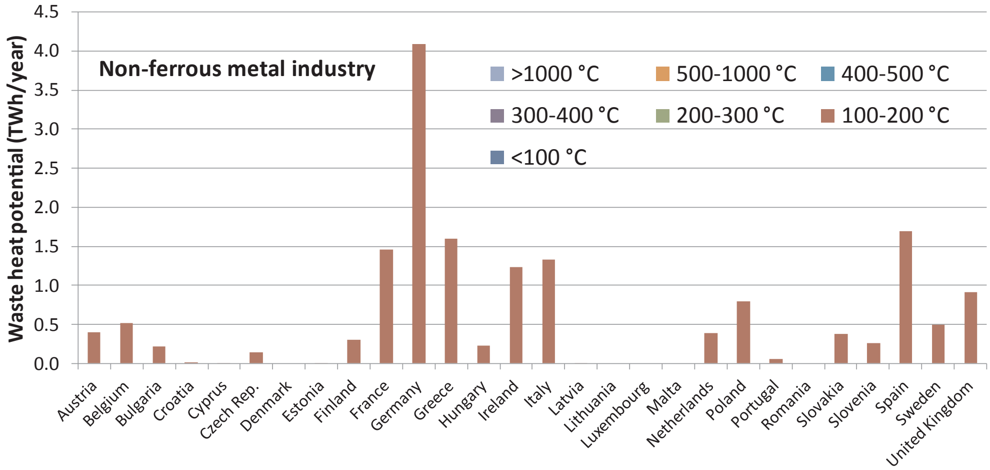

Fig. 6. Waste heat potential in each EU country per temperature level in non-ferrous metal industry.

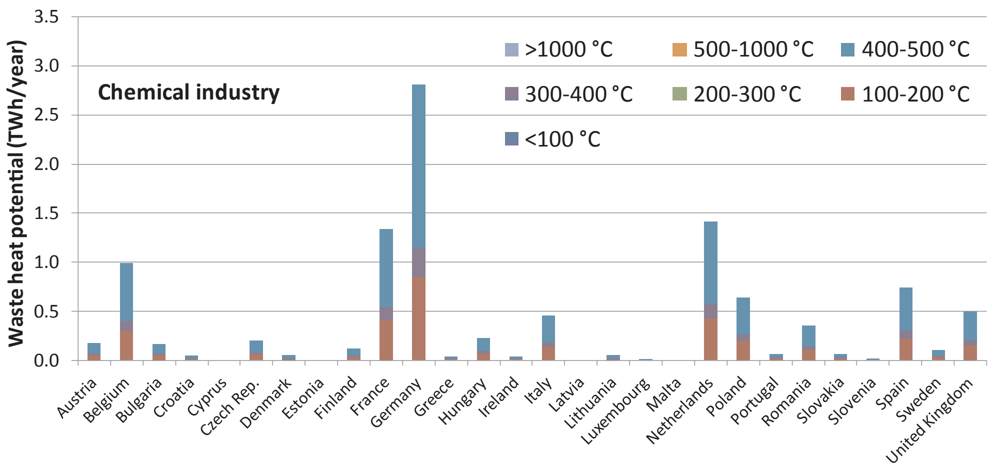

Fig. 7. Waste heat potential in each EU country per temperature level in chemical industry.

