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Stratego

ENHANCED HEATING & COOLING PLANS

Quantifying the Excess Heat Available for District Heating in Europe

Work Package 2

Background Report 7

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STRATEGO Website: http://stratego-project.eu
Heat Roadmap Europe Website: http://www.heatroadmap.eu
Online Maps: http://maps.heatroadmap.eu

Contents

1 Background

In terms of quantifying the excess heat available for district heating systems, the approach within the Stratego project is to assess these availabilities on facility level and aggregate found volumes to regional and national levels for planning and modelling purposes. Since explicit information on excess heat from unique thermal power generation plants and fuel transformation processes in industrial activities are principally unavailable in international energy statistics, and very seldom quantified and reported in general, this task poses a methodological challenge for the project. The chosen approach to meet this challenge, which corresponds to that developed and used in the Heat Roadmap Europe project (HRE, 2014), rests on the idea to use publicly available carbon dioxide emission data on facility level in combination with a reversed calculation sequence to establish primary energy inputs and anticipated excess heat volumes from considered activities.

The purpose of quantifying excess heat available for district heating systems in this context is two-fold and aims to illustrate the vast European potential of the long neglected and often disregarded domestic resource of excess heat. First, determining the geographical locations of considered activities is pre-conditional for any regional or national assessments of future heat synergy collaborations, where increased shares of current excess heat available from these plants and activities are to be recovered and distributed in district heating networks. Second, quantification of annual excess heat volumes available from these plants is essential to provide an idea of the magnitude and extent by which these assets may be utilised to replace current heat supply to meet building heat demands.

It should be underlined that anticipated annual excess heat volumes in the following represent maximal levels of rejected secondary heat from the considered activities, levels that due to a multitude of reasons (e.g. thermo-dynamical, geographical, infrastructural, and seasonal) very well may prove difficult to realise fully in unique heat recovery projects. For the local projects within the Stratego project, as well as for any local heat synergy collaboration in future Europe, it is recommended to carry out detailed assessments of available excess heat from any plausible source. Such detailed assessments should ideally be based on actual energy and thermo-dynamical data (temperature levels, state-of-matter etc.), include sensitivity analyses, and as well address organisational aspects such as collaboration agreements with mutually beneficial allocation of synergy benefits to all involved parties.

2 Method

The methodological approach used to quantify excess heat available for district heating systems in this report is mainly based on the use of publicly available carbon dioxide emission data from the European Pollutant Release and Transfer Register (E-PRTR) (EEA, 2013a), energy statistics from the International Energy Agency (IEA, 2012) and a reversed calculation sequence. The approach has previously been partly documented in (Connolly et al., 2014; Connolly et al., 2013; Connolly et al., 2012), as well as in (Persson, 2015), and with full detail in (Persson et al., 2014). The most significant steps in this methodology can be summoned according to the following key bullets:

- Retrieve geographical coordinates and annual carbon dioxide emissions on facility level from the E-PRTR dataset
- Establish characteristic carbon dioxide emission factors, per Member State and per main activity sector, by use of IEA energy statistics on fuel use and standard carbon dioxide emission factors (See Appendix, Table 6 and Table 5, respectively)
- Calculate primary energy supply on facility level based on annual carbon dioxide emissions and characteristic carbon dioxide emission factors
- Apply default recovery efficiencies (see Table 1) to calculated primary energy supplies to assess theoretically available annual excess heat volumes on facility level

The excess heat activities considered in this report includes large scale (> 50 MW) thermal power generation (TP) fuel combustion plants, fuel supply and refineries (FSR), and industrial facilities within six significant energy-intensive industrial sectors; chemical and petrochemical (CPC), iron and steel (IS), non-ferrous metals (N-FM), non-metallic minerals (N-MM), paper, pulp and printing (PPP), and the food and beverage sector (FB). The report also considers Waste-to-Energy (WTE) facilities, although annual excess heat volumes available from European waste incineration plants are calculated by an alternative approach. By performing a separate and dedicated study on the European WTE sector, annual capacity data from 410 facilities was gathered from several complementary sources (CEWEP, 2014; IndustryAbout, 2014; ISWA, 2012). For this sector, annual excess heat volumes are therefore assessed based on found capacities, a default recovery efficiency of 60%, and an anticipated average energy content of waste at 10.3 MJ/kg from European waste incineration (CEWEP, 2013). Considered main activity sectors and corresponding default recovery efficiencies are detailed in Table 1.

