Preliminary assessment of waste heat potential in major European industries

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ICSEF2017 – 20th April 2017

Presentation outline

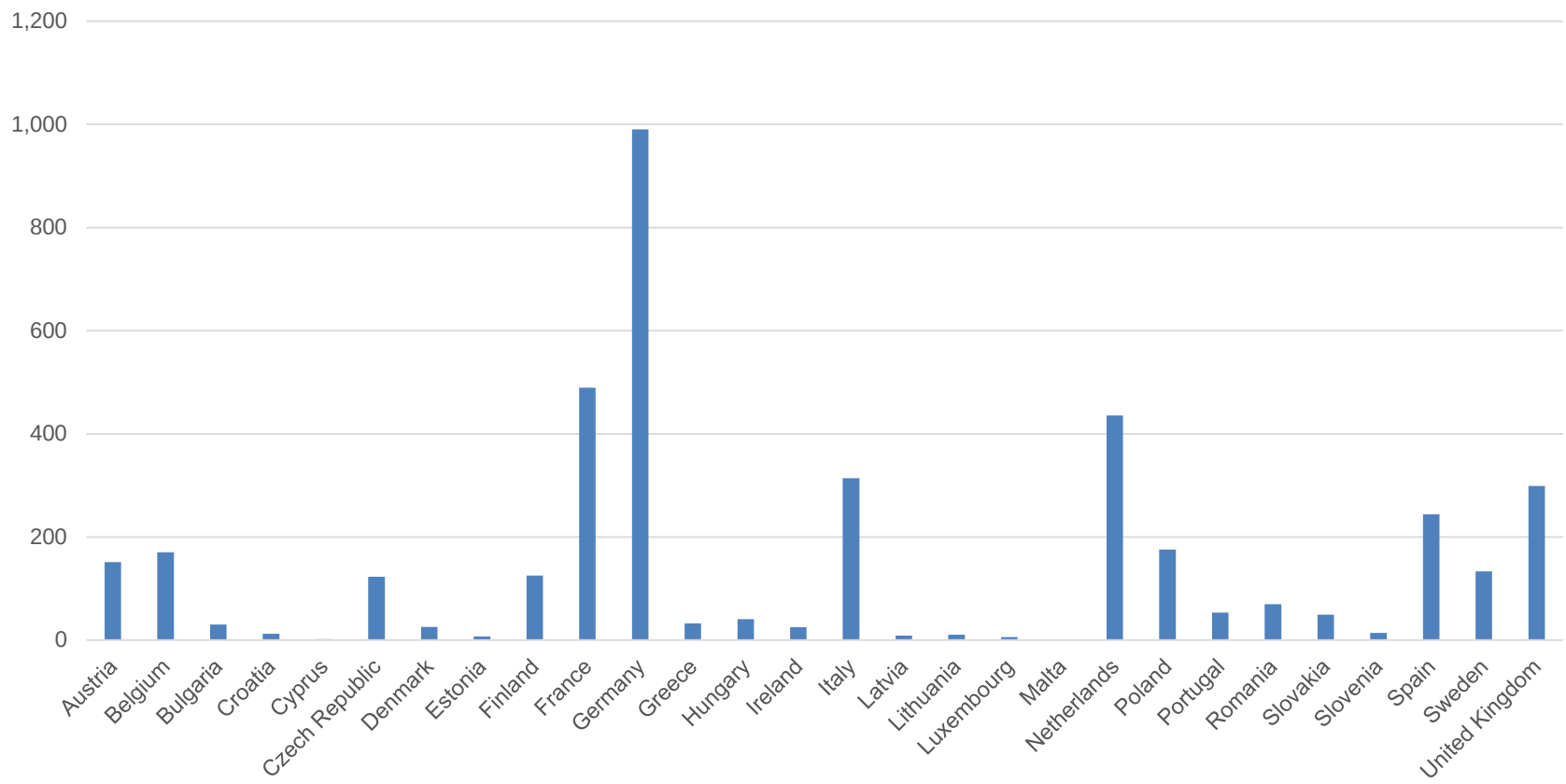
- Introduction
- EU countries energy consumption per sector
- Categorisation of major industrial processes according to temperature range
- Waste heat potential definition
- Preliminary waste heat potential calculations

