Developing a georeferenced database of energy-intensive industry plants for estimation of excess heat potentials

Pia Manz, Tobias Fleiter & Ali Aydemir
Fraunhofer Institute for Systems and Innovation Research ISI
Breslauer Str. 48
76139 Karlsruhe
Germany
pia.manz@isi.fraunhofer.de

Keywords

database, excess heat, industrial processes, waste heat recovery, spatial analysis

Abstract

Industrial excess heat may be one of the pillars needed to transform the energy system. Integrating excess heat in district heating networks can reduce the primary energy demand of the heating sector. Thus, industrial sites need to be analysed in high spatial resolution with regard to heating demand and excess heat potentials. This paper presents a methodology to estimate site-specific excess heat potentials for industrial plants in Europe. Different data sources are matched and analysed to collect information about CO_2 emissions, subsector (NACE and ETS activity), process and production capacity per site in the EU28, Switzerland and Norway. From this dataset of energy-intensive industries (steel, paper, cement and glass), the fuel demand is calculated for each site and process. Two different approaches are used to calculate the fuel demand: first, based on the CO_2 emissions, and second, the production capacity in tonnes per year of each site. These two approaches are compared and their accuracy is analysed. In this paper, the excess heat potentials for the most important industrial sectors in Europe are estimated based on process-specific fuel demand for different temperature levels.

Introduction and background

The EU target to reduce greenhouse gas (GHG) emissions by 80 up to 95 % in 2050 compared to 1990 necessitates the transformation of the energy system to renewable sources and the improvement of energy efficiency in all sectors. While the share of renewable energies in electricity generation has increased over the last decade, the heat sector still depends strongly on fossil energy sources and improvements here have been slow. In the EU28, space heating demand accounts for about 25 %, and industrial process heat demand for about 16 % of final energy consumption (Fleiter et al. 2017). These figures illustrate the importance of heating demand and supply in industry and buildings. Industrial excess heat as a potential supply source for district heating can contribute to improving the efficiency and decarbonising the heating sector and should play a major role in local strategic heat planning. However, estimating regional excess heat potentials and identifying potential regions for district heating requires disaggregated information on the locations of energy-intensive plants.

Excess heat, sometimes also referred to as waste heat, is the amount of energy released from combustion or industrial processes (mainly process heat and steam generation) to the environment via waste water, latent heat or exhaust gases at different temperature levels (Brückner, 2016). The industrial excess heat potentials included here are defined as the heat released from industrial processes through exhaust gases above 100 °C. We focus on the basic materials industries including steel, cement, glass and paper. Power plants are not included in this study.

Until recently, the vast potential of industrial excess heat has been neglected and only a few studies have presented a systematic approach to estimating the site-specific excess heat potential. Estimations on an EU-wide scale have been conducted by Persson et al. (2014); other studies focus on specific countries (Bühler et al. 2016, McKenna 2010, Brückner et al.

2017, Hammond et al. 2014, Rattner et al. 2011) or processes (Seck et al. 2013). Most studies analyse the theoretical (Brückner et al. 2017, Persson et al. 2014) or technical (McKenna 2010) potential. Economic potentials also consider energy prices and investment costs (Karner et al. 2017, Blesl et al. 2008). Estimations of excess heat potentials are often based on site-specific emission data (Brückner 2016, McKenna 2010, Persson et al. 2014) and derived based on emission factors. These approaches are mainly driven by data availability. Only a few take into account more specific sector databases that include other indicators (Bühler et al. 2015). Industrial processes are heterogeneous between countries and even between individual sites with regard to the fossil fuel mix and design of the process, so that even emission factors per subsector neglect these individual differences. Information about the production and processes of individual sites can therefore be a more precise indicator than CO_2 emissions. This emphasizes the need for refined methodologies for bottom-up excess heat estimations.

In this study, we present an approach using the georeferenced production capacity of energy-intensive processes to estimate excess heat potentials at different temperature levels. The overall aim is to derive a georeferenced dataset of energy-intensive industries, including emissions, processes, production capacities as well as the energy consumption of each site. The developed georeferenced dataset enables more accurate energy system analyses on the one hand, and enables urban planners to identify regional heat integration potentials on the other hand.

Data and methodology

This paper presents an elaborated approach that matches several databases to estimate excess heat potentials. We combined several databases including the EU ETS (European Union Emission Trading System), the E-PRTR (European Pollutant Release and Transfer Register) and various sectoral databases (glass, cement, steel, paper etc.). Combining these databases helps to overcome the limitations of individual databases and validates the data at the same time. Combining the databases requires matching individual plants across the databases. The matching algorithm considers company name, location and sector/activity. This approach makes it possible to access georeferenced production capacity in energy-intensive industry sectors in the EU28. This enables the estimation of energy demand and excess heat potentials for over 30 individual production processes. The main advantage of including the sectoral databases is a more precise distinction of the activity, which permits a more precise estimation of process-specific excess heat potentials. The sectoral databases provide information on specific processes (e.g. electric steel, oxygen steel, steel rolling, flat glass, container glass, etc.) and on yearly production output or capacity in physical units (e.g. tonnes of rolled steel). Further, this approach can include smaller plants not listed in the EU ETS or E-PRTR. This methodology is compared with emission-based estimations of excess heat potentials by emission factors taking into account the national production data. These approaches are compared and used for calculation of excess heat potentials. All emission and production data in this analysis refer to the year 2014.

