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DOI: 10.15199/180.2019.4.2

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AN ATTEMPT TO ESTIMATE CO_2 EMISSIONS CAUSED BY ENERGY CONSUMPTION IN POLISH AGRICULTURE

PRÓBA OSZACOWANIA EMISJI CO_2 WYNIKAJĄCEJ Z ZUŻYCIA ENERGII W POLSKIM ROLNICTWIE

***Summary**: Based on Central Statistical Office (GUS) data and emissive indicators according to the National Center for Balancing and Managing Emissions (KOBiZE), emission of carbon dioxide, caused by direct energy consumption in Polish agriculture in 2015, has been estimated. The value of this emission totaled 12 535,0 Tg (thous. metric tons). It was 86,9 Gg per 100 ha of utilized agricultural area (UAA) and 877,2 Gg per 100 farms. Solid fuels had the largest share (46%) in CO_2 emission, including steam coal – 27,7%, and wood and peat – 16.7%. The share of liquid fuels amounted to 41%, including diesel oil 39% in CO_2 emission. The share of other energy carriers amounted to a total 13% in CO_2 emission. Electricity caused 10% of the total CO_2 emission resulting from consumption of energy carriers in agriculture, gaseous fuels – in total 2% (of that liquid petroleum gas 1,3%), and heat – 1%. Emission of CO2 resulting from the diesel oil consumption in agriculture amounted to 4 906,6 Tg (34,1 Gg·100 ha^{-1} UAA and 343,4 Gg per 100 farms). The consumption of the diesel oil in agriculture of particular voivodeships in 2015 has been estimated as proportional to the share of these voivodeships in national resources of selected categories of the agricultural land. This consumption amounted from 39 thou metric tons in Silesian Voivodeship to 205 thou metric tons in Mazovia voivodeship in 2015. Based on diesel oil consumption regional distribution, the CO_2 emission resulting from its use has been calculated for particular voivodeships. Yearly CO_2 emission per unit of UAA amounted from 30,9 Gg·100 ha^{-1} UAA in Warmia- and Mazury Voivodeship to 35,2 Gg·100 ha^{-1} UAA in Silesian voivodeship, with the country average 34,1 Gg·100 ha^{-1} UAA. Yearly CO_2 emission per 100 farms amounted from 124,1 Gg per 100 farm in Małopolskie Voivodeship to 958,5 Gg per 100 farm in West Pomeranian Voivodeship, with the country average 343,4 Gg per 100 farm.*

***Keywords**: emission GHG, carbon dioxide, energy carriers, agriculture*

***Streszczenie**: Na podstawie danych GUS i wskaźników emisyjnych według Narodowego Centrum Bilansowania i Zarządzania Emisjami (KOBiZE) oszacowano emisję dwutlenku węgla spowodowaną bezpośrednim zużyciem energii w polskim rolnictwie w 2015 r. Wartość tej emisji wyniosła 12 535,0 Tg (tys. Ton metrycznych). Było to 86,9 Gg na 100 ha użytków rolnych (UAA) i 877,2 Gg na 100 gospodarstw. Paliwa stałe miały największy udział (46%) w emisji CO_2, w tym węgiel energetyczny - 27,7%, a drewno i torf - 16,7%. Udział paliw ciekłych wyniósł 41%, w tym olej napędowy 39% w emisji CO2. Udział innych nośników energii wyniósł łącznie 13% w emisji CO_2. Energia elektryczna spowodowała 10% całkowitej emisji CO_2 wynikającej ze zużycia nośników energii w rolnictwie, paliw gazowych - ogółem 2% (z tego ciekłego gazu naftowego 1,3%), a ciepła - 1%. Emisja CO_2 wynikająca ze zużycia oleju napędowego w rolnictwie wyniosła 4 906,6 Tg (34,1 Gg · 100 ha^{-1} UAA i 343,4 Gg na 100 gospodarstw). Zużycie oleju napędowego w rolnictwie poszczególnych województw w 2015 r. Oszacowano jako proporcjonalne do udziału tych województw w zasobach krajowych wybranych kategorii gruntów rolnych. Zużycie to wyniosło od 39 tys. Ton w województwie śląskim do 205 tys. Ton w województwie mazowieckim w 2015 r. Na podstawie regionalnego rozkładu zużycia oleju napędowego wyliczono emisję CO_2 wynikającą z jego zużycia dla poszczególnych województw. Roczna emisja CO_2 na jednostkę UAA wyniosła od 30,9 Gg · 100 ha^{-1} UAA w województwie warmińsko-mazurskim do 35,2 Gg · 100 ha^{-1} UAA w województwie śląskim, przy średniej krajowej 34,1 Gg · 100 ha^{-1} UAA. Roczna emisja CO_2 na 100 gospodarstw wyniosła od 124,1 Gg na 100 gospodarstw w województwie małopolskim do 958,5 Gg na 100 gospodarstw w województwie zachodniopomorskim, przy średniej krajowej 343,4 Gg na 100 gospodarstw.*

