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CHARACTERISTICS OF INDUSTRIAL CO_2 EMISSIONS IN POLAND IN 2014 IN TERMS OF ITS UNDERGROUND STORAGE**

1. INTRODUCTION

The period of increased industrial activity, which is the result of the industrial revolution, which beginning dates back to the turn of the XVIII and XIX, resulted in a significant increase in energy demand. Increasing demand for energy from coal and other fossil fuels, which took place in the last century and consequently greenhouse gas emissions could lead to a significant climate change [2, 3]. There have been many climate changes before, but the question is still the same: has civilization based on fossil fuels, generating significant emissions of carbon dioxide, led to a balance disruption in the heat of the Earth and a significant warming of the atmosphere [6].

Production of greenhouse gases (mainly CO_2) and the possibility of its limitations and disposal are considered as one of the most serious problems of the modern, developed world. CO_2 emission is mainly generated by burning fossil fuels, transport and a wide range of other industrial activities [1]. It is extremely important though, that companies minimize their impact on the environment through activities such as, for example, using energy-saving solutions and recyclable waste [3] CO_2 limitations can be introduced by, among others, the use of renewable energy sources or nuclear power, reforestation or implementation carbon sequestration process in geological structures [11, 14].

Reducing emissions through carbon sequestration involving its uptake and subsequent storage in underground structures allow large stationary sources of CO_2, characterized by its large production [4, 7].

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In many countries there have been taken numerous actions in reducing carbon dioxide emissions. Already in 1997 in Kyoto, Japan was organized a conference aimed at agreement on reducing greenhouse gas emissions by industrialized countries [5]. Poland being a member of the Organisation for Economic Cooperation and Development (OECD) is also committed to reduce CO_2 emissions. The possibilities of reducing carbon dioxide emissions in our country through its underground storage are presented, among others, by Tarkowski [9] and Stopa and Tarkowski [8].

Analyzing the amount of annual CO_2 emissions in Poland per citizen in the years 1970–2014 (Fig. 1) can be seen that the high emissions per capita remained in 1975–1990. After this period, it fell sharply in the 2000–2014 period and remained relatively constant at 8 tonnes/year, what in comparison to western Europe, is a relatively low value.

Important seems to be what the structure of CO_2 in Poland is, taking into account the kind of source, its size and location, especially in the context of opportunities its underground storage or using it in advanced option of exploration.

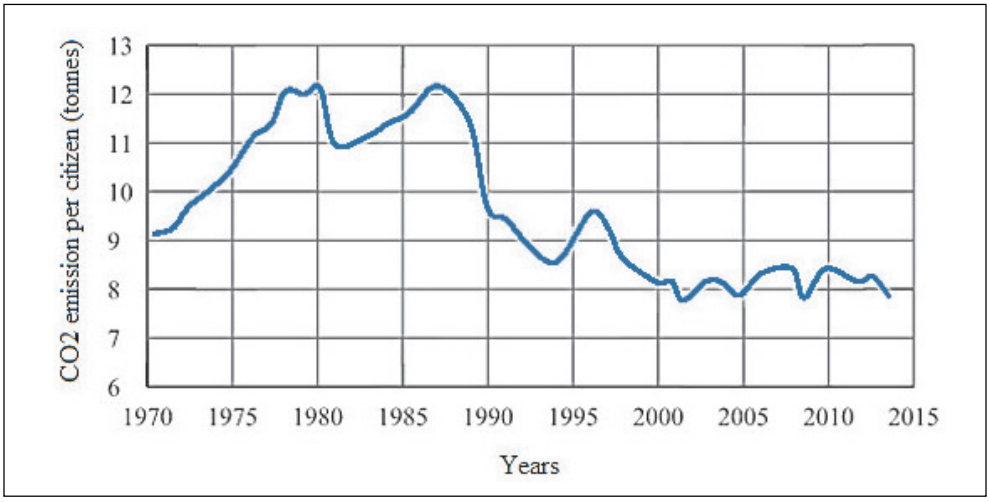

Fig. 1. CO_2 emission in Poland per citizen in 1970–2014 [15]

This article contains a detailed statistical analysis of the database carbon emitters in Poland for 2014, provided by the Institute of Environmental Protection – National Research Institute. It enables to assess the potential CO_2 emissions in Poland in terms of geological sequestration and advanced extraction methods. Similar considerations regarding carbon dioxide emissions in Poland in terms of underground storage has been previously carried out by Tarkowski and Uliasz-Misiak [11], but there was not yet a nationwide base of CO_2 emitters. Included in the characteristics of each emitter includes the name of the plant, place of registration activity, state, sector to which the emitter belongs (separated 10 sectors), the type of installation that generates CO_2 and annual emissions of carbon dioxide given in tonne.

This database, created by the National Centre for Emission Management, contains a list of all registered in Poland CO_2 emitters that generate at least 1 tonne of carbon dioxide per year. The characteristics of each emitter includes the name of the plant, place of registration activity, province, sector to which the emitter belongs (10 sectors were separated), the type of installation that generates CO_2 and annual emissions of carbon dioxide given in tonnes.

2. GENERAL ANALYSIS

In 2014, in Poland reported 26 320 installations generating carbon dioxide. In 2014, which meet established quantitative criterion. However, this figure is reduced to 24 015 issuers, as some of them work in several sectors, or by using several systems. The average emissions for installation is 8030.92 tonnes of carbon dioxide per year, while the total annual emission for our country is 211.37 million tonnes of CO_2, and the largest emitter is a power plant in Belchatów (PGE) which annually produces 36.89 million tonnes of CO_2 (Tab. 1).