MATCHING OF DATABASES

Databases commonly used to estimate excess heat are the E-PRTR[1] (Persson et al. 2014), EU ETS[2] (McKenna and Norman 2010) and national pollutant records (Bühler et al. 2016, Brückner et al. 2016). The E-PRTR database contains coordinates, pollutant and GHG emissions for industrial sites in the EU, classified by four-digit NACE[3]-codes in the industrial demand sectors defined by Eurostat, the statistical office of the European Union. This database was matched with the ETS-database, which covers 40 % of the total CO_2 emissions in the EU by including major emission sources, but only indicates addresses of the company headquarters. The sectors are defined by 40 different activities that indicate the produced product. Combining these two databases by matching individual plants also includes industrial sites that may be missing in one database as well as georeferencing the ETS sites that could be matched with E-PRTR sites. The number of relevant entries, i.e. industrial sites emitting greenhouse gases, is 1,600 in E-PRTR and over 4,500 in ETS. These numbers are obtained after excluding non-relevant sectors and countries as well as non-GHG emissions. Furthermore, we expected the CO_2 equivalent values to be more accurate in the ETS-register as this is the main purpose of this database.

The resulting combined ETS and EPRT-R database forms the base for including additional sectoral databases as listed in Table 1. As mentioned earlier, the inclusion of process-specific production capacities or annual production data allows a more precise estimation of excess heat potentials. These data can be obtained by matching sectoral databases. Table 1 illustrates that the information provided by the original databases is heterogeneous, especially regarding sectoral differentiation (4-digit NACE or ETS-activity), the resolution of location (from coordinates, address, to city or just country) and emissions or capacity/effective production.

We used a database in SQLite and a matching algorithm in C# to match the databases (see Fydrich 2017). The matching algorithm takes into account several indicators like company name, location and sector/activity for each country (see Figure 1). Difficulties identified are that not all databases contain complete datasets, list differing company names due to language and translation differences and provide poor quality data in some cases. Therefore, a matching score ranging from 0 to 100 was calculated for each database and adapted taking into account the available information. Consequently, we had to confirm the found matches with a high matching score afterwards as in the worst cases only the company name was a valid indicator whether this concerned entry is the same in both databases.

Emissions analysis of ETS and E-PRTR

As mentioned above, we first applied this approach to the two emission databases, ETS and E-PRTR. We compiled a combined database consisting of over 5,000 individual site entries by matching all the industrial sites in EU28, Switzerland and

---

[1] European Pollutant Release and Transfer Register.

[2] European Emissions Trading System.

[3] NACE (fr.: Nomenclature statistique des activités économiques dans la Communauté européenne): Statistical Classification of Economic Activities in the European Community.

Table 1. Databases used to develop the georeferenced industrial database.

	Company	***Geographical Data***				***Product***	***Quantity produced/ emitted***		
Database	Name	Address	Country	Lat/ Long	NUTS3	Product/ NACE	Effective production	Production capacity	Emissions
E-PRTR	Yes	Yes	Yes	Yes	No	Yes	Few	No	Yes
ETS	Yes	No	Yes	No	Few	Yes	No	No	Yes
Cement (Global Cement Directory)	Yes	Few	Yes	No	No	No	Few	Yes	No
Paper (RISI Pulp and Paper)	Yes	No	Yes	Yes	No	Yes	Yes	No	No
Steel (VDEh)	Yes	No	Yes	No	No	No	No	Yes	No
Glass (glassglobal)	Yes	Yes	Yes	No	No	Yes	Yes	No	No
Chemicals (internet research)	Yes	Few	Yes	No	Few	No	No	Yes	No

Norway. Of these entries, almost 1,000 are matched, about 600 are from non-matched E-PRTR entries, and about 3,500 are from non-matched ETS entries.

The emissions from all sites in the database in the year 2014 were compared to assess structural differences of the ETS and E-PRTR dataset. There are two main issues when comparing the databases: First, ETS emissions include CO_2 emissions for all processes, and additionally N_2O from several chemical products and PFCs from aluminium production. Therefore, the respective emissions per sector are included from the E-PRTR in the comparison. Second, the ETS does not account for emissions from biomass. Figure 2 depicts the result of the emission analysis. Structural differences can be seen in the E-PRTR values, especially for the pulp and paper sector, where the main fuel sources are wood-based production residuals. Therefore, the E-PRTR values excluding the use of biomass must be considered. This means that the further elaborated emission factors for each process cannot be considered actual values because they do not represent the effective emissions, especially in cases where the fuel source is strongly based on biomass. Furthermore, even though only 20 % of the entries in ETS could be matched with E-PRTR entries, the matched emission values represent over 70 % of all ETS emissions. This is due to the fact that facilities with a high output of emissions are likely to be represented in both databases.

Even though the total emissions by each subsector differ in each database, the emissions for matched sites converge for the iron and steel sector and non-ferrous metals after the matching. However, deviations of 50 % and 65 % remain in the sectors paper and printing, and glass, respectively. In the other sectors, deviations are below 10 %. Possible causes for these deviations may be the measurement and calculation methods used, differing threshold values for single units, high numbers of smaller companies and differing system boundaries, e.g. the inclusion of on-site electricity generation units. Consequently, different emission factors for the two databases are derived for all sectors. This study uses ETS emissions for matched sites, and the corresponding origin database for non-matched sites. The results of the georeferenced, combined dataset are depicted in Figure 3, differentiated by subsector and emission quantities.