***Słowa kluczowe**: semisja gazów cieplarnianych, dwutlenek węgla, nośniki energii, rolnictwo*

Introduction

On average, around 10% of total greenhouse gas (GHG) emitted to the Earth's atmosphere in the EU comes from agriculture in the European Union. [Eurostat 2015]. Smaller values of this share (7%) are given: for Great Britain – by FRANKS & HADINGHAM [2012], and for the USA - PARTON et al. [2011]. The differences probably result from the uneven degree of industrialization of individual countries and the share of agriculture in the production of national income, with which the share of greenhouse gas emissions is positively correlated.

Despite a small share of total greenhouse gas emissions, measured in carbon dioxide equivalent, agriculture, however, emits as much as 53% of global greenhouse gas emissions other than CO_2 [BEACH et al. 2015]. Nitrogen fertilizers are the largest source of greenhouse gas emissions in plant production [NALLEY et al. 2011]. Soils, including grassland, have the largest share in the structure of greenhouse gas emissions (45%). The share of animal production, from which most methane comes, is 25%, exploitation of agricultural mechanization measures – 13%, manure handling, storage and application to fields – 11%, and other sources - 6%. In the greenhouse gas reduction programs, agriculture is in the non-ETS area (not covered by the emissions trading scheme). The national inventory includes the following gases and greenhouse gas groups: carbon dioxide (CO2), methane (CH_4), nitrous oxide (N_2O), HFC gas group (fluorocarbons), PFC gas group (perfluorocarbons), sulfur hexafluoride (SF_6) and nitrogen trifluoride (NF_3). The first three of these gases are dominant.

According to The National Centre for Emissions Management (Polish abbreviation: KOBiZE) data, [2014] in the structure of greenhouse gases emitted in Polish agriculture in 2014, carbon dioxide had the largest share (59,8%). The share of methane in this structure was 36,8%, and nitrous oxide 3,4%. Agriculture only generated 0,3% of carbon dioxide emissions (excluding the use of agricultural mechanization measures, which is not reported in the agriculture sector), but 33,7% of methane and as much as 78,9% of nitrous oxide.

Carbon dioxide is emitted as a result of the oxidation of an organic substance, among others during the breathing of animals and plants, as well as as a result of processes taking place in soil. Agricultural land use, changes in land use and forestry, on the other hand, cause the absorption of carbon dioxide from the earth's atmosphere, mainly due to photosynthesis in the plant world. However, for methane and nitrous oxide, these effects cause a small increase in emissions.

One of the sources of this emission is energy consumption for production purposes in agriculture [Camargo et al. 2013]. They are also used as the basis for estimating macro-scale energy costs [Pawlak 2016a] and greenhouse gas emissions [Aday et al. 2016, Pawlak 2017]. A lot of attention was paid to the issues of energy consumption in rural areas and the impact of energy management on the natural environment in the work of foreign and Polish scientific institutions, including the Institute of Technology and Life Sciences (ITP). Many works were also devoted to assessing the possibilities and purposefulness of increasing production and consumption of energy from renewable resources [Grzybek, Pawlak 2015a, b,c; Konieczna et al. 2019; Wardal et al. 2019; Niedziółka & Szpryngiel 2014; Pawlak 2004; Roszkowski 2013a, b; Terlikowski 2012; Wójcicki 2007, 2009, 2012;2015, 2015a,b] and the impact of renewable energy use on the natural environment and rural development [Hryniewicz, Grzybek 2013; Namyślak 2012; Pawlak 2013; Xiaohua et al. 2015; Wójcicki & Rudeńska 2014].

