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A novel method for calculating greenhouse gas emissions from the combustion of energy fuels

ILIYA KRASTEV ILIEV[a*]
HRISTO IVANOV BELOEV[a]
DIANA IVANOVA ILIEVA[b]
JANUSZ BADUR[c]

[a] University of Ruse, Heat, Hydraulics and Environmental Engineering, Studentska 8, 7017 Ruse, Bulgaria

[b] University of Telecommunications and Post, Akad. Stefan Mladenov 1, 1700 Sofia, Bulgaria

[c] Energy Conversion Department, Institute of Fluid Flow Machinery, Polish Academy of Sciences, Fiszera 14, 80-251 Gdańsk, Poland

Abstract An analysis of the methods used in Bulgaria for estimating CO_2, SO_2 and dust emissions has been conducted. The first methodology, which is officially used by all energy auditors at the Agency for Sustainable Energy Development targets the energy efficiency of combustion devices installed mainly at industrial enterprises. The second methodology, used by the Ministry of Environment and Water, is more comprehensive and can be applied to thermal power plants, small combustion plants as well as industrial systems. In recent years, many projects related to energy efficiency and renewable energy projects, including hydrogen technologies, which require an assessment of reduced greenhouse gas emissions, have been implemented as a priority. The use of reliable and accurate methods is essential in the assessment of greenhouse emissions. A novel methodology, based on stoichiometric equations of the combustion process for solid, liquid and gaseous fuels has been proposed and comprised. This novel methodology is characterized by higher precision compared to the methods currently in place and this is achieved through calculating emissions from the combustion of energy fuels accounting for the full elemental composition of the fuel and its heating value, whereas the current commonly applied methods use only

*Corresponding Author. Email: iiliev@enconservices.com

the fuel type and the carbon content. A further benefit of the proposed methodology is the ability to estimate emissions of fuels for which there is no alternative method for calculating CO_2, SO_2 and dust. Results of emission calculations according to the analysed methods are presented. Finally, a comparative analysis between the presented methodologies including an assessment of their accuracy and universal applicability has been made.

Keywords: Emission factors; CO_2 emissions; SO_2 emissions; Dust emissions; Stoichiometric equations; Fuel-technical calculations

Nomenclature

A^r	–	ash content in the fuel, wt.%
a_{fly}	–	proportion of ash from fuel carried away by gases
C^r	–	carbon content in the fuel, wt.%
CO	–	carbon monoxide content in the gaseous fuel, vol.%
$\mathrm{C}_m\mathrm{H}_n$	–	content of hydrocarbons in the gaseous fuel, vol.%
HHV	–	higher heating value, kJ/kg
$\mathrm{EF_{CO2}}$	–	emission factor of CO_2, t CO_2/t fuel (t CO_2/1000 m^3)
$\mathrm{EF_{dust}}$	–	emission factor of dust, t dust/t fuel
$\mathrm{EF_{SO2}}$	–	emission factor of SO_2, t SO_2/t fuel
H^r	–	hydrogen content in the fuel, wt.%
H_2	–	hydrogen content in the gaseous fuel, vol.%
H_2S	–	hydrogen sulfide content in the gaseous fuel, vol.%
m	–	number of carbon in the hydrocarbon compounds
N^r	–	nitrogen content in the fuel, wt.%
n	–	number of hydrogen in the hydrocarbon compounds
O^r	–	oxygen content in the fuel, wt.%
O_2	–	oxygen content in the gaseous fuel, vol.%
Q^r	–	lower heating value (LHV) of the fuel, GJ/t
S^r	–	sulphur content in the fuel, wt.%
V^0	–	theoretical amount of dry air, Nm^3/kg fuel
V^{0g}	–	theoretical amount of dry air for gaseous fuel, m^3/m^3 gas fuel
V_{CO2}	–	volume of CO_2, Nm^3/kg (m^3/m^3 for gaseous fuel)
V^0_{H2O}	–	volume of water vapour, Nm^3/kg
V^0_{NO2}	–	volume of nitrogen in flue gases, Nm^3/kg
V_{RO2}	–	volume of triatomic gases, Nm^3/kg (m^3/m^3 for gaseous fuel)
V_{SO2}	–	volume of SO_2, Nm^3/kg
W^r	–	water content in the fuel, wt.%