Introduction

- EU is currently responsible for 11.6% of the world final energy consumptions (9425 Mtoe in 2014) and for 10.8% of the world final CO_2 emissions (33.3 $GtCO_2$ in 2014) [1, 2].
- In EU, industry accounts for the 25.9% of the final energy consumptions and for the 47.7% of the final CO_2 emissions [3].
- European Union has always been a forefront body in terms of awareness and involvement for the mitigation of nowadays environmental issues. Indeed, to date, greenhouse gas emissions have been lowered by 22.9% compared to the ones in 1990 while one of the key targets for 2030 is reduction of at least 40% with respect to the same reference year [2]. In order to achieve this challenging goal, energy saving and a more intensive usage of renewable energy sources are unquestionably suitable trajectories to pursue.
- The waste heat recovery market is projected to reach $53.12 billion by 2018 [4]. Europe dominates this market and in 2012 the European market accounted for 38% of the global heat recovery equipment market.

1. *International Energy Agency, Key world energy statistics, 2016, Available online: https://www.iea.org/publications/freepublications/publication/key-world-energy-statistics.html (accessed on 30 November 2016)*
2. *European Commission, EU energy in figures: statistical pocket book, 2016, ISBN 978-92-79-58247-9, DOI:10.2833/670359*
3. *European Commission, Eurostat Database, 2016, Available online: http://ec.europa.eu/eurostat/data/database (accessed on 30 November 2016)*
4. *Research and Markets, Waste Heat Recovery System Market by Application (Preheating and Steam & Electricity Generation), End-Use Industry (Petroleum Refining, Metal Production, Cement, Chemical, Paper & Pulp, and Textile) - Global Trends & Forecasts to 2018, URL: www.researchandmarkets.com/research/mhdr87/waste_heat*

EU countries energy consumption – industrial sector



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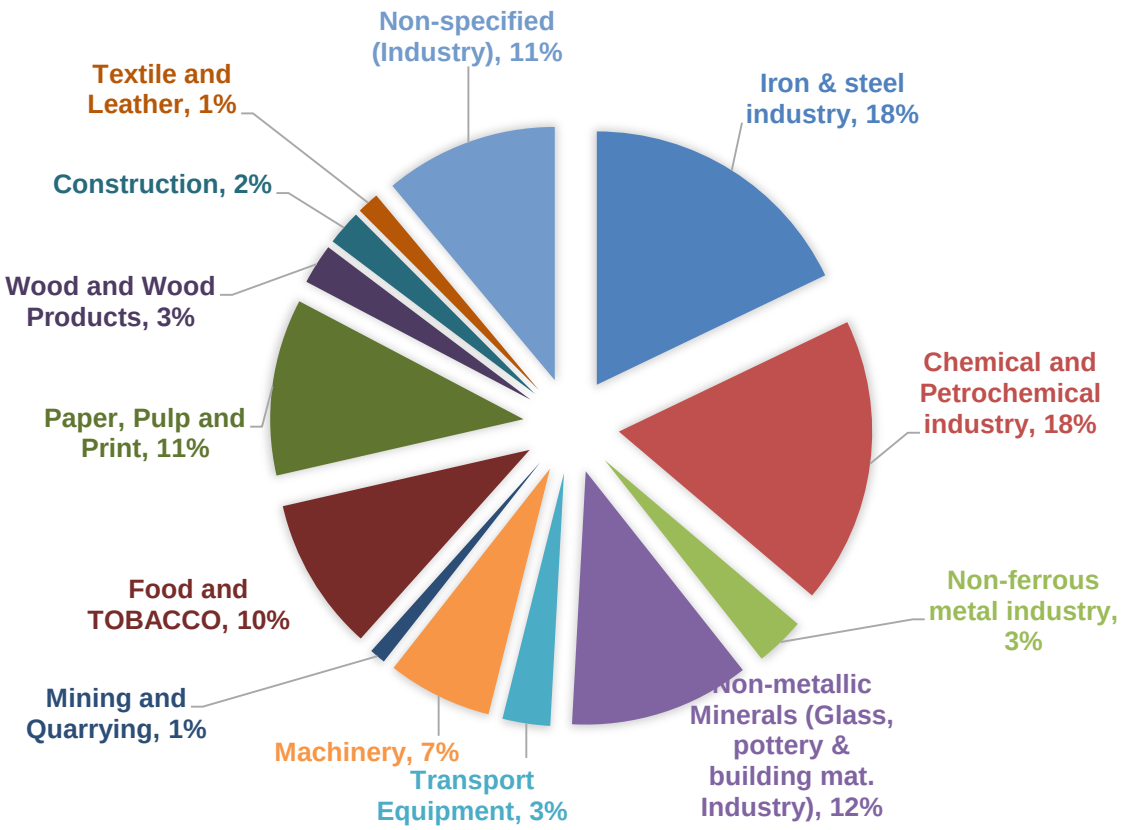
EU countries energy consumption per sector