The level of CO_2 emissions in regional terms is proportional to the consumption of diesel oil in agriculture in individual voivodships. This consumption depends on many factors. They are influenced by, among others:

- share of mechanical draft sources in the production technology used,
- production directions on farms,
- yield level of cultivated plants,
- amount of work to be done using tractors and internal combustion engines,
- working conditions, including: soil type and condition, terrain, surface and shape of fields, distances in internal and external transport, and road condition,
- technical condition of tractors as well as machines and tools cooperating with them,
- quality of selection of agricultural equipment for working conditions and power of the tractor used for the parameters of machines and tools cooperating with it,
- qualifications of personnel servicing equipment and work organization.

It is practically impossible to include most of these factors in the estimates of diesel oil consumption and, consequently, in carbon dioxide emissions from this source. More simplified methods are needed. One of them consists in estimating diesel oil consumption on the scale of voivodships based on the area of cultivated plants as well as their yields and specific consumption of this fuel per hectare of each cultivated plant, taking into account the level of yield. It was used to estimate diesel oil consumption in Poland [PAWLAK 2012a] and in the Małopolskie Voivodeship [Pawlak 2012b]. At that time, data on the sown area of individual plants according to the results of the 2010 general census was used as the basis for calculations.

Objective of the work

The basis for developing solutions enabling the reduction of greenhouse gas emissions in agriculture is recognition of the current state. The purpose of this work was to estimate CO_2 emissions caused by energy consumption in agriculture on the basis of data from the Central Statistical Office of Poland – (Polish abbr. GUS) [2016a], referring to the state of 2015 and emission indicators according to the National Center for Emission Balancing and Management (KOBiZE) [2016a] and the regional differentiation of these emissions into example of diesel fuel. An additional objective is to present a method for estimating diesel oil consumption and related CO_2 emissions in a voivodship system.

The main terms and abbreviations have been used in accordance with the nomenclature recommended in the EU [Eurostat 2019], as follows:

AA – agricultural area, describes the area already used for farming, or that could be brought back into cultivation using the resources normally available on an agricultural holding.

UAA – utilized agricultural area, is the total area taken up by arable land, permanent grassland, permanent crops and kitchen gardens used by the holding, regardless of the type of tenure or of whether it is used as a part of common land.

ARA – arable land is land worked (ploughed or tilled) regularly, generally under a system of crop rotation.

PECR – permanent crops are ligneous crops, meaning trees or shrubs, not grown in rotation, but occupying the soil and yielding harvests for several (usually more than five) consecutive years. Permanent crops mainly consist of fruit and berry trees, bushes etc.

J0000 (or PEGR) – permanent grassland (pasture and meadow) is land used permanently (for several consecutive years, normally

5 years or more) to grow herbaceous fodder, forage or energy purpose crops, through cultivation (sown) or naturally (self-seeded), and which is not included in the crop rotation on the holding. The grassland can be used for grazing, mown for silage and hay or used for renewable energy production.

Source materials and methodological assumptions

The main sources of data on the consumption of the most important energy carriers in agriculture in 2015 was the publication of the Central Statistical Office (GUS) [2016a]. Based on these data and the carbon dioxide emission factors resulting from the consumption of individual ones (Table 1), adopted on the basis of the work of KOBiZE [2016a, b], CO_2 emissions were estimated.

The value of the indicator for heat energy delivered to consumers via the network was calculated on the basis of KOBiZE [2016b] data on domestic electricity and heat production and associated CO_2 emissions.

Table 1. Carbon dioxide emission factors as a result of consumption of selected energy carriers [KOBiZE 2016a, b].
Source: own study based on Central Statistical Office data [2016a].

Specification	CO_2 emission factor [Mg·TJ⁻¹]
Black coal	94.05
Brown coal	111.21
Brown coal briquettes	97.50
Coke (fuel)	107.00
Firewood	112.00
Other solid biomass	98.00
High-methane natural gas	56.10
Nitrogen-rich natural gas	56.10
Liquefied gas	63.10
Biogas	54.60
Motor gasoline	69.30
Aviation gasoline	70.00
Diesel fuel	74.10
Light fuel oil	74.10
Other fuel oils	77.40
Electricity	229.28
Heat from the network	110.59

The values of CO_2 emissions due to the consumption of individual energy carriers in agriculture were calculated using the formula:

$$Zen_{CO_2} = \frac{En \cdot Wen_{CO_2}}{1000} \quad (1)$$

where:

Zen_{CO_2} – CO_2 emissions due to the consumption of the nth energy carrier in agriculture [Gg];

En – energy consumed in agriculture in the form of its nth carrier in 2015 [TJ];

Wen_{CO_2} – CO2 emission factor for the nth energy carrier [Mg·TJ^{-1}].