Table 1. Main activity sector category labels and corresponding default recovery efficiencies (η_{heat}). Default values set to reflect the maximal excess heat recovery potential from considered main activity sectors at current conditions

Main activity sector category	Abbreviation	η_{heat}
Thermal Power – Main Activity	TP-MA	50%
Thermal Power – Auto-producer	TP-AP	60%
Thermal Power – Waste-to-Energy	TP-WTE	60%
Fuel supply and refineries[a]	FSR	50%
Chemical and petrochemical[b]	CPC	25%
Iron and steel[c]	IS	25%
Non-ferrous metals	N-FM	25%
Non-metallic minerals[d]	N-MM	25%
Paper, pulp and printing	PPP	25%
Food and beverage[e]	FB	10%

[a] *Not including NACE main economic activities: Extraction of crude petroleum, Extraction of natural gas.*

[b] *Not including NACE main economic activities: Extraction of salt, Growing of citrus fruits.*

[c] *Not including NACE main economic activities: Mining of iron ores, Other mining and quarrying n.e.c.*

[d] *Not including Annex I activities: Opencast mining and quarrying, Underground mining and related operations, and NACE main economic activity; Quarrying of ornamental and building stone, limestone, gypsum, chalk and slate.*

[e] *Including NACE main economic activities; Manufacture of oil and fats, Manufacture of starches and starch products, Manufacture of sugar, and Manufacture of other organic basic chemicals.*

Fuel input to thermal power generation in both power-only and cogeneration facilities are compiled with respect to main activity (MA) and autoproducer (AP) facilities. By excluding nuclear energy in the assessment, which is motivated partly since there is a generally weak interest for recovery of nuclear excess heat today, an additional excess heat volume of approximately 6.7 EJ rejected from European nuclear facilities (operating at average total conversion efficiencies of 33%) is neglected here. According to (IEA, 2012), only 5.0 PJ, from a total primary energy supply of 10.0 EJ, was recovered as usable heat during the year 2010, which reflects very low utilisation levels at current. Additionally, several other plausible sources for excess heat recovery, such as sewages, exhaust air ventilation shafts, and server stations, are omitted in this assessment focusing on energy and industry sectors. See for example (Ebrahimi et al., 2014, 2015) for investigations on the use of excess heat from server stations, and (CEC, 1982; McKenna and Norman, 2010; Morandin et al., 2014; Persson and Werner, 2012; Rattner and Garimella, 2011; Swithenbank et al., 2013) for some general references on excess heat recovery from energy and industry sector activities in district heating systems.

The total annual carbon dioxide emission volume from considered excess heat activities amounts to 2.02 billion metric tonnes (see Table 2), which by validation (comparison to corresponding main activity sectors greenhouse gas emissions sent by countries to the UNFCCC (EEA, 2013c) and to verified 2010 EU ETS data reported through the Community Independent Transaction Log (CITL) (EEA, 2013b)), proved reasonable. Although not fully compatible, since UNFCCC main activity sector data includes all sub-sectors and EU ETS data includes combustion installations with rated thermal inputs > 20 MW, both sources indicate European carbon dioxide emission volumes of about 2.2 billion tons from stationary combustion in given sectors for 2010.

All gathered data, carbon dioxide emissions, energy statistics, and geographical coordinates, are assembled in a relational database to allow systematic calculations, where after spatial representation of each considered facility and the creation of continental and national maps are managed and performed within the ArcMap 10.1 GIS interface (ESRI, 2014). In this Background Report, these maps are withheld at a continental scale, while national maps for five Stratego countries are presented in the Country Reports.

3 Data

The E-PRTR dataset includes annual facility reports on land, water, and air emissions, and is publicly available through the European Environmental Agency (EEA). In this data compilation, general, sectorial, and quantitative (emissions) information on European energy and industry sector facilities are stored together with e.g. geographical coordinates, which enables spatial determination of each emitting site. For the purpose in this report, study facilities were retrieved from the dataset by structured query language (SQL) selection on carbon dioxide emissions to air and mainly for the year 2010. Since Croatia, the 28th European Union Member State since July 1, 2013, is not included in the used version of the E-PRTR dataset, corresponding information on carbon dioxide emissions from Croatian energy and industry sector activities were gathered mainly from the European Union Transaction Log (EC, 2014) and from some national reports on fuel use. As detailed in Table 2, the assessments in this report are hereby based on carbon dioxide emissions from 2712 facilities in all.

Table 2. Count of energy and industry sector facilities extracted from the E-EPRTR dataset and additional sources, with reported annual carbon dioxide emissions aggregated to national level, mainly for 2010

Member State	Count of facilities [n]	CO_2 [Mt]	Count of TP facilities	Count of WTE facilities	Count of Industrial facilities
AT	59	33	22	10	27
BE	97	55	28	16	53
BG	34	33	20	-	14
CY	5	5	3	-	2
CZ	76	73	45	3	28
DE	485	497	175	84	226
DK	55	22	17	30	8
EE	9	14	7	-	2
EL	39	61	22	-	17
ES	230	120	99	10	121
FI	89	61	52	3	34
FR	333	119	57	126	150
HR	57	9	10	-	47
HU	42	22	24	2	16
IE	21	16	13	1	7
IT	311	196	130	52	129
LT	8	6	5	-	3
LU	7	2	1	1	5
LV	3	1	1	-	2
MT	2	2	2	-	-
NL	99	90	42	13	44
PL	155	195	94	1	60
PT	40	28	14	2	24
RO	68	48	33	-	35
SE	123	51	41	28	54
SI	8	7	3	1	4
SK	32	21	14	1	17
UK	225	236	106	26	93
EU28 Total	**2712**	**2024**	**1080**	**410**	**1222**