Greek symbols

λ	–	access air ratio
μ_{dust}	–	concentration of ash particles, kg/kg fuel
ρ_{CO2}	–	density of CO_2, kg CO_2/Nm^3
ρ_{SO2}	–	density of SO_2, kg SO_2/Nm^3
ρ_{dust}	–	density of dust, kg dust/N m^3

Acronyms

LPG	–	liquefied petroleum gas
MoEW	–	Ministry of Environment and Water
SEDA	–	Sustainable Energy and Development Agency
RES	–	renewable energy sources

1 Introduction

Bulgaria, similarly to other countries particularly in Europe, is on the path to the long-term transformation of its energy system in the coming decades to 2050 and in the next years the role of the methods used to estimate greenhouse gas emissions will bear increasing significance [1, 2]. From statistical data we know that 3/4 of the EU's greenhouse gas emissions today are a result of energy production and consumption. Restructuring the energy sector is a prerequisite for the EU to take the path to climate neutrality by 2050 [3].

The EU Member States have committed themselves to improving energy efficiency by at least 32.5% by 2030, reducing energy consumption and increasing the share of renewable energy sources by at least 32%. The European Green Deal [4], announced in December 2019, has given an even stronger impetus to the decarbonisation of the EU's energy system. Directive 2012/27/EU on energy efficiency [5] recommends that the Member States use the data set out therein for the energy content of fuels and energy for final consumption, but also allows for other justified national values to be used instead.

One of the main objectives of energy-saving measures is to combat climate change. Reducing fuel and energy consumption leads to reduced greenhouse gas emissions. Directive 2012/27/EU on energy efficiency [5] does not specify the requirements for the methods of determining emission reductions and emission factors that will be used to assess the reduction of greenhouse gas emissions as a result of energy savings [6]. In Bulgaria, Poland, and other countries estimates of this reduction in emissions are based mainly on the principles of the UN Framework Convention on Climate Change and IPCC Methods (Intergovernmental Panel on Climate Change) [7, 8]. It should be underlined that the official institutions in Bulgaria apply mainly two methodologies for calculating the emissions of carbon dioxide (CO_2), sulfur dioxide (SO_2) dust and other harmful components [9, 10].

The methodology of the Ministry of Environment and Water (MoEW) [10] is more comprehensive and allows for the calculation of emissions of greenhouse gases and other harmful components. The methodology is based on the principles set out in [1, 8].

The second officially applied methodology is that of the Sustainable Energy and Development Agency (SEDA) [9], which is used by certified consulting companies in the field of energy efficiency and renewable energy sources (RES).

Both official methodologies have their advantages and disadvantages, but this paper aims to offer a much more precise methodology, with a high degree of versatility, which can be used for fuel emissions that are absent from those officially presented in the reference literature.

2 Nature of the MoEW method

The methodology for calculating the balance of emissions of harmful substances (pollutants) released into the atmosphere is regulated by Article 25, paragraph (6) of the Clean Air Act [11] and has been developed by adapting the methodological tools, reflected in [1] for the conditions of Bulgaria. It takes into account the national specifics in terms of activities, technologies, equipment, raw materials used and the current regulations for ambient air in the country. The methodology is intended to be used in the activities of the Ministry of Environment and Water and its divisions in the country for the purpose of air management, for annual inventories of emissions at national and regional levels and by companies, for individual settlements and sources, for the needs of national statistics, in conducting environmental impact assessments, in environmental expertise, in preparing forecasting programs, for scientific, research, and other purposes. The nomenclature of activities is developed at three levels and includes 393 activities but in our analysis, we will focus only on the first level, and in particular on combustion processes in energy production and transformation [10]. Emission factors are determined based on studies on emissions from thermal power plants conducted in Germany, the Netherlands, the Czech Republic, Sweden, the United States, France, Poland, and other countries.