The CO_2 emission values obtained in this way as a result of the consumption of energy carriers in agriculture were calculated per unit of utilized agricultural area:

$$Zenjs_{CO_2} = \frac{10000 \cdot Zen_{CO_2}}{S_{UAA}} \quad (2)$$

where:

$Zenjs_{CO_2}$ – CO_2 emissions due to the consumption of the n-th energy carrier in agriculture per 100 ha of utilized agricultural area [kg·100 ha^{-1}];

$SUAA$ – utilized agricultural area [thous. ha];

and per 100 farms:

$$Zenjg_{CO_2} = \frac{10000 \cdot Zen_{CO_2}}{N_g} \quad (3)$$

where:

$Zenjg_{CO_2}$ – consumption of the n-th energy carrier in agriculture per 100 farms [kg];

N_g – the number of farms [thous.].

The criterion for dividing the value of domestic diesel oil consumption in the period covered by the analysis into individual voivodships was the structure of the share of each of them in the total area of sown, permanent crops and meadows. The permanent crops group includes orchards and perennial plantations, including plantations of fruit trees and shrubs, tree nurseries and fruit shrubs, tree nurseries and decorative shrubs, forest tree nurseries for commercial purposes, other permanent crops, including wicker, trees and fruit shrubs growing outside plantations, as well as permanent crops under cover [GUS 2016b]. Data on the domestic consumption of diesel oil in agriculture were obtained from the relevant Central Statistical Office (PL: GUS) publications [2016a], and on the area of the aforementioned categories of agricultural land - from GUS agricultural statistical yearbooks [2016b].

When determining the share of individual voivodships in diesel oil consumption, categories of agricultural land were deliberately selected that were characterized by higher than average unit fuel consumption per unit area. The area of fallow land, home gardens and permanent pastures, where the consumption of diesel fuel is low or non-existent, was omitted. However, permanent meadows were included, because due to the large share of permanent grasslands in some voivodships, their omission could cause distortions of results, especially since pastures were not included. However, as a reference basis in the comparative analysis of unit consumption of diesel in the regional system, all types of arable land were included.

Indicators of the share of individual voivodships (provinces) in the domestic consumption of diesel oil were calculated using the formula

$$Uw_r = \frac{100 \cdot (Zw_r + Tw_r + Gw_r)}{Zk_r + Tk_r + Gk_r} \qquad (4)$$

where:

Uwr – share od w[th] – voivodeship in the domestic consumption of diesel oil in r-[th] year [%],

Zwr – sown area in the wth province and r-[th] year [ha],

Twr – area of permanent crops (PECR) in the wth voivodship and r-[th] year [ha],

Gwr – area of permanent grassland in the w-[th] voivodship and r-[th] year [ha],

Zkr – domestic area of crops in the r-[th] year [ha],

Tkr – domestic area of permanent crops in the r-[th] year [ha],

Gkr – domestic area of permanent meadows (grassland) in the r-[th] year [ha].

Data on the area of included arable land categories and designated values of voivodships' share ratios in their resources are given in Table 2.

By multiplying the value of the Uwr indicator calculated in this way by domestic diesel consumption, we obtain diesel consumption in a given province:

$$DFw_r = \frac{ONk_r \cdot Uw_r}{100} \qquad (5)$$

where:

DFwr – diesel fuel consumption in the w-[th] voivodship (province) in the r-[th] year [thous. tonnes],

DFkr – domestic consumption of diesel fuel in r-[th] year [thous. tonnes]

By dividing the diesel fuel consumption in individual voivodships by the number of ha of utilized agricultural area in good culture, we obtain the consumption of this fuel per unit of the utilized agricultural area in a given year:

$$JDFw_r = \frac{1000000 \cdot DFw_r}{UAAw_r} \qquad (6)$$

where:

JDFwr – specific consumption of diesel fuel in the w-[th] voivodship and r-[th] year [kg·ha-[1] UAA],

UAAwr – utilized agricultural area in the w-[th] voivodship and r-[th] year [ha].