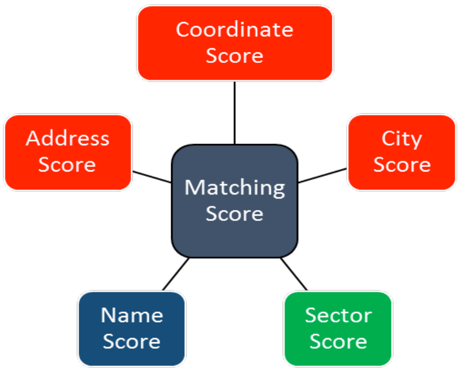

Figure 1. Indicators used to calculate the "matching score" when combining the datasets. Source: Fydrich 2017.

Analysis of sectoral databases

In a second step, the sectoral databases of energy-intensive industries are included in the combined ETS/E-PRTR database. The sectors steel, paper, glass, and cement are included in this study, which account for about 40 % of industrial fuel demand and have the highest potential for the use of excess heat, because high temperature processes are common in these sectors.

The processes included from the sectoral databases are clinker calcination (cement), paper production, flat and container glass, sintering, coking, electric arc furnaces and oxygen steel. The matching algorithm was adapted to the indicators provided by the sectoral databases. As with the emission databases, the matches needed to be confirmed afterwards. The different definition of system boundaries was a challenge here. For example, the ETS-database includes emissions from an entire steel-producing plant, but the different processes are listed in the sectoral databases. In some cases, we had to decide whether to include processes. Even though the sectoral databases are extensive, there are still entries from ETS and E-PRTR which could not be matched. Vice versa, entries from the sectoral databases which could not be matched to the emission database, needed to be georeferenced manually. This is a laborious process requiring internet research.

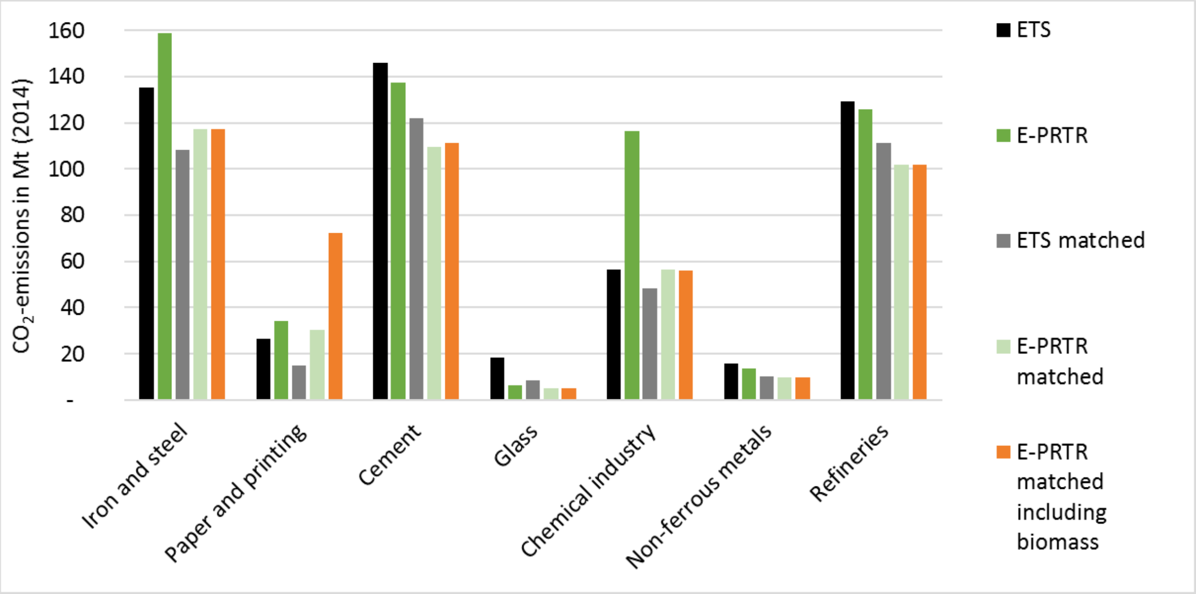

Figure 2. Sectoral CO_2 emissions in the E-PRTR and ETS databases and combined database.

