Domestic Lignite Emission Factor Evaluation for Greenhouse Gases Inventory Preparation of Republic of Serbia

Predrag Stefanović[a], Zoran Marković[a], Vukman Bakić[a], Dejan Cvetinović[a], Vuk Spasojević[a], Nikola Živković[a]

[a] *University of Belgrade, Institute of Nuclear Sciences "Vinča", Laboratory for Thermal Engineering and Energy, P.O. Box 522, 11001 Belgrade, Serbia, pstefan@vinca.rs*

Abstract:
This paper presents the evaluation of carbon emission characteristics of low calorific Kolubara open pit mined lignite. The samples of Kolubara Basin coal were carefully selected to cover a wide range of the net calorific value, ash and wather content, in order to ensure the coverage of wide spectra of the expected lignite qualities that are usually supplied to Serbian thermal power plants. Data base with results of complete proximate and ultimate analysis for the set of selected coal samples is formed. In accordance with the Revised 1996 IPCC Guidelines for National Greenhouse Gas (GHG) Inventories, it is recommended that more precise and reliable data characteristics of the locally used fossil fuel should be introduced in GHG inventory preparation. Performed correlation analysis indicated that linear correlation exists between the net calorific value and the content of combustible matter in the coal samples. The analyses also indicated a linear correlation between carbon content and the content of combustible matter in the representative coal samples. From obtained set of results was possible to determine the between the carbon content and the net calorific value of the coal as well as the dependence between the carbon content and carbon emission factor. For the range of coal with net calorific values taken separetly in the consideration in this analysis (6≤Hd≤10 MJ/kg), derived correlation gives considerably higher values for the carbon emission factor (30.8–28 tC/TJ) compared to the standard IPCC recommended value for lignite of 27.6 tC/TJ. Relevant correlations were also used as a project basis for the introduction of a system for continuous monitoring and homogenization of coal and the analysis of the effects that introduction of this system would have on the balance of GHG emissions.

Keywords: greenhouse gases, Kolubara mine lignite, emission factor.

1. Introduction

By the end of the 20th century the anthropogenic interference with the climate has been proclaimed one of the main causes of the environmental issues in the modern world. Serbia is a non-Annex I Party of the United Nations Framework Convention on Climate Change (UNFCCC) [1] that defines the principles of global action against the climate change. The main task of the UNFCCC is to stabilise the emission of greenhouse gases (GHG) at a level which would cause no further damage to the climate. Having ratified the Kyoto Protocol [2], Serbia has committed to the international cooperation in the field of climate research and survey. Being a developing country, Serbia has no obligation to reduce GHG emission, but is obliged to report National Communications to the UNFCCC only. Furthermore, in the statutory acts of the EU it is explicitly stated that candidate and potential candidates for the EU membership are to commit to reducing or to limiting the increase of GHG emission. Therefore, securing the national communications becomes one of the Serbia's major objectives.

In accordance with the UNFCCC directives, instructions for devising a GHG inventory are summarised in [3] employing the Tier 1 Method.

Carbon dioxide (CO_2) stands for the one of the most important green house gas emitting from fossil fuel combustion. According to results of the GHG inventory for the Republic of Serbia [4], emission of CO_2 originated as a result of fossil fuel combustion in the energy sector were 94.1% of the total CO_2 emissions in 1990 and 93.7% in 1998. Since the basic energy source in the Republic of Serbia with a share of nearly 50% in the total primary energy consumption and over 90% of the power generation is low calorific pit-mined lignite, emissions of CO_2 from lignite combustion constitute a very significant contribution to total emission of greenhouse gases from anthropogenic sources.

In general, emissions of CO_2 are evaluated as the product of the quantity of the fuel sort and the corresponding carbon dioxide emission factor. According to the Standard IPCC methodology [3], Carbon Emission Factors (*CEFs*) are referred to the energy unit of each sort of fuel, expressed as tons of carbon per unit of energy[1]. This is a subsequent of the fact that carbon content in fuel per unit of energy shows less variation than the carbon content per unit of mass. The *CEF* for each sort of coal is defined as the ratio of the mass of carbon and the quantity of energy contained in this mass *m* of coal. If we denote X_C as a mass fraction of carbon and Q_d for the net calorific value:

$$CEF = mX_C/mQ_d = X_C/Q_d \tag{1}$$

Since the net calorific value is usually given in MJ/kg, the carbon content in percent of mass, *CEF* in tC/TJ = gG/MJ and with all of these values related to the raw material (with original water content, upper index *r*), the above equation can be modified to yield:

$$CEF^r\ (\mathrm{tC/TJ}) = 10C^r\ (\%)\ /\ Q_d^r\ (\mathrm{MJ/kg}) \tag{2}$$

Default *CEF* values given in the IPCC guidelines [3] Workbook for bituminous, sub-bituminous and lignite coal are considered to be general values. The same reference also suggests using country-specific (national CEF_s) or even district-specific values (regional CEF_s), if appropriate information is available. Recommended net calorific values for the same coal rank vary between countries. The greatest difference is demonstrated for lignite, where recommended values range from 4.19 MJ/kg (Israel), to 17.94 MJ/kg (France). Lignite recovered from the Central [5, 6] and South-eastern Europe [7, 8] open pit mines is also characterised by the significant divergence from the recommended values.