Categorisation of major industrial processes

<u>Temperature ranges</u>:

- Low Temperatures (LT): < 100 ^{o}C
- Medium Temperatures (MT): 100-299 ^{o}C
- High Temperatures (HT): ≥ 300 ^{o}C

Categorisation of major industrial processes

Type of Industry	Processes used	Temperature range (°C)	Temperature range (LT, MT, HT)
Iron and Steel Production	Sinter Process	1300 – 1480	HT
	Pelletisation Plants - Induration process	straight grate process: 1300 – 1350 grate kiln process: 1250	HT
	Coke oven plants – Jewell - Thompson oven	1150 – 1350	HT
	Blast furnace – Hot Stoves	900 – 1500	HT
	Basic Oxygen Steelmaking	1200	HT
Large Combustion Plants	Combustion process – Gasification / Liquifaction process	430 – 630	HT
	Steam process - Boiler	Coal and Lignite fuels: 540-570 Liquid fuels: 120 – 140	HT
	Co-generation/combined heat and power	100	LT
	Combined cycle plants	430 – 630	HT
Large Volume Inorganic Chemicals-Ammonia, Acids and Fertilizers	Conventional steam reforming - Desulphurization process	350-400	HT
	Conventional steam reforming - Primary and Secondary reforming	Primary: 400-600 Secondary: 400-600 Exhaust gas: 1000	HT
	Sulphuric Acid	400-1500	HT
Large Volume Inorganic Chemicals - Solids and Others industry	Sulphur burning process	145	MT
	Tank furnace process	430-650	HT
	Sodium silicate plant (revolving hearth furnace) process	600	HT

Categorisation of major industrial processes

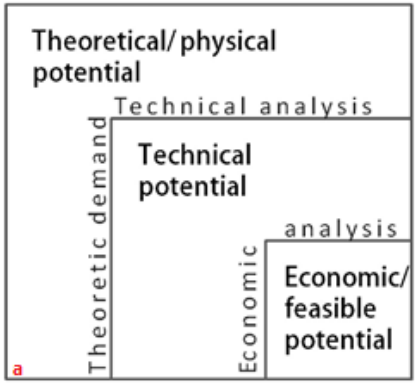
Food, Drink and Milk Industry	Solubilisation/alkalizing process	45-130	MT
	Utility processes -CHP	60-115	MT
	Heat recovery from cooling systems	50-60	LT
	Frying	180-200	MT
Production of Glass	Heating the furnaces and primary melting	750 – 1650	HT
Production of OFC	Energy Supply	45 – 130	LT
	Thermal oxidation of VOCs and co-incineration of liquid waste	950 – 1000 (SNCR) or SCR	HT
	Recovery and abatement of acetylene	N/A	N/A
Production of Non-ferrous metals	Primary lead and secondary lead production	200 – 400	MT
	Smelting Process	400 – 1200	HT
	Zinc sulphide (sphalerite)	900 – 1000	HT
Production of Cement, Lime & Magnesium Oxide	Kiln firing	≥2000	HT
	Clinker burning	1400 – 2000	HT
Production of Polymers	Thermal treatment of waste water	N/A	N/A
Ferrous Metals Processing	Hot rolling mill	1050 – 1300	HT
	Re-heating and heat treatment furnaces	N/A	N/A