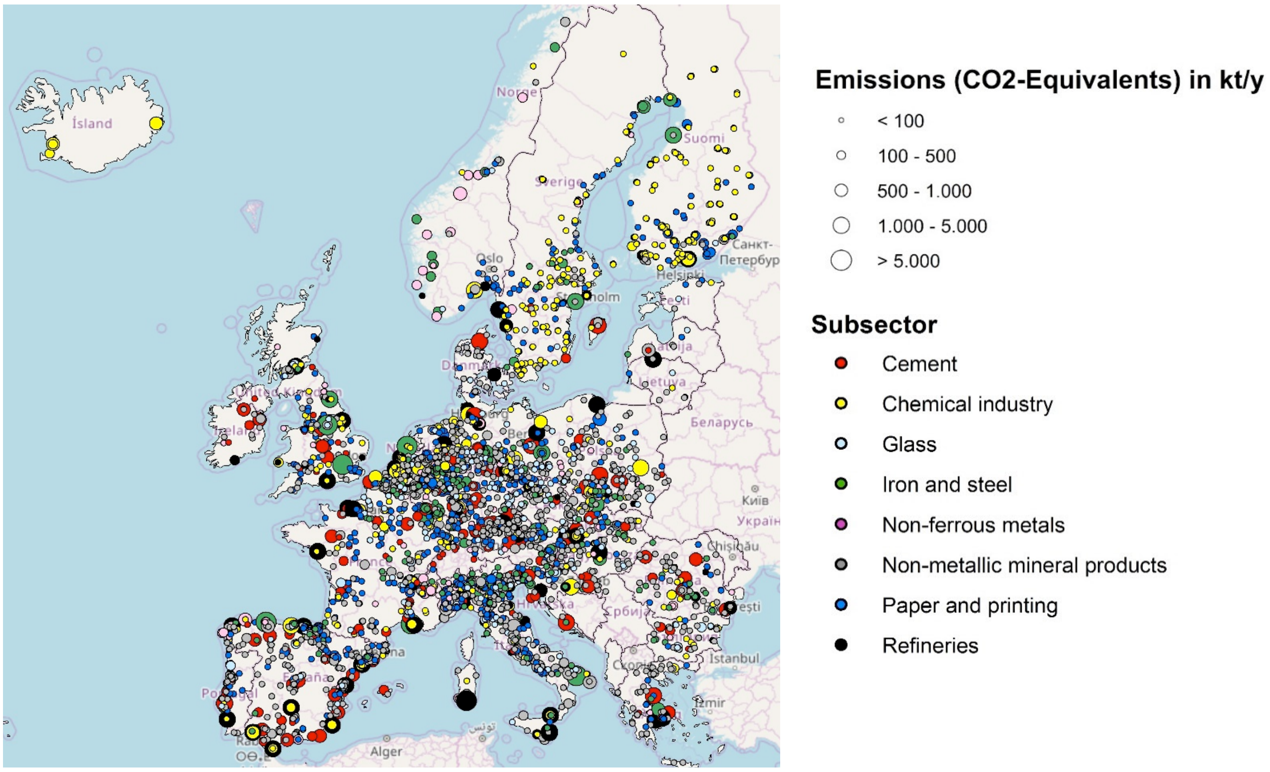

Figure 3. Georeferenced dataset of ETS and E-PRTR for EU28 + Norway and Switzerland, differentiated by subsector and emission quantities.

CALCULATION OF EXCESS HEAT POTENTIALS

The fuel and electricity demand and excess heat potentials can be derived from this dataset featuring emissions and production capacity by site. Two different approaches are possible to do so: one based on the production by process and one based on emission data. The majority of studies in the literature uses emissions as a basis for excess heat analysis (Brückner 2016, Persson et al. 2014). We compare this approach to the production-based approach.

Specific energy consumption values and emission factors

Based on the literature, specific energy consumption values were defined (Rehfeldt et al. 2017, Fleiter et al. 2013), which indicate the fuel and electricity demand per tonne of produced product for each significant process of the energy-intensive industries considered (Figure 4). As expected, the most energy-intensive processes are steel making and paper and glass production with high temperatures above 500 °C. The theoretical energy consumption in GJ/year is calculated by multiplying these values with the site-specific production or production capacity. These values are validated by comparing them with the energy balances from Eurostat. The next step was to consider the capacity utilization rate for sector databases that only indicate the production capacity. This was done by comparing production statistics to the sum of the theoretical energy consumption by country.

With the calibrated production in tonnes/year, country-specific emission factors per produced tonne can be derived for each process of the matched sites. For each process and country, the total emissions and the total production are summed up and divided to obtain the emission factor expressed as CO_2 emissions per tonne produced product. As mentioned before, the emissions data do not represent the actual physical CO_2 emissions because biomass use is neglected. Figure 5 shows the CO_2 emission factors based on the example of the dry clinker calcination process. Especially in cement production, the fuels used for high temperature processes are very heterogeneous, ranging from coal, gas to waste, which results in different emission factors. This emphasizes the need for site-specific analysis; even country-specific values are a simplification as they neglect the differences between different companies. The process is unknown for sites that are included in ETS/E-PRTR but not in the sectoral databases, an average value is assumed for the whole sector. As the emissions differ even for the same sites in the databases of ETS and E-PRTR, two emission factors are calculated. The emission factors can differ for smaller countries like Luxembourg with a low number of companies. However, the emission factors derived from both databases tend to converge

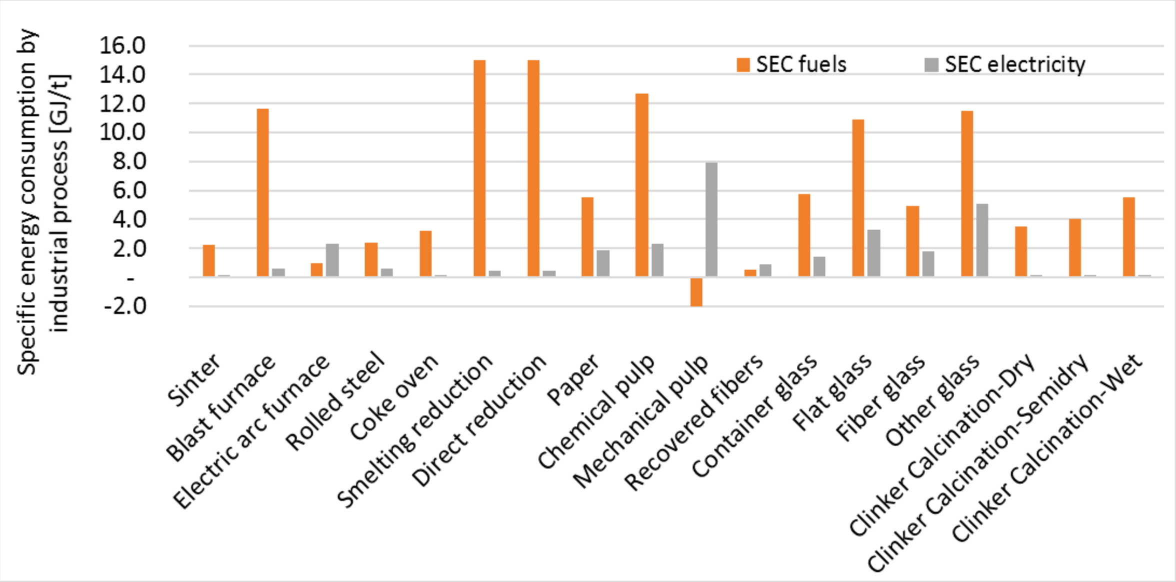

Figure 4. Specific energy consumption (SEC) for fuels and electricity in GJ per tonne produced product. Based on: Rehfeldt et al. (2017), Fleiter et al. (2013).

