

Estimation Method of Greenhouse Gases Emissions at Thermal Power Plants

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Abstract – A method for calculating CO₂ emissions from coal combustion at the TPP is developed on the basis of carbon emission factors, taking into account the heat value of coal and heat losses due to the presence of unburnt carbon in ash. The values of CO₂ emissions at Ukrainian TPPs are obtained. Specific emissions of carbon dioxide are closely 1100 g CO₂/kWh, which correlates with high specific consumption of fuel for electricity production at the TPP.

Keywords – environment, thermal power plant, flue gases, carbon dioxide, emission factor, calorific value.

Introduction

On October 31, 2018 the Cabinet of Ministers of Ukraine approved the draft Law of Ukraine "On the Basics of Monitoring, Reporting and Verification of Greenhouse Gas Emissions", aimed at fulfilling the obligations assumed by Ukraine under the Association Agreement between Ukraine and the EU. This Law is a framework, it defines the legal and organizational frameworks for the functioning of the monitoring, reporting and verification of greenhouse gas emissions (MRV). It is ready Draft Resolution of the Cabinet of Ministers of Ukraine "On Approval of the Procedure for the Monitoring and Reporting of Greenhouse Gas Emissions". The basis of the MRV system is a set of methods for calculating GHG emissions, but in Ukraine does not have a single appropriate methodology that would be based on the use of the emission factor that takes into account the heat value of fuels, as required by Directive 2003/87/EC

One of the largest sources of greenhouse gas emissions is thermal power plants (TPPs). At the Ukrainian TPPs in recent years 13–19% of the total volume of anthropogenic emissions of greenhouse gases is thrown out. In 1990, they emitted 50 million tons of carbon dioxide, in recent years – about 60 million tons per year. Mainly, it is carbon dioxide that is the main greenhouse gas that is produced by combustion of organic fuels. The main factors that determine the large emissions of carbon dioxide at the TPP are the volume of coal consumption and high specific fuel consumption for electricity production (see Table 1).

Table 1

Volume of coal consumption and specific fuel consumption for electricity production at Ukrainian thermal power plants in 2013–2017

Показник	Years				
	2013	2014	2015	2016	2017
Coal consumption, mln. t	36.8	32.5	26.7	29.2	22.4
by A and P coals	17.8	14.5	8.4	12.1	4.4
by G and DG coals	19.0	18.0	18.3	17.1	18.0
% in fuel balance	98.0	98.3	98.0	98.3	98.7
Specific consumption, g CE/kWh	394.8	397.7	400.8	403.7	402.6

A – anthracite, P – semiathracite, G – bituminous coal, DG – subbituminous coal.

Coal consumption at the TPP has been decreasing in recent years, mainly due to a reduction in the use of anthracite and semianthracite, but its volume remains high – tens of

millions of tons. In the fuel balance of Ukraine's TPPs, the share of coal is very high – more than 98 % [1]

In addition, all Ukrainian TPPs, in accordance with the Monitoring and Reporting Procedure for greenhouse gas emissions, belong to Category B plants, in which the average annual emission of greenhouse gases exceeds 500 kt of CO₂. Coal at these thermal power plants refers to a "substantial material flow". When applying the calculation methods for estimating CO₂ emissions from burning "significant material flows" for Category B plants, the following techniques should be used which allow obtaining accuracy levels of at least 2.5%. Fuel oil and natural gas at Ukrainian coal-fired thermal power plants are "minor" and "minimal material flows", the amount of CO₂ emissions generated during their combustion is less than 5 kt and 1 kt of CO₂ per year, respectively. For their calculations, the accuracy levels are allowed to be less than 5.0 % and 7.5 %, respectively, which are achieved with the application of standard techniques. Therefore, the issue of creating a methodology for calculating CO₂ emissions from coal combustion, which takes into account the heat value of fuel and allows to obtain levels of accuracy less than 2.5%, is of interest.