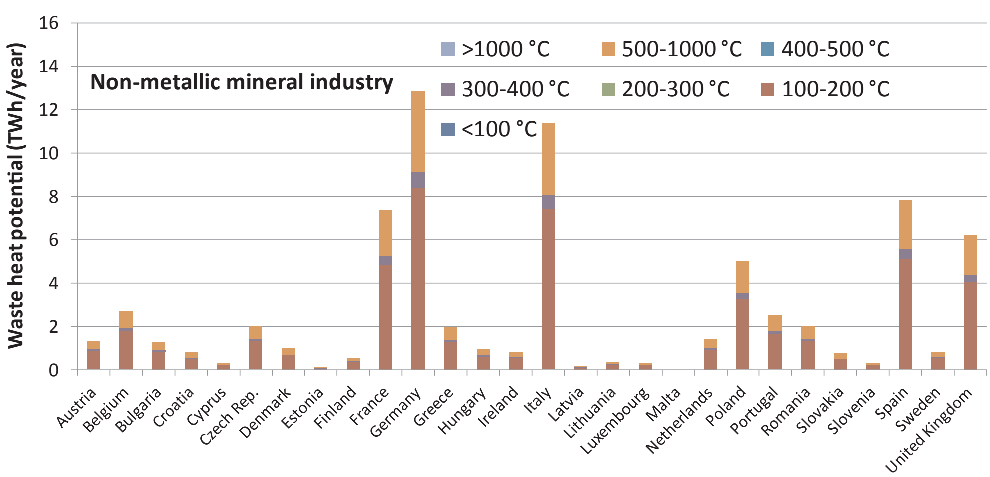

Fig. 8. Waste heat potential in each EU country per temperature level in non-metallic mineral industry.

calculated for each country is very close to the one calculated here, and the somewhat lower values reached in our work could be well attributed to the improvement of industrial energy efficiency over the period 2012–2015. A large difference was observed for the case of the Netherlands; this comes down to a very high value that they have used for energy consumption in the category “other industries” and it is not clear where that comes from as it is not in-line with the Eurostat data. In case the I-Therm results at country level are adjusted considering the difference of energy intensity of each country’s industry from the year 2012 to 2015, and the potential in the Netherlands is corrected, then the total waste heat potential is reduced to 321.86 TWh/year (5.8% difference from our results). Fig. 13 provides a more detailed comparison per country among the current results and the I-Therm ones (the reported and the adjusted ones).

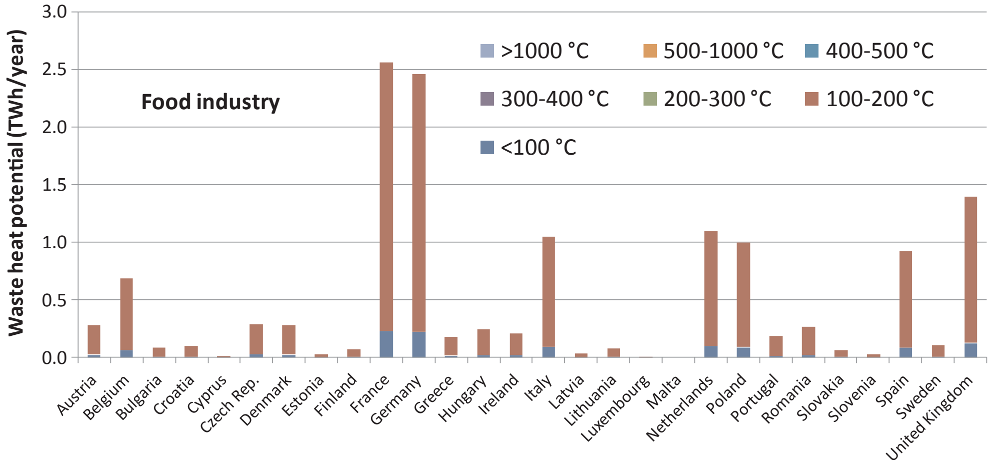

Fig. 9. Waste heat potential in each EU country per temperature level in food industry.

