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Industrial Waste Heat Potential for Meeting Heat Demand in the Republic of Serbia

Potencijal industrijske otpadne toplote za zadovoljenje toplotnih potreba u Republici Srbiji

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Abstract **-** Final energy consumption in the industrial sector accounts for almost 25% of energy-related final energy consumption in the Republic of Serbia. It is estimated that 50-70% of energy consumption in industry, is intended to heat production in various industrial processes. Some of the produced heat is irreversibly wasted: through walls of process equipment, as the energy of flue gases, wastewater, etc.

Utilization of waste heat for meeting heating needs, within or outside of an industrial facility, although possible and recommended, is a challenging task. Carriers of waste heat may be different (flue gases from the combustion process, liquid fluids from the washing, drying or cooling process, etc.), as well as their temperature range (from below 50°C to over 500°C.). Availability of waste heat is highly dependent on industrial processes, while potential consumers often may be distanced from an industrial site.

The paper presents the results of the evaluation of waste heat potential for some industrial subbranches in Serbia, based on a previously developed methodology. Based on data about energy consumption in selected subbranches of industry, and the temperature of waste heat carriers, the theoretical potential of this alternative source for direct utilization or utilization by compression heat pumps in district heating systems is determined.

Index Terms - Waste heat, Industry, Heat demand

Rezime **-** Finalna potrošnja energije u industrijskom sektoru čini skoro 25% finalne potrošnje energije u Republici Srbiji. Procenjuje se da je 50-70% potrošnje energije u industriji namenjeno proizvodnji toplotne energije u različitim industrijskim procesima. Deo proizvedene toplotne energije se nepovratno gubi kao energija odvedena u okolinu: prenosom toplote kroz zidove procesne opreme, dimnim gasovim, otpadnim vodama itd.

Korišćenjem otpadne toplote povećava se efikasnost korišćenja primarne energije i smanjuje ukupna potreba za energijom. Otpadna toplota se može koristiti u samom industrijskom objektu ukoliko postoji takva potreba, ili van njega. Raspoložive temperature otpadne toplote su različite (od ispod 50°C do preko 500°C), kao i sami nosioci otpadne toplote (dimni gasovi iz procesa sagorevanja, tečni fluidi iz procesa pranja, sušenja ili hlađenja i dr.). Dostupnost otpadne toplote u velikoj meri zavisi od tipa industrijskog procesa, dok potencijalni potrošači često mogu biti udaljeni od lokacije industrijskog objekta.

U radu su prikazane procene potencijala otpadne toplote za pojedine industrijske grane u Srbiji, primenom prethodno razvijene metodologije. Na osnovu podataka o potrošnji energije u odabranim granama industrije i temperaturama nosioca otpadne toplote, određen je teoretski potencijal ovog izvora energije za direktno korišćenje, ili korišćenje putem kompresorskih toplotnih pumpi u sistemima daljinskog grejanja.

Ključne reči – otpadna toplota, industrija, toplotne potrebe

I INTRODUCTION

The waste heat from industrial site is considered as a part of the heat content of all streams (gas, water, air, etc.) which are discharged from an industrial process at a given moment and that can be internally or externally usable, technically and economically [1]. Sources for waste heat generation in industries can be a single machine or whole systems that release waste heat into the environment. These sources include furnaces, wastewater from washing, drying or cooling processes, and also refrigeration systems, motors or the exhaust air from production halls [2]. Depending on its characteristics, waste heat can be used for power generation, and for heating/cooling (directly without upgrading or after upgrading, by heat pumps).

In this paper, the waste heat potential from industrial sites in Serbia for using in district systems for heating/cooling is considered. The assessment of technical potential of this alternative energy source is based on data of energy consumption in industry presented in an official energy balance for 2021 [3]. Using top-down approach developed in [4] the amounts of energy that could be used directly in district heating system or by using compression heat pumps are determined.

The paper is organized in sections. After introduction section, final energy consumption and heat consumption in Serbian industry are presented in sections II and III. General methodology for industrial waste heat assessment is presented in a section IV. The results of implementation of a selected methodology and assessment of technical potential of industrial waste heat for utilization in district heating systems are presented in a section V. Conclusion remarks and suggestion for further work are presented in a section VI.

II Energy Consumption in Industry in Serbia

Energy consumption in industry accounts about 22-25% of final energy consumption in Serbia. Historical data related to structure of consumption of the industry sector by energy source are presented in Figure 1. Annual consumption in industry in the analysed period (2012-2021) was in the range of 22,727 GWh in the year 2014 up to 28,473 in 2012. Final energy consumption in industry shows the relation with GDP growth rate. In addition, the increasing trend in electricity consumption is observed, while the consumption of oil products and coal are declining. Electricity has the highest share in the energy mix (37.9%), followed by natural gas (24.8%), oil derivatives (12.2%), bioenergy (9.1%) and heat (9%) (Figure 2).

The main energy consumers are the following industrial sub-sectors: Food, Beverages & Tobacco (19%), Iron & Steel (16%), Non-metallic minerals (16%), and Chemical & petrochemical (15%) sectors (Figure 3).