Excess heat activities in industrial sectors dominate the selection and are present in all Member states, with the exception of the Republic of Malta (MT) if considering WTE facilities as a special branch of thermal power generation. Nineteen Member States currently have waste incineration plants in operation, while dedicated thermal power generation plants are present in all Member States.

4 Results

In this section, the results from the performed assessments are presented in a main result map and two tables, considering all main activity sectors for EU28 (in the Appendix, see Figure 2, Figure 3, and Figure 4, divisional maps detailing energy sector, waste incineration, and industrial sectors facilities respectively, are also available). The main result map, Figure 1, depicts the geographical locations of all considered activities from all main activity sectors, as well as anticipated annual excess heat volumes on facility level by use of a scaled legend. A general observation form this map is that excess heat activities are widely distributed over the European continent today, albeit both highly concentrated clusters as well as vacancy areas are visible.

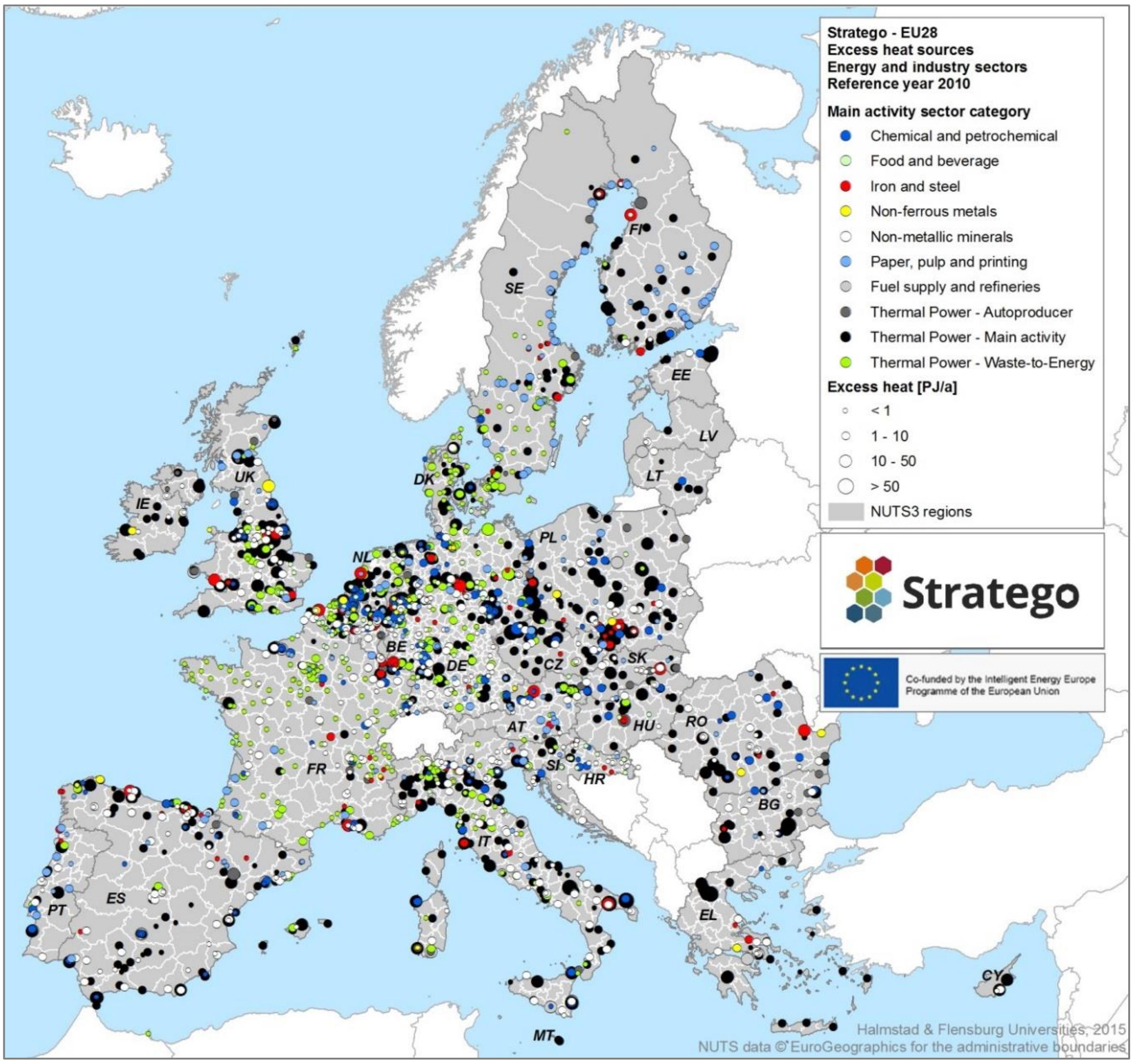

Figure 1. EU28 excess heat facilities by main activity sectors and assessed annual excess heat volumes. Thermal power generation activities > 50 MW. Sources: (CEWEP, 2014; EEA, 2013a; IndustryAbout, 2014; ISWA, 2012).

Persson et. al. (2014) concluded, when performing spatial analysis on regional level to determine the geographical correlation between European excess heat sources (same data source used) and high heat demand density locations (to identify heat synergy regions), that a majority of current excess heat facilities are located inside, or in close vicinity of, large urban zones and major city areas. From a heat recovery and heat distribution perspective, district heating systems being principally local energy infrastructures, this key circumstance suggest general viability of many future heat synergy projects.

As presented in Table 3, a total primary energy supply of 26.2 EJ is anticipated to have been used in the 2712 considered facilities, which, given applied default recovery efficiency values, correspond to a total excess heat volume of approximately 11.3 EJ for the year 2010. Comparison to corresponding main activity sectors primary energy volumes reported by the International Energy Agency (IEA, 2012), amounting to 24.8 EJ in the same year (not including Croatia), indicate a plausible 5% overestimation by the performed reversed calculation sequence. However, given the continental analytical scope withheld and default recovery efficiency values set principally to reflect highest possible recovery levels, this minor deviance is considered negligible. Other possible deviances in the results may be due to inclusion of large-scale thermal activities (> 50 MW) and fuel combustion activities in industrial sectors only. Given the presence of excess heat also from smaller boilers, as well as from industrial exothermic chemical processes, these estimates are considered conservative.