Pulp, Paper and Board production	Kraft pulping process (chemical pulping)	155 – 175 (Cooking and delignification)	MT
		90 – 100 (Oxygen delignification)	LT
	Sulphate pulping process (chemical pulping)	800 – 1100 (calcination reaction - lime kiln)	HT
	Mechanical pulping and Chemimechanical pulping	95 – 125 (Grinding- Pressure Groundwood pulping) 70 – 170	LT-MT
	Papermaking and related processes	45 – 90 (Paper machine)	LT
		>350 (Coated wood-free printing tissue process with conventional Yankee dryer)	HT
Surface Treatment Using Organic Solvents	Printing	700-800	HT
	Drying and curing	400-700	HT
	Waste gas treatment from enamelling	500-750	HT
	Manufacturing of Abrasives	35-110 in the drier	LT
		700 for the exhaust air treatment	HT
	Coil coating	150-220	MT
Tanning and Hides and Skins	Drying	60-90	LT
Textiles industry	Dirt removal	1200	HT
	Optimisation of cotton warp-yarn	60-110	LT-MT
	Dyeing	80-100	LT
	Oxidation	750	HT
	Drying	130	MT
Waste Incineration	Drying and degassing	100-300	MT
	Pyrolysis	250-700	MT-HT
	Gasification	500-1600	HT
	Oxidation, Combustion	800-1450	HT
Waste Treatment	Thermal Treatment	Vitrification 1300-1500 Sintering 900-1200	HT
	Drying	100	LT
	Regeneration of carbon	650-1000	HT
	Incineration	850-1200	HT
	Catalytic combustion	200-600	MT-HT
	Dying of wood particles	200-370 for single/triple pass dryers	MT
		500 at rotary dryers	HT
Wood based panels production	Drying of wood fibres	60-220	MT
	Pressing	100-260	MT

Waste heat potential definition

Types of waste heat potential [5]:

- the theoretical (or physical) potential [6],
- the technical potential or
- the economic feasible potential [7]



The theoretical potential only considers physical constraints: the heat has to be above ambient temperature, bound in a medium, etc. Not considered here is whether it is possible to extract the heat from the carrier fluid or whether it is possible to use it. The above-mentioned constraints set the technical potential.

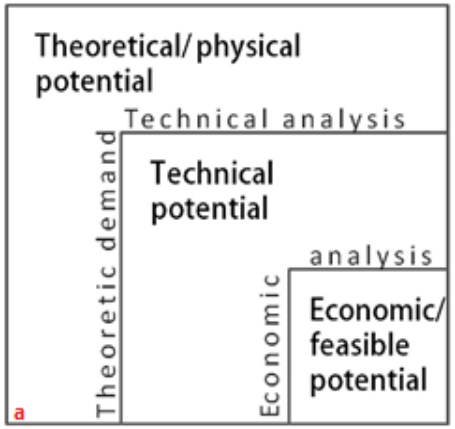
In addition, the technical potential depends on the technologies considered. An example of a technical constraint is the required minimum temperature. The technical potential to use waste heat is defined by two major constraints: in addition to the boundary conditions of the technology itself, a heating or cooling demand is necessary.

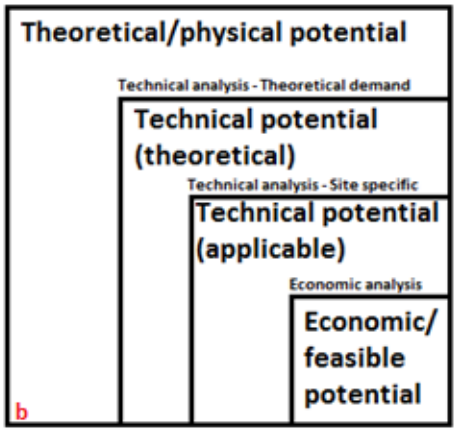
5. *Sarah Brueckner, Laia Miró, Luisa F. Cabeza, Martin Pehnt, Eberhard Laevemann, Methods to estimate the industrial waste heat potential of regions – A categorization and literature review, Renewable and Sustainable Energy Reviews, Volume 38, October 2014, Pages 164-171, ISSN 1364-0321, DOI:10.1016/j.rser.2014.04.078*
6. *Metz B, Davidson OR, Bosch PR, Dave R, Meyer LA. (2007). IPCC fourth assessment report: climate change 2007. Working Group III: mitigation of climate change. Cambridge University Press, Cambridge, United Kingdom and New York, NY, USA.*
7. *Roth H, Lucas K, Solfrian W, Rebstock F. (1996). Die Nutzung industrieller Abwõrme zur Fernwõrmeversorgung – analyse der Hemmnisse fór die Nutzung industrieller Abwõrme zur Fernwõrmeversorgung. Umweltbundesamt.*

Waste heat potential definition

The technical potential can be then separated into a theoretical technical potential and the applicable technical potential, which are distinguished by the fact that the first one is calculated using a theoretical/generic process-related analysis, while the second one is calculated by using onsite data with all plant specific parameters taken into consideration.

Accordingly, the feasibility of the technology considered is eventually analysed using economic criteria/analysis.