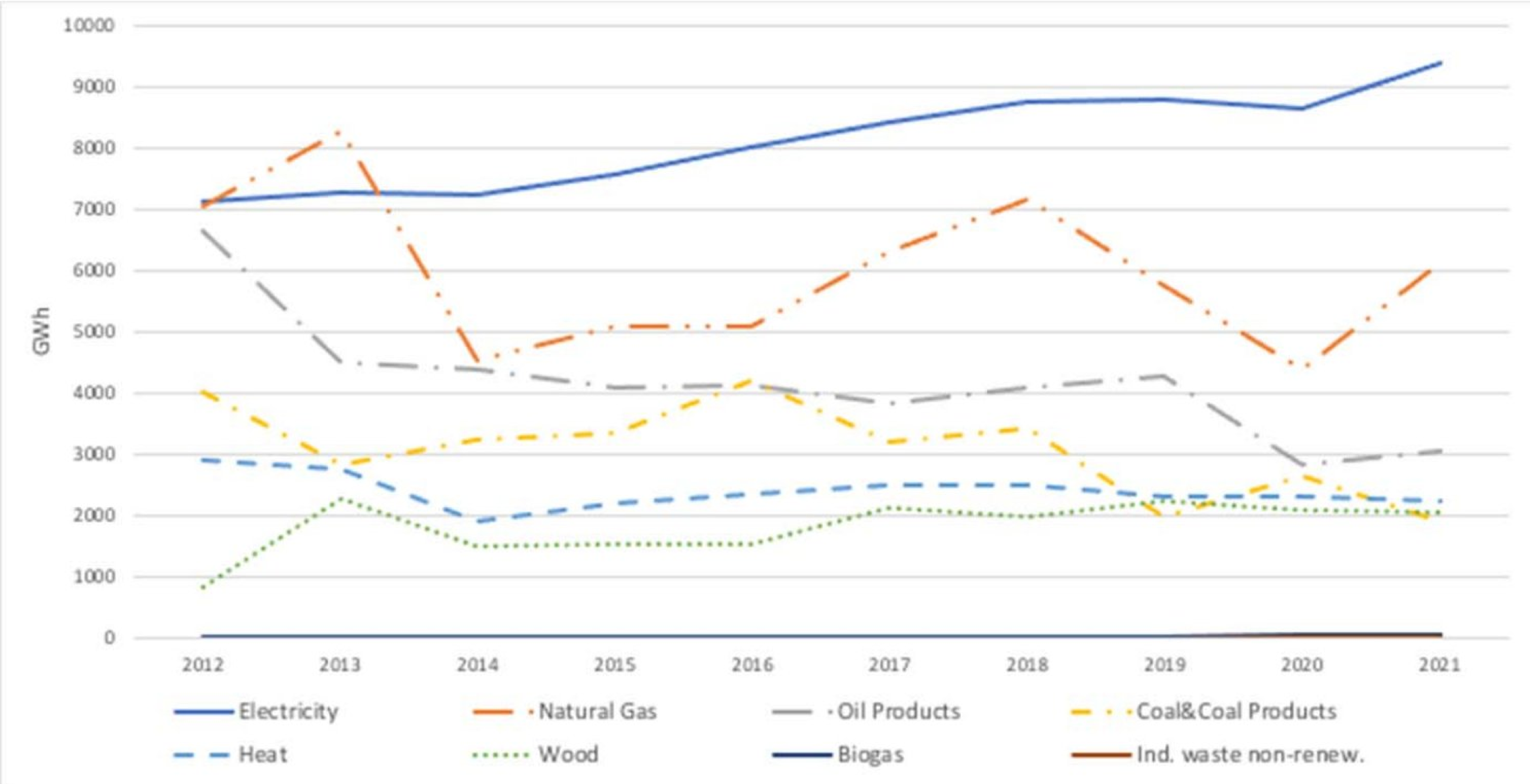

Figure 1. Final energy consumption in industry for period 2012-2021, by energy source, in ktoe, [3]