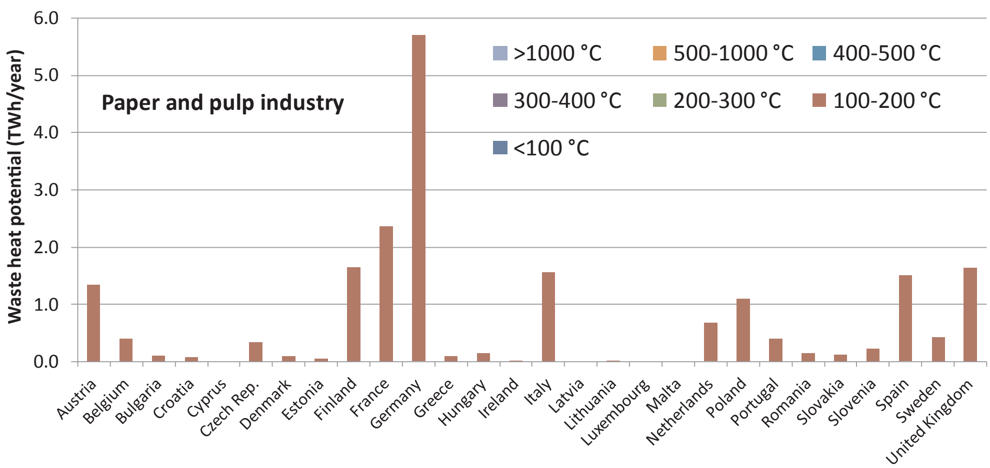

Fig. 10. Waste heat potential in each EU country per temperature level in paper and pulp industry.

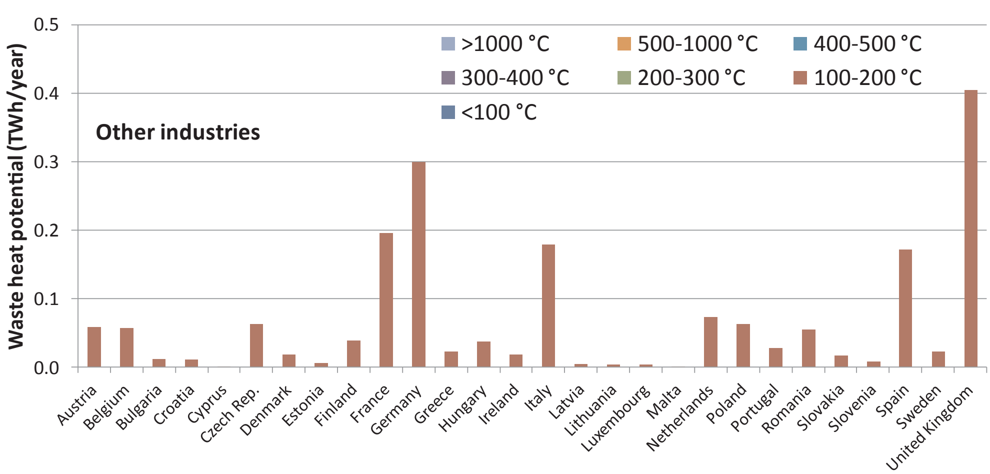

Fig. 11. Waste heat potential in each EU country per temperature level in other industries.

In general, our results area at similar levels with the results from previous studies. The main advantage of the present study is that waste heat potential has been also adjusted to take into account the different energy efficiency levels between European countries. In addition, we provide a more detailed breakdown of the waste heat potential per temperature level, which makes it interesting for exploring the applicability feasibility of different recovery technologies.

5. Conclusions

The analysis of the present work assessed the technically recoverable part of waste heat in the main industrial sectors in the EU. Waste heat recovery fractions have been calculated for each EU country, industrial sector and temperature level (country/industrial sector/temperature-specific). The different levels of energy efficiency per industrial sector between the EU countries and the energy efficiency

