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Assessment of the impact of the implementation of air protection programs, anti-smog resolutions and the "Clean Air" program on CO_2 emission

ABSTRACT: The main objective of the article is to assess the changes in carbon dioxide emissions in residential sector caused by the implementation of the plans contained in the Air Protection Programs, anti-smog resolutions adopted in 9 voivodeships and the nationwide "Clean Air" program. The reduction of emissions of pollutants which directly affecting air quality and human health, i.e. particulate matter and benz(a)pyrene, which residential sector is the main source, can also affect the amount of emitted of carbon dioxide. To determine the changes in carbon dioxide emissions in the residential sector, emissions of CO_2 in base year of 2017 from various energy carriers were determined, plans for reducing of low-stack emission were reviewed and the future structure of

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energy carriers used in households was estimated. The processes of increasing the efficiency of energy use through both the replacement of boilers and thermomodernization were also taken into account. The obtained results show that the highest CO_2 emission reduction of 6% is achieved in case of "Clean Air" program. In frame of this program in 3.5 million of single-family houses a heating system replacement and thermomodernization is planned. Implementation of plans included on Air Protection Programs and anti-smog resolutions can lead to a relatively small (approx. 1%) reduction of CO_2 compared to base year 2017. The detailed results of future fuel consumption and CO_2 emission for individual voivodeships and for the whole of Poland was presented.

KEYWORDS: residential sector, CO_2, smog, Air Protection Programs, anti-smog resolutions

Introduction

Poland has been struggling with poor air quality for years. The data of the World Health Organization and the European Environment Agency indicate that the concentration of pollutants such as particulate matter and benzo(a)pyrene are above the limit and target levels in Poland. Data of the World Health Organization shows that the mortality rate due to poor air quality in Poland amounted to 36.3 (36.3 deaths per 100,000 inhabitants) in 2016 (WHO 2018). The European Environment Agency also indicates that air quality in Poland is very bad compared to other EU members. In Poland, the factor of the years of life lost (YOLL) due to the concentration of particulate matter equals 1,403 per 100 thousand inhabitants (EEA 2018). According to a study conducted in 2018 in Poland, due to the impact of emission from the residential sector in 2016, the number of premature deaths amounted to 19,000 and the number of lost years almost 440,000 (Adamkiewicz 2018).

In Poland, the air quality is assessed in 46 zones covering agglomerations above 250,000 inhabitants (in total 12 zones), cities over 100 thousand inhabitants (in total 18) and other areas of the voivodship not classified in the first two zones (12 in total – one in province). A health protection evaluation is conducted for 12 pollutants for which limit levels are defined (sulphur dioxide SO_2, nitrogen dioxide NO_2, carbon monoxide CO, benzene C_6H_6, PM10, Pb lead in PM10 and PM2.5) and target levels (arsenic As in PM10, cadmium Cd in PM10, nickel Ni in PM 10, benzo(a)pyrene B(a)P in PM10, ozone O_3) (Minister of Environment 2012). Zones are classified in two groups, i.e.: class A – when there are no exceedances of the limit or target level and class C – when such exceedances occur. 4 zones due to exceeding the annual NO_2 concentration, 6 zones due to exceeding 8 hour O_3 concentrations, 19 zones due to exceeding the annual PM2.5 concentration, 10 and 34 zones due to exceeding the annual and daily levels of PM10 concentration, respectively, and 44 zones due to exceeding the level of B(a)P concentration were categorized as class C in 2017 (GIOS 2018). Poor air condition regarding NO_2 concentrations was noticed in the agglomerations (Warsaw, Katowice, Krakow and Wroclaw) and the main cause is road transport. Exceeded ozone concentrations occur in the south of Poland and are

associated with meteorological and terrain conditions. However, Poland mainly has problems with particulate matter and B(a)P concentrations, which are very harmful to health (WHO 2018; Brunekreef and Holgate 2002; Bell 2012). According to the Institute of Environmental Protection assessment, in 91% and 90% of cases, the main reason for exceeding the limits level of 24 hour PM10 concentrations and PM2.5 annual concentrations in zones classified as class C in 2017 was emissions from households, i.e. burning of poor quality solid fuels in low-efficiency, high-emission and often old devices (GIOS 2018). Also, the main cause of high concentrations of B(a)P is emissions from residential sector. In 2017, on a national scale, residential sector were responsible for the emission of 47% of PM10, 48% of PM2.5 and 78% B(a)P (KOBIZE 2019a).

During COP24 in Katowice in December 2018, the parties agreed to make efforts to reduce greenhouse gas emissions in order to fend off the global temperature rise above 2 K. Unfortunately, Poland remains one of the largest CO_2 emitters in Europe. This is because of the still high share of coal in the production of electricity and heat. In Poland in 2018 approximately 338 million tons of CO_2 were emitted into the atmosphere, which was 10.3% of the emissions from all EU countries. Emissions in Poland increased in the years 2017–2018 by 3.5% (EUROSTAT 2019). The European Union plans to reduce emission of greenhouse gases of 60% by 2050 compared 1990 (EU 2018). The aim for 2030 is to reduce the greenhouse gases by 40% (compared 1990) (Regulation EU 2018a). In the sectors which are not included in the ETS (EU Emission Trading Scheme) system the emission of greenhouse gases from 2005 to 2030 has to be reduced by 30%, including in Poland by 7% (Regulation EU 2018b). In Poland, the total CO_2 emissions in 2017 were estimated at 336,591 Gg (without LULUCF). This was 81.34% of national total greenhouse gas emissions estimated at 413,805 Gg CO_2 eq. (without LULUCF) in 2017 92% of the emitted CO_2 stemmed from fuel combustion (KOBIZE 2019b).