Table 1

Basic descriptive statistics for CO_2 emission in [Mg] for Poland

Average	8 030.92
Mediana	26.68
Minimum	1.00
Maximum	36 886 457.00
Total	211 373 855.35
Number of installations	26 320
Emitters	24 015

For the vast majority of emitters typical emission is less than 100 tonnes of CO_2. Distribution of emission is characterized by a strong right-sided asymmetry of distribution – the larger emission the smaller number of installations. The median for the emissions of a single installation is only 26.68 tonnes of CO_2 (Fig. 2).

The analysis of emissions' structure in Poland divided into provinces (Fig. 3) shows that the largest total emissions is typical for provinces: Łódzkie (20% of total emissions), Śląskie (18%) and Mazowieckie (14%).

The lowest emission value, representing only 1% of the national production of carbon dioxide, is in Lubuskie, Warmińsko-mazurskie, Podlaskie and Podkarpackie. In 2014 in Lubuskie province reported emissions of only 1.54 million tonnes of carbon dioxide. The size of the total annual production of CO_2 in the individual provinces is shown in Figure 4.

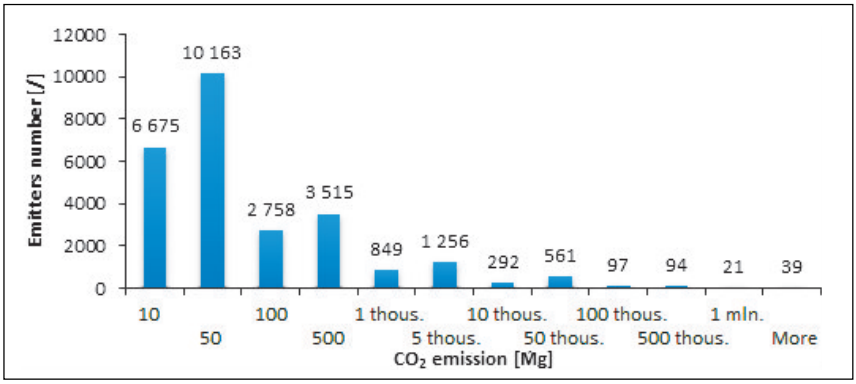

Fig. 2. Histogram of emitters number at specified CO_2 emission intervals [tonnes]

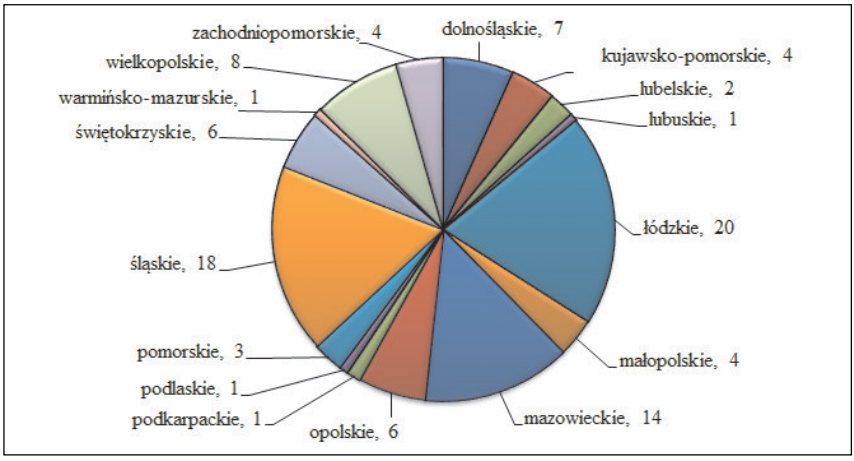

Fig. 3. The share of individual regions in total CO_2 emissions in Poland in 2014 [%]

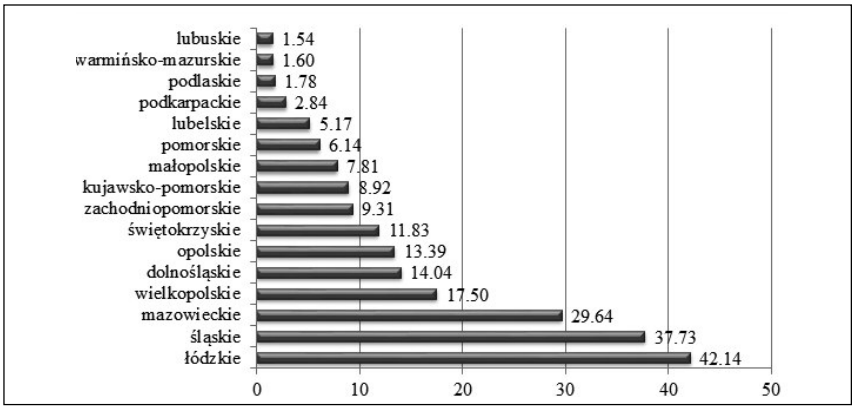

Fig. 4. Total emission of carbon dioxide in 2014 for provinces [mm tonnes]

The largest number of producers of carbon dioxide is in the region of Wielkopolska, Silesia, Lower Silesia and Mazowsze (Fig. 5). Other provinces focus less than 10% of all emitters. The smallest number of plants emitting CO_2 is present in Podlaskie (356) (Fig. 6).