The emission factors are given in Tables 1, 2, 3, and 4, respectively, for the four groups of pollutants for each fuel type as follows:

- Anthracite coal – a type of coal used for industrial and residential applications. It has generally less than 10% of volatile matter and a high carbon content (about 90% of fixed carbon). Its higher calorific value (HHV) is greater than 23865 kJ/kg (5700 kcal/kg) on an ash-free but moist basis (IPCC 2006 [7]).

- Bituminous coal – coal characterized by higher volatile matter content than anthracite (more than 10%), with lower carbon content (less than 90% of fixed carbon). Its higher calorific value is greater than 23865 kJ/kg (5700 kcal/kg) on an ash-free but moist basis (IPCC 2006 [7]).
- Lignite – non-agglomerating coal with a higher calorific value of less than 17435 kJ/kg (4165 kcal/kg) and greater than 31% of volatile matter on a dry mineral matter-free basis (IPCC 2006 [7]).
- Heavy fuel oil (HFO).
- Light fuel oil (LFO) (or Diesel oil).
- Natural gas – fossil gaseous fuel formed as a result of a complex process of accumulation, degradation and distillation of animal and vegetable biomass under anaerobic conditions, at particularly high pressures and temperatures [7].

However, it should be noted that the coal used in Bulgaria does not exactly meet the criteria formulated in the literature [12]. This makes the current analysis different from the known studies and the results obtained are mainly related to the fuels used in Bulgaria.

A drawback of the MoEW method is its lack of assessment of the actual pollution of the flue gases immediately at the exit from the combustion device. However, it does take into account the supposed pollution after the purification device (electrical precipitator, scrubber, etc.).

3 Emission factors for the MoEW method

The CO_2 emission factors from combustion processes are given in Tables 1–5. In order to estimate the emission of a pollutant, heat production should be calculated, i.e. the amount of heat released from fuel combustion. The product of the emission factor with the value of heat production gives the emission. Therefore, the amount of fuel burned and its lower combustion heat (Q^r) must be present in the initial data.

Table 1: Emission factors for the first group of pollutants (anthracite coal/bituminous coal).

Substances	Emission factor (g/GJ)
Sulphur oxides (SO_x as SO_2)	$1.9 \times 10^4 \frac{S^r}{Q^r}$
Nitrogen oxides (NO_x)	300
Carbon dioxide (CO_2)	$3.52 \times 10^4 \frac{C^r}{Q^r}$
Nitrous oxide (N_2O)	10
Dust	$61Q^r$

Table 2: Emission factors for the first group of pollutants (lignite/brown coal).

Substances	Emission factor (g/GJ)
Sulphur oxides (SO_x as SO_2)	$1.6 \times 10^4 \frac{\mathrm{S}^r}{Q^r}$
Nitrogen oxides (NO_x)	140
Carbon dioxide (CO_2)	$3.52 \times 10^4 \frac{\mathrm{C}^r}{Q^r}$

Table 3: Emission factors for the first group of pollutants (heavy fuel oil).

Substances	Emission factor (g/GJ)
Sulphur oxides (SO_x as SO_2)	$490\mathrm{S}^r$
Nitrogen oxides (NO_x)	180
Carbon dioxide (CO_2)	$3.63 \times 10^4 \frac{\mathrm{C}^r}{Q^r}$
Nitrous oxide (N_2O)	14
Dust	$30Q^r$

Table 4: Emission factors for the first group of pollutants (light fuel oil/Diesel oil).

Substances	Emission factor (g/GJ)
Sulphur oxides (SO_x as SO_2)	$470\mathrm{S}^r$
Nitrogen oxides (NO_x)	140
Carbon dioxide (CO_2)	70180
Nitrous oxide (N_2O)	14
Dust	–

Table 5: Emission factors for the first group of pollutants (natural gas).