Preliminary waste heat potential calculations

The data used for the estimation of the waste heat potential are those presented by Forman *et al.* (2016). As aforementioned the waste/rejected heat can be further distinguished by its applicability according to the respective temperature range (qualitative analysis).

In terms of Thermodynamic analysis, energy is described as the sum of exergy and anergy, whereby exergy stands for the energy that can be totally turned into technical work. Thus, the exergy content of waste/rejected heat can be calculated by Carnot's theorem, which states that the maximum efficiency of a heat engine is determined by the two available heat reservoirs. Applying the Carnot factor to the waste heat amounts and their corresponding waste heat temperatures (T_{high}) gives the respective technical work potential further indicated as Carnot's potential.

$$\eta_{max} = \eta_C = 1 - \frac{T_{low}}{T_{high}}$$

Preliminary waste heat potential calculations

Waste heat potential and Carnot's potential according to Forman *et al.* (2016)

Potential	LT	MT	HT
Waste Heat	12.60%	6.00%	11.40%
Carnot's	1.73%	2.00%	6.40%

Using the above table with the temperature ranges of each process in each industrial sector an approximation of the potentials was estimated

	Type of Industry	Waste heat potential	Carnot's potential
1	Iron & Steel Industry	11.40%	6.40%
2	Chemical and Petrochemical Industry	11.00%	5.13%
3	Non-ferrous metal industry	9.59%	4.93%
4	Non-metallic minerals (glass, pottery & building materials industry)	11.40%	6.40%
5	Food and Tobacco	8.64%	1.89%
6	Paper, Pulp and Print	10.56%	4.59%
7	Wood and Wood Products	6.00%	2.00%
8	Textile and Leather	11.04%	2.72%
9	Non-Specified industry	10.38%	4.84%

Preliminary waste heat potential calculations

Waste heat potential for the industrial sectors of each EU-28 country

Industry	COUNTRY																											
	AU	BE	BG	CR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	GB
Iron & steel industry	4.63	4.41	0.13	0.03	0.00	3.87	0.06	0.00	1.49	10.2	24.9	0.19	0.52	0.00	6.90	0.04	0.00	0.31	0.00	4.35	3.20	0.23	2.22	2.92	0.20	4.24	2.09	5.14
Chemical and Petrochemical industry	1.82	4.98	1.00	0.18	0.01	1.81	0.31	0.10	1.34	9.2	25.4	0.14	0.96	0.29	5.27	0.03	0.39	0.07	0.00	10.7	3.81	0.63	2.11	0.38	0.19	5.13	0.71	4.16
Non-ferrous metal industry	0.31	0.47	0.16	0.02	0.00	0.10	0.00	0.00	0.33	1.7	3.06	0.98	0.17	0.54	0.71	0.00	0.00	0.00	0.00	0.48	0.45	0.03	0.00	0.27	0.17	1.22	0.37	0.61
Non-metallic Minerals	1.62	2.42	0.66	0.44	0.18	1.79	0.50	0.23	0.35	7.7	12.0	0.96	0.50	0.40	6.62	0.19	0.25	0.14	0.00	1.02	3.38	1.44	1.05	0.52	0.24	4.48	0.42	3.47
Food and Tobacco	0.79	1.88	0.24	0.22	0.03	0.78	0.63	0.06	0.35	6.9	6.96	0.47	0.51	0.44	2.67	0.09	0.19	0.03	0.00	2.68	1.85	0.42	0.53	0.14	0.06	2.18	0.38	2.69
Paper, Pulp and Print	2.93	1.27	0.31	0.07	0.00	1.00	0.21	0.07	7.23	4.7	10.0	0.12	0.22	0.03	2.48	0.01	0.05	0.01	0.00	1.18	1.93	1.73	0.10	0.53	0.20	2.52	7.18	2.00
Wood and Wood Products	0.67	0.24	0.04	0.02	0.00	0.21	0.06	0.08	0.43	0.5	1.44	0.02	0.04	0.10	0.28	0.25	0.06	0.01	0.00	0.05	0.60	0.07	0.18	0.03	0.03	0.35	0.38	0.00
Textile and Leather	0.16	0.35	0.09	0.04	0.00	0.24	0.03	0.02	0.04	0.5	0.89	0.06	0.05	0.02	1.50	0.01	0.04	0.02	0.00	0.19	0.15	0.37	0.00	0.04	0.03	0.44	0.03	0.93
Non-specified (Industry)	0.43	0.78	0.19	0.00	0.01	0.78	0.17	0.03	0.32	1.6	4.40	0.16	0.30	0.21	1.92	0.02	0.00	0.02	0.01	22.9	0.80	0.16	0.00	0.14	0.09	1.55	0.96	8.44