As the residential sector remains the main source of particulate matter and benzo(a)pyrene and affects local air quality, wide activities have been undertaken to reduce emissions from this sector. The main activities affecting emissions and the future fuel structure from the residential sector are Air Protection Programs (APP), anti-smog resolutions and the “Clean Air” program. Air Protection Programs (APP) and anti-smog resolutions are shaped by the province authorities and the “Clean Air” program is managed by the National Fund for Environmental Protection and Water Management.

Reasonable and complex activities to reduce low-stack emission of pollutants such as particulate matter and benzo(a)pyrene from the residential sector and improve the local air quality can and should contribute to the increase of energy efficiency and reduction of the energy poverty and, above all, the reduction of CO_2 emissions. It is estimated that in Poland about 12% of the population is affected by energy poverty (Sałach and Lewandowski 2018). The energy poverty also has a significant impact on the air quality.

So far, only Air Protection Programs for Lesser Poland links the reduction of PM10, PM2.5 and B(a)P emissions with CO_2 emissions. The reduction of CO_2 emissions of 471,845 Mg/year due to the elimination of low-efficiency solid fuels boilers in the years 2017–2023 was estimated (UMWM 2017). The replacement of old coal-fired boilers into gas boilers can lead to CO_2 emissions reduction of approx. 43%. In the case of the use oil boilers, the reduction equals approx. 23%

(Schönfelder et al. 2011). However, there is still no total elimination of coal combustion in the residential sector in the Air Protection Programs implemented in Poland (Cieślik et al. 2018). A ban on burning solid fuels (including solid biomass) in households will be in effect only in Krakow as of September 2019. There is still a lack of a full analysis of the effects of these activities not only on PM10, PM2.5 and B(a)P emissions, but also on fuel consumption, CO_2 emission and energy poverty.

Therefore it is important to undertake such works as estimating the possible reduction of CO_2 in the case of the implementation of Air Protection Programs (APP), anti-smog resolutions and the "Clean Air" program. This becomes especially important in future years when Poland has to improve air quality but also reduce CO_2 emissions (including non-ETS sectors), improve energy efficiency as well as reduce energy poverty (Directive EU 2018; Directive EU 2008; Directive EU 2016; Regulation EU 2018a; EU 2018; Regulation EU 2018b).

1. Methodology

In this work the emission of CO_2 in 2017 was calculated based on equation 1.

$$CE = FC2017 \cdot CF \tag{1}$$

where:

- *CE* – emission of CO_2 in 2017 [Mg],
- *FC2017* – fuel consumption in 2017 [TJ],
- *CF* – emission factor for CO_2 for various fuels [Mg/TJ]

The emission of CO_2 (*CEN*) in the case of the implementation of the plans contained in the Air Protection Programs (APP), anti-smog resolutions and the nationwide "Clean Air" program were calculated based on equation 2.

$$CEN = (FC2017 - HAO \cdot HFO + HAN \cdot HFN) \cdot CF \tag{2}$$

where:

- *CEN* – emission of CO_2 in the future [Mg],
- *HAO* – heating space of flats or houses which is heated by old boilers in 2017 and is planned to be replaced by new devices [m^2] (Tab. 2),
- *HFO* – fuel consumption required to heat 1 m^2 of heating space linked to old boilers operated in 2017 and is planned to be replaced by new devices [TJ/m^2] (Tab. 3),
- *HAN* – heating space of flats or houses which is to be replaced by new coal or gas boilers and/or thermo-modernization will take place [m^2] (Tab. 2),

HFO – fuel consumption required to heat 1 m^2 of heating space which is to be replaced by new coal or gas boilers and/or thermo-modernization will take place [TJ/m^2] (Tab. 3).

Therefore the future fuel consumption (*FCN*) associated with the implementation of the plans contained in the Air Protection Programs (APP), anti-smog resolutions and the nationwide "Clean Air" program is calculated based on equation 3.

$$FCN = (FC2017 - HAO \cdot HFO + HAN \cdot HFN) \tag{3}$$

where:

FCN – fuel consumption in the future [TJ].

The consumption of fuel carriers as well as CO_2 per capita was calculated based on population data for 2017 provided for each provinces (Fig. 1).

In the calculation the average flat area of 74 m^2 (including houses) and 140 m^2 of single-family house were assumed. The first values were used in the calculation of the impact of Air Protection Programs (APP) and anti-smog resolutions (anti-smog), second in the case of the "Clean Air" programs (clear air).

Fig. 1. Population in provinces in December 31, 2017 [thousands of people]. Based on (GUS 2018a)

Rys. 1. Ludność w województwach na dzień 31 grudnia 2017 r. [tysiące osób]

1.1. Fuel consumption in residential sector

The fuel (hard coal, natural gas, liquefied petroleum gas, light fuel oil, heat from the district heating network, electricity and biomass) consumption (*FC*) for 2017 were provided by (GUS 2018b). In the residential sector 679,042 TJ of energy (without biomass) was used in Poland in 2017 (Tab. 1). The contribution in overall energy consumption of hard coal was 34.1%, 22.4% of natural gas, 3.5% of liquefied petroleum gas (excluding vehicles), 0.40% of light fuel oil, 24.1% of heat (from district heat network) and 15.5% of electricity. The data for 2017 is split into provinces but does not include the estimation of consumption of wood and other biomass (Tab. 1, Figs. 2–4).