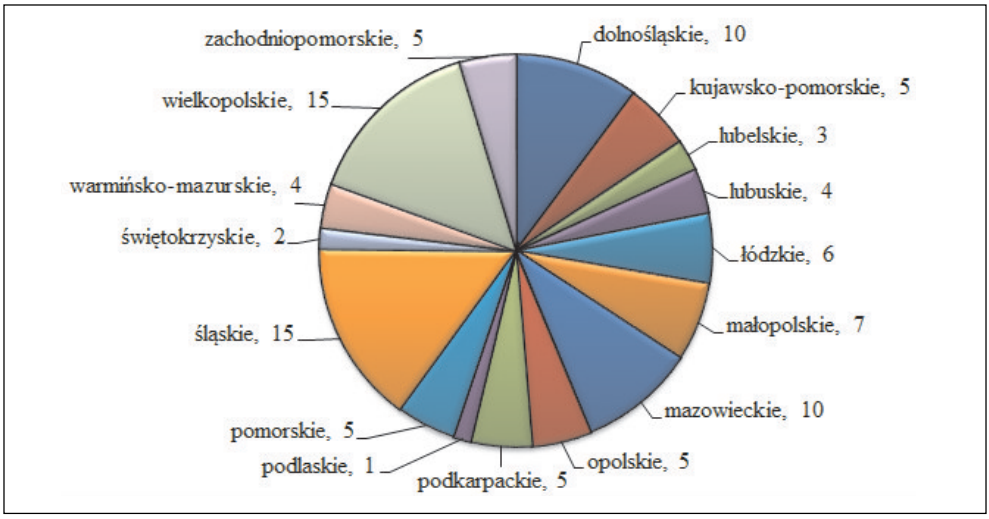

Fig. 5. Location of emitters of CO_2 in Poland in 2014 [%]

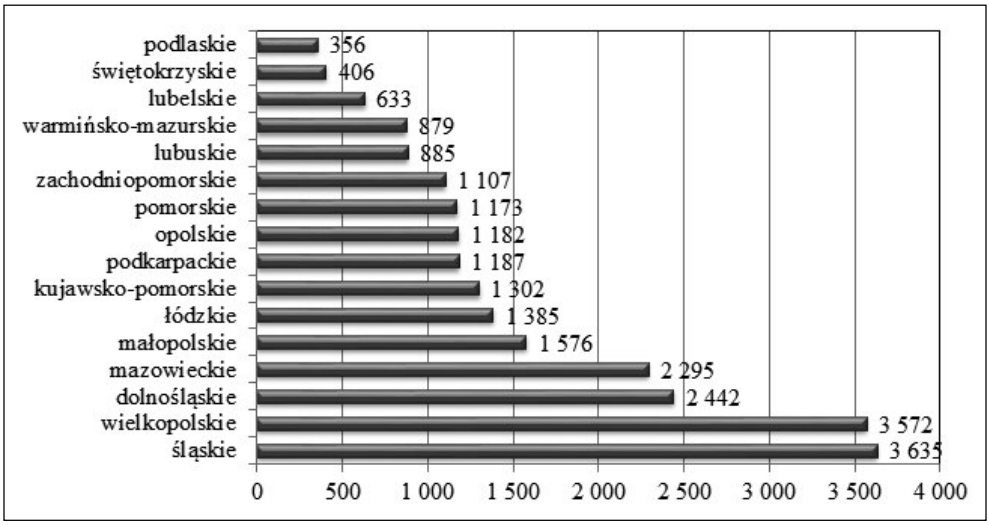

Fig. 6. Amount of carbon dioxide emitters in provinces in 2014

The highest average annual emission is in installation in Świętokrzyskie province and is 29 129 tonnes of CO_2. Province is not characterized by a very high emission on the national level, but there are only 406 emitters (2% of all registered in Poland). While

Lubuskie province, where are also not many plants – 885 (4% of the total), has the lowest average emissions (1744 tonnes), and its total size is 1.54 million tonnes of CO_2 (Tab. 2).

Table 2

Size of total and average emission and number of emitters for provinces in 2014

Province	Emission CO_2 in [tonnes]	Number of emitters	Average emission CO_2 [tonnes]
Łódzkie	42 144 355	1 385	30 429
Śląskie	37 728 661	3 635	10 379
Mazowieckie	29 640 817	2 295	12 915
Wielkopolskie	17 496 536	3 572	4 898
Dolnośląskie	14 039 418	2 442	5 749
Opolskie	13 386 223	1 182	11 325
Świętokrzyskie	11 826 572	406	29 129
Zachodniopomorskie	9 306 743	1 107	8 407
Kujawsko-pomorskie	8 924 663	1 302	6 855
Małopolskie	7 813 910	1 576	4 958
Pomorskie	6 143 520	1 173	5 237
Lubelskie	5 169 895	633	8 167
Podkarpackie	2 835 216	1 187	2 389
Podlaskie	1 778 721	356	4 996
Warmińsko-mazurskie	1 595 333	879	1 815
Lubuskie	1 543 274	885	1 744
Total	**211 373 855**	**24 015**	**–**
Average	**13 210 866**	**1 501**	**–**

Similar considerations may be made for emitters by sector of their activity. Of course, the greatest amount of carbon dioxide as much as 179.84 million tonnes, which is 85.08% of the total national emissions, generates the energy sector (Fig. 7). What is more, the largest number of installations – 21 870, belong to this sector. Average emission is highest for chemical sector, producing 2.32% of the total CO_2 emissions (with only 104 plants) (Tab. 3). The smallest total and the average annual emissions falls on activities of technical support, producing an average of only 58 tonnes of CO_2 (458 emitters) (Fig. 8).