Table 3. Primary energy supply (PES), and excess heat (EH) by EU28 Member State as assessed by the reversed calculation sequence. Excess heat specified by sectors: Thermal power (TP), Waste-to-Energy (WTE), and Industrial (Ind)

Member State	PES [PJ]	EH [PJ]	*TP [PJ]*	*WTE [PJ]*	*Ind [PJ]*
AT	456	167	*63*	*21*	*84*
BE	805	313	*157*	*17*	*138*
BG	382	180	*161*	-	*19*
CY	66	29	*26*	-	*3*
CZ	812	353	*288*	*5*	*61*
DE	6119	2707	*1980*	*161*	*566*
DK	285	139	*103*	*23*	*12*
EE	153	74	*71*	-	*3*
EL	733	335	*277*	-	*59*
ES	1704	705	*458*	*15*	*233*
FI	685	275	*181*	*2*	*92*
FR	1712	645	*236*	*90*	*319*
HR	125	42	*23*	-	*19*
HU	306	136	*106*	*3*	*27*
IE	227	102	*88*	*1*	*13*
IT	2839	1263	*879*	*43*	*341*
LT	100	42	*21*	-	*21*
LU	35	13	*8*	*1*	*4*
LV	13	4	*2*	-	*2*
MT	25	13	*13*	-	-
NL	1348	583	*366*	*46*	*171*
PL	2171	975	*809*	*0*	*165*
PT	373	147	*76*	*10*	*61*
RO	613	252	*177*	-	*75*
SE	594	217	*82*	*30*	*106*
SI	81	37	*34*	*0*	*3*
SK	258	90	*41*	*1*	*48*
UK	3229	1477	*1140*	*40*	*297*
EU28 Total	**26248**	**11316**	***7865***	***508***	***2943***

As is also visible in Table 3, excess heat from thermal power generation is, at current, by far the richest source to exploit for future heat synergy collaboration, and approximately 70% of all available excess heat originates in main activity and autoproducer power plants. Corresponding relative shares for WTE incineration and industrial excess heat out of total volumes are 4% and 26% respectively. Seven Member States (Germany (23%), Spain (6%), France (7%), Italy (11%), the Netherlands (5%), Poland (8%), and the United Kingdom (12%)) account for a major share of the total primary energy supply (~72%), which is correspondingly reflected in anticipated excess heat availabilities.

From a sectorial perspective, i.e. by main activity sectors, as presented in Table 4, it is clear that main activity thermal power generation plants account for a majority of both total excess heat volumes (68%) as well as thermal power generation main activity sector volumes (91%). Among industrial main activity sectors, fuel supply and refineries (however depicted together with energy sector facilities in Figure 2) represent highest annual excess heat availabilities (9% of the total excess heat volume and 36% of total industrial sectors volumes), while Non-metallic minerals facilities account for 5% of the total excess heat volume and 20% of total industrial sectors volumes.