Preliminary waste heat potential calculations

Carnot's potential for the industrial sectors of each EU-28 country

Industry	COUNTRY																										
	AU	BE	BG	CR	CY	CZ	DK	EE	FI	FR	DE	GR	HU	IE	IT	LV	LT	LU	MT	NL	PL	PT	RO	SK	SI	ES	SE	GB
Iron & steel industry	2.60	2.48	0.07	0.02	0.00	2.17	0.03	0.00	0.84	5.78	14.0	0.10	0.29	0.00	3.88	0.02	0.00	0.18	0.00	2.44	1.80	0.13	1.24	1.64	0.11	2.38	1.17	2.88
Chemical and Petrochemical industry	0.85	2.32	0.47	0.08	0.00	0.85	0.15	0.04	0.63	4.33	11.8	0.07	0.45	0.14	2.46	0.01	0.18	0.03	0.00	5.03	1.78	0.30	0.98	0.18	0.09	2.39	0.33	1.94
Non-ferrous metal industry	0.16	0.24	0.08	0.01	0.00	0.05	0.00	0.00	0.17	0.92	1.57	0.51	0.09	0.28	0.37	0.00	0.00	0.00	0.00	0.25	0.23	0.01	0.00	0.14	0.09	0.63	0.19	0.31
Non-metallic Minerals	0.91	1.36	0.37	0.25	0.10	1.00	0.28	0.13	0.20	4.35	6.74	0.54	0.28	0.22	3.72	0.11	0.14	0.08	0.00	0.57	1.90	0.81	0.59	0.29	0.13	2.52	0.24	1.95
Food and Tobacco	0.17	0.41	0.05	0.05	0.01	0.17	0.14	0.01	0.08	1.52	1.52	0.10	0.11	0.10	0.58	0.02	0.04	0.01	0.00	0.59	0.40	0.09	0.12	0.03	0.01	0.48	0.08	0.59
Paper, Pulp and Print	1.27	0.55	0.13	0.03	0.00	0.44	0.09	0.03	3.14	2.05	4.35	0.05	0.10	0.01	1.08	0.00	0.02	0.01	0.00	0.51	0.84	0.75	0.04	0.23	0.09	1.09	3.12	0.87
Wood and Wood Products	0.22	0.08	0.01	0.01	0.00	0.07	0.02	0.03	0.14	0.19	0.48	0.01	0.01	0.03	0.09	0.08	0.02	0.00	0.00	0.02	0.20	0.02	0.06	0.01	0.01	0.12	0.13	0.00
Textile and Leather	0.04	0.09	0.02	0.01	0.00	0.06	0.01	0.00	0.01	0.14	0.22	0.01	0.01	0.01	0.37	0.00	0.01	0.01	0.00	0.05	0.04	0.09	0.00	0.01	0.01	0.11	0.01	0.23
Non-specified (Industry)	0.20	0.36	0.09	0.00	0.00	0.37	0.08	0.02	0.15	0.76	2.05	0.08	0.14	0.10	0.89	0.01	0.00	0.01	0.01	10.7	0.37	0.07	0.00	0.06	0.04	0.72	0.45	3.94

Preliminary waste heat potential results for EU countries

EU COUNTRY	Potential (TWh)	
	Waste heat	Carnot's
Austria	13.36	6.43
Belgium	16.79	7.89
Bulgaria	2.81	1.30
Croatia	1.02	0.45
Cyprus	0.22	0.11
Czech Republic	10.59	5.18
Denmark	1.96	0.79
Estonia	0.60	0.27
Finland	11.89	5.35
France	43.52	20.03
Germany	89.18	42.82
Greece	3.11	1.47
Hungary	3.27	1.48
Ireland	2.03	0.88
Italy	28.36	13.44
Latvia	0.65	0.26
Lithuania	0.99	0.42
Luxembourg	0.62	0.32
Malta	0.03	0.01
Netherlands	43.72	20.17
Poland	16.17	7.56
Portugal	5.08	2.28
Romania	6.18	3.03
Slovakia	4.96	2.59
Slovenia	1.20	0.58
Spain	22.14	10.45
Sweden	12.52	5.72
UK	27.44	12.71
EU28	**370.42**	**173.98**