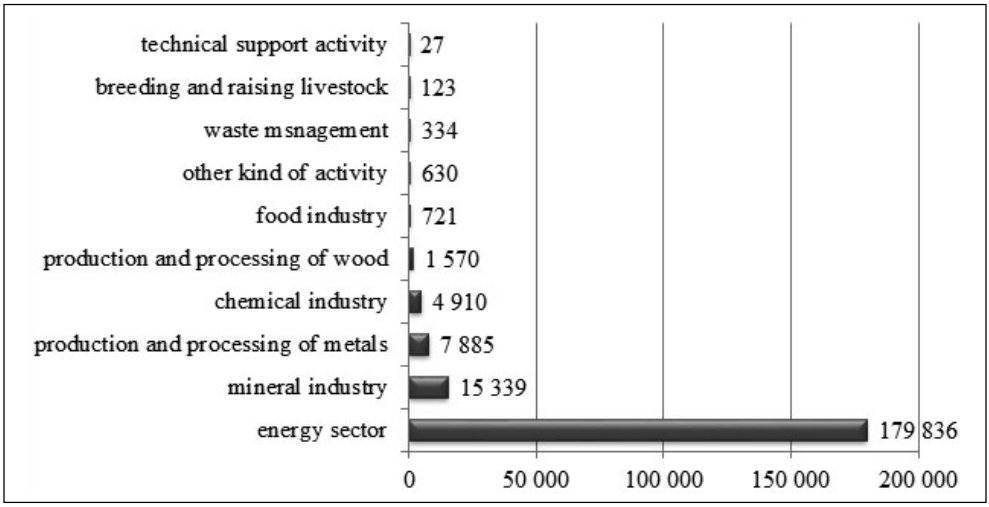

Fig. 7. The total carbon dioxide emissions in the thousands of tonnes in sectors

Table 3

The size of total and average emissions of CO_2 and the number of emitters for sectors

Sectors	Emission CO_2 [tonnes]	Emission CO_2 [%]	Number of emitters	Number of emitters [%]	Average emission CO_2 [tonnes]
Energy sector	179 835 623	85.08	21 870	86.50	8223
Mineral industry	15 339 470	7.26	452	1.79	33 937
Production and processing of metals	7 885 457	3.73	303	1.20	26 025
Chemical industry	4 910 344	2.32	104	0.41	47 215
Production and processing of wood	1 569 800	0.74	62	0.25	25 319
Food industry	720 798	0.34	821	3.25	878
Other kind of activity	629 591	0.30	876	3.46	719
Waste management	333 521	0.16	191	0.76	1 746
Breeding and raising livestock	122 615	0.06	147	0.58	834
Technical support activity	26 636	0.01	458	1.81	58
Total	**211 373 855**	**100.00**	**25 284**	**100.00**	–
Average	**21 137 386**	**10.00**	**2 528**	**10.00**	–

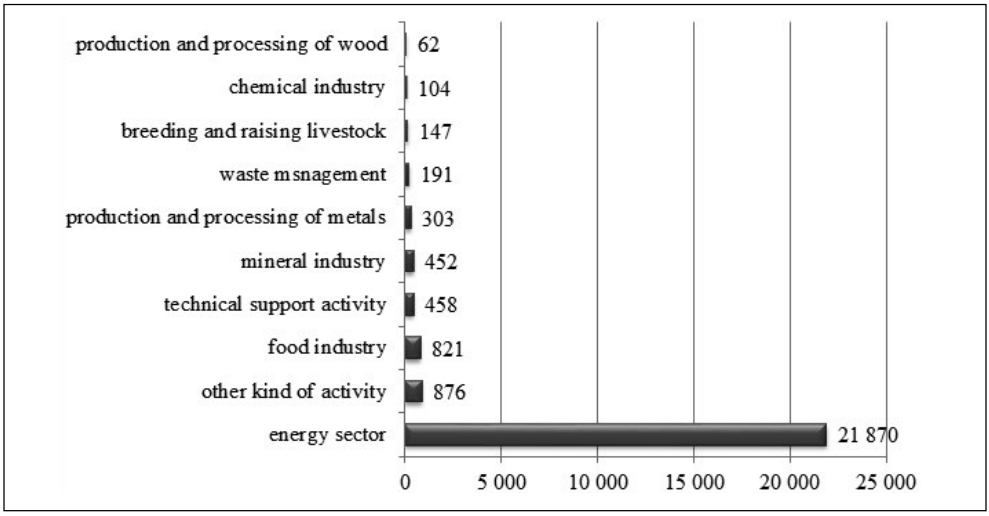

Fig. 8. The number of carbon emitters in sectors

It is worth mentioning that the total number of emitters with division into sectors is higher than in previous analysis for the whole country, as a part of the entities operate in different sectors, that is why they are taken into account several times.

3. DETAILED ANALYSIS WITH DIVISION INTO SECTORS

Analysis takes into account a structure of CO_2 emission and number of producers for each sector, as well as average emission connected with particular type of installation.

Energy Sector

The main source of carbon emission in the country is energy sector. It generates 179.84 mln tonnes CO_2 per year, equivalent to over 85% of national emissions. This sector has been divided into three main groups, but installations associated with fuel combustion dominate over others.

The total production of CO_2 for this type of installation is 97% of emissions of the entire sector (Fig. 9). Heating systems are responsible for only 1% of production, while the group of "other" generates 2%.

Similarly to the total emissions, installations related to the fuel combustion far outweigh its amount the other installations occurring not only in the energy sector but also in Poland. Number of plants associated with the burning of fuels reported in the database is equal to 21 632, while the heating system only 235, while the group of "other" consists with only 75 emitters. For fuel burning, average annual emissions are only 8039 tonnes of CO_2, so it is close to the average for the heating system (8037 tonnes of CO_2).