Material and Methods

With a known the elemental composition of coal, according to the standard method, it is possible to determine the gross emission of carbon dioxide in dry flue gas generated by coal combustion. Information on carbon dioxide emissions from combustion of fossil fuels is obtained either by continuous measurements of CO₂ concentrations and flow rates of flue gas or calculated methods based on data of fuels consumption, composition of used fuel and characteristics of power boilers. For the organization of continuous continuous measurements of concentrations of pollutants and volumetric flow rates of flue gas, it is necessary to use measuring equipment, which today is not available at most of Ukrainian thermal power plants

Calculated methods for determining CO₂ emissions from fuel combustion are based on the use of the emission factor and the degree of oxidation of carbon in a fuel in a boiler [2]:

$$E_{CO_2} = 10^{-6} k_{CO_2} \cdot B \cdot LHV, (1)$$

where E_{CO_2} – CO₂ gross emissions, kt; k_{CO_2} – emission factor of CO₂, g/GJ; LHV – low heat value of fuel, MJ/kg; B – fuel consumption during the time (year), kt.

The emission factor characterizes the ratio of mass of the emitted substance at the power plant into the atmosphere to the unit of energy emitted during combustion of the fuel. It depends on many factors. There are two emission factors - generalized and specific. In the presence of both coefficients, it is necessary to use a specific one.

The generalized CO₂ emission factor is the average specific emission value for a specific type of fuel. It does not take into account the features of the chemical composition of fuel. The CO₂ specific emission factor is the specific emission value, which is determined for a power plant, taking into account the individual characteristics of the fuel and the specific characteristics of the combustion process. The CO₂ specific emission factor for coal can be written as [2]:

$$k_{CO_2} = \frac{44}{12} \cdot \frac{C^r}{100} \cdot \frac{10^6}{LHV} \varepsilon_C = 3,67 k_C \varepsilon_C, (2)$$

where C^r – carbon content in coal as row, %; LHV – low heat value of coal, MJ/kg; ε_C – oxidation degree of fuel carbon; k_C – emission factor carbon, g/GJ.

Oxidation degree of fuel carbon ε_C is defined according [3]:

$$\varepsilon_C = 1 - \frac{q_4}{C^r} \cdot \frac{LHV}{Q_C}, (3)$$

where q_4 – heat losses due to present of unburnt carbon in ash, %; Q_C – heat value of coal equivalent (CE), 32,68 MJ/kg.

According to our calculations, the oxidation degree of fuel carbon ε_C with an accuracy of 0.6% can be determined by the formula [3]:

$$\varepsilon_C = 1/(1 - q_4/100). \quad (4)$$

The specific carbon emission factor k_C is the ratio of the carbon content of the coal to coal heat value:

$$k_C = \frac{C^r}{100} \cdot \frac{10^6}{LHV}. \quad (5)$$

In the absence of data on the carbon content of coal and its combustion heat, for estimation calculations, generalized emission factors of carbon k_C , g/GJ, may be used, or in the Ukrainian national document GKD 34.02.305-2002 (hereinafter – GKD) or in the report of the Intergovernmental Panel on Change Climate (IPCC). It should be noted that European guidelines and methodological documents on the definition of greenhouse gases have determined that the values of carbon dioxide specific emission factors depend on the country of coal production, and it is recommended to use the national values of these factors.

Consequently, the calculation of the specific carbon emission factor is based on the use of carbon content in coal C^r , the values of lower heat values LHV and heat losses due to present of unburnt carbon in ash at the power plant q_4 . But in real terms, the coal batches supplied to the TPPs are accompanied only by a technical analysis in which only such fuel characteristics are provided, which do not allow to calculate a specific carbon emission (directly by standard method). Therefore, the purpose of the work was to developing the engineering method for calculating the CO₂ emissions generated by combustion of coal at the TPP, according to the technical analysis, taking into lower heat value LHV.

The engineering method of calculation was developed on the basis of 140 certificates for coal and coal products from mines and cleaning factories of Donetsk coal basin, for samples of coal of the anthracite (A), semi-anthracite (P), gas (G) and gas flame (DG) types, with a LHV range from 16.1 to 31.3 MJ/kg [4]. The certificates were drafted and approved by the state enterprise "UkrNDIvuhlezbahacennia". According to the certificates, the elemental composition for each fuel sample was determined and the carbon specific emission factors k_C were calculated. It is established that for coal of the A, P, G and DG types the dependence of specific coal emission factors k_C , g/GJ on the heat value of coal LHV, MJ/kg, has a linear character: $k_C = a - b \cdot LHV$, where a and b are coefficients, depending on the of coal type. For coal of the P type, the dependence of specific carbon emission factors on the heat of combustion of coal was not detected.