Table 4. Total count of facilities, annual carbon dioxide emissions, primary energy supply (PES), and excess heat (EH) by main activity sector as assessed by the reversed calculation sequence

Main activity sector	Count of facilities [n]	CO_2 [Mt]	PES [PJ]	EH [PJ]
Chemical and petrochemical	242	123	1868	467
Food and beverage	59	9	145	14
Fuel supply and refineries	116	155	2118	1059
Iron and steel	144	166	2101	525
Non-ferrous metals	35	13	204	51
Non-metallic minerals	454	173	2398	600
Paper, pulp and printing	172	79	908	227
Thermal Power Generation - AP	82	28	354	212
Thermal Power Generation - MA	998	1257	15305	7653
Thermal Power Generation - WTE	410	21	847	508
EU28 Total	**2712**	**2024**	**26248**	**11316**

5 Conclusions

The major conclusions from these Stratego estimations to quantify the excess heat sources available for district heating systems are that:

1. Publicly available carbon dioxide emission data on facility level (e.g. from the European Pollutant Release and Transfer Register (E-PRTR)) may be used in combination with energy statistics and a reversed calculation sequence to assess annual volumes of rejected excess heat from fuel combustion processes in European energy and industry sector facilities

2. Default recovery efficiencies, set here to reveal maximal volumes of rejected secondary heat, may in local heat synergy projects be altered, reduced, and used to characterise viable and realistic excess heat recovery levels

3. For the local projects within Stratego, as well as for local heat synergy collaboration in general, it is recommended to retrieve actual and detailed data on energy and thermo-dynamical properties (temperature levels, state-of-matter etc.) of excess heat to be recovered from considered activities

4. Local heat synergy projects should address also organisational aspects such as collaboration agreements, where mutually beneficial allocation of synergy benefits to all involved parties is a key priority

5. Approximately 26.2 EJ of primary energy was supplied to 2712 considered energy and industry sector facilities in EU28 during the year 2010. A total excess heat volume of 11.3 EJ is anticipated to have been rejected from these activities during this year

6. Excess heat activities in industrial sectors dominate the selection in terms of number of facilities, while main activity thermal power generation plants constitute the major share of annual excess heat volumes. Nineteen EU28 Member States currently have waste incineration plants in operation

7. Seven Member States (Germany, Spain, France, Italy, the Netherlands, Poland, and the United Kingdom) account for 72% of the total primary energy supply, which is correspondingly reflected in anticipated excess heat availabilities.

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Appendix

Table 5. Standard carbon dioxide emission factors from stationary combustion, by fuel type. Source: (IPCC, 2006)

Fuel type	Standard carbon dioxide emission factors (sf_{CO_2}) [$g,CO_2/MJ$]
Coal and coal products	94.6
Peat	106.0
Crude, NGL and feedstock	73.3
Oil products	74.1
Natural gas	56.1
Biofuels	101.2[a]

[a] Average value of standard carbon dioxide emission factors for fuel categories "Municipal wastes (non-biomass fraction)": 91.7, "Municipal wastes (biomass fraction)": 100.0, and "Wood - wood wastes": 112.0.

Table 6. Characteristic EU28 Member State carbon dioxide emission factors by main activity sector. Weighted mean average values based on standard carbon dioxide emission factors and national compositions of fuel use. Sources: (IEA, 2012; IPCC, 2006)