For the energy sector by far the highest average issue falls on the plants using installations included in the "other". High production of this group spread over just 75 companies generate an average of 53 828 tonnes of carbon dioxide per year.

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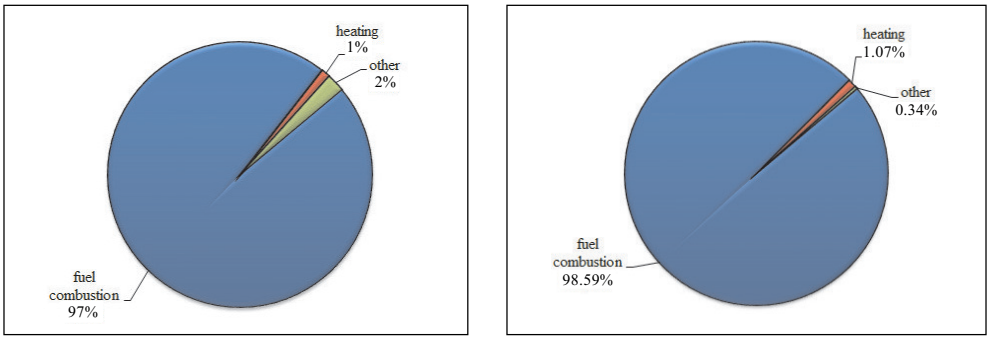

Fig. 9. Structure of CO_2 emissions (a) and the number of emitters (b) in the energy sector

Mineral industry

For the mineral industry, producing more than 7% of national emissions, it has been distinguished six types of installations. The biggest carbon dioxide stands out the production of cement and related products on its basis (68%). The lowest value, only 2% of the total manufacturing sector, generating plants related to the mining and processing of minerals (Fig. 10).

a) b)

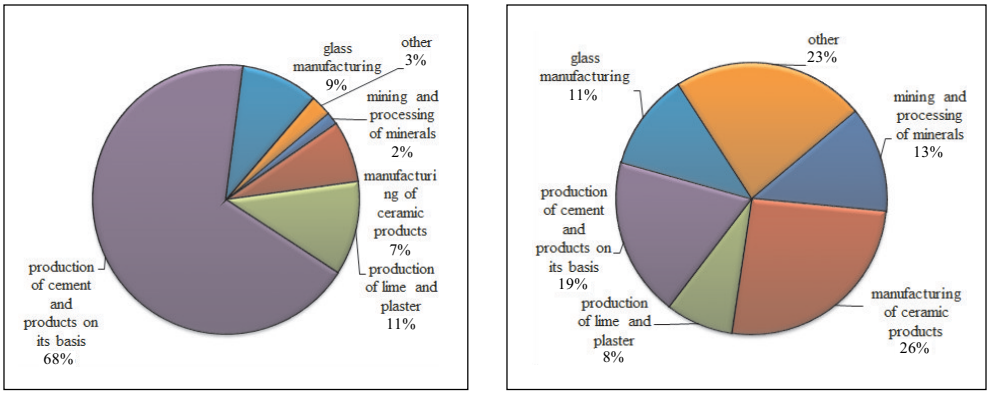

Fig. 10. Structure of CO_2 emissions (a) and the number of emitters (b) in the mineral industry

Despite the large disparities between installations in terms of emissions of CO_2 distribution of the number of emitters for the mineral industry is relatively uniform.

The greatest number of plants focuses manufacture of ceramic products, while the smallest production of lime and plaster. The average emission due to the very high total production sector, is from several hundred to several thousand tonnes of CO_2. The largest (119 762 tonnes of CO_2) for the installation related to the production of cement, and the smallest (3614 tonnes of CO_2) for the "other".

Production and processing of metals

The sector associated with reworking and metalworking generates almost 4% of total emissions in our country, equivalent to 7.89 million tonnes of carbon dioxide. Divided into four types of installations, from which a group of "other" is responsible for only 0.4%. Other groups are characterized by a uniform distribution of emissions, the production of metal products generates the greatest amount of CO_2 (Fig. 11).

a) b)

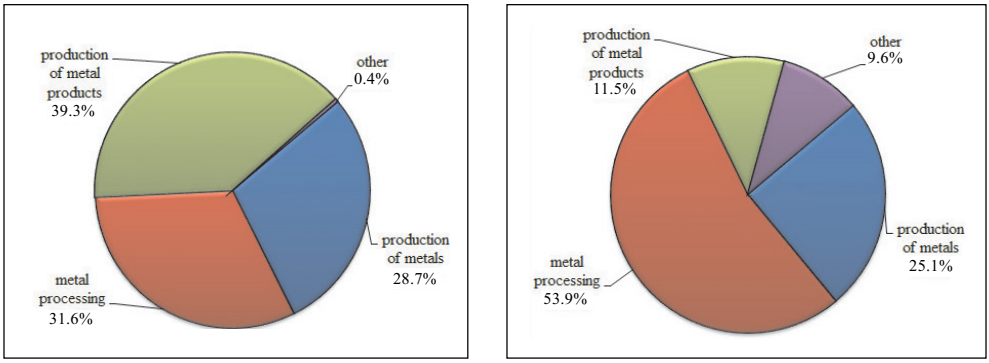

Fig. 11. Structure of CO_2 emissions (a) and the number of emitters (b) in the production and processing of metals

In contrast to the total emissions, the distribution of the number of emitters is uneven. Most factories engaged in metal processing, while a group of "other" brings together up to 9.6% of the total number of emitters. Due to the large production of CO_2 and a small number of emitters in the production of metal products average emissions for this type of installation is as high as 83 660 tonnes. Then, 27 941 tonnes of carbon dioxide go to the emitter in the production of metals. A large amount of CO_2 generators makes installation associated with the processing metals average of 14 342 tonnes. Due to the very low total emission, the smallest average falls on installations from the "other" and is 1009 tonnes of CO_2.