Table 2 summarizes the results of calculations, namely the dependence of the values of carbon specific emission factors k_C on the lower heat value of coal, MJ/kg, relative errors, δ , %, the range of the obtained values of carbon specific emission factors and the values of the generalized carbon emission factors for charcoal of grades A, P, G and DG. In addition, for comparison in Table 2 shows the values of the generalized carbon emission factors k_C from the national control document GKD 34.02.305-2002 and the IPCC report. It is evident that the values of fuel-aggregate carbon emission factors differ significantly from national and European carbon emission factors.

The analysis of the results shows that for coal of the P, G and DG types the values of generalized carbon emission factors from different sources are in the range of values obtained from calculations of specific carbon emission factors (see Table 2, the maximum and minimum values are given). For coal of the A type, the values of the carbon emission factors are much higher. The error of calculating the specific emission factor of carbon for the dependencies given

in Table 2 is less than 2.5%, which meets the requirements for monitoring, reporting and verification of greenhouse gas emissions from power industrial installations. It should be noted that fuel combinations of coal of the A and P types are burned at the Ukrainian TPPs. The use of the values of the generalized carbon emission factors from Table 2 is associated with some errors, because in the official report TPP is not provided with information on mass part of coal of this or that type. Therefore, for the estimated calculations of carbon specific emission factors for the combustion of coal mixtures of A and P types, it is proposed to use the dependence $k_C = 28900 - 50 \times LHV$ [4].

Table 2

Specific and generalized carbon emission factors for Ukrainian coal of different types

Carbon emission factors k_C , g/GJ	Coal types		
	A	P	G and DG
Specific carbon emission factor: got dependence	$k_C = 29900 - 40 \times LHV$	26450	$k_C = 26800 - 55 \times LHV$
δ , %	0.97	0.90	2.39
maximum value	29735	26805	27292
minimum value	28200	25934	24116
Generalized emission carbon factors:			
our calculations	28760	26450	25630
are given in the	28160	26050	25180
shown in the IPCC report	26810	no data	25800

Results and discussion

According to Table 2 data and formula (4), the values of specific carbon emission factors and gross carbon dioxide emissions, kt, were calculated from the combustion of coal at the Ukrainian TPPs. The calculations used information on the quality, the cost of coal supplied to the TPPs, and the values of q_4 from the official TPP statistics - 3Tech.

Table 3 shows the results of these calculations for coal-fired power plants and 5 power generating companies of Ukraine for 2017. Table 3 also shows the fuel types burned at the TPP and the percentage of coal in the fuel balance of the TPP. For comparison, in Table 3 also results of the corresponding calculations according to the method of GKD 34.02.305-2002 on the carbon generalized emission factors without considering the information on the heat value of coal.

GHG gross emissions from coal combustion at Ukraine's TPPs in 2017 amounted to 44.4 million tons. The use of carbon emission factor calculations taking into account the lower calorific value of coal has given the value of gross CO₂ emissions at Ukraine's TPPs in 2017 by 800 kt more than by using generalized emission factors from GKD 34.02.305-2002.

In order to determine the exact values of specific and gross emissions of carbon dioxide at the TPP, the calculations should take into account the emissions generated by the combustion of coal, natural gas and fuel oil:

$$E_{CO_2}^{fuel} = E_{CO_2}^{coal} + E_{CO_2}^{fueloil} + E_{CO_2}^{gas}, \quad (6)$$

where $E_{CO_2}^{fuel}$ – gross emissions of CO₂ formed during combustion of fuel at the TPP in a year, kt; $E_{CO_2}^{coal}$ – gross emissions of CO₂ formed during combustion of coal at the TPP in a year, kt; $E_{CO_2}^{fueloil}$ – gross emissions of CO₂ formed during combustion of fuel oil at the TPP in a year, kt; $E_{CO_2}^{gas}$ – gross emissions of CO₂ formed during the combustion of gas at the TPP in a year, kt.