Substances	Emission factor (g/GJ)
Sulphur oxides (SO_x as SO_2)	–
Nitrogen oxides (NO_x)	50
Carbon dioxide (CO_2)	55 080
Nitrous oxide (N_2O)	3
Dust	–

It should be noted that the emission factor for dust (soot), determined according to the formulas given in Tables 1–3 for different types of fuel, corresponds to the emission of dust 150 mg/m^3 and soot 100 t/m^3, respectively, according to emission limit values for thermal power plants 0.5 to 50 MW, provided in Appendix N4-1 to Art. 22, Paragraph 1 of Ordinance No. 2 / 19.02.1998 for emission limit values [5].

The emission factor for dust is valid in cases when the amount of dust discharged from heat plants whose emissions meet the norm is calculated. In the cases when calculating the amount of dust emitted by the thermal power plant, the emissions of which are outside the norm, the extent of this deviation should be established and to the same extent, a correction of the emission factor needs to be made.

4 Nature of the SEDA method

Ordinance No. RD-16-1058 [5] on the energy performance of buildings stipulates that the energy performance for annual energy consumption has an environmental equivalent of carbon dioxide emissions. The effect of the emission reduction as a result of energy savings is determined based on the assessment of two emission sources:

1. Source of direct CO_2 emissions. This approach includes all CO_2 emissions that are a direct result of on-site fuel combustion and emissions during fuel extraction, processing and transportation. Using the standard methodology for determining direct emissions, an enterprise should calculate fuel emissions for each emitting fuel stream by multiplying the data on the amount of fuel burned, based on the lower heating value, according to the environmental equivalent given in Table 6 (emission factor), corresponding to the type of fuel.

2. Source of indirect CO_2 emissions from the combustion of fuels related to the production of consumed electricity, and heat purchased and supplied from an external source (electricity network of the country or district heating network, or heat production capacity of another enterprise).

Using the standard methodology for determining indirect emissions, the enterprise should calculate the fuel emissions of CO_2 resulting from the combustion of fuels in a thermal power plant, central heating plant or plant for the production of energy purchased and supplied from an external source. Emissions are calculated by multiplying the data on the quantities of electricity and heat supplied to the enterprise, by the respective environmental equivalents (emission factors) for electricity and heat.

The ecological equivalent of electricity, as given in Table 6 [7], is 819 t CO_2/GWh, but this coefficient is also not accurate, because it should decrease every current year depending on the increasing share of RES in the energy mix.

The environmental equivalent (emission factor) of the European Commission's Report on Sustainable Production Requirements for the Use of Solid and Gaseous Biomass in Electricity and Power Systems can be used to estimate the reduction of greenhouse gas emissions from heat savings; heat and cooling energy. There the recommended value of the emission factor for heat production is 87 kg CO_2/GJ (0.313 t CO_2/MWh).

5 Emission factors for the SEDA method

According to Ordinance No. E-РД-04-3 of 4.05.2016 [9] on the eligible measures for energy savings in final consumption, the ways of proving the achieved energy savings along with the requirements to the methodologies for their evaluation and the ways for their confirmation, issued by Minister of Energy, promulgated, SG, no. 38 of 20.05.2016, in force since 20.05.2016, amended, and add., no. 79 of 25.09.2018, the reference values of the coefficient of the emission factors of energy/fuel are presented in Annex 4 of Ordinance No. E-РД-04-3 (Table 6).

From the reference values [3] of the emission factor it follows that the SEDA methodology allows for the calculation of only the reduced CO_2 emissions, and its accuracy is not high, particularly with regard to emissions from coal combustion. Only four emission factors (for several types of coal: anthracite, brown coal (lignite), and black coal) are presented in

Table 6: Reference values of the emission factor for energy/fuel.