Chemical industry

In case of chemical industry producing 4.91 million tonnes of carbon dioxide, one of four types of installation is associated with the production of chemical compounds generates up to 91% of the emissions of the sector, although it gathers only 21% of emitters. Therefore, this group has the highest average of annual emissions of 177 626 tonnes of CO_2. The average of 15 208 tonnes are allocated to the production of chemicals and

fertilizers, focusing 6% of the emissions of the sector, at least, among the selected groups, the number of installations. The other two groups have an average just above 2200 tonnes of carbon dioxide per year. Their total emissions of only 2% for the production and processing of plastics and 1% for the group of "other". However, these groups gather most emitters from the sector, relatively, 37% and 25% (Fig. 12).

a) b)

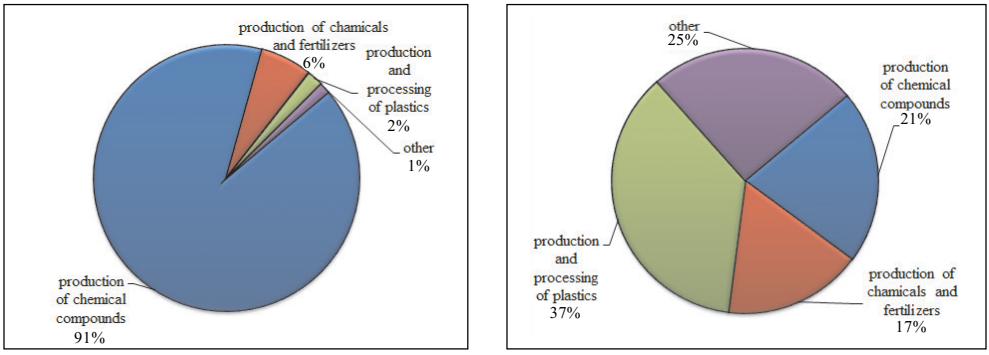

Fig. 12. Structure of CO_2 emissions (a) and the number of emitters (b) in the chemical industry

Production and processing of wood

In a sector of production and processing paper and wood, four types of installations can be selected. Manufacture of paper and wood is the largest group in terms of CO_2 production and the number of plants – 53% of sector's emitters focuses 60% of its total emissions of 1.57 million tonnes of CO_2. Only 1% of emission in the sector is generated by paper and wood processing. A specific group is lye regeneration, as it produces 35% of emission, despite the fact that this installation is being used by only one plant in the country. Also distinguished group of "other" includes 27% of plants and 4% of the emissions of the sector (Fig. 13).

a) b)

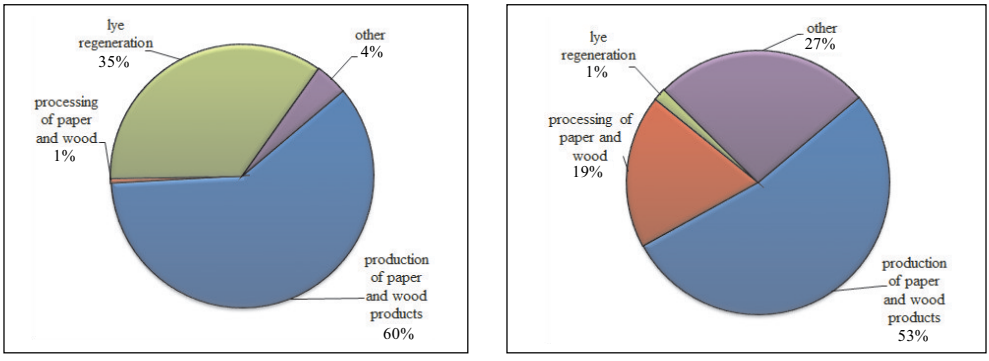

Fig. 13. Structure of CO_2 emissions (a) and the number of emitters(b) in the sector of production and processing of paper and wood

A group with the highest average production of carbon dioxide is by far the lye regeneration – 551 759 tonnes of CO_2. A significant average emission, with a value of 27 832 tonnes of CO_2, it stands out in the production of paper and wood products. While the processing of paper and wood has an average equal to only 732 tonnes of carbon dioxide, which is the lowest value for the sector. Despite the small total CO_2 emissions, the group "other" has an average of 3704 tonnes of carbon dioxide.

Food industry

The analyzed sector is characterized by small total emission of CO_2 (0.34% nationally), although a relatively large number of emitters operate in this sector, corresponding to 3.25% of the total. For the food industry, five types of installations were distinguished. Of these, up to 64% of sector's emission, generates production or processing of food products. The lowest emission falls on gastronomy and is close to the size generated by heating systems. Similarly to the structure of the emission, the largest number of emitters is engaged in the production or processing of food products (Fig. 14).