TABLE 1. Fuel consumption in residential sector in 2015, 2016 and 2017 (GUS 2017a; GUS 2017b; GUS 2018b)

TABELA 1. Zużycie paliwa w sektorze gospodarstw domowych w latach 2015, 2016 i 2017

Fuel carriers	Year			Units
	2015	2016	2017	
Consumption of hard coal	15 425 401 040	10 350 234 945*	10 200 231 540*	Gg TJ
Consumption of natural gas	114 271	145 148	151 972	TJ
Consumption of liquified petroleum gas (excluding vehicles)	549 25 262	490 23 177*	500 23 650*	Gg TJ
Consumption of light fuel oil	70 3 027	70 2 828*	70 2 828*	Gg TJ
Consumption of heat	170 890	163 000	164 000	TJ
Consumption of electricity	29 195 105 101	28 909	29 181 105 052	GWh TJ
Wood	39 597 277 178	No data available thous. m^3 TJ		thous. m^3 TJ
Other biomass	3 512 24 585			thous. m^3 TJ

* Own calculation based on the data of heat of combustion for hard coal of 22.70 Mg/kg, for liquefied petroleum gas of 47.30 Mg/kg and for light fuel oil of 40.40 Mg/kg provided for 2017 by (KOBIZE 2019c).

Data on the consumption of liquefied petroleum gas, heat, light fuel oil and electricity in the residential sector in 2015–2017 presented in Table 1 is at a similar level. A very significant difference occurs for hard coal and natural gas. Between 2015 and 2016 the hard coal consumption decreased by 50% and on the other hand the consumption of natural gas increased by 27%.

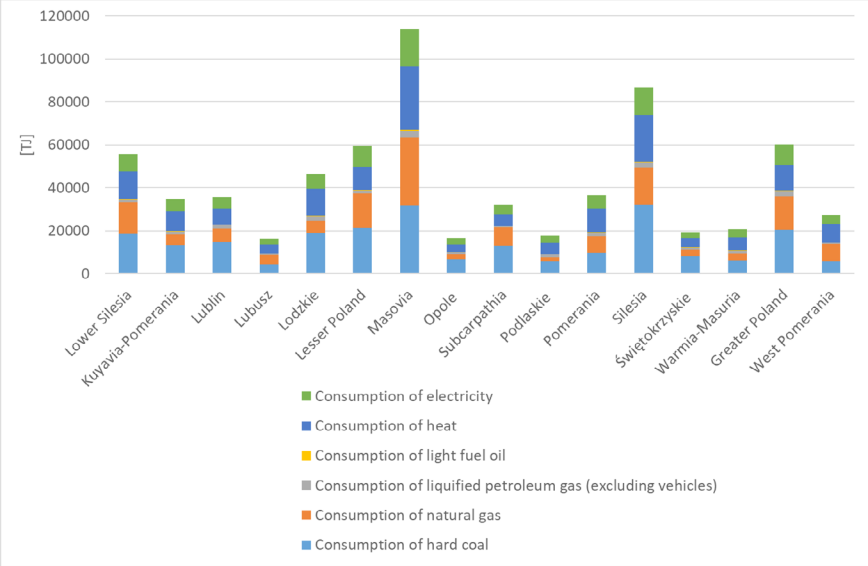

Fig. 2. Consumption of fuel (*FC2017*) in the residential sector in 2017 [TJ]. Based on (GUS 2018b)

Rys. 2. Zużycie paliw (FC2017) w sektorze gospodarstw domowych w 2017 r. [TJ]

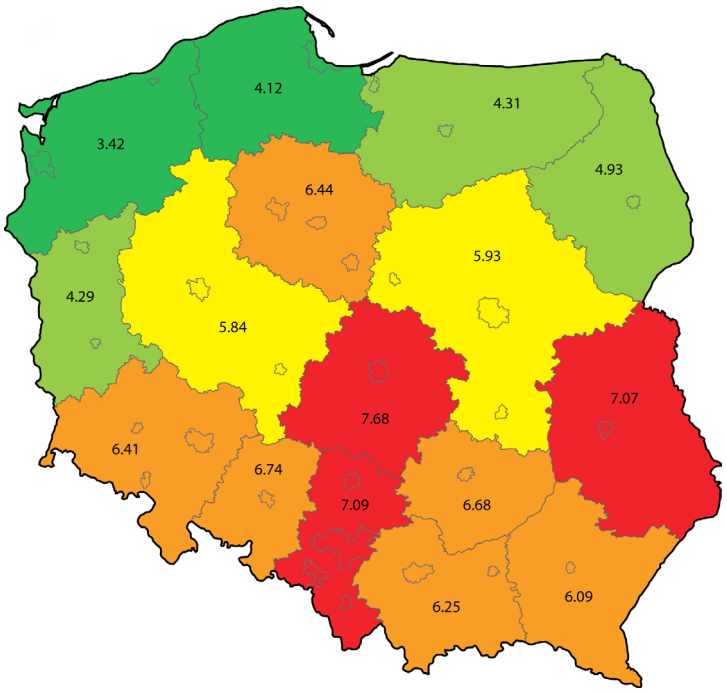

Fig. 3. Consumption of hard coal in residential sector in 2017 [GJ/person]. Based on (GUS 2018b)

Rys. 3. Zużycie węgla kamiennego w sektorze gospodarstw domowych w 2017 r. [GJ/osobę]

Such large changes could not take place during the year, therefore the estimation methodology has probably been changed.

The data presented in Figure 2 does not contain the biomass consumption, however the biomass consumption does not affect CO_2 emissions. Therefore in the future analysis, the biomass consumption and possible changes due to implementation of Air Protection Programs (APP), anti-smog resolutions and "Clean Air" program are not conducted.

The most of hard coal amounts per capita is consumed in the Lodzkie and Silesia provinces and the least in West Pomerania and Pomerania provinces (Fig. 3). The highest consumption per capita of natural gas, district heat and electricity and total energy is observed in the Masovia province (Fig. 4). This is probably due to the fact that the province is the richest in Poland.