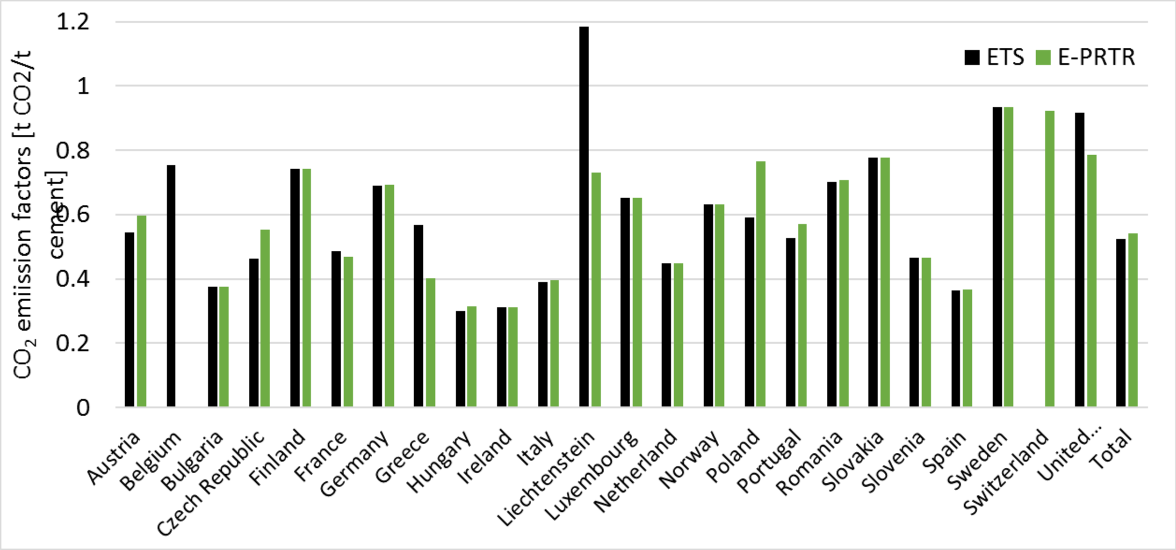

Figure 5. Calculated specific emissions of clinker calcination (dry process) for each country with emissions from ETS and E-PRTR. Considered are matched sites, for which the cement production is known from the cement database. Source: Global Cement Directory.

with an increasing number of entries, and differences between the countries become more significant. The observed difficulties reveal that the emission-based excess heat calculation does not eliminate deviations originating from measurement methods and needs to cope with this uncertainty.

Calculation of production values based on CO_2 emissions
Deriving average CO_2 emission factors for each country and production process makes it possible to estimate the annual production for each site in ETS and E-PRTR from the emission data. This approach is usually chosen if no information about production capacity is available. In this study, it was possible to compare the accuracy of this approach with actual production data. Additionally, it is possible to include sites that could not be matched with sectoral databases and that therefore have no production values. Figure 6 shows the median and deviation of the derived production value from the actual production taken from the sectoral databases for each matched site for the four sectors analysed in this study. Even though the median is close to one for most countries, major deviations can be observed, especially for smaller countries and heterogeneous sectors like cement and paper.

Estimating excess heat based on production in tonnes
The excess heat potential can be derived from the production in tonnes per year and process-specific values are shown in Table 2. For the results shown here, the actual production data were integrated instead of calculated data. The excess heat potentials for each process are assumed identical for all countries and were derived based on the literature and our own assumptions (McKenna et al. 2010, Rehfeldt et al. 2014). We include three ranges of temperature levels above 100 °C. These values are based on the specific fuel and electricity consumption values per tonne of produced product already shown above multiplied with excess heat shares. Only the processes with excess heat potentials are included here. For the majority of processes, the excess heat share is based on fuel combustion processes. However, electric arc furnaces have excess heat potentials above 500 °C based on their electricity consumption.

Results: Excess heat potentials in European countries

Estimating the excess heat potentials for energy-intensive industries in the EU28, Switzerland and Norway yields a bottom-up excess heat potential of 63.3 TWh per year for

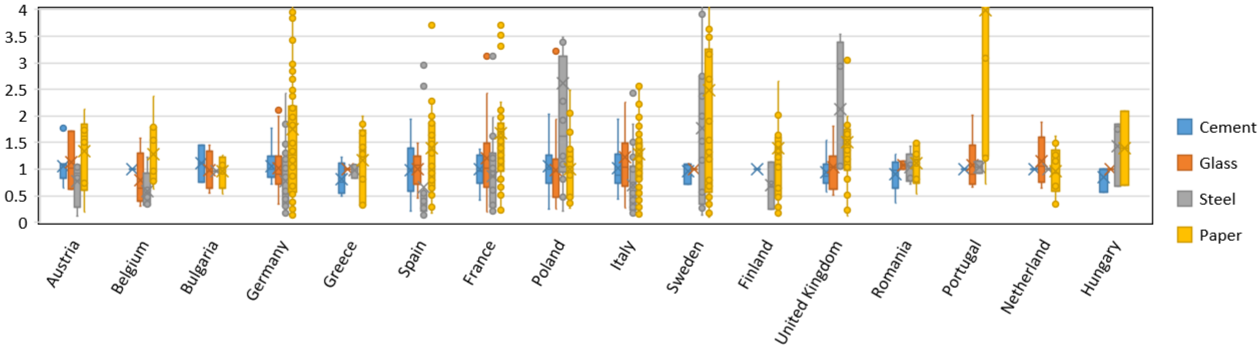

Figure 6. Deviations from the median of production values derived from emission data, shown for main countries.