Type of energy/fuel	CO_2 emission factor (t CO_2/GWh)
Diesel/Light fuel oil	267
Heavy fuel oil	279
Natural gas	202
Liquefied petroleum gas	227
Black coal	341
Lignite/Brown coal	364
Anthracite coal	354
Coal briquettes	351
Firewood, Pellets	43
Heat from district heating	290
Electricity	819

the methodology. However, this does not exhaust the rich variety of coal used in Bulgaria. In factories that produce cellulose, the so-called "black liquor" is also used as energy fuel. There are no methodologies for calculating CO_2, SO_2, and dust emissions for this fuel. And these are not all shortcomings of the presented methodology. The SEDA methodology also does not provide information on the emissions of SO_2, dust, and other harmful components.

6 Estimation of emissions by the novel stoichiometric method

The presented official methodologies of the MoEW and SEDA are not universal and are not very accurate. They do not take into account the specifics of individual fuels or the variable elemental composition and lower heat value (LHV). Therefore, a new methodology is presented, which is based on stoichiometric calculations of the combustion process, which allows for the most accurate calculation of CO_2, SO_2, and dust emissions from combustion plants. The novelty of the method is that, by using well-known equations for combustion processes, those emission factors can be calculated but unlike all other known methods the complete elemental composition of the fuel is used to achieve this, and not just some of its components (for example, LHV and carbon content, as in some other methodologies). Additionally, the method allows for the calculation of greenhouse gas emissions whose emission factors are not specified in the literature (suitable examples are glycerine and black liquor, which are fuels for some production processes and emit greenhouse gases).

The methodology for calculating emissions is carried out in the following sequence [3, 13–15]:

1. Determination of the theoretical amount of dry air required for complete combustion of the fuel

$$V^0 = 0.0889\,(\mathrm{C}^r + 0.375\,\mathrm{S}^r) + 0.265\,\mathrm{H}^r - 0.0333\,\mathrm{O}^r, \tag{1}$$

where C^r, H^r, O^r, and S^r are the contents of carbon, hydrogen, oxygen and sulphur in the fuel, respectively.

2. Determination of the theoretical (minimum) volumes of combustion products obtained during the complete combustion of the fuel with the theoretically required amount of air ($\lambda = 1$, where λ represents excess air ratio):

for nitrogen

$$V^0_{\mathrm{NO2}} = 0.79V^0 + \frac{0.8}{100}\,\mathrm{N}^r, \tag{2}$$

for triatomic gases

$$V_{\mathrm{RO2}} = 1.866\frac{1}{100}\,(\mathrm{C}^r + 0.375\,\mathrm{S}^r)\,, \tag{3}$$

where V^0_{NO2} is the volume of nitrogen in flue gases, V_{RO2} is the volume of triatomic gases, and N^r represents the nitrogen content in the fuel. After reworking Eq. (3), we obtain formulas for separately calculating volumes of CO_2 and SO_2 respectively:

$$V_{\mathrm{CO2}} = \frac{1.866}{100}\,\mathrm{C}^r, \tag{4}$$

$$V_{\mathrm{SO2}} = \frac{1.866}{100}0.375\,\mathrm{S}^r, \tag{5}$$

for water vapour

$$V^0_{\mathrm{H2O}} = 0.111\,\mathrm{H}^r + 0.0124W^r + 0.0161V^0, \tag{6}$$

where V^0_{H2O} is the volume of water vapour and W^r is the water content in the fuel.

In the presence of excess air ($\lambda > 1$), the calculations are as follows: the volume of water vapour

$$V_{\mathrm{H2O}} = V^0_{\mathrm{H2O}} + 0.0161(\lambda - 1)V^0, \tag{7}$$

flue gas volume

$$V_g = V_{\mathrm{RO2}} + V^0_{\mathrm{NO2}} + V_{\mathrm{H2O}} + (\lambda - 1)V^0. \tag{8}$$