Specific carbon emission factors and gross CO₂ emissions from coal combustion at Ukraine's TPPs in 2017

Power generating companies of Ukraine / TPPs	Types of coal	Coal		q_4 , %	Results of calculation			
		LHV, MJ/kg	B, kt		considering LHV and q_4		according GKD considering q_4	
					k_C , g/GJ	$E_{CO_2}^{coal}$, kt	k_C , g/GJ	$E_{CO_2}^{coal}$, kt
PJSC Donbasenergo			1048.4			2510.4		2457.9
Slov'yanska	A	24.32	1048.4	2.88	27684	2510.4	27105	2457.9
PJSC Centerenergo			3047.7			6313.6		6196.6
Vuhlegirska	G, DG	21.86	1935.6	0.22	25598	3963.1	25180	3898.5
Trypilska	A, P	21.73	464.1	6.36	27814	963.2	27105	938.6
Zmiyivska, в т.ч.		22.48	648.0					
No. 1–4	A, P, G	22.42	259.4	1.53	27779	556.3	27105	545.6
No. 5–6	A, P, G	22.42	315.6	2.66	27779	674.0	27105	660.5
No.7–10	A, P	22.95	73.0	7.89	27982	157.0	27105	153.3
PJSC DTEK Dniproenergo			4756.3			9676.5		9502.8
Kryvorizka	P	23,42	1220.8	6.14	26450	2602.7	26050	2563.4
Prydniprovska, в т.ч.		23.29	689.4			1498.2		1466.1
No. 7–10	A, P, G	23.29	572.9	6.17	27736	1248.3	27105	1221.9
No. 11–14	A, P	23.28	116.5	9.42	27736	249.9	27105	244.2
Zaporizka	G, DG	20.90	2846.1	0.34	25650	5575.6	25180	5473.3
PJSC DTEK Zakhidenergo			8391.0			16423.6		16125,8
Burshtynska	G, DG	21.06	4441.0	0.97	25642	8708.0	25180	8551.2
Dobrotvirska, в т.ч.		21.15	1348.8		25642	2641.3	2641,3	2594.2
No.7–8	G, DG	21.12	790.4	1.58	1544,3	1544.3	25180	1516.7
4×50 MW		21.21	558.4	1.44	1097,0	1097.0	25180	1077.5
Ladyzhinska	G, DG	20.83	2601.2	0.42	25655	5074.3	25180	4980.4
DTEK Skhidenergo Ltd.			5182.0			9461.0		9301,4
Kurakhivska	G, DG	18.07	3922.7	1.9	25806	6577.3	25180	6417.7
Luhanska	A, P	23.84	1259.3	5.45	27708	2883.7	27708	2883.7
Total, of them			22425.4			44385.1		43584.5
for grades of A, P		23.54	4874.9			11845.5		11669.1
G, DG		20.45	17550.5			32539.6		31915.4

Calculations of $E_{CO_2}^{fueloil}$ and $E_{CO_2}^{gas}$ were performed using formulas (1) and (2) using the values of carbon generalized emission factors k_C , g/GJ, from GKD 34.02.305-2002: for fuel oil $k_C = 21100$ g/GJ, for gas $k_C = 15300$ g/GJ. The calculations also used information on the quality, consumption of fuel oil and gas supplied to the TPP, and the value of q_4 from the official statistics of TPP – 3Tech.

Table 4 presents the results of calculations of CO₂ gross emissions from fuel combustion at coal-fired power plants of Ukraine and separately for coal, natural gas and fuel oil. Data are provided for power generating companies of Ukraine. The obtained values coincide with operational data of Ukrainian TPPs. The calculation error for CO₂ gross emissions at the TPP was 1.3%.

Table 4

Estimated and available values of gross CO₂ emissions from fuel combustion at Ukraine's TPPs in 2017

Power generating companies of Ukraine	Results of calculation, kt				TPP data $E_{CO_2}^{fuel}$, kt	δ , %
	$E_{CO_2}^{coal}$	$E_{CO_2}^{fueloil}$	$E_{CO_2}^{gas}$	$E_{CO_2}^{fuel}$		
PJSC Donbasenergo	2510.4	0.05	21.2	2531.6	2576.0	1.7
PJSC Centerenergo	6313.6	23.4	40.2	6377.2	6130.5	4.0
PJSC DTEK Dniproenergo	9676.5	45.4	92.3	9814.3	9692.1	1.3
PJSC DTEK Zakhidenergo	16423.6	29.0	169.9	16622.5	16388.1	1.4
DTEK Skhidenergo Ltd.	9461.0	63.7	26.4	9551.0	9527.5	0.2
Total	44385.1	161.55	350.0	44896.65	44314.2	1.3

According to the developed method, the calculations of gross CO₂ emissions at coal-fired power plants of Ukraine in recent years have been made. Table 5 shows the gross and specific emissions of CO₂ from coal-fired power plants in Ukraine in 2017 and, for comparison, in 2014–2016 [4]. The results are summarized for TPPs, burning coal of the A and P type and coal of G and DG type.