Table 2. Excess heat potentials for considered processes depending on production in tonnes per year.

Industrial sector		***Excess heat potential per tonne of product [GJ/t]***			***Source/based on***
Subsector	*Process*	*100–200 °C*	*200–500 °C*	*>500 °C*	
Iron and Steel	*Sinter*	–	0.7	–	McKenna et al. (2010)
Iron and Steel	*Blast furnace*	0.3	–	–	McKenna et al. (2010))
Iron and Steel	*Electric arc furnace*	–	0.3	0.2	Element energy et al (2014), Rehfeldt (2014)
Iron and Steel	*Coke oven*	–	–	1.9–	McKenna et al. (2010)
Iron and Steel	*Direct reduction*	–	3.8	–	Rehfeldt (2014)
Pulp and paper	*Paper*	0.6	–	–	McKenna et al. (2010)
Non-metallic minerals	*Container glass*	–	1.2	–	Rehfeldt (2014)
Non-metallic minerals	*Flat glass*	–	–	2.2	McKenna et al. (2010)
Non-metallic minerals	*Clinker calcination (dry)*	–	0.5	–	McKenna et al. (2010), Element energy et al. (2014)
Non-metallic minerals	*Clicker calcination (semidry)*	–	0.6	–	McKenna et al. (2010), Element energy et al. (2014)
Non-metallic minerals	*Clinker calcination (wet)*	–	0.8	–	McKenna et al. (2010), Element energy et al. (2014)

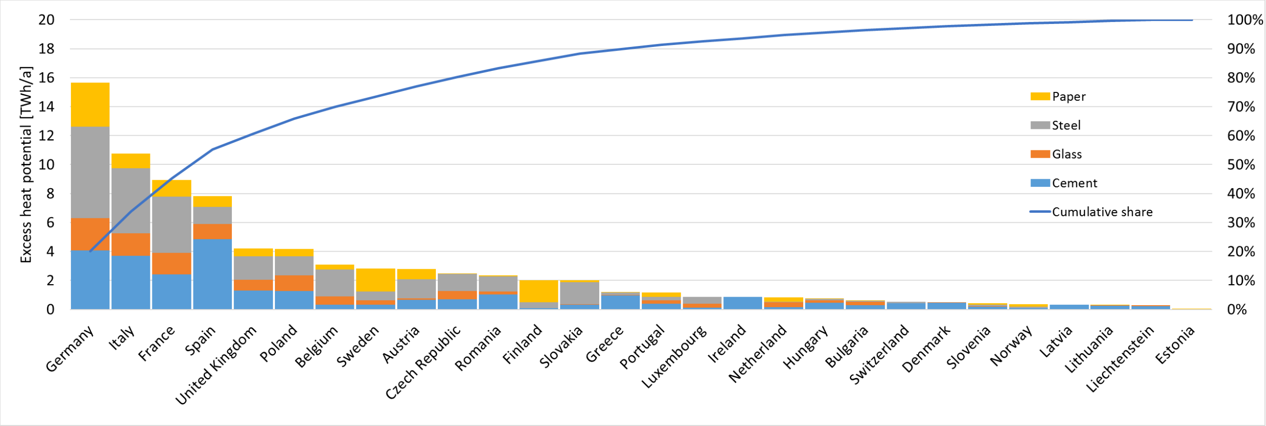

Figure 7. Country-specific and sectoral excess heat potentials for European countries and cumulative share.

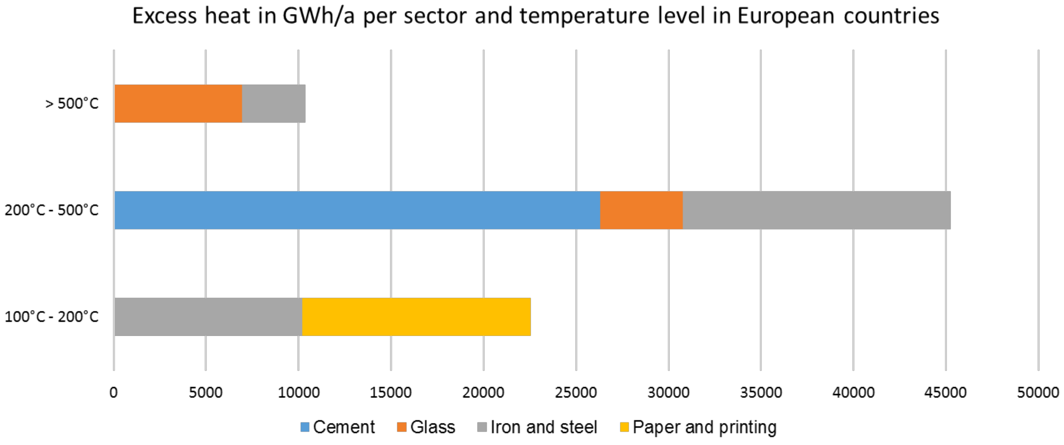

Figure 8. Excess heat potential for the sectors cement, glass, paper and steel for different temperature ranges.

the sectors paper, steel, glass and cement. Figure 7 shows the country-specific excess heat potentials for the cement sector, where just four countries (Spain, Germany, Italy and France) contribute more than half the total excess heat potential. The sectoral distribution of theoretically available excess heat from energy-intensive industries differs across the countries, nevertheless cement and steel are high contributors to excess heat potentials.