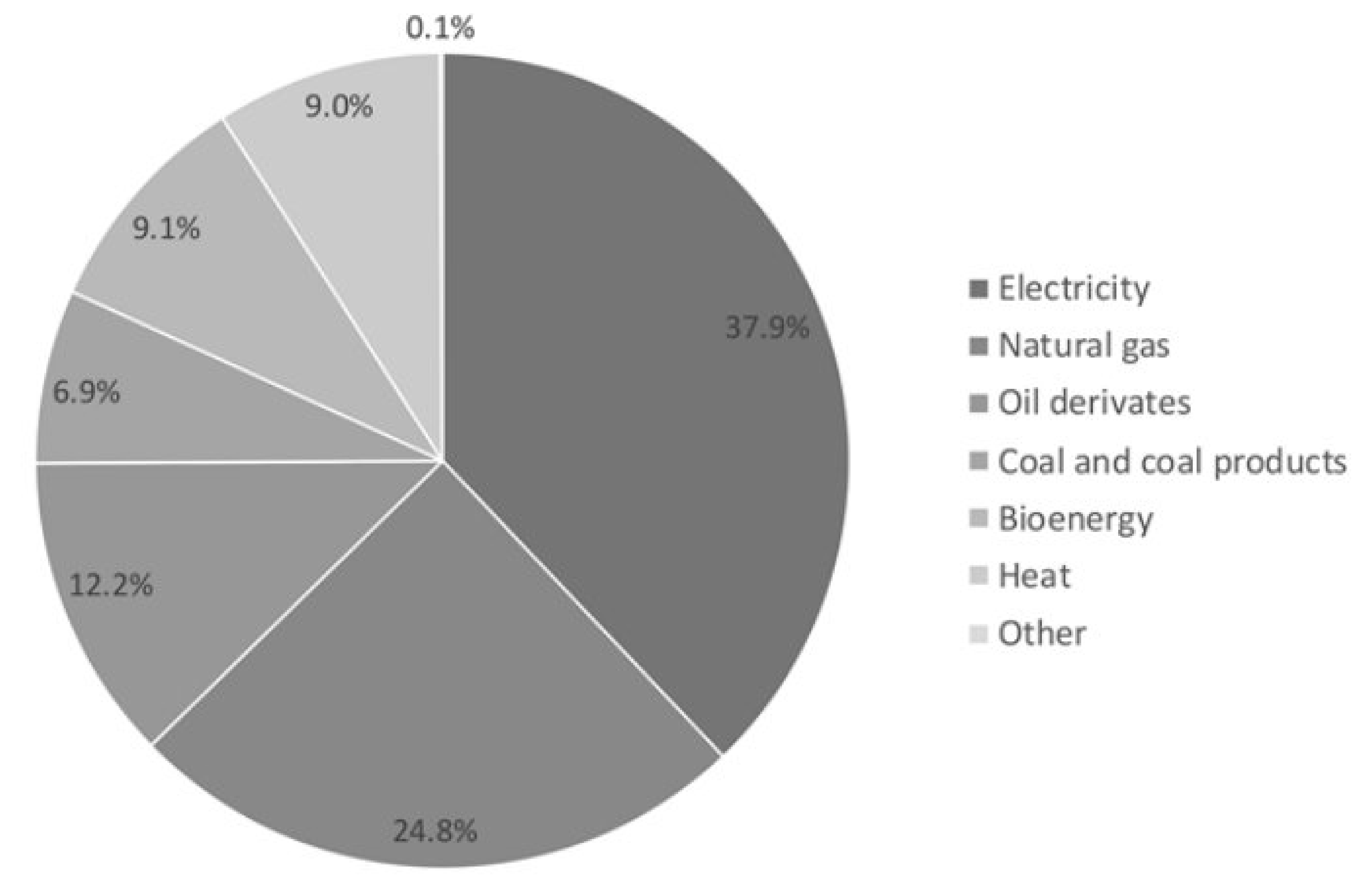

Figure 2. Structure of consumption in industry 2021, by energy source [3]