Table 2. Share of voivodships in the resources of selected types of arable land in 2015
Source: own study based on Central Statistical Office data [2016a].

Voivodships (V.)	Sown area [ha]	Area of permanent crops [ha]	Area of permanent meadows [ha]	Total [ha]	Share of voivodships [%]
Lower Silesia Voivodship	760 329	7 009	111 512	878 850	6.4
Kuyavian-Pomeranian V.	945 994	7 322	83 332	1 036 648	7.5
Lubelskie V.	1 103 653	83 485	209 891	1 397 029	10.1
Lubuskie V.	277 543	4 807	87 352	369 702	2.7
Łódzkie V.	765 270	39 412	137 040	941 722	6.8
Małopolskie V.	312 964	10 770	174 488	498 222	3.6
Masovian V.	1 259 848	119 210	438 907	1 817 965	13.2
Opolskie V.	449 675	1 840	37 430	488 945	3.5
Subcarpathia V.	320 216	10 902	186 004	517 122	3.8
Podlaskie V.	655 567	7 260	323 002	985 829	7.1
Pomeranian V.	598 626	12 079	112 287	722 992	5.2
Silesian V.	263 955	3 036	71 753	338 744	2.5
Świętokrzyskie V.	327 055	36 998	96 005	460 058	3.3
Warmia-and Mazury V.	608 740	8 956	237 371	855 067	6.2
Wielkopolskie V.	1 463 453	19 148	222 146	1 704 747	12.4
West Pomeranian V.	640 067	18 747	129 606	788 420	5.7
Poland (total)	**10 752 955**	**390 979**	**2 658 126**	**13 802 060**	**100.0**

Table 3. Consumption of energy carriers in Polish agriculture in 2015
Source: own study based on Central Statistical Office data [2016a].

Energy carriers	Consumption [TJ]
Black coal	36 400
Brown coal	1 142
Brown coal briquettes	613
Coke (fuel)	252
Firewood and peat	19 000
Solid biomass	116
Total solid fuels	57 523
High-methane content natural gas	931
Nitrogen-rich natural gas	213
Liquefied gas	2 622
Biogas	385
Total gaseous fuels	4 151
Motor gasoline	42
Aviation gasoline	7
Diesel fuel	66 216
Light fuel oil	3 010
Mazut	420
Total liquid fuels	69 695
Electricity	5 425
Heat from the network	890
Total	**137 684**

Results: energy consumption in agriculture in 2015

Direct consumption of energy carriers in Polish agriculture in 2015 totaled 137 684 TJ (Table 3). After calculation per 100 ha of utilized agricultural area (UAA), it was 954,5 GJ · 100 ha^{-1}, and per 100 farms – 9 635 GJ.

Liquid fuels had the largest share in direct energy consumption (50%) (Fig. 1), including diesel fuel - 48%. The share of solid fuels amounted to 42%, including black coal 26,4%, wood and peat 13,8%, and other solid biofuels – only 0,1%. The share of other energy carriers was small and totaled 8%. Electricity accounted for 4% of the total consumption of energy carriers in agriculture, gas fuels - a total of 3% (including liquid gas 1,9%, biogas 0,3%), and heat - 1%.

The share of energy carriers from renewable resources amounted to a total of 14.2%, assuming that in the group of fuels defined by the Central Statistical Office as peat and wood, the share of peat as fuel used in agriculture is minimal.

Results: carbon dioxide emissions as a result of direct energy consumption in agriculture in 2015

The estimated value of CO_2 emissions as a result of direct energy consumption in Polish agriculture amounted to a total of 12 535,0 Tg in 2015 (Table 4). After calculation per 100 ha of utilized agricultural area (UAA), it amounted to 86,9 Gg · 100 ha^{-1}, and 887,2 Gg per 100 farms.

Solid fuels had the largest share in CO_2 emissions as a result of direct energy consumption (46%) (Fig. 2), including black coal - 27,7%, and wood and peat - 16,7%. The share of CO_2 emissions from liquid fuels was 41%, including diesel fuel 39%. The share of other energy carriers in CO_2 emissions totaled 13%. Electricity generated 10% of total CO_2 emissions as a result of consumption of energy carriers in agriculture, gaseous fuels - 2% in total (including liquid gas 1,3%), and district heating - 1%.