The highest share of the excess heat potential of exhaust gases is in the temperature range between 200 °C and 500 °C, as depicted in Figure 8. This is mainly because of the available excess heat of the cement sector of 25 TWh in this temperature range. The pulp and paper industry typically already uses excess heat in higher temperature ranges in drying processes, so that only low temperature excess heat below 200 °C is available here, while glass and steel also have excess heat potentials above 500 °C from high-temperature furnace processes.

Differences can be observed for the sectors when analysing the spatial site-specific excess heat potential for Europe (Figure 9). Steel manufacturing plants have high excess heat potentials above 1,000 TWh per site, but there are not many of them, while the sectors cement, glass and paper are widespread but have only medium excess heat shares.

Discussion and conclusions

To conclude, this paper outlined a new methodology to estimate excess heat based on production data and compared it to an emission-based approach. The excess heat potential in European countries identified in this study of about 63 TWh/a is a fraction of the 2,580 TWh/a found by Persson et al. 2014, who included all relevant industrial sectors plus power plants. It is also substantially lower than the top-down value for industrial excess heat of 752 TWh found by Miro et al. (2015). This result is not surprising because we only included four sectors in this study. Comparing our results with those of other sectoral studies shows similar values, e.g. for Germany (Brückner et al. 2017) or Denmark (Bühler et al. 2016). When comparing the emission-based approach with the production-based one, it becomes clear that using actual site-specific production data to estimate excess heat potentials is more accurate, but also that this approach involves greater effort because of different definitions and the laborious matching process. Calculating the annual production or energy consumption based on emissions is a valid approach if no production data are available. However, this features greater uncertainty because the energy demand of industrial process is more closely correlated to physical production than emissions. Nevertheless, emissions are still a

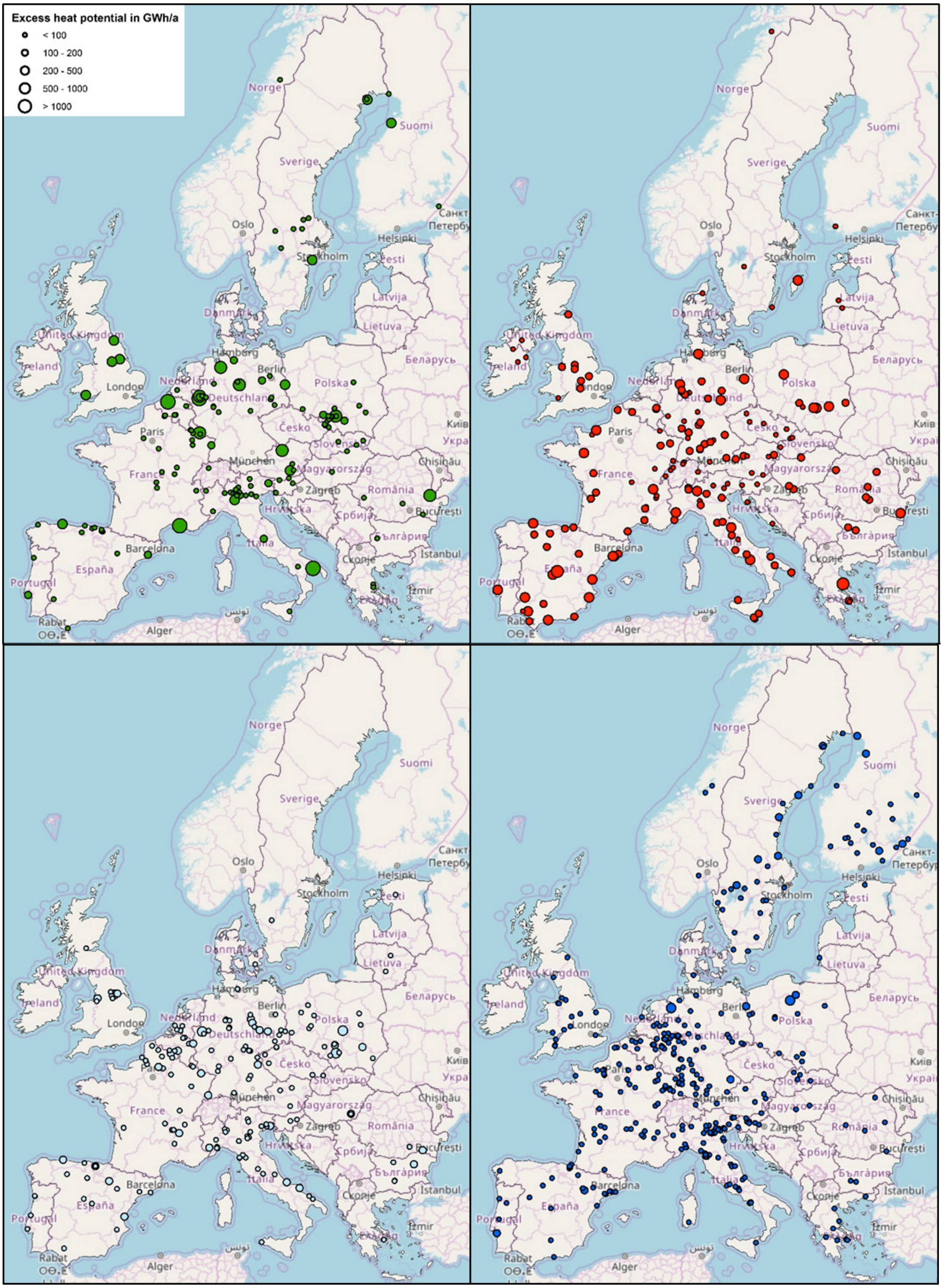

Figure 9. Site-specific excess heat potentials in Europe for the sectors steel (green), cement (red), glass (white) and paper (blue) in GWh per year.

good indicator as shown by the emission factors in this study. Other identified uncertainties include the different measurement methods, reporting conventions and system boundaries.