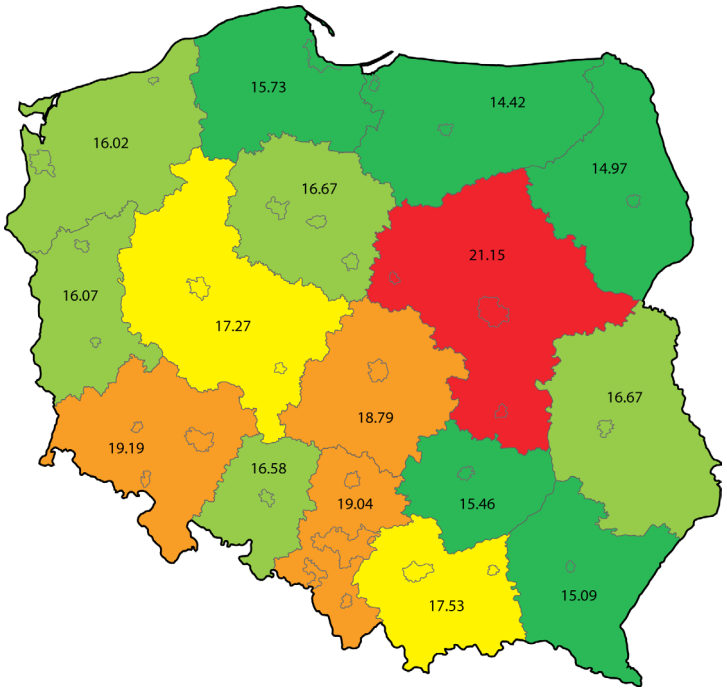

Fig. 4. Consumption of energy (heat, electricity, natural gas, hard coal, light fuel oil and liquefied petroleum gas) in the residential sector in 2017 [GJ/person]. Based on (GUS 2018b)

Rys. 4. Zużycie energii (ciepło, energia elektryczna, gaz ziemny, węgiel kamienny, lekki olej opałowy i gaz płynny) w sektorze gospodarstw domowych w 2017 r. [GJ/osobę]

1.2. CO_2 emission factors

The CO_2 emission factor (*CF*) [Mg of CO_2 per TJ of energy] of 94.71 Mg/TJ for hard coal, 55.43 Mg/TJ for natural gas, 63.1 Mg/TJ for liquefied petroleum gas, 77.4 Mg/TJ for light fuel

oil, 99.5 Mg/TJ for heat (from district heat network) and 216.11 Mg/TJ for electricity were used based on the reported data for 2017 (KOBIZE 2019c; KOBIZE 2018; URE 2018).

1.3. Air Protection Programs

In the event the level of even one of the substances exceeds the limit or target value, an Air Protection Program (APP) is defined for the zone (Directive EU 2008; Act 2001; Minister of Environment 2012b). Until 30 April each year, the province inspector for environmental protection evaluates air quality and classifies the zones into those with exceedance (class C) and those without exceedances (class A) of limit or target levels of pollutants concentrations. For the zones categorized as class C in 18 months from the day in which the results of air quality assessment were published the Air Protection Program is defined by means of a resolution by province councils (regional governments). The air quality protection program defines the extent and cause of the exceedances and indicates the ways to achieve the limit and target levels. Air Protection Programs predict activities for several years. Currently, the applicable programs have a perspective until 2020 (13 zones), 2022 (2 zones), 2023 (for 12 zones), 2024 (7 zones), 2025 (12 zones) (Fig. 5).

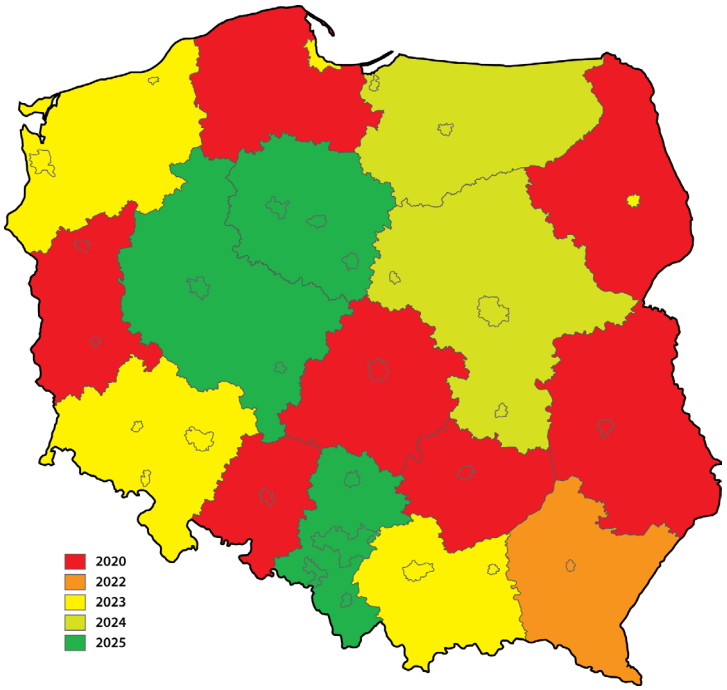

Fig. 5. The year of completion of planned activities in Air Protection Programs in particular zones [year]

Rys. 5. Rok zakończenia planowanych działań w Programach Ochrony Powietrza w poszczególnych strefach [rok]

All of 42 Air Protection Programs implemented in Poland have been reviewed. Based on the review, the estimation of the residential space, where the old boilers use coal and biomass simultaneously will be converted into:

- new coal-fired boilers using only hard coal,
- new biomass boilers,
- natural gas heating (Tab. 2).

The division into coal and biomass boilers was developed on the basis of coal consumption in 2017 and biomass consumption in 2015 (Tab. 1). The consumption of coal equaled 231540 TJ in 2017 and biomass (including wood) of 301763 TJ in 2015. Therefore, in this work, it was assumed that 43% of households will choose coal-fired boilers and 57% biomass boilers. The results are presented in Table 2, Figure 2.