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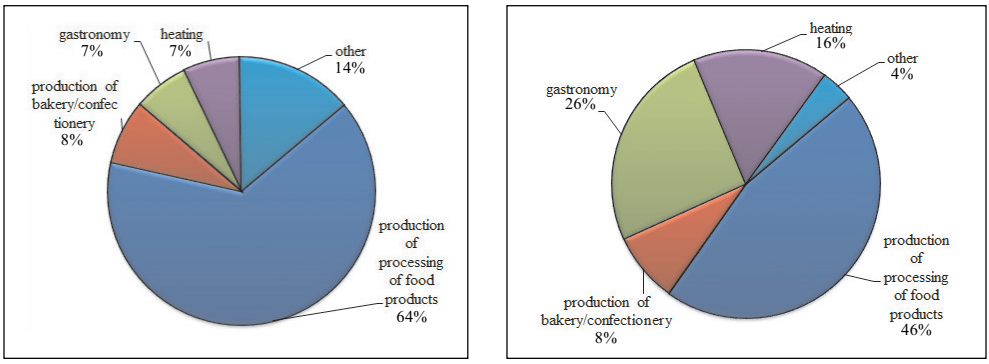

Fig. 14. Structure of CO_2 emissions (a) and the number of emitters (b) in the food industry

Average emissions for this type of installation is 1209 tonnes of carbon dioxide. In the group "other", were the least emitters, but their total CO_2 production is the second largest in the sector.

This results in the largest average emission of 3081 tonnes of CO_2 in food industry. Gastronomy equipment and heating installations, despite the low total emissions, are used by a large number of plants, that is why its average is small – respectively 224 and 364 tonnes of carbon dioxide. The production of bakery/confectionery is characterized by an average annual emission of 790 tonnes of CO_2.

Other kind of activity

Sector connected with the other kind of activity emits annually 629 591 tonnes of carbon dioxide, including 3.46% of domestic emitters.

The largest total CO_2 production, of the four distinguished groups, is production and processing – 39%. While the smallest amount of CO_2 produce fuel combustion,

generating only 9% of the sector's emission. For heating, and those assigned to the group of "other", emissions are respectively 28% and 24% (Fig. 15).

The largest number of plants using heating systems representing 45% of all the 900 installations in the sector. In contrast, only 5% of them are burning fuels. In connection with the decomposition of CO_2 production and the number of issuers, average emission reaches a minimum value for the heating installation and amounts to 432 tonnes of CO_2.

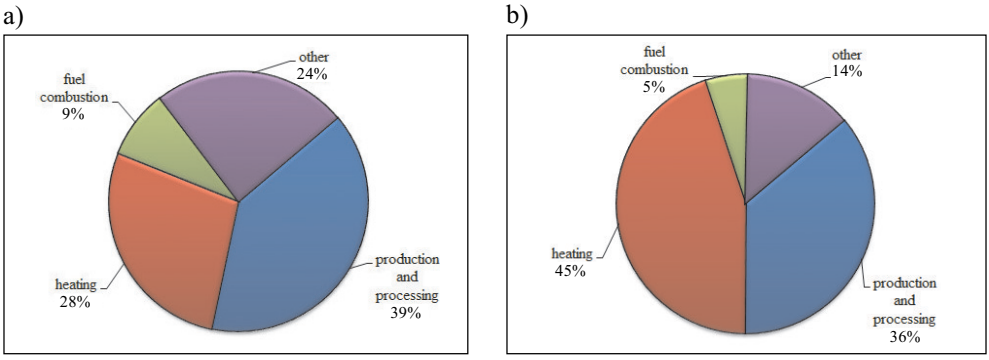

Fig. 15. Structure of CO_2 emissions (a) and the number of the emitters(b) in other kind of activity

Waste management

Within waste management, generating only 0.16% of the total emissions of the country, have been distinguished four types of installations. Those associated with waste disposal produce as much as 78% of the total emissions of the sector, despite the fact that they cover 28% of the 199 plants. Thus, their average annual emissions is 4672 tonnes of CO_2 (the largest value in the sector). While the lowest average carbon dioxide emissions of 356 tonnes, is connected with the waste storage, which involves 50% of manufacturers, releasing only 11% of the sector's emissions (Fig. 16). A similar value of the average emission reaches a group of "other". While recovery and the waste conversion have average emissions at the level of 1193 tonnes of CO_2.

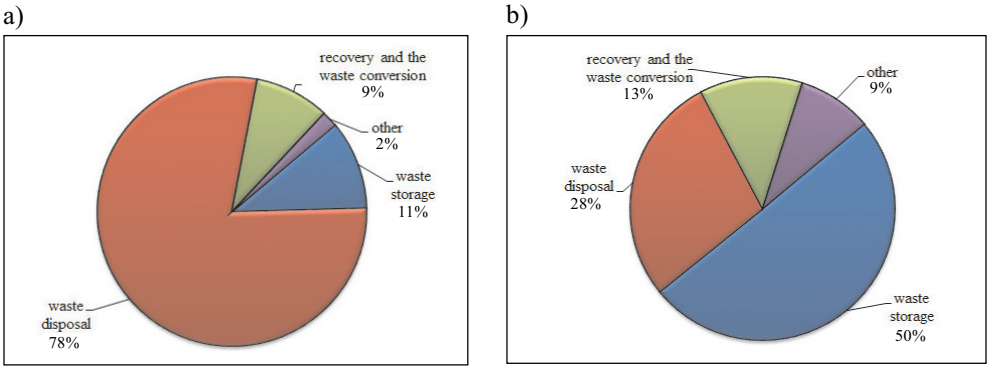

Fig. 16. Structure of CO_2 emissions (a) and the number of emitters (b) in the field of waste management

Breeding and raising livestock

In the sector of breeding and raising livestock were distinguished two types of installation – farming and animal husbandry and intensive animal husbandry. This sector emits in total 122 615 tonnes of CO_2, of which only 5% is plain breeding, and 95% intensive breeding. The number of emitters is very similar in proportions to emissions – 4% and 96% (Fig. 17). Accordingly, the average annual carbon dioxide emissions per producer in case of the two installations is similar. It amounts to respectively 970 tonnes of CO_2 for the raising and breeding of animals and 823 tonnes of carbon dioxide for intense variations of this process.