Table 5

Total and specific CO₂ emissions from coal-fired power plants in Ukraine in 2014–2017

TPPs	Supplied electric energy,		Gross CO ₂ emissions		Specific CO ₂ emissions		Coal LHV, MJ/kg	Specific fuel consumption, g/kWh
	kWh	%	kt	%	g CO ₂ /kWh	t CO ₂ /t coal		
2014								
Total	62032.7		68114.1		1098.0	2.09	21.9	397.7
TPPs burning A + P	28561.6	46.0	33111.6	48.6	1159.3	2.27	23.4	413.6
TPPs burning G + DG	33471.0	54.0	35002.5	51.4	1045.8	1.94	20.7	387.9
2015								
Total	49397.8		54592.9		1105.2	2.04	21.3	400.8
TPPs burning A + P	15564.5	31.5	19102.4	35.0	1227.3	2.29	23.2	428.5
TPPs burning G + DG	33833.2	68.5	35490.5	65.0	1049.0	1.93	20.4	389.8
2016								
Total	52726.3		60636.2		1150.0	2.07	21.6	403.7
TPPs burning A + P	21454.9	40.7	27534.4	45.4	1283.4	2.28	23.3	423.8
TPPs burning G + DG	31271.4	59.3	33101.8	54.6	1058.5	1.90	20.4	395.6
2017								
Total	40526.1		44896.5		1107.8	2.0	21.1	402.6
TPPs burning A + P	9046.8	22.3	11679.8	26.0	1291.1	2.63	25.9	431.2
TPPs burning G + DG	31479.9	77.7	33216.7	74.0	1055.2	1.85	20.0	391.5

Table 5 shows that the values of CO₂ specific emissions at the TPP are at the level of 1100–1150 g CO₂/kWh. At the TPP burning coal of the A and P type, values of specific CO₂

remissions reach 1200–1300 g CO₂/kWh, that is, by 30 % higher, than at the TPP, burning coal of the G and DG type. This correlates with higher values of the heat value of coal of the A and P type, compared with coal of the G and DG type.

For comparison, this value is 860–940 g CO₂/kWh at the coal-fired power plants of Japan, Europe, and America with the supercritical steam parameters (240–260 bar vapor pressure, such as at coal-fired TPPs in Ukraine) with installed desulfurization and denitrification equipment. At the TPPs with ultra super-critical parameters of steam (pressure more than 280 bar), specific CO₂ emissions are 760–840 g CO₂/kWh [5]. This correlates with high values of specific fuel consumption per 1 kWh of electricity generated at Ukrainian thermal power plants.

Ukrainian TPPs must pay an environmental tax. The environmental tax rate for CO₂ emissions by stationary sources in 2017, according to Article 243 of the Tax Code of Ukraine, was to 0.41 UAH per/t. Estimated total cost of CO₂ emission amounted to UAH 18.55 mln. or EUR 0.62 mln. Since January 1, 2019, the environmental tax rate for CO₂ emissions from stationary sources has been emissions at Ukraine's TPP increased to 10 UAH/t.

Conclusions

Based on the above mentioned the following conclusions can be summarized as follows.

1. The basis of the monitoring, reporting and verification of greenhouse gas emissions is a set of methods for assessing greenhouse gas emissions. Today in the Ukrainian power sector of Ukraine there is no single obligatory methodology for calculating greenhouse gas emissions based on the use of the GHG emission factor and takes into account the heat value of fuels, as required by Directive 2003/87/EC.
2. The method was developed for calculating the CO₂ emissions generated by combustion of coal at the TPP, based on specific carbon emission factors, taking into account the heat value of coal and heat losses due to present of unburnt carbon in ash.
3. The developed method allow to calculate the values of specific carbon emission factors and gross CO₂ emissions at Ukraine's TPPs in 2017. The value of specific CO₂ emissions at the TPP in recent years is 1100 g CO₂/kWh.

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