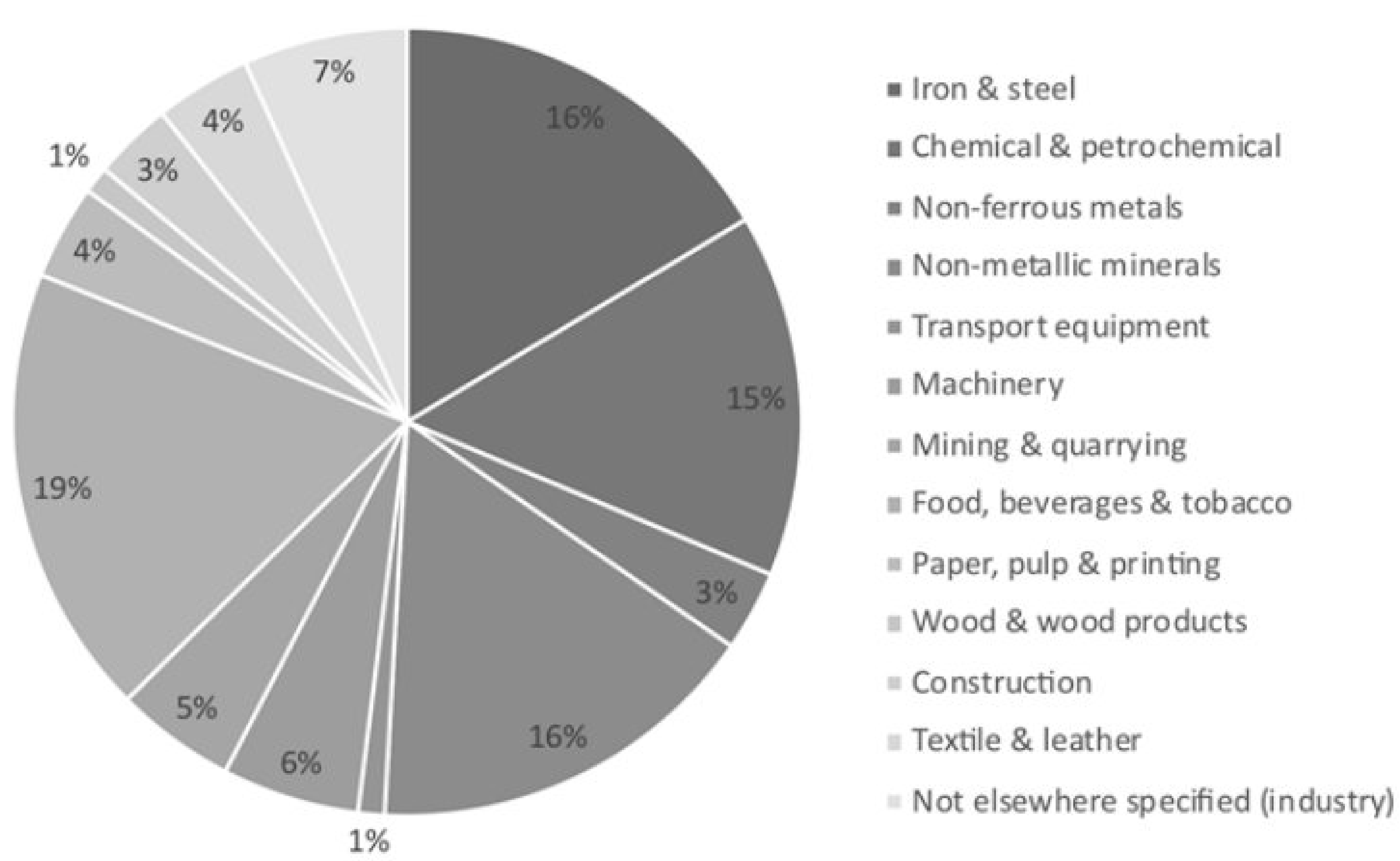

Figure 3. Structure of consumption in industry 2021, by sub-sector [3]

III Heat Consumption in Industry in Serbia

Heat consumption in industry is related to industrial process heat and energy used for space heating. Industrial process heat is defined as thermal energy used directly in the preparation or treatment of materials used to produce manufactured goods [5]. Data about derived heat by industrial sub-sectors in 2021 are presented in Table 1. These are the amounts of thermal energy supplied to the industry from external sources (e.g., district heating systems).

Table 1. Derived heat and shares of industry sub-sectors in Serbia (2021), [3]

Sub-sector	Heat	
	[GWh]	%
Iron and steel	**651**	**29.1%**
Chemical and petrochemical	**694**	**31.0%**
Non-ferrous metals	**82**	**3.7%**
Non-metallic minerals	**14**	**0.6%**
Transport equipment	**10**	**0.4%**
Machinery	**6**	**0.3%**
Mining and quarrying	**0**	**0.0%**
Food, beverages and tobacco	**311**	**13.9%**
Paper. pulp and printing	**199**	**8.9%**
Wood and wood products	**0.2**	**0.0%**
Construction	**0**	**0.0%**
Textiles and leather	**13**	**0.6%**
Not elsewhere specified (Industry)	**259**	**11.6%**
Total	**1980.2**	**100.0%**

Energy consumption of combustible energy sources is dominantly related to heat production at the place of consumption, except for gasoline and diesel, whose utilization is subjected to internal combustion engines. Table 2 presents data about produced heat due to direct utilization of fuels. For the calculation of useful heat, harmonized efficiency reference values for separate production of heat were applied [6].

Table 2. Heat consumption in industry, Serbia (2021)

Sub-sector	Produced heat (combustion of fuels) [GWh]
Iron and steel	**1,755**
Chemical and petrochemical	**1,452**
Non-ferrous metals	**323**
Non-metallic minerals	**1,986**
Transport equipment	**46**
Machinery	**425**
Mining and quarrying	**22**
Food, beverages and tobacco	**2,307**
Paper, pulp and printing	**312**
Wood and wood products	**85**
Construction	**14**
Textiles and leather	**529**
Not elsewhere specified (Industry)	**330**
Total	**9,587**