1.4. Anti-smog resolutions

Unfortunately, the actions presented in Air Protection Programs have been not implemented to a satisfactory degree. Many provinces have decided to introduce anti-smog resolutions in their

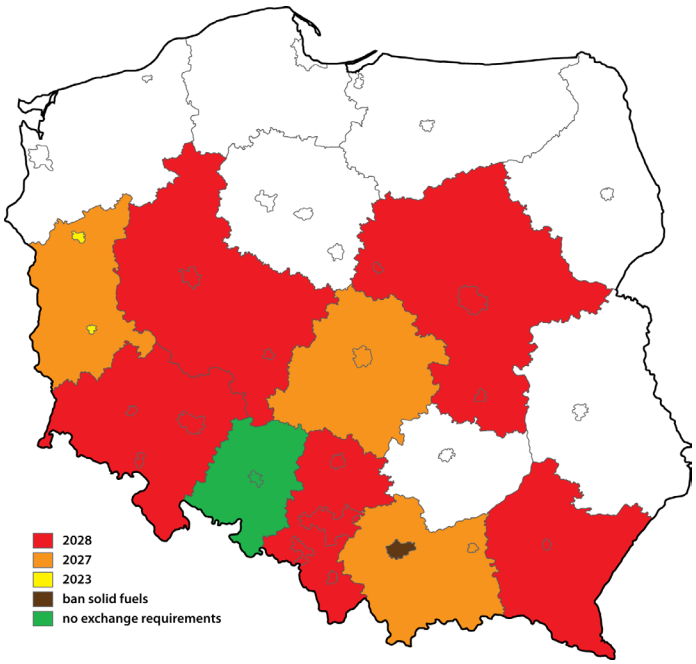

Fig. 6. The year of completion of the planned replacement of boilers below class 5 with ecodesign boilers in the framework of anti-smog resolutions in particular zones [year]

Rys. 6. Rok zakończenia planowanej wymiany kotłów poniżej klasy 5 na kotły ekoprojekt przewidziany w uchwałach antysmogowych w poszczególnych strefach [rok]

areas. The first anti-smog resolution was adopted in 2016 for Krakow and introduces a ban for solid fuels combustion in the residential sector as of September 1, 2019. So far, the anti-smog resolutions were adopted in 9 provinces. Most of them prohibit the use of poor quality solid fuels and force the replacement of low-effective and high-emission boilers (class 4 and worst) with ecodesign boilers. Boilers of class 5 can be used for an unlimited time. The year of completion of planned replacement of boilers below class 5 with ecodesign boilers in anti-smog resolutions in particular zones is presented in Figure 6.

In this work regarding anti-smog resolutions it was assumed that the old boilers (worse that class 5) are replaced by new coal or biomass boilers (compatible with ecodesign) (Tab. 2). The number of replaced boilers was estimated based on the calculation presented in the Air Protection Program for Lesser Poland province, which takes the actions taken in anti-smog resolutions for Lesser Poland province into account. In this Air Protection Program it was calculated that approx. 512 500 old boilers should be replaced in Lesser Poland province (UMWM 2017). Taking the population of of 3.3914 million residents in the Lesser Poland province into account, it was assumed that one old boiler operates for 6.62 people in Poland. The division between biomass (57%) and coal boilers (43%) is based on the same assumptions as in the case of APP.

1.5. The "Clean Air" program

In order to improve the quality of air in Poland the nationwide "Clean Air" program was implemented in 2018. The program subsidizes changing the source of heating and conducting

TABLE 2. The residential space (*HAO* and *HAN*) aggregated for Poland for which the old coal and biomass boilers are planned to be replace by new (ecodesign) coal, biomass or gas boilers according to the Air Protection Programs (APP), antismog resolution (anti-smog) and "Clean Air" program [million m^2]

TABELA 2. Powierzchnia mieszkalna (*HAO* i *HAN*) zagregowana dla Polski, dla której stare kotły na węgiel i biomasę mają być zastąpione przez nowe (ekoprojekt) kotły na węgiel, biomasę lub gaz, zgodnie z Programami Ochrony Powietrza (APP), uchwałami antysmogowymi (*anti-smog*) i programem „Czyste Powietrze" [mln m^2]

Action	APP	Anti-smog	Clean Air
Residential space with old coal and biomass boilers (worse than class 5)	163.46	429.62	490.00
Residential space with new coal boilers	62.85	184.73	
Residential space with new biomass boilers	83.31	244.88	
Residential space with new natural gas boilers	27.30		
Residential space with new coal boilers and thermo-modernization			210.70
Residential space with new biomass boilers and thermo-modernization			279.30

a thermo-modernization in single-family houses. It was assumed that in the frame of the "Clean Air" program, 3.5 million houses will undergo thermo-modernization and old boilers will be replaced by new hard coal or biomass boilers (Tab. 2). The division between biomass (57%) and coal boilers (43%) is based on the same assumptions as in the case of APP. The number of houses using this program were disaggregated into the province based population data for 2017.

1.6. Fuel consumption per unit of heating area

The challenge in this works, which is very important and at the same time the most difficult, is to estimate amount of fuel carriers used to heat the 1 m^2 of the heating area of a flat or house. Most of the households in Poland use more than one fuel to heat the residential space. In 2015, 5.8% and 4.6 % of households used only coal or wood, respectively. In Poland, coal and biomass are usually used at the same time. In 2015 coal, wood and other biomass, natural gas and heat from the district heat network was used in 40.45%, 45.23%, 55.11% and 41.67% of households, respectively (GUS 2017a). In 2015, the household which used only natural gas to heat residential space consumed 0.38 GJ (average) or 0.35 GJ (median) of natural gas to heat 1 m^2 of flat of house. For hard coal these values were 0.78 GJ/m^2 (average) and 0.75 GJ/m^2 (median) (GUS 2017a).