The concentration of ash (dust) in fuels is estimated by the formula

$$\mu_{\mathrm{dust}} = \frac{A^r a_{\mathrm{fly}}}{100 G_g}\,, \tag{9}$$

where A^r is the ash content in the fuel, a_{fly} is the proportion of ash from fuel carried away by gases, and G_g is the mass of combustion product calculated from

$$G_g = 1 - \frac{A^r}{100} + 1.306\lambda V^{0g}. \tag{10}$$

The following formulas can also be used for gaseous fuel calculations, including in the first place the theoretical amount of dry air required for complete combustion required for burning 1 m^3 of natural gas (Nm^3/m^3)

$$V^{0g} = 0.047\left[0.5\mathrm{CO} + 0.5\mathrm{H_2} + 1.5\mathrm{H_2S} + \Sigma\left(m + \frac{n}{4}\right)\mathrm{C}_m\mathrm{H}_n - \mathrm{O_2}\right], \tag{11}$$

where m and n are the number of carbon and hydrogen in the hydrocarbon compounds of the gas fuel, whereas CO, H_2, H_2S, C_mH_n, and O_2 represent the contents of carbon monoxide, hydrogen, hydrogen sulphide, hydrocarbons, and oxygen in the gaseous fuel, respectively.

Similarly for triatomic gases

$$V_{\mathrm{RO2}} = V_{\mathrm{CO2}} = 0.01\left(\mathrm{CO_2} + \mathrm{CO} + \Sigma m \mathrm{C}_m\mathrm{H}_n\right). \tag{12}$$

7 Emission calculations

To estimate the emissions of harmful components from the combustion process, the densities of CO_2, SO_2 and ash are determined based on the reference book [13], as follows: $\rho_{\mathrm{CO2}} = 1.976$ kg/Nm^3, $\rho_{\mathrm{SO2}} = 2.858$ kg/Nm^3, and $\rho_{\mathrm{dust}} = 2.2$ kg/Nm^3. The emission factor of CO_2 for solid and liquid fuels can be represented as the product of the density of CO_2 and its theoretical volume

$$\mathrm{EF}_{\mathrm{CO2}} = \rho_{\mathrm{CO2}} V_{\mathrm{CO2}}\,. \tag{13}$$

The emission factors of SO_2 and dust are determined in a similar way:

$$\mathrm{EF}_{\mathrm{SO2}} = \rho_{\mathrm{SO2}} V_{\mathrm{SO2}}\,, \tag{14}$$

$$\mathrm{EF}_{\mathrm{dust}} = \frac{A^r}{100} a_{\mathrm{fly}} V_g \rho_{\mathrm{dust}}\,. \tag{15}$$

The emission factor of CO_2 for gaseous fuels can be represented as the product of the density of CO_2 and its theoretical volume V_{CO2}, calculated *via* Eq. (12):

$$\mathrm{EF}_{\mathrm{CO2}} = \rho_{\mathrm{CO2}} V_{\mathrm{CO2}} = 1.976 V_{\mathrm{CO2}}\,. \tag{16}$$

Sulfuric compounds and dust are absent from gaseous fuels, and therefore the methodology does not offer the calculation of these emission factors, as is the case with solid and liquid fuels.

8 Results and discussion

Tables 7–9 present the emission factors of CO_2, SO_2, and dust for different types of fuels commonly used in Bulgaria. The calculations of the emission factors were made following the methods presented herein, i.e. the SEDA and MoEW methods, and the novel stoichiometric one. The highest accuracy is achieved by all three described methods in terms of CO_2 emissions (see Table 7).

Table 7: CO_2 emission factors by different methodologies.

Type of energy/fuel	Emission factor of CO_2 (t CO_2/GWh)		
	SEDA	MoEW	New stoichiometric method
Light fuel oil / Diesel oil	267	252.6	267.7
Heavy fuel oil	279	275.0	279.4
Natural gas	202	200.9	205.7
LPG	227	N/A	237.8
Black coal	341	324	339.4
Lignite	364	386.1	404.4
Brown coal	364	333.8	349.7
Anthracite coal	354	362.9	380.1

In Fig. 1, a comparison between the CO_2 emission factors according to the three considered methodologies is presented. The presented graphical results depict that in the case of CO_2 emission factors the difference in the three presented methodologies is insignificant. The relatively small differences in the determination of CO_2 are explained by the stronger focus of the two established methodologies on CO_2 as the main indicator of greenhouse gas pollution. The CO_2 values for liquid and gas fuels are closest because the elemental composition and LHV of those used in Bulgaria are relatively constant. The difference is more significant in the case of solid fuels, which differ significantly in terms of their elemental composition and calorific value. To achieve higher accuracy, it is necessary to apply the stoichiometric method, which always takes into account the specifics of the fuels.