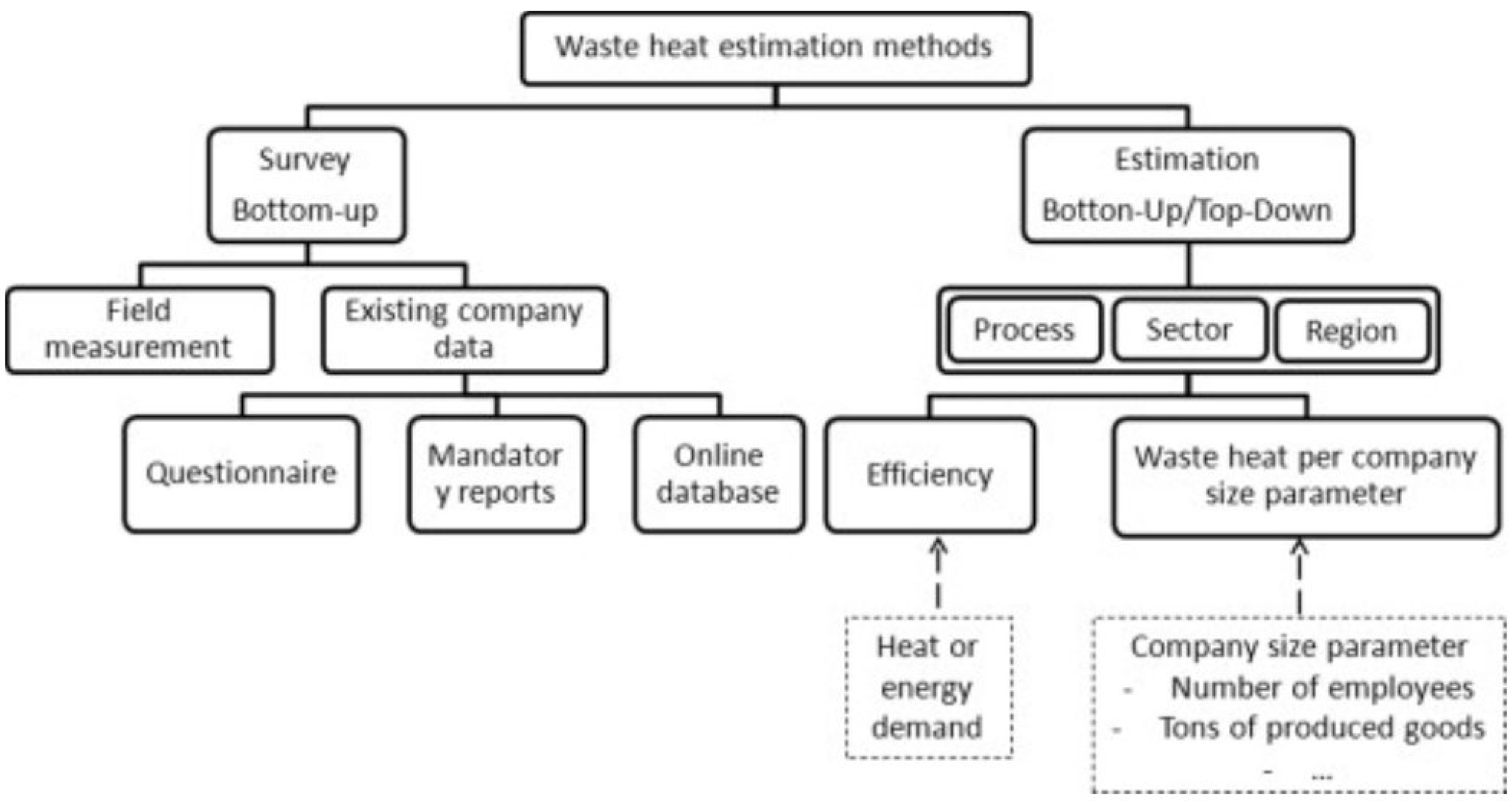

Figure 4. Classification of approaches for industrial waste heat determination [2]

IV Methodology for Waste Heat Assessment

The data about waste or surplus heat from industrial facilities is not systematically recorded in international and national energy statistics. Furthermore, waste heat recovery potential is sector-specific and even for a same product depends on site-specific process routes [7]. Therefore, different approaches to estimating the industrial waste heat potential may be applied (Figure 4). In general, these approaches can be considered as top-down and bottom-up.

A top-down approach is based on the use of primary energy, the assumptions about energy efficiency and energy distribution. It allows only rough estimation of the potential of waste heat in different industry sectors, without conclusions about the temperature and availability of waste heat.

Bottom-up approach is based on specific data on representative companies collected through questionnaires or even measurements. Depending on the level of detail of the questionnaire, this method allows conclusions to be drawn about the technical potential of a particular company or sector. Measurements are by far the most complex method. Several companies/sites need to be reviewed and re-measured and there may be a conflict with the confidentiality of process data [8]. Mentioned approaches could also be combined.