District heating demand in EU28 was about 180 TWh in the year 2014 (Fleiter et al. 2017), which emphasizes the vast potential for integration of industrial excess heat in heating networks. As district heating is still mainly based on fossil fuels like coal and gas, excess heat offers a possibility for decarbonizing the centralized heating supply. Reinforcement and implementation of new heating networks is needed for the integration of excess heat potentials and the supply for buildings. When it comes to local level, communities need to assess the economic district heating potential, while constraints for industries could be the need for long-term contracts.

Tapping the excess heat potentials in Europe requires the inclusion of more sectors like chemicals and metal products other than steel. Furthermore, excess heat potentials below 100 °C should be included as well to assess the potential for the new generation of low-temperature district heating networks and their combined use with heat pumps. Estimating the technical and economic potentials of utilizing excess heat requires the analysis of the temperature profiles of each process, mapping different temperature levels of heat demand as well as developing scenarios of future heat demand and supply.

References

Bühler, F.; Nguyen, T.; Elmegaard, B. (2016). Energy and exergy analyses of the Danish industry sector. Applied Energy 184, 1447–1459.

Brückner, S.; Arbter, R.; Pehnt, M.; Laevemann, E. (2017). Industrial waste heat potential in Germany – a bottom up analysis. Energy Efficiency 10, 513–525.

Brückner, S. (2016). Industrielle Abwärme in Deutschland – Bestimmung von gesichertem Aufkommen und technischer bzw. wirtschaftlicher Nutzbarkeit, Dissertation TU München.

Blesl, M.; Kempe, S.; Ohl, M.; Fahl, U.; König, A.; Jenssen, T.; Eltrop, L. (2008). Wärmeatlas Baden-Württemberg: Erstellung eines Leitfadens und Umsetzung für Modellregionen. Forschungsbericht. FZKA-BWPLUS.

Element Energy, Ecofys, Imperial College London (2014). The potential for recovering and using surplus heat from industry. Final report for the Department for Energy and Climate Change.

Eurostat (2017). Database on energy demand/energy balances. http://ec.europa.eu/eurostat/data/database. Accessed 08/01/2018.

Fleiter, T.; Schlomann, B.; Eichhammer, W. (2013). Energieverbrauch und CO_2-Emissionen industrieller Prozesstechnologien – Einsparpotentiale, Hemmnisse und Instrumente. Fraunhofer-Verlag, Stuttgart.

Fleiter, T.; Elsland, R.; Rehfeldt, M. et al. (2017). Profile of heating and cooling demand in 2015. Report D 3.1 to the European Commission of the project Heat Roadmap Europe 4 (grant agreement No. 695989).

Fydrich, M. (2017). Assembly of a Site-specific Database for the European Basic Materials Industry – Application for Regional CO_2 Storage Potential. Master's Thesis, Karlsruhe Institute of Technology.

Gils, H.C. (2012). A GIS-based Assessment of the District Heating Potential in Europe. In: Proceedings of the 12th Symposium Energieinnovation, 15–17 February, Graz, Austria.

Hammond, G.P.; Norman, J.B. (2014). Heat recovery opportunities in UK industry. Applied Energy 116, 387–397.

Karner, K., Theissing, M.; Kienberger, T. (2017). Modeling of energy efficiency increase of urban areas through synergies with industries. Energy 136, 201–209.

McKenna, R.C.; Norman, J.B. (2010). Spatial modelling of industrial heat loads and recovery potentials in the UK. Energy Policy 38, 5878–5891.

McKenna, R.C. (2009). Industrial energy efficiency. Interdisciplinary perspectives on the thermodynamic, technical and economic constraints. Dissertation, University of Bath.

Miro, L, Brückner, S., Cabeza, L.F. (2015). Mapping and discussing Industrial Waste Heat (IWH) potentials for different countries. Renewable and Sustainable Energy Reviews 51, 847–855.

Persson, U.; Möller, B.; Werner, S. (2014). Heat Roadmap Europe: Identifying strategic heat synergy regions. Energy Policy 74, 663–681.

Rattner, A.; Garimella, S. (2011). Energy harvesting, reuse and upgrade to reduce primary energy usage in the USA. Energy 36, 6172–6183.

Rehfeldt, M.; Fleiter, T.; Toro, F. (2017). A bottom-up estimation of the heating and cooling demand in European industry. Energy Efficiency DOI 10.1007/s12053-017-9571-y.

Seck, G.; Guerassimoff, G.; Maizi, N. (2013). Heat recovery with heat pumps in non-energy intensive industry: A detailed bottom-up model analysis in the French food & drink industry. Applied Energy 111, 489–504.

Acknowledgements

The work presented in this paper is part of the work conducted in the Horizon 2020 Hotmaps project (Grant Agreement number 723677), which provided the funding to carry out this investigation. The authors would also like to thank Yannick Träris for his laborious work with the databases.