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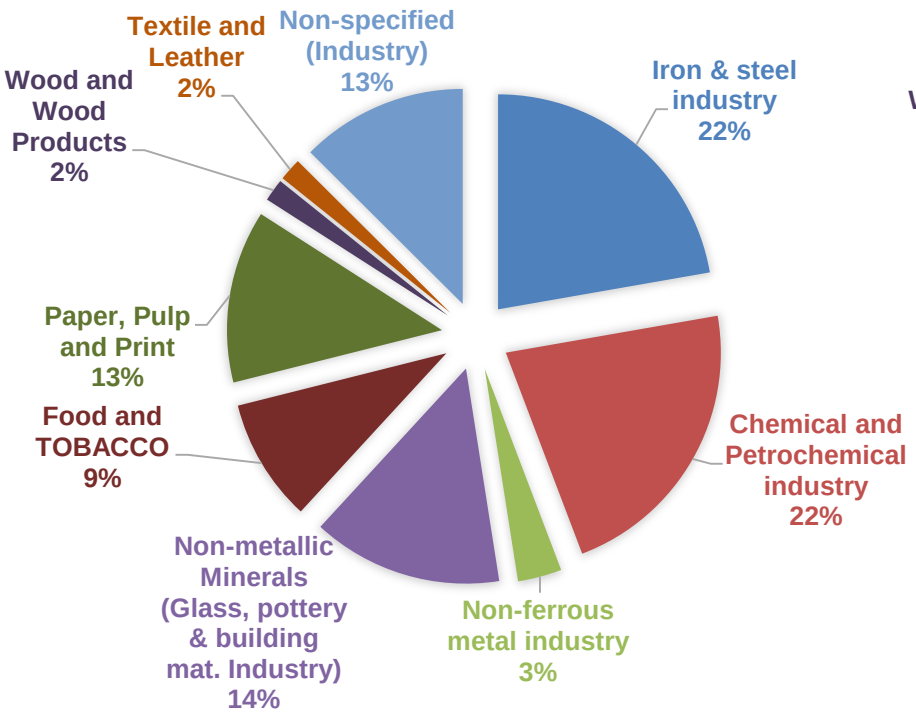
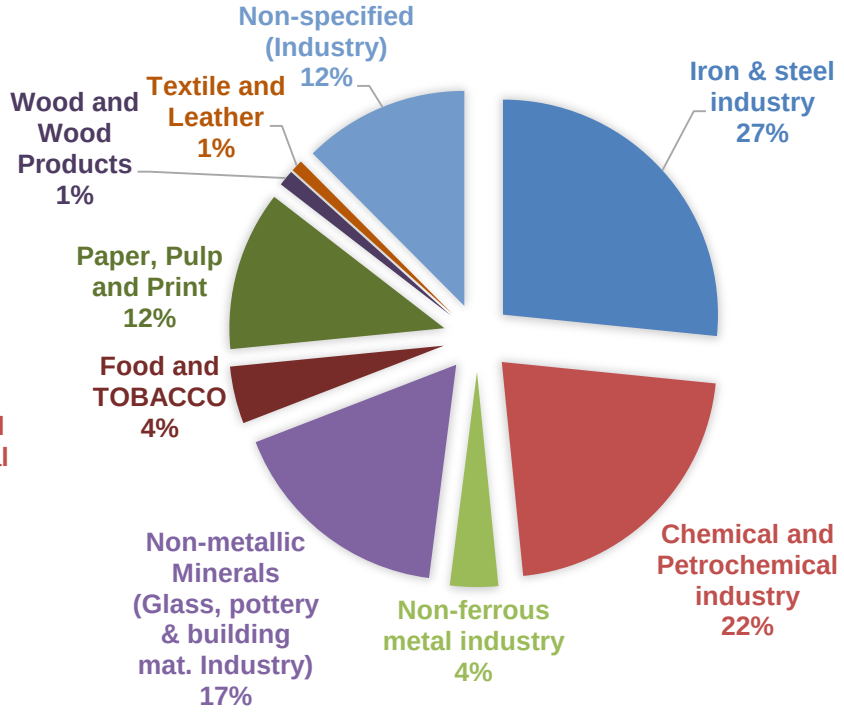
Preliminary waste heat potential results

WASTE HEAT POTENTIAL



CARNOT POTENTIAL



Thank you for your attention!

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