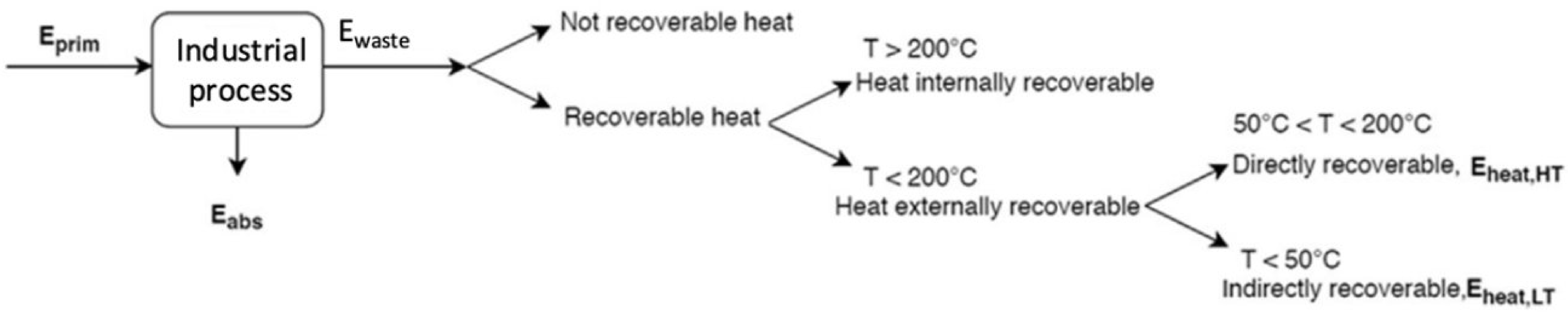

Figure 5. Procedure for calculating the industrial waste heat, recoverable in a district heating system [4]

For the estimation of waste heat recoverable in district heating systems the procedure proposed in [4] will be used. It is based on the energy input of the industrial facility and it is a combination of bottom-up and top-down approaches. The scheme of the procedure is presented in Figure 5.

Applying the first law of thermodynamics to an industrial process gives:

$$E_{prim} = E_{abs} + E_{waste}[MWh] \quad (1)$$

Where:

E_{prim} is the primary energy input consumed by the production site,

E_{abs} is the energy absorbed by the industrial process - the process energy used for the realization of the final product, and

E_{waste} indicates all the waste heat which is not embedded in the final product and that is usually dissipated in the environment.

According to the temperature level at which this waste heat is produced, the last term in the equation (1) can be divided, as follows [9]:

$$E_{waste} = E_{heat,steam} + E_{heat,HT} + E_{heat,LT} + E_{heat,lost} \quad [MWh] \quad (2)$$

Where:

$E_{heat,steam}$ is high temperature waste heat (above 200°C) coming from steam processes,

$E_{heat,HT}$ is high temperature water recoverable waste heat (mainly heat coming from flue gases at a temperature above 90°C),

$E_{heat,LT}$ is low temperature water recoverable waste heat (mainly heat resulting from cooling processes with a temperature around 40°C that requires a temperature lift by compression heat pumps to be used in DH), and

$E_{heat,lost}$ represents a fraction of irreversible losses.

The level of temperature considered here is relative to the purpose of the recovery. The average operational temperature of DH around approximately 90°C is adopted. A bottom-up approach has been applied in [9] to identify the amount of every component of equation (2) for each industrial sector investigated, so that it has been possible to identify the coefficients η_{steam}, η_{HT}, η_{LT} and η_{loss} allowing the calculation of each component starting from primary energy:

$$E_{waste} = E_{prim}(\eta_{steam} + \eta_{HT} + \eta_{LT} + \eta_{lost}) \quad [MWh] \quad (3)$$

The sum of the three recoverable components represents theoretical potential:

$$E_{heat.th} = E_{prim}(\eta_{steam} + \eta_{HT} + \eta_{LT}) \quad [MWh] \quad (4)$$

In order to calculate the technical potential, some recovery factors η_{tech} need to be applied; they consider the technological efficiencies in the recovery process, such has heat exchanger efficiency, and the eventual temperature upgrade so that the equation (4) can be rewritten as:

$$E_{heat.tech} = \eta_{tech}\left(E_{heat,\mathrm{steam}} + E_{heat,\mathrm{HT}} + \eta_{HP}E_{heat,LT}\right) \quad [MWh] \quad (5)$$

The technical recovery potential of waste heat calculated by (5) represents the fully recoverable waste heat considering heat quality and technological efficiency.

A final step that has been conducted is a simplified method to take into account the time correspondence between waste heat availability and the heat demand in DH. In fact, the time dependent profile of heat effluents in the production plants is often quite flat and so it does not match with the required heat profile by users in a DH system. Therefore, to have a full recovery of $E_{heat.tech}$ an important storage capacity would be required.

In this paper, the recovery in DH is precautionarily considered without the introduction of seasonal storages so that the correspondence in time is taken into account by considering the ratio between the equivalent operating hours of the industrial process, usually around 7,000 ($oh_{process}$), and of DH, which have been considered as 2,500 (oh_{DH}) for Serbia, so that the practical potential heat recovery in DH should be calculated as follows:

$$E_{heat.tech} = \eta_{tech}\left(25\% E_{heat,\mathrm{steam}} + E_{heat,\mathrm{HT}} + \eta_{HP} E_{heat,LT}\right) \cdot oh_{DH}/oh_{process} \quad [MWh] \qquad (6)$$

In the previous equation, only the fraction (25%) of waste heat coming from steam processes is considered to be available for external waste heat recovery [4]. It was rational to assume that the majority of the high-level temperature waste heat is going to be recovered internally.