Member State	Characteristic carbon dioxide emission factors (f_{CO_2}) [$g,CO_2/MJ$]									
	TP-MA	**TP-AP**	**TP-WTE[a]**	**FSR**	**CPC**	**IS**	**N-FM**	**N-MM**	**PPP**	**FB**
AT	77.3	82.8	-	73.3	72.2	73.0	58.2	79.6	80.6	60.9
BE	71.2	77.1	-	73.3	56.4	70.5	57.6	82.9	90.5	60.9
BG	90.5	61.9	-	73.3	70.4	68.1	77.6	72.9	90.4	63.8
CZ	93.8	93.0	-	73.3	85.3	84.8	59.6	70.6	89.4	61.0
CY	74.1	76.1	-	na[b]	na	na	na	79.2	na	na
DK	85.9	91.1	-	73.3	58.7	58.0	56.1	75.3	82.0	65.1
EE	94.1	84.9	-	na	61.3	56.1	68.9	86.3	65.0	63.1
FI	90.2	90.3	-	73.3	73.7	84.7	79.3	80.4	94.1	77.8
FR	73.7	86.7	-	73.3	71.6	83.4	64.2	67.3	75.4	67.0
DE	89.3	79.1	-	73.3	65.5	77.8	59.9	75.4	72.6	63.0
EL	85.5	69.8	-	73.3	68.7	57.2	78.6	77.1	65.7	85.3
HR	75.0	64.4	-	73.3	56.7	61.5	73.6	76.6	63.9	63.2
HU	76.1	72.5	-	73.3	56.5	88.5	56.1	73.9	61.6	62.4
IE	70.7	61.2	-	73.3	67.5	74.1	65.7	83.6	69.2	74.0
IT	71.0	64.9	-	73.3	58.2	77.1	58.3	66.7	57.3	58.8
LT	59.7	68.2	-	73.3	57.8	73.4	na	87.1	60.5	59.7
LU	59.2	101.2	-	na	62.3	59.2	na	75.3	56.1	64.6
LV	58.1	71.1	-	na	67.9	60.5	56.1	84.5	83.5	65.8
MT	74.1	na	-	na	na	na	na	na	na	na
NL	70.0	77.1	-	73.3	65.5	80.0	56.1	59.1	56.6	57.5
PL	93.8	89.7	-	73.3	85.4	79.6	76.8	77.3	91.6	77.3
PT	76.0	70.3	-	73.3	70.6	61.6	78.6	76.7	96.7	78.2
RO	83.5	85.0	-	73.3	62.9	76.1	na	68.6	58.4	62.8
SK	81.9	94.3	-	73.3	64.9	87.4	59.1	72.8	90.9	56.5
SI	92.3	85.1	-	na	65.8	59.6	62.7	67.6	66.8	61.9
ES	71.3	65.6	-	73.3	62.5	77.7	64.3	68.6	77.0	73.1
SE	92.9	99.1	-	73.3	66.0	86.4	82.2	81.7	99.2	68.9
UK	75.3	79.1	-	73.3	57.9	81.1	60.7	70.0	59.0	58.6
EU28 Total	**81.8**	**77.7**	**-**	**73.3[c]**	**66.5**	**79.0**	**64.6**	**72.2**	**83.3**	**65.2**

[a] Characteristic carbon dioxide emission factors not established for TP-WTE. Separate analysis and data used for this main activity sector.
[b] Notation "na" for "no activity", indicating zero reported volumes of fuel use in respective main activity sector in (IEA, 2012).
[c] Standard carbon dioxide emission factor of 73.3 $g,CO_2/MJ$ for crude, NGL, and feedstock used for main activity sector FSR in all Member States where activity is present, according to (IEA, 2012).