Based on these value and also keeping in mind that most of household use the hard coal and biomass simultaneously and also taking into account the coal consumption of 231540 TJ in 2017 and the biomass consumption 301763 TJ in 2015 (Tab. 1) the coal consumption per square matter of heating area (*HF*) for exiting old solid fuel boilers was calculated as is presented in equation 4.

$$HFO = 231540\ \text{TJ}/(301763\ \text{TJ} + 231540\ \text{TJ}) \cdot 0.78\ \text{GJ/m}^2 = 0.33\ \text{GJ/m}^2 \quad (4)$$

TABLE 3. Assumed fuel consumption required to heat 1 m^2 of heating area (*HFO* and *HFN*) [GJ/m^2]

TABELA 3. Zakładane zużycie paliwa wymagane do ogrzania 1 m^2 powierzchni grzewczej (*HFO* i *HFN*) [GJ/m^2]

Usage	Fuel carrier	Value of HFO	Value of HFN	Application
Boilers worse than class 5, assumption that use coal and biomass simultaneously	coal	0.33		APP anti-smog clean air
Boilers of class 5 or ecodesign, assumption that coal is only used, increase in combustion efficiency by 10%	coal		0.70	APP, anti-smog
Boilers of class 5 or ecodesign, assumption that is only used, increase in combustion efficiency by 10%, thermo-modernization carried out, reduction of fuel consumption by a further 40%	coal		0.52	clean air
Natural gas boilers, data reported by (GUS 2017a)	gas		0.38	APP

The value of *HF* of 0.33 GJ/m^3 was used for the existing coal fired boilers lower than class 5. The value for others technologies and fuel are presented in Table 3.

1.7. Other assumptions

In this work the change of biomass amount used in residential sector and emission of CO_2 from biomass was not taken into consideration because of CO_2 zero emission of biomass. It also was assumed, that old coal-fired boilers will not be exchanged into district heat network. This assumption were made because of the low share of such exchanges, especially in rural areas, and the fact that CO_2 emission factor (*FC*) for hard coal (94.71 Mg/TJ) is similar to this for the district heating network (99.5 Mg/TJ), consequently the CO_2 emissions will be not significantly different (KOBIZE 2019c; URE 2018). The impact of thermo-modernization planed in the "Clean Air" program will also be not significant due to the referral of this program to single-family house, where district heat network is used sporadically.

2. Results

2.1. CO_2 emissions from the residential sector in 2017

Based on equation 1 and data provided by (GUS 2018b) the emission of CO_2 (*CE*) from the residential sector was calculated. The total emission in Poland from the residential sector (taking the emission from the power sector into account to produce electricity and heat supplied to households but not including emissions from modes of transport used in households) equaled approx. 71 Tg which is around 20% of the total emission of CO_2 in Poland. 21 Tg of CO_2 was emitted due to coal combustion, 8.4 Tg from natural gas consumption. Approximately 16 and 22.7 Tg was associated with heat and electricity production, receptively.

The calculated emission of CO_2 per capita from the conversion of energy consumed in the residential sector is presented in Figure 7. Please note that the presented emission of CO_2 can be released to the air directly from houses and/or from power and heat plants in the case of electricity and district heat.

The highest emission of 2.17 Mg of CO_2 per person was calculated for the Masovia province, where the consumption of energy in the residential sector is the highest (Figs. 4 and 7). Differences between the provinces amount to a maximum of 20%.

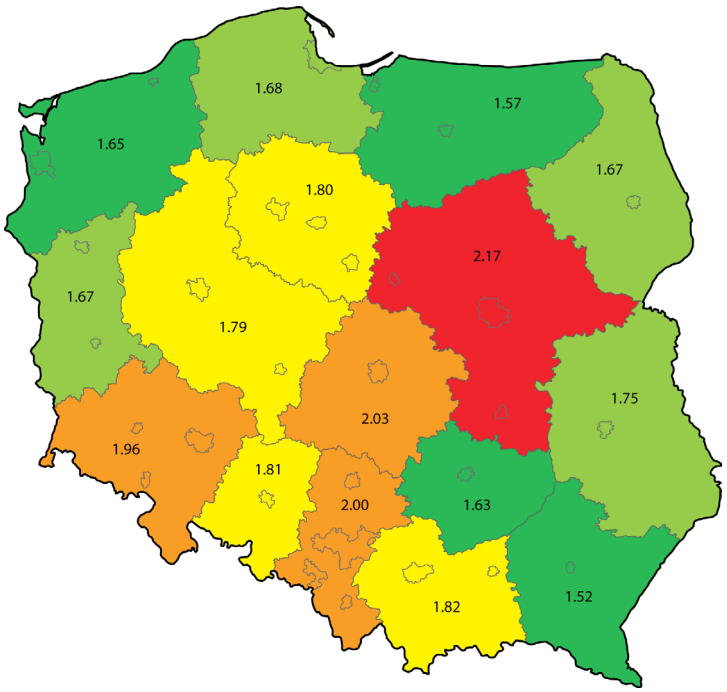

Fig. 7. Emission of CO_2 from the conversion of energy consumed in the residential sector in 2017 [Mg/person]

Rys. 7. Emisja CO_2 z konwersji energii zużywanej w sektorze gospodarstw domowych [Mg/osobę]

2.2. Estimated coal and natural gas FUTURE consumption

Based on the assumption presented in Table 2 and Table 3, fuel consumption in 2017 (*FC2017*) and equation 3, the future fuel consumption (*FCN*) use was estimated. The coal and gas consumption in 2017 *(FC2017)* in the implementation of the Air Protection Programs, anti-smog resolutions and the "Clean Air" program (FCN) is presented in Table 4.