The equation (6) can be rewritten considering the technological integration in DH, which is direct in case of high temperature levels of waste heat, or indirect, needing a compression heat pump, in case of low temperature waste heat, so that the final heat recoverable in DH can be calculated as follows:

$$E_{heat,\mathrm{DH}} = E_{heat,\mathrm{HT,DH}} + \eta_{HP} E_{heat,LT,DH}$$

$$= E_{prim}\left(\eta_{DH,HT} + \eta_{DH,LT}\eta_{HP}\right) \cdot oh_{DH}/oh_{process} \ [MWh] \qquad (7)$$

Where

$\eta_{DH,HT} = \eta_{tech}(25\%\eta_{steam} + \eta_{HT})$, and

$\eta_{DH,LT} = \eta_{tech}\eta_{LT}$

Table 3. Recovery coefficients defined by industrial sector, according to the temperatures of both the heat source and district heating system [9]

Activity Sector	Waste heat				DH recovery	
	η_{steam}	η_{HT}	η_{LT}	η_{loss}	$\eta_{DH,HT}$	$\eta_{DH,LT}$
Fuel supply and refineries	–	–	–	–	28.1	–
Food products and beverages	18.2	3.6	28.1	2.1	6.1	21.1
Pulp, papers and printing	36.1	7.9	0.5	1.8	12.7	0.3
Basic chemicals	8.3	11.2	6.5	–	9.9	4.9
Other non-metallic mineral products	6.4	11	2.6	–	9.5	2.0
Capital goods manufacturing	7.8	7.8	7.8	2.6	7.3	5.9
Fine chemical products	12.5	16.8	9.8	–	14.9	7.3
Iron and steel	3.5	3.5	3.5	1.2	3.3	2.7
Fabricated metals products	4.5	4.5	4.5	1.5	4.2	3.3
Textile	7.8	7.8	7.8	2.6	7.3	5.9
Others	15.6	15.6	15.6	5.2	14.6	11.7

The coefficients used in the calculation of waste heat, for the specific industrial sub-sectors, are presented in Table 3.

V Industrial Waste Heat Potential for Utilization in District Heating Systems in Serbia

he determination of waste heat potential of the industry sector in Serbia is a relatively "new" topic [10]. There is no systematic research, and collecting data about the potential in different sub-sectors. In [4,7,9,10,11], for the cases when data from individual industrial installations are not available, the proposed methodology for determination of industrial waste heat were based on combined approach and on using of site-specific data contained in the EU ETS database for determination of primary energy consumption (E_{prim}). However, such data are not available for Serbia. Therefore, in this paper, for the estimation of primary energy input consumed by the specific industry sub-sectors the data from national energy balances will be used. It is assumed that the primary energy consumption in the specific sub-sector is equal to final energy consumption reduced by final electricity and heat consumption. This assumption means that the electricity is used mainly for purposes with the low ability for energy recovery (mechanical work, lighting, etc.), and that the heat is used with a high efficiency. The primary energy consumption in Serbian industry subsectors with the potential for direct use in district heating systems, estimated by previously explained methodology, is presented in Table 4.

Table 4. Estimation of primary energy consumption by the specific industry sub-sectors in the Republic of Serbia in 2021

Industry sub-sector	E_{prim} (GWh)
Iron and steel	2,070.9
Chemical and petrochemical	1,761.2
Non-ferrous metals	411.2
Non-metallic minerals	2,583.8
Transport equipment	59.3
Machinery	568.5
Food, beverages and tobacco	2,982.5
Paper, pulp and printing	372.0
Wood and wood products	130.1
Textiles and leather	653.9
Not elsewhere specified (Industry)	419.1

The result, the estimation of waste heat from industrial sites in the Republic of Serbia that could be recovered directly in district heating systems, obtained by the proposed methodology and by using equation (7) is presented in Table 5.