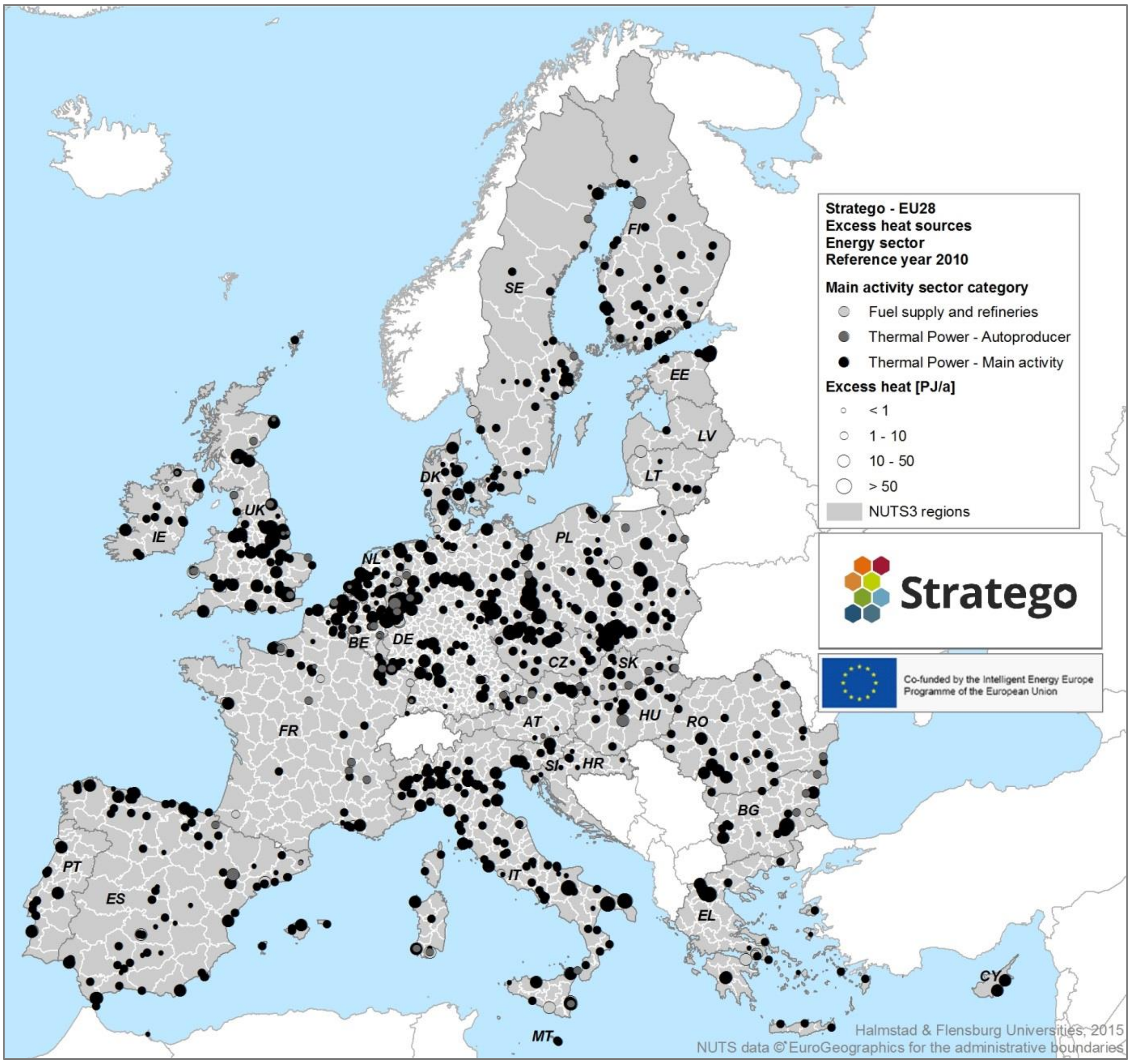

Figure 2. EU28 energy sector excess heat facilities by main activity sectors and assessed annual excess heat volumes. Thermal power generation activities > 50 MW.