The results presented in Table 4 show that the amount of coal used in the residential sector will decrease significantly, an average of a 6% difference occurs for Air Protection Programs (APP), anti-smog resolutions and 23% for the "Clean Air" program. The implementation of the "Clean Air" program in West Pomerania will allow coal consumption to be reduced by 40%. The gas consumption may increase in Poland by 6% and in the Lodzkie province by more than 25%.

TABLE 4. The consumption of coal and natural gas in 2017 in the implementation of Air Protection Programs (APP), anti-smog resolutions (anti-smog) and the "Clean Air" program [TJ/year]

TABELA 4. Zużycie węgla i gazu ziemnego w 2017 r. oraz w przypadku wdrażania programów ochrony powietrza (APP), postanowienia antysmogowe (*anti-smog*) i program „Czyste Powietrze" [TJ/rok]

	Coal consumption				Gas consumption	
	2017	APP	anti-smog	Clean Air	2017	APP
Lower Silesia	18 591	17 842	17 650	14 654	14 614	15 330
Kuyavia-Pomerania*	13 416	13 292	13 416	10 590	5 007	5 125
Lublin*	15 027	14 683	15 027	12 143	6 093	6 422
Lubusz	4 358	4 232	4 029	2 979	4 435	4 556
Lodzkie	19 023	16 588	18 220	15 663	5 731	7 178
Lesser Poland	21 202	18 269	20 102	16 601	16 307	18 621
Masovia	31 939	29 147	30 193	24 635	31 399	34 067
Opole*	6 674	6 338	6 674	5 331	2 543	2 878
Subcarpathia	12 962	12 599	12 272	10 074	8 862	9 237
Podlaskie*	5 834	5 816	5 834	4 227	1 945	1 962
Pomerania*	9 579	9 567	9 579	6 426	7 966	7 978
Silesia	32 234	30 624	30 760	26 064	17 090	17 892
Świętokrzyskie*	8 331	8 071	8 331	6 638	2 941	3 210
Warmia-Masuria*	6 174	6 006	6 174	4 229	3 287	3 448
Greater Poland	20 362	19 427	19 231	15 629	15 809	16 464
West Pomerania*	5 834	5 787	5 834	3 520	7 943	7 981
Poland	231 540	218 289	223 326	179 404	151 972	162 350

* For provinces where anti-smog resolution are no adopted the fuel consumption in 2017 was used.

2.3. Estimated CO_2 emission from the residential sector

The future CO_2 emission (*CEN*) and reflective change of this emission associated with the implementation of Air Protection Programs, anti-smog resolutions and the "Clean Air" program was calculated with use of data presented in Table 4 and emission factors (*FC*). The results are presented in Tables 5–6.

The results presented in Table 5 and Table 6 show that the highest potential to reduce of CO_2 emission is linked to the "Clean Air" program. It is possible to reduce CO_2 emissions from the

TABLE 5. The emission of CO_2 [Gg] (*CEN*) and the emission of CO_2 per capita [Mg/person] from the conversion of energy consumption in the residential sector in the implementation of Air Protection Programs (APP), anti-smog resolutions (anti-smog) and the "Clean Air" program

TABLE 5. Emisja CO_2 [Gg] (CEN) i emisja CO_2 na mieszkańca [Mg/osobę] z konwersji energii zużywanej w sektorze gospodarstw domowych w przypadku wdrażania programów ochrony powietrza (APP), uchwał antysmogowych (*anti-smog*) i programu „Czyste Powietrze"

	CO_2 emission [Gg]				CO_2 emission per capita [Mg/person]			
	2017	APP	anti-smog	Clean Air	2017	APP	anti-smog	Clean Air
Lower Silesia	5 692	5 661	5 603	5 359	1.96	1.95	1.93	1.85
Kuyavia-Pomerania*	3 753	3 748	3 753	3 492	1.80	1.80	1.80	1.68
Lublin*	3 714	3 700	3 714	3 459	1.75	1.74	1.75	1.63
Lubusz	1 700	1 695	1 669	1 576	1.67	1.67	1.64	1.55
Lodzkie	5 020	4 870	4 944	4 783	2.03	1.97	2.00	1.93
Lesser Poland	6 183	6 033	6 079	5 875	1.82	1.78	1.79	1.73
Masovia	11 679	11 563	11 514	11 135	2.17	2.15	2.14	2.07
Opole*	1 794	1 781	1 794	1 685	1.81	1.80	1.81	1.70
Subcarpathia	3 234	3 221	3 169	2 982	1.52	1.51	1.49	1.40
Podlaskie*	1 976	1 975	1 976	1 825	1.67	1.67	1.67	1.54
Pomerania*	3 911	3 910	3 911	3 613	1.68	1.68	1.68	1.55
Silesia	9 097	8 989	8 958	8 557	2.00	1.98	1.97	1.88
Świętokrzyskie*	2 028	2 018	2 028	1 883	1.63	1.62	1.63	1.51
Warmia-Masuria*	2 252	2 245	2 252	2 076	1.57	1.57	1.57	1.45
Greater Poland	6 245	6 193	6 138	5 833	1.79	1.77	1.76	1.67
West Pomerania*	2 806	2 804	2 806	2 589	1.65	1.64	1.65	1.52
Poland	71 085	70 404	70 306	66 722	1.85	1.83	1.83	1.74

* For provinces where anti-smog resolution are no adopted the emission of CO_2 in 2017 was used.

residential sector by more than 6%. This program imposes the implementation of thermo-modernization as well as the replacement of heating. In our calculation, only in the case of Air Protection Programs did we assume the replacement of old boiler by gas heating. However, previous experience shows that inhabitants forced to liquidate old boilers also exchange them for gas heating, biomass boilers or district heat. Poland has to reduce the emission of greenhouse gases from non-ETS (ESD) sources by 7% by 2020 compared to the base year 2005 (Regulation EU 2018b). In Poland almost 200,000 [Gg CO_2-equivalent] of greenhouse gases is emitted each year. Therefore, activities related to the reduction of low-stack emissions will be able to fill this goal only in 1/3.