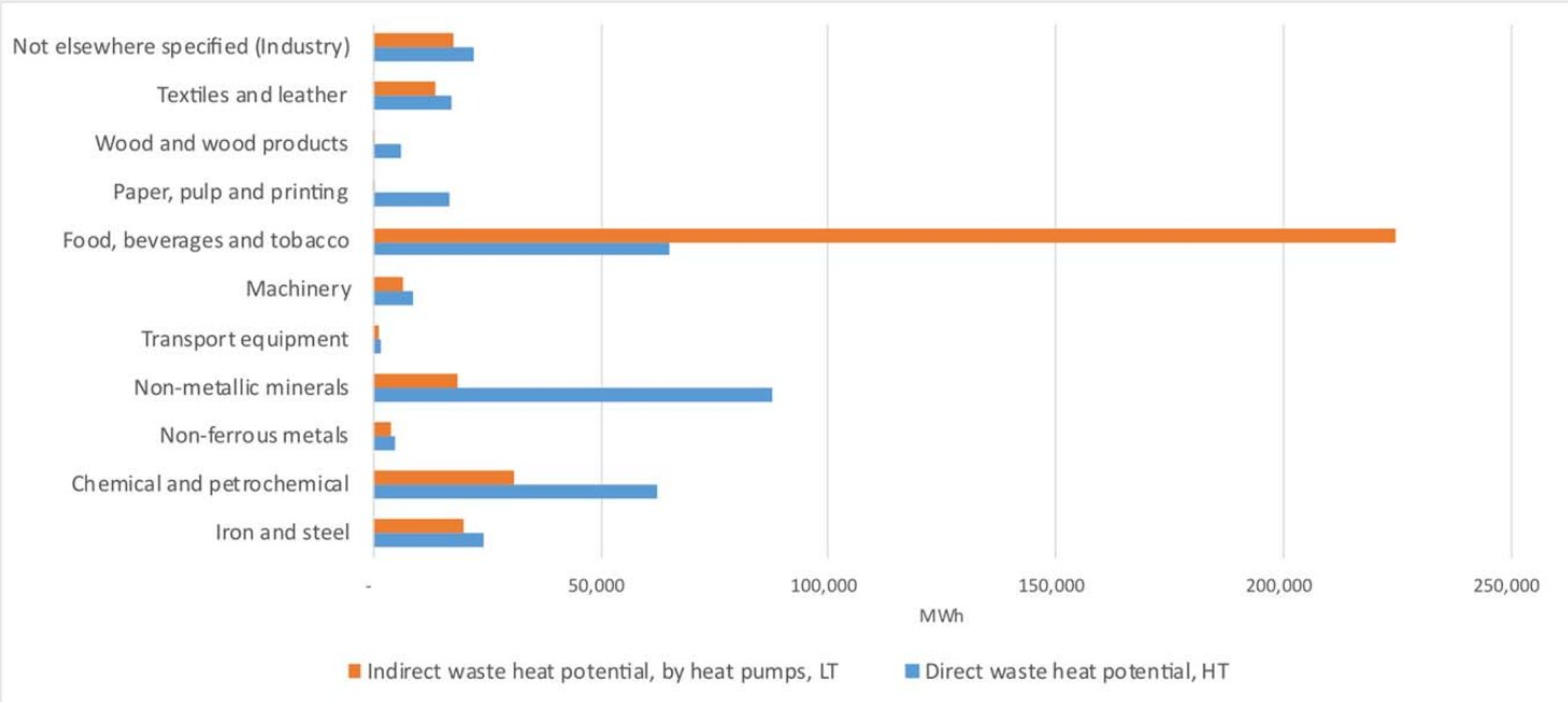

Figure 6. Waste heat from industrial sites in the Serbia that could be recovered directly in district heating systems

Table 5. Waste heat from industrial sites in Serbia that could be recovered directly in district heating systems

Industry sub-sector	High temperature water recoverable waste heat	Low temperature water recoverable waste heat	Total heat for district heating systems*
	$E_{heat,HT,DH}$ (GWh)	$E_{heat,LT,DH}$ (GWh)	$E_{heat,DH}$ (GWh)
Iron and steel	24	20	51
Chemical and petrochemical	62	31	103
Non-ferrous metals	5	4	10
Non-metallic minerals	88	18	112
Transport equipment	1	1	3
Machinery	8	7	17
Food, beverages and tobacco	65	225	364
Paper, pulp and printing	17	0.4	17
Wood and wood products	6	0.1	6
Textiles and leather	17	14	35
Not elsewhere specified	22	18	45
Total	**316**	**338.5**	**763**

*Recovery of low-temperature waste heat was assumed by utilization of compression heat pumps with COP = 4.

Obtained results show that the total available heat from this renewable source could be estimated to be 765 GWh per year. It corresponds to 11.1% of total heat produced in all district heating plants in Serbia in 2021 [13].

VI CONCLUSION

The intention of this paper was to point out the potential of industrial waste heat as the source of alternative renewable energy available for utilization in Serbian district heating systems. The optimal way for this potential determination is in a combination of top-down and bottom-up approaches. Due to the lack of studies and surveys related to the quality and quantity of industrial waste heat, the top-down approach was used in this research, supplemented by quality indicators taken over from available research in selected EU countries. The accepted approach allowed partly overcoming the problems related to an exclusively top-down approach. Some results related to the temperature of waste heat are obtained.

Obtained results indicate that, theoretically, approximately 4,6% of the heat produced in district heating systems in Serbia by combustion of fossil fuels could be directly substituted by industrial waste heat available at temperatures between 50°C and 200°C. An additional 6,5% of heat demand could be met by the utilization of compression heat pumps. These heat pumps would use waste heat available with temperature lower than 50°C. It was shown that the Food, beverages and tobacco, Non-metallic minerals, and Chemical and petrochemical are industry sub-sectors with the most significant waste energy potential.

However, although very significant, presented potentials are still only hypothetical. The approach used couldn't show the feasibility of waste heat utilization in district heating systems. This means that further, more detailed researches are necessary. These researches should be conducted for every district heating system in Serbia and should include surveys of industrial facilities in their vicinity. Only by detailed analysis of companies' data regards to energy consumption and technologies for energy utilization (obtained by questionnaires, mandatory reports, measurement, etc.) the real technical and economic potential of industrial waste heat could be determined.

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