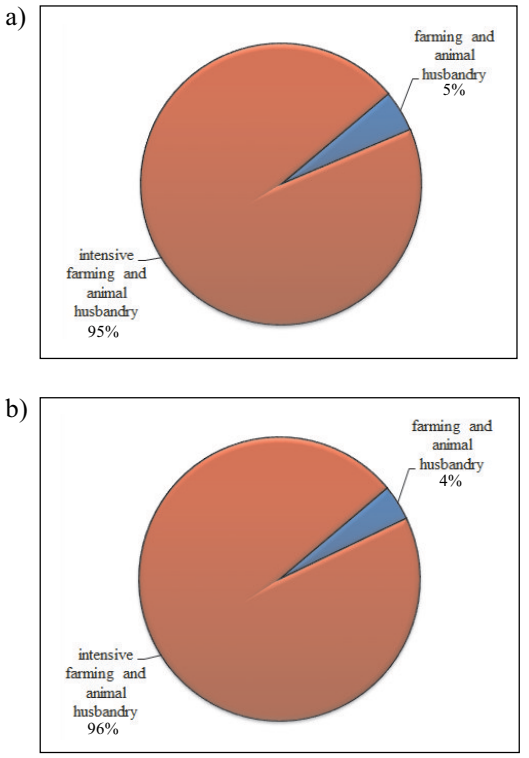

Fig. 17. Structure of CO_2 emissions (a) and the number of emitters (b) in the breeding and raising livestock

Technical support activity

This sector has been divided into three main groups. There have been selected following installations: heating, the one connected with production and processing, and a group with other minor installations. Technical support is characterized by the lowest total emissions which is only 26 636 tonnes of CO_2 most of which produce heating systems (54%). They appear in majority of plants of this sector – 73% of 463 emitters.

Due to the fact that facilities related to the production and processing emit up to 37% of the total emissions of the sector, and gather only 15% of producers of carbon dioxide, they are characterized by the highest average emission of 135 tonnes of CO_2 (Fig. 18). While for the other two groups of the sector, average is slightly more than 40 tonnes of carbon dioxide per year.

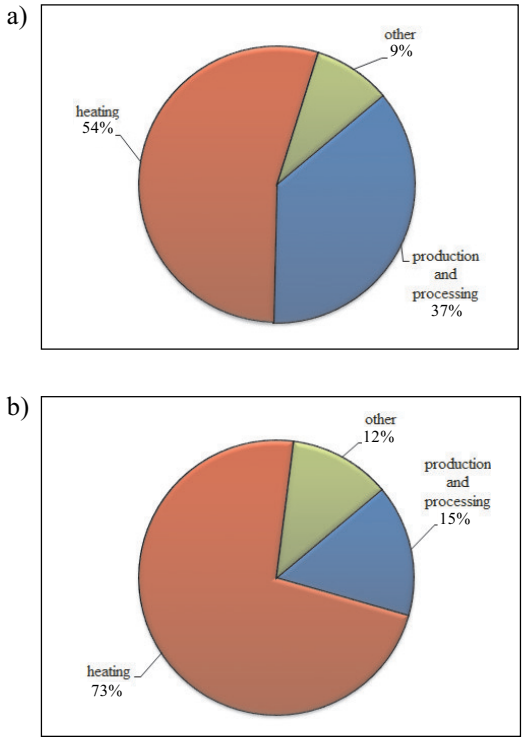

Fig. 18. Structure of CO_2 emissions (a) and the number of the emitters (b) in the sector of technical activity

4. SUMMARY

In 2014 in Poland reported 26 320 installations which meet established quantitative criterion of a minimum annual emission of 1 ton of CO_2. They are used in 24 015 plants and generate a total of 211.37 million tonnes of carbon dioxide. The average annual emissions from one installation is 8031 tonnes of CO_2, with the vast majority of emitters has been producing less than 100 tonnes of CO_2 per year. The largest total CO_2 production falls for Łódzkie province (20% of national emissions), and the least carbon dioxide is emitted in Lubuskie (1.54 million tonnes). Due to the very low emission plants in this region, the smallest in the country's average annual production of carbon dioxide of only

1744 tonnes. Highest average emissions for the installation falls on Świętokrzyskie province (29 129 tonnes of CO_2). While the largest number of emitters is located within the region of Silesia (15% of all recorded in the country). The minimum number of plants producing CO_2 occurs in Podlaskie province (only 356).

Taking into account sector division, the largest amount of carbon dioxide per year, as many as 179.84 million tonnes of CO_2, representing 85.08% of the total national emissions, generates the energy sector. It also includes the largest number of installations equal to 21 870 (average installation – 8223 tonnes). The highest average emissions for the installation are found in the chemical sector – 47 215 tonnes (total is only 4.91 million tonnes). The smallest total (26 636 tonnes) and the average (58 tonnes) of annual emissions go to technical support activities.

The results of the analysis indicate that in Poland there is a large number of emitters, who may participate in projects of geological sequestration of carbon dioxide. An object of interest for this type of project should not only be the biggest producers of CO_2, for which you can rely on economies of scale, but on the other hand, can be problematic to find a suitable geological structure, able to accommodate such a large amount of gas, but also smaller emitters.

In their case, it may be worth a combination of CO_2 sequestration with advanced methods of oil production, which allow for a significant increase in the coefficient of exhaustion of reserves and obtain substantial additional income (e.g. The method of CCS-EOR). This applies in particular entities located in south-eastern Poland and the Polish Lowlands, or in areas where are conducted extraction of hydrocarbons.

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