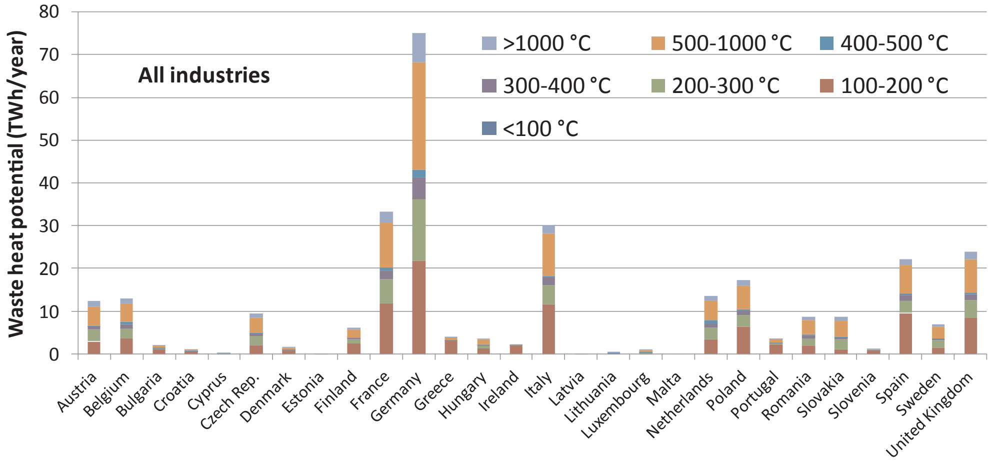

Fig. 12. Waste heat potential in each EU country per temperature level in all industries.

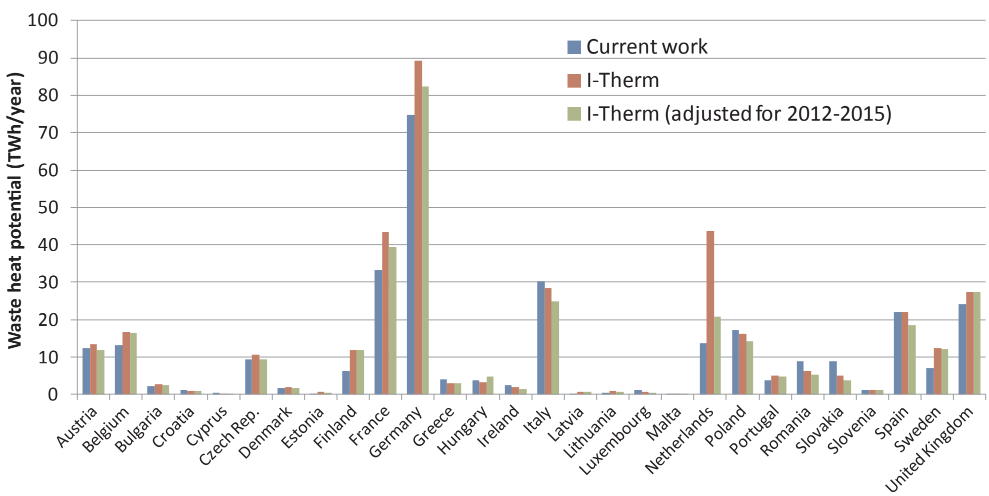

Fig. 13. Comparison of the current results with the I-Therm data (original and adjusted) per EU country.

improvements within each country over time have been taken into account when calculating the waste heat fractions.

These fractions have been then used for calculating per temperature level, industrial sector and EU country the waste heat potential, using 2015 (process) heat consumption data. The waste heat potential in the EU has been estimated to be 304.13 TWh/year, with its largest part within the 100–200 °C range. Waste heat below 100 °C is minor, while significant quantities exist within the 200–500 °C range.

The analysis presented here provides an insight into the potential for waste heat exploitation, especially at low temperature range; which can be used as a first indication of the market size for technologies that can recover and use heat, either upgrading it (heat pumps) or converting it to electricity (heat to power engines). At this point, it has to be clearly stressed again that this kind of analysis includes important uncertainties. The results presented can help for providing an insight in terms of how the waste heat is spread between temperature levels, countries and industrial sectors. However, the actual figures in terms of the amount of waste heat available at any specific country, or industrial sector, could vary considerably from the results presented above. Where more accurate figures are required, it is recommended to focus on a restricted geographical area, where it is feasible to assess key technical factors influencing the waste heat potential at different temperature ranges.

Finally, even if waste heat availability is defined accurately, the feasibility of recovering the heat cannot be determined from that study and should be assessed on a case-by-case basis [30].

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