Due to the dominant share of solid and liquid fuels, the reduction of CO_2 emissions associated with the direct consumption of energy carriers in Polish agriculture should be seen in improving the efficiency of these fuels. This can be achieved by implementing energy-saving agricultural production technologies and environmentally friendly energy consumers.

Fig. 1. The structure of the calorific value of energy carrier groups consumed in agriculture in 2015.
Source: own study based on Central Statistical Office data [2016a].

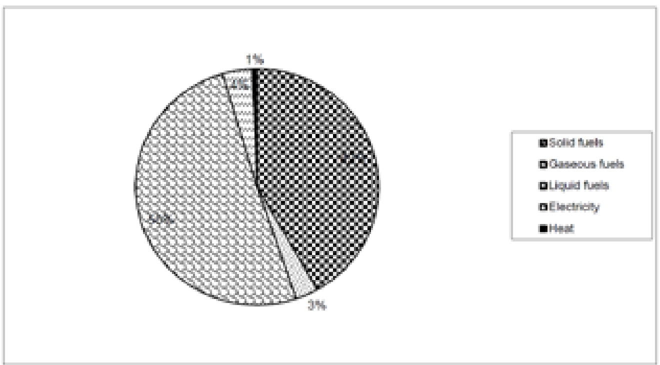

Fig. 2. The share of groups of energy carriers used in agriculture in 2015 in CO_2 emissions.
Source: own study based on Central Statistical Office data [2016a].

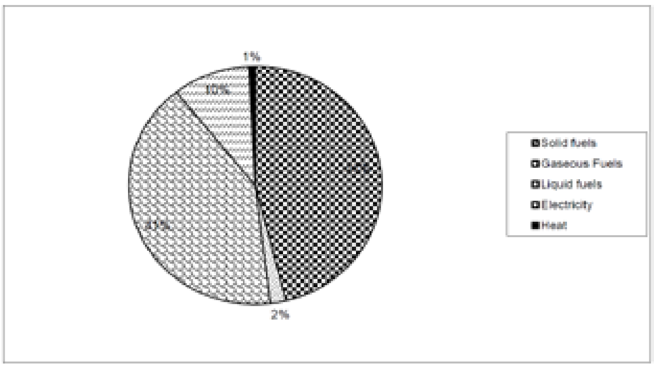

Table 4. CO_2 emission as a result of the consumption of energy carriers in agriculture in 2015 [own study based on data from the Central Statistical Office of Poland 2016 and KOBIZE 2016 a, b].
Source: own study based on Central Statistical Office data [2016a].

Specification	Annual CO_2 emissions		
	Gg	[kg] per	
		100 ha UAA	100 farms
Black coal	3 423.4	23.7	239.6
Brown coal	127.0	0.9	8.9
Brown coal briquettes	59.8	0.4	4.2
Coke (fuel)	27.0	0.2	1.9
Firewood and peat	2 128.0	14.8	148.9
Solid biomass	11.4	0.1	0.8
Total solid fuels	5 776.5	40.0	404.2
High-methane content natural gas	52.2	0.4	3.7
Nitrogen-rich natural gas	11.9	0.1	0.8
Liquefied gas LPG	165.4	1.1	11.6
Biogas	21.0	0.1	1.5
Total gaseous fuels	250.6	1.7	17.5
Motor gasoline	2.9	0.0	0.2
Aviation gasoline	0.5	0.0	0.0
Diesel fuel	4 906.6	34.0	343.4
Light fuel oil	223.0	1.5	15.6
Mazut	32.5	0.2	2.3
Total liquid fuels	5 165.6	35.8	361.5
Electricity	1 243.8	8.6	87.0
Heat from the network	98.4	0.7	6.9
Total	**12535.0**	**86.9**	**877.2**

Results: consumption of diesel fuel in a regional system

Such large regional differences in the level of fuel consumption were a consequence of unequal arable land area in individual voivodships. In 2015, agricultural land in good culture was over five times larger in the Mazovia voivodship than in the Silesia voivodship.