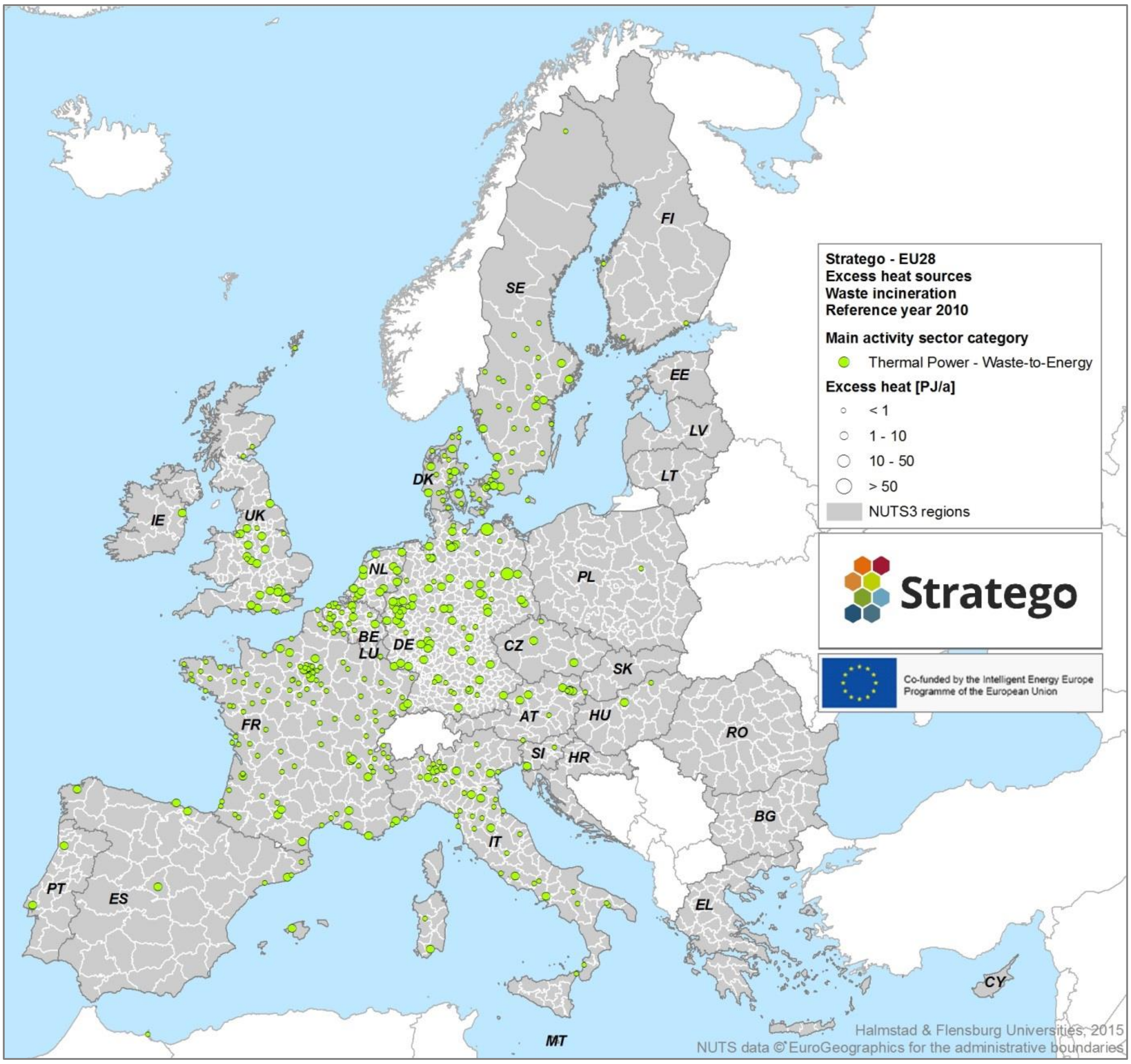

Figure 3. EU28 waste incineration excess heat facilities by main activity sector and assessed annual excess heat volumes.

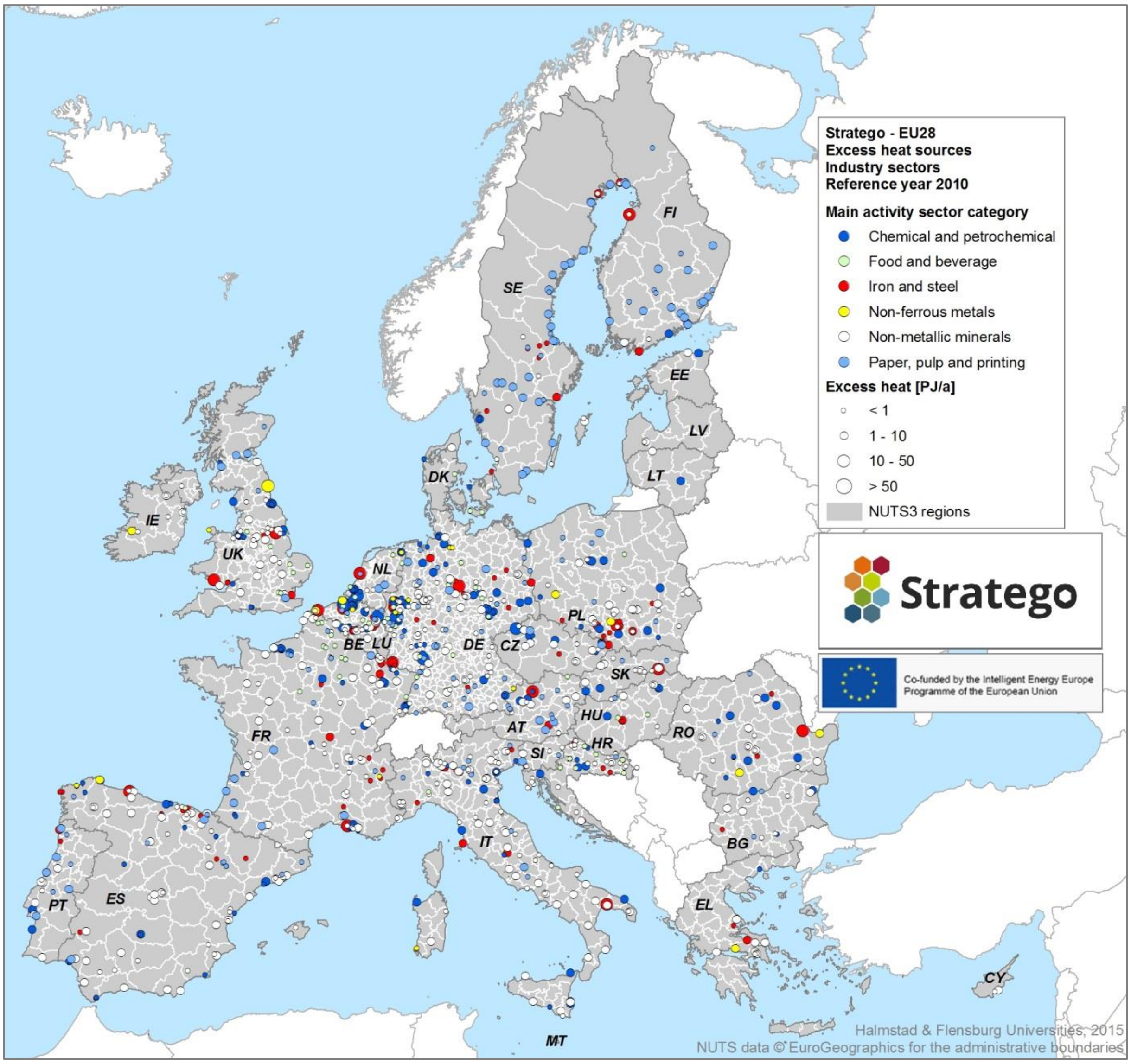

Figure 4. EU28 industry sectors excess heat facilities by main activity sectors and assessed annual excess heat volumes.