TABLE 6. The relative reduction of CO_2 emission from the conversion of energy consumption in the residential sector in the implementation of the Air Protection Programs (APP), anti-smog resolutions (anti-smog) and the "Clean Air" program compared to 2017 [%]

TABLE 6. Względne zmniejszenie emisji CO_2 z konwersji energii zużywanej w sektorze gospodarstw domowych w przypadku wdrażania programów ochrony powietrza (APP), uchwał antysmogowych (*anti-smog*) i programu „Czyste Powietrze" w porównaniu do 2017 r. [%]

	APP	Anti-smog	Clean Air
Lower Silesia	0.55	1.57	5.85
Kuyavia-Pomerania	0.14	0.00	6.96
Lublin	0.39	0.00	6.86
Lubusz	0.31	1.84	7.29
Lodzkie	3.00	1.51	4.74
Lesser Poland	2.42	1.68	4.97
Masovia	1.00	1.42	4.66
Opole	0.74	0.00	6.06
Subcarpathia	0.42	2.02	7.81
Podlaskie	0.04	0.00	7.65
Pomerania	0.01	0.00	7.62
Silesia	1.19	1.53	5.93
Świętokrzyskie	0.48	0.00	7.17
Warmia-Masuria	0.31	0.00	7.78
Greater Poland	0.84	1.72	6.60
West Pomerania	0.08	0.00	7.73
Poland	0.96	1.10	6.14

* For provinces where anti-smog resolution are no adopted the relative reduction of CO_2 emission equals 0.

Summary

In Poland, we still have a problem with local air quality. Emissions from the residential sector have the biggest impact on local air quality. Therefore, many efforts to reduce the amount of emitted pollutants are focused on this sector. These are Air Protection Programs, anti-smog resolutions and the "Clean Air" nationwide program. Measures aimed at improving air quality regarding particulate matter and benzo(a)pyrene may also give an opportunity to reduce greenhouse gas emissions, especially carbon dioxide. The obtained results showed that thanks to the imple-

mentation of Air Protection Programs and anti-smog resolutions, the symbolic reduction of CO_2 emission can be obtained. In this work the reduction was near 1%. Therefore, we can also expect an increase in CO_2 emissions, especially when inhabitants stop using biomass. In Poland a lot of biomass is still burned with coal simultaneously in the residential sector. A smooth change of fuel is possible in old boilers which unfortunately are ineffective and emit significant amounts of harmful pollutions such as particulate matter and benzo(a)pyrene. New ecodesign boilers allow only one fuel type to be burned. Therefore, the choice of a coal-fired ecodesign boiler stops the combustion of biomass which can lead to an increase of CO_2 emission. Only thermo-modernization which is foreseen in the "Clean Air" nationwide program noticeably (approx. 6%) affects the reduction of CO_2 emission. The obtained results based of assumption that may be far from the real data. The future fuel consumption structure and energy demand in the residential sector depend on many factors, among others, the cost of fuel carriers, affluence of residents, support programs, ecological awareness. In Poland, the lack detailed and full data of the residential sector is still present. We still do not know exactly how we heat our flats, what equipment we have, what energy demand is what fuels are used and what the condition of buildings is. There is also a lack of sufficient and deep research on the environmental effects of measures taken to reduce low-stack emissions. Therefore, the effects of actions taken to reduce low-stack emissions are largely unpredictable.

It seems that the most important thing at the moment is to increase the environmental awareness among residents and policy makers both in the area of air quality (smog) and global climate change.

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Oszacowanie wpływu realizacji programów ochrony powietrza, uchwał antysmogowych oraz programu „Czyste Powietrze" na emisję CO_2

Streszczenie

Głównym celem tego artykułu jest oszacowanie zmian emisji dwutlenku węgla w sektorze gospodarstw domowych spowodowanych realizacją planów zawartych w Programach Ochrony Powietrza (POP), uchwałach antysmogowych przyjętych w 9 województwach oraz ogólnopolskim programie „Czyste Powietrze". Zmniejszenie emisji zanieczyszczeń, które bezpośrednio wpływają na lokalną jakość powietrza i zdrowie ludzi, tj. pyłu zawieszonego i benzo(a)pirenu, których sektor gospodarstw domowych jest głównym źródłem, mogą również wpływać na ilość emitowanego do atmosfery CO_2. Aby oszacować zmiany emisji dwutlenku węgla w sektorze gospodarstw domowych, obliczono emisję CO_2 z różnych nośników energii w roku bazowym 2017, przeanalizowano plany ograniczenia niskiej emisji i oszacowano przyszłą strukturę nośników energii stosowanych w gospodarstwach domowych. W obliczeniach uwzględniono także procesy zwiększenia efektywności wykorzystania energii poprzez wymianę kotłów i termomodernizację. Otrzymane rezultaty wskazują, że najwyższą, ponad 6% redukcję emisji dwutlenku węgla, uzyskano w przypadku realizacji ogólnopolskiego programu „Czyste Powietrze". W programie tym założono, że 3,5 miliona domów będzie objętych wymianą systemu grzewczego i termomodernizacją. Realizacja Programów Ochrony Powietrza oraz uchwał antysmogowych powoduje zmniejszenie emisji CO_2 o około 1% w stosunku do roku 2017. Przedstawiono wyniki przyszłego zużycia nośników energii oraz emisji dwutlenku węgla dla poszczególnych województw i dla całej Polski.

SŁOWA KLUCZOWE: CO_2, smog, gospodarstwa domowe, Programy Ochrony Powietrza, uchwały antysmogowe