Diesel fuel consumption in the Lesser Poland voivodship in 2010, estimated on the basis of data on the sown area of individual plants according to the results of the 2010 general agricultural census and on unit consumption of diesel oil based on [PAWLAK 2012b] amounted to 67 Tg (by 8% more than value calculated for this voivodship and 2010 using the method adopted in this paper). Considering the fact of continuous technical progress, the obtained results should be treated as approximate.

Less varied than the absolute values of diesel oil consumption in individual voivodships were the values of the unit fuel consumption per hectare of arable land in good culture (Table 5). This consumption in 2015 ranged from 97,7 kg · ha-[1] UR in the Warmian-Masurian Voivodeship to 111,3 kg · ha-[1] UAA in the Silesia Voivodeship. Higher than the domestic average value of diesel consumption index per unit of UAA in good culture was recorded in the following voivodships: Lower Silesia Voivodship, Kuyavian-Pomeranian V., Lubelskie V., Lubuskie V., Łódzkie V., Opolskie V., Pomeranian, Silesian and Wielkopolskie V. These voivodships had a smaller share of permanent pasture in the arable land structure than the national average. On the other hand, voivodships characterized by a greater than the national average share of permanent pasture in the structure of agricultural land: Małopolskie, Mazovian, Subcarpathia, Podlaskie, Świętokrzyskie, Warmia- and Mazury and West Pomeranian Voivodeship had diesel oil consumption per unit of agricultural land area lower than the average in Polish agriculture .

The significant variation in the level of unit CO_2 emissions from diesel oil per 100 farms was also affected by the average UAA in individual voivodships. It ranged from 392,5 kg per farm

Table 5. Diesel oil consumption in Polish agriculture by voivodship
Source: own study based on Central Statistical Office data [2016a].

Voivodships (V.)	Diesel fuel consumption		
	[Tg (thous. tonnes)]	[kg] per	
		ha UAA	farm
Lower Silesia Voivodship	99	109.6	1 662.6
Kuyavian-Pomeranian V.	116	109.5	1 781.5
Lubelskie V.	157	109.6	881.4
Lubuskie V.	42	108.7	1 975.9
Łódzkie V.	105	108.7	818.3
Małopolskie V.	56	105.9	392.0
Masovian V.	205	107.4	966.3
Opolskie V.	54	109.4	2 018.5
Subcarpathia V.	59	106.1	444.2
Podlaskie V.	110	104.7	1 390.9
Pomeranian V.	81	108.2	2 027.2
Silesian V.	39	111.3	661.2
Świętokrzyskie V.	51	107.4	565.2
Warmia-and Mazury V.	96	97.7	2 289.6
Wielkopolskie V.	192	110.9	1 563.7
West Pomeranian V.	88	106.6	3 028.0
Poland (total)	**1 550**	**107.7**	**1 084.7**

in the Małopolskie Voivodeship to 3028,0 kg per farm in the West Pomeranian Voivodeship.

Results: regional differences in CO_2 emissions resulting from fuel oil consumption in agriculture

CO_2 emissions per 100 ha of UAA ranged from 30,9 Gg · 100 ha-[1] UAA in the Warmia- and Mazury Voivodeship to 35,2 kg · 100 ha-[1] in the Silesia Voivodeship, and per 100 farms - from 124,1 Gg in the Lesser Poland voivodship to 958,5 Gg per 100 farm in the West Pomeranian Voivodship (Table 6). Higher than the domestic average value of the carbon dioxide emission index from diesel fuel per unit of UAA in good culture was recorded in the following voivodships: Lower Silesia Voivodship, Kuyavian-Pomeranian V, Lubelskie V., Lubuskie V., Łódzkie V., Opolskie V., Pomeranian, Silesian and Wielkopolskie V. These voivodships had a smaller share of permanent pasture in the arable land structure than the national average. On the other hand, voivodships characterized by a greater than the domestic average share of permanent pasture in the structure of agricultural land: Małopolskie, Mazovian, Subcarpathia, Podlaskie, Świetokrzyskie, Warmia- and Mazury and West Pomeranian Voivodeship had diesel oil consumption per unit of agricultural land area lower than the average in Polish agriculture. The significant variation in the level of unit CO_2 emissions from diesel oil per 100 farms was also affected by the average UAA in individual voivodships. Higher than the domestic average value of the unit CO_2 emission rate from diesel fuel per 100 farms was recorded in the following voivodships: Lower Silesia Voivodship, Kuyavian-Pomeranian V., Lubuskie, Opolskie V., Podlaskie, Pomeranian, Warmia- and Mazury V., Wielkopolskie V. and West Pomeranian V., and smaller in Voivodships: Lubelskie, Łódzkie, Małopolskie, Masovian, Subcarpathia, Silesian and Świętokrzyskie V. Regional differences in CO_2 emissions as a result of diesel consumption in agriculture have also been shown by foreign studies [ADAY et al. 2016].