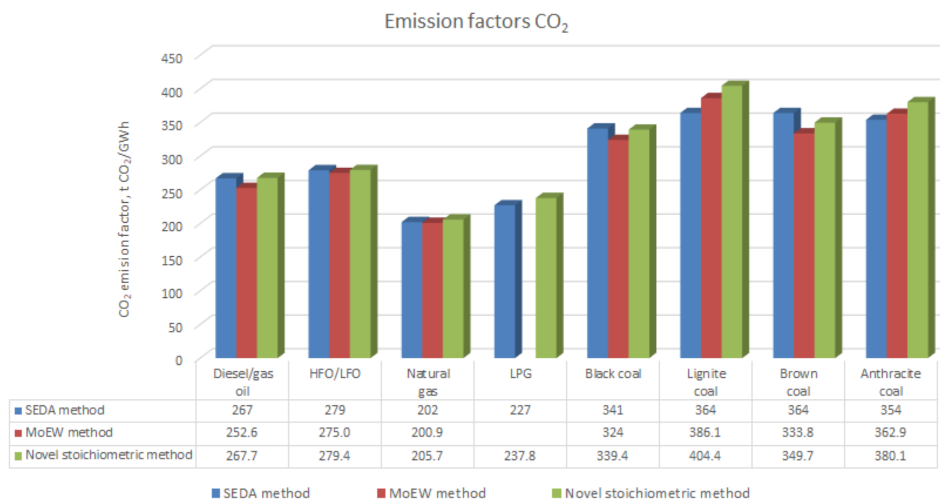

Figure 1: Comparison between the CO_2 emission factors calculated using various methods.

The comparative analysis of the data from Table 8 shows that there is a satisfactory overlap of the data for SO_2 emissions for the MoEW method and the proposed stoichiometric method, but only with regard to Diesel fuel and heavy fuel oil. However, there is a significant difference between the emission factors for solid fuels. This significant difference in the calculated SO_2 emission factors is a direct result of the lack of reliable and accurate methodologies. The calculated SO_2 emission factors (Table 8) are graphically presented in Fig. 2, clearly showing the similarity of results of both methods (MoEW and stoichiometric method) for liquid fuels. For solid fuels, the difference is significant and is obviously due to incorrectly selected fuels. The SEDA methodology's drawback is its lack of data on SO_2 emission factors.

Table 8: SO_2 emission factors by different methodologies.

Type of energy/fuel	Emission factor of SO_2 (t SO_2/GWh)		
	SEDA	MoEW	New stoichiometric method
Diesel oil / Light fuel oil	N/A	0.846	0.844
Heavy fuel oil	N/A	4.092	4.121
Natural gas	N/A	0	0
LPG	N/A	0	0
Black coal	N/A	11.500	12.104
Lignite	N/A	11.499	22.142
Brown coal	N/A	7.151	8.939
Anthracite coal	N/A	5.628	5.924

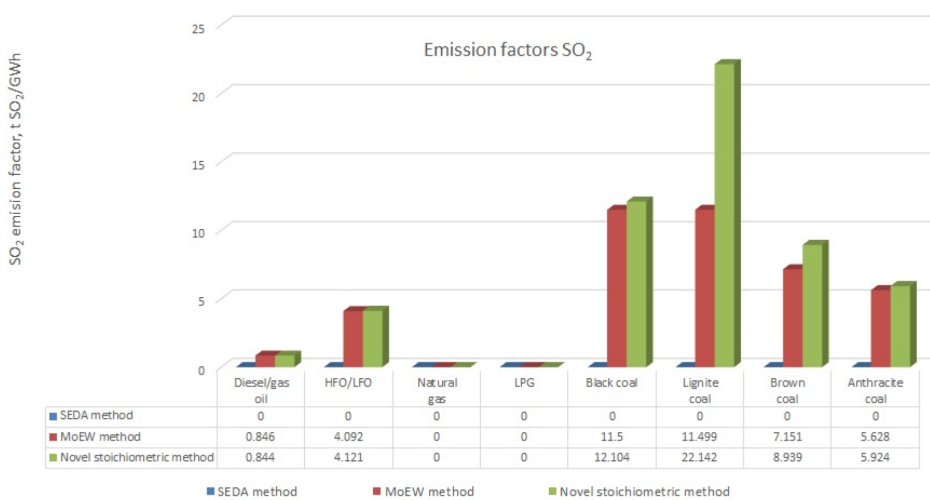

Figure 2: Comparison between the SO_2 emission factors derived using various methods.

The big differences between the emission factors for dust (see Table 9) are due to the different meaning that is attributed to the concept. For example, according to the methodology of the Ministry of Environment and Water, the emission factor of dust calculates the amount of emitted dust from thermal power plants, whose emissions meet the norm. Meanwhile, the stoichiometric method gives the actual amount of dust emitted with the flue gases, but without the use of purification devices (electrostatic precipitators, bag filters, scrubbers, etc.).

Table 9: Dust emission factors by different methodologies.

Type of energy/fuel	Emission factor of dust (t dust/GWh)		
	SEDA	MoEW	New stoichiometric method
Light fuel oil / Diesel oil	N/A	0	0
Heavy fuel oil	N/A	4.092	0.042
Natural gas	N/A	0	0
LPG	N/A	0	0
Black coal	N/A	1.080	55.117
Lignite	N/A	1.080	89.184
Brown coal	N/A	2.026	133.754
Anthracite coal	N/A	1.080	65.286

The analysis of the results from Tables 7–9 shows that the three methodologies differ significantly in the values of emission factors. The methodology proposed by the authors is significantly more accurate because it gives the most objective assessment and is consistent with the elemental composition and calorific value of the fuel considered.

9 Summary

It is shown that the two official methodologies of the Ministry of Environment and Water and Sustainable Energy and Development Agency, considered above, do not give an objective assessment of the emissions of harmful components resulting from the combustion of different types of fuels. The widely used methodology of SEDA is the most incomplete. It is limited to the calculation of CO_2 emissions and does not consider other harmful components such as SO_2 and dust.

The performed emission analysis shows that the novel method using stoichiometric calculations has an advantage in terms of accuracy as it takes into account the specifics and elemental composition of fuels. It should be noted, however, that it does not allow NO_x emissions to be calculated. These calculations for NO_x require semi-empirical methods, including analytical and experimental studies.

The analysis of the results gives grounds to conclude that the method of stoichiometric calculations gives 4.5% more accurate results in terms of CO_2 emissions. There are no significant differences in SO_2 emissions but only for liquid fuels (0.2–0.7%). For coal, the difference in emission factors is significant and ranges between 20–48% depending on the type of coal – owing to the substantial differences in the elemental composition and calorific value of coal accepted as average by the MoEW. The MoEW method takes an average fuel composition with medium heat of combustion, whereas the stoichiometric method takes into account the total elemental composition and calorific value of the fuel.

The comparative analysis of the presented results for the emission factors for dust according only to the methodology of the MoEW and the stoichiometric method cannot be given an objective assessment based on the way the data is presented as elaborated above, due to the different approaches in defining what dust emissions are considered. As such both methodologies present results that differ significantly in their content. However, the novel stoichiometric method still has the upper hand as it can be used to evaluate the efficiency of treatment plants and would be useful in the design of flue gas cleaning systems.

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