Final conclusions

As a result of direct energy consumption in Polish agriculture, a total of 12 535,0 Tg CO_2 was emitted into the atmosphere in 2015. Solid fuels had the largest share in CO_2 emissions as a result of direct energy consumption in Polish agriculture (46%), including hard coal - 27,7% as well as wood and peat - 16,7%. The share of liquid fuels amounted to 41%, including diesel oil 39%, and other energy

Table 6. The CO_2 emissions as a result of the consumption of diesel oil in the Polish agriculture in individual regions
Source: own study based on Central Statistical Office data [2016a].

Voivodships (V.)	Carbon dioxide emission per year		
	[Gg]	[Gg]	
		100 ha UAA	100 farms
Lower Silesia Voivodship	313 389.6	34.7	526.3
Kuyavian-Pomeranian V.	367 204.0	34.7	563.9
Lublin V.	496 991.7	34.7	279.0
Lubusz V.	132 953.2	34.4	625.5
Lodz V.	332 383.0	34.4	259.0
Lesser Poland V.	177 270.9	33.5	124.1
Masovian V.	648 938.2	34.0	305.9
Opole V.	170 939.8	34.6	639.0
Subcarpathia V.	186 767.6	33.6	140.6
Podlasie V.	348 210.7	33.1	440.3
Pomeranian V.	256 409.7	34.2	641.7
Silesian V.	123 456.5	35.2	209.3
Swietokrzyskie V.	161 443.2	34.0	178.9
Warmia-Masurian V.	303 893.0	30.9	724.8
Greater Poland V.	607 786.0	35.1	495.0
West Pomeranian V.	278 568.6	33.7	958.5
Poland (total)	**4 906 605.7**	**34.1**	**343.4**

carriers in CO_2 emissions - 13% in total. Due to the dominant share of solid fuels and diesel oil in CO_2 emissions as a result of direct energy consumption in Polish agriculture, the possibility of reducing this gas emissions should be sought primarily in the more efficient use of these energy carriers due to the implementation of energy-saving agricultural production technologies and the use of environmentally friendly energy receivers. Lack of official statistical data on diesel oil consumption in the provincial system makes it necessary to make appropriate estimates. This involves the use of methods differing in the degree of precision and labor intensity. Due to the progressive outdated indicators of unit consumption of diesel oil in individual agricultural production processes in Poland, determined on the basis of technological cards developed in the 1980s, a simplified method of estimating the consumption of this fuel in the regional system was used in this paper. This method consists in dividing the value of domestic consumption into voivodships in proportion to the share of these voivodships in the resources of three categories of agricultural land.

Comparison of the results of the application of the proposed method with the method previously used on the example of the Małopolskie Voivodship [PAWLAK 2012b] taking into account the structure of crops in the voivodship and the indicators of unit consumption of diesel oil appropriate for these crops showed that the difference between the results obtained is about 8%. Considering the fact that as a result of the progressive improvement of agricultural mechanization measures, the current values of the specific fuel consumption indicators are lower than those adopted in the work from which the results constituting the basis of this comparison come from, it can be assumed that the actual difference is less than 8%.

The above facts justify the use of the presented method to estimate the approximate regional distribution of diesel oil consumption in Polish agriculture. CO_2 emissions per 100 ha of UAA ranged from 30,9 Gg · 100 ha^{-1} UAA in the Warmia- and Mazury Voivodeship to 35,2 kg · 100 ha^{-1} UAA in the Silesian Voivodeship (domestic average 34,1 kg · 100 ha^{-1} UAA), and calculated per 100 farms - from 124,1 Gg in the Małopolskie Voivodeship to 958,5 Gg per 100 farm in the West Pomeranian Voivodeship (domestic average 343,4 Gg per 100 farms.

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Article reviewed

Received: 22.11.2019/Accepted: 30.12.2019