The several correlation dependencies are known to exist between standard coal characteristics. One of the most important parameter usually considered is the carbon content in combustible matter C^{daf}. It is confirmed in [5] that straight line correlation between carbon content C^d and net calorific value Q_d^d for dry lignite sample stands even for the plot of C^r versus Q_d^r for the raw lignite sample, which is more suitable for *CEF* determination.
The following linear correlations were obtained by regression analysis of the numerous data for Czech coals of different quality (ranging from lignite to bituminous coal) [6]:

Sample set A $$C\,(\%) = 2.333\ Q_\mathrm{d}\ (\mathrm{MJ/kg}) + 5.511 \tag{3}$$

Sample set B $$C\,(\%) = 2.344\ Q_\mathrm{d}\ (\mathrm{MJ/kg}) + 5.056 \tag{4}$$

Sample set C $$C\,(\%) = 2.4\ Q_\mathrm{d}\ (\mathrm{MJ/kg}) + 4.123 \tag{5}$$

Sample set E $$C\,(\%) = 2.334\ Q_\mathrm{d}\ (\mathrm{MJ/kg}) + 5.786 \tag{6}$$

---

[1] Actual CO_2 emission in [Gg CO_2] could be obtained multiplying actual carbon emission, expressed in [Gg C], by the ratio of 44/12. The actual carbon emission relates to carbon emission factor over the fraction of carbon oxidised, which depends on the type of combusting utilities and characteristics of coal combustion process. According to [3], the fraction of carbon oxidised is taken to be 0.98 for pulverised lignite combusted in Serbian power plants [4].

The correlation (6) for set E, also recommended by the authors of [6] to be applicable for all European coals, is obtained from averaged values Q_d and *CEF* for coals used in selected power stations in 11 European countries.

Based on statistical data of the quality of Velenje raw lignite used in Thermal Power Plant "Šoštanj", Slovenia over a period of several years [7], correlations as seen with equations (3) ÷ (6) were also derived:

$$C^r (\%) = 2.2477\, Q_d^r\, (\text{MJ/kg}) + 5.8216 \tag{7}$$

Additional analyses of thirty representative samples of Velenje lignite [7] derived another linear dependency between carbon content C^r (%) and the net calorific value Q_d^r:

$$C^r (\%) = 2.3878\, Q_d^r\, (\text{MJ/kg}) + 4.6548 \tag{8}$$

The survey on the emission factors for Velenje lignite, based on the statistical data gathered over a period of several years, on the quality of coal used for power production in the power station "Šoštanj", shows that for the values of the net calorific values in the range 6–12 MJ/kg above mentioned dependence may be approximated with sufficient accuracy with the straight line [7]:

$$CEF^r\, (\text{tC/TJ}) = 35.242 - 0.6941\, Q_d^r\, (\text{MJ/kg}) \tag{9}$$

Another equation was derived based on analysis of 30 representative samples of Velenje lignite [7]:

$$CEF^r\, (\text{tC/TJ}) = 34.454 - 0.5843\, Q_d^r\, (\text{MJ/kg}) \tag{10}$$

Three open pit lignite mines have been in service in Serbia with total production up to 48 million tons per annum. Lignite recovered from the open pit mines is predominantly (as much as 90% of the total annual production) used in power production. The coalfield with the highest share in power production is the Kolubara basin with a share of ≈64% on the national level. Total electric power of thermal power plants that use raw lignite from Kolubara coalfield exceeds 3000 MW. Comprehensive studies of the raw lignite characteristics, pit mined from Kolubara basins, were made on several occasions during the past. In general, Kolubara basin lignite is characterized by low and uneven level of carbonization (stadium of soft brown coal), with inorganic waste mineral matter presented in the forms of pure clay, sand or sand-clay matter. The western parts of Kolubara coalfield contain significant quantities of interlayer waste.

Based on long-term statistics of raw Kolubara lignite characteristics, the relation between the net calorific value and content of waste matters - water W^r and ash A^r in the lignite was given [8]:

$$Q_d^r\, (\text{KJ/kg}) = 25{,}053 - 250.53\, A^r - 273.56\, W^r \tag{11}$$

The pit-mined raw lignite from Kolubara basin has a water content of around 50%, mineral matter content of 10–25% and content of combustible matter of 25–40%. For the observed set of coal samples with $W^r = 50\%$ the following correlation was derived:

$$Q_d^r\, (\text{KJ/kg}) = 250.53\, combustible\, (\%) - 1151.5 \tag{12}$$

as well as linear dependency between carbon content C^r and combustible matter in the raw lignite:

$$C^r = 0.668\, combustiblle\, (\%) \tag{13}$$

From equations (12) and (13) follows:

$$C^r (\%) = 2.6663\, Q_d^r\, (\text{MJ/kg}) + 3.0703 \tag{14}$$

According the eq. (2) the carbon emission factor for this set of samples is derived as:

CEF^r (tC/TJ) = 26.66 + 30.703/ Q_d^r (MJ/kg) (15)

The carbon emission factor is inversely proportional to the net calorific value. However, the recommended value (27.6 tC/TJ) for lignite carbon emission factor [3] is the same for all countries. It is obvious that such a concept of using general values, although much simpler and thus more suitable for GHG inventories, could leads to fallacies in related CO_2 emission modelling. Moreover, the carbon emission factor found for the lignite with low net calorific value (from the range 6–10 MJ/kg) are somewhat higher then recommended one.

This paper presents results of the raw lignite samples from Kolubara open pit-mine emission characteristics examination. It was found that raw lignite from Kolubara basin has significantly lower net calorific value and higher *CEF* value in comparison to those recommended by the international GHG emissions evaluation method.

2. Coal sample characteristics

Aimed at determining the characteristics of the Kolubara basin raw lignite, primarily the net calorific value, the carbon contents and their correlation with the emission factor for different grades of lignite, data from the more recently made survey [9] was used. This study required specific care in performing the coal sampling (wide range of ash content (A^r = 6.92–48.5 %), water (W^r = 31–51.7 %), net calorific value (Q_d^r =2850–9940 kJ/kg) and other accompanying characteristics of the raw coal) in order to ensure, as far as possible, the simulation of a wide spectra of the expected qualities of coals that are conveyed to the thermal power plants. Therefore, samples extraction and selection was based on previous geological explorations and determination of potential areas (locations) with coal of required quality. Samples were taken from the western ("Tamnava Zapadno Polje") and eastern ("Polje D'') part of the Kolubara basin. Special procedures were conducted with main goal of acquiring representative samples from coal fields [9]. Sampling of coal and preparation of representative samples were taken out according the ISO 5069-1 (1983) and ISO 5069-2 (1993) standards. After detailed core drill site mapping, interval samples were taken and mass fraction of each layer in the sample calculated. Based on sample layer proximate analysis results, lower calorific value and quality class for that coal sample is defined. From the location of western parts of basin ("Tamnava zapadno polje"), samples were taken from extraction coal core drill sites, which included 20 samples from coal core drill sites and 6 samples of surface coal. Sampling of eastern part of basin ("Polje D''), included 10 samples taken from coal mine floors and 4 samples of surface coal.

The coal samples underwent complete proximate and ultimate analysis and a number of other physical and chemical analyses[2]. Water content W^r (%), ash content A^r (%), gross calorific value Q_g^r (kJ/kg) and net calorific value Q_d^r (kJ/kg) according to ISO/R 1928 (2009) standard, coke percentage (%), fixed carbon content C_{fix}^r (%), volatile content V^r (%), combustible **(**%), total sulphur S^r (%), sulphur in the ash S_A^r (%) and combustible sulphur S_c^r (%) levels were established through the ultimate analysis (according to ISO 17247 (2005) standard). Proximate analysis revealed the percentage of carbon C^r (%), hydrogen H^r (%), combustible sulphur S_S^r (%) and nitrogen +oxygen (%) in the raw coal samples. Ranges of coal parameters for thirty representative samples are summarised in Table 1.

According to standard, reproducibility of upper heating value determination is defined as a difference between two serial measurements with results lower than 120 kJ under conditions of measurements, which are conducted by the same operator, under the same laboratory conditions and using the same apparatus.

[2] The complete proximate and ultimate analysis of the coal sample were done in the Institute of Nuclear Sciences "Vinca", Laboratory for Thermal Engineering and Energy, Department for the fuel characterization. The testing laboratory is accredited according to ISO/IEC 17025, accreditation certificate number 01-264.

Table 1. Ranges of coal parameters extracted from data set obtained by proximate and ultimate analysis of Kolubara basin lignite samples.

Parameter	W^r (%)	A^r (%)	Q_g^r (kJ/kg)	Q_d^r (kJ/kg)	C_{fix}^r (%)	V^r (%)	*combustible* (%)	S_u^r (%)	C^r (%)	H^r (%)	S_s^r (%)
Maximal value	51.70	48.15	11594	9939	20.38	24.46	42.62	1.32	28.57	2.52	1.04
Minimal value	31.00	6.92	3813	2847	5.82	14.64	20.85	0.24	10.28	1.23	0.06

Regarding the whole set of samples, reproducibility of Q_g^r determination achieved was 97 kJ. Remaining measured values are defined with reproducibility that depends of reproducibility of the measured parameters involved into calculations. The values of the reproducibility required by the governing standard and reproducibility achieved for each measured value are presented in Table 2.

Table 2: Achieved reproducibility of measured values

Parameter	**Reproducibility [%] (required by standard)**	**Achieved reproducibility [%]**
W^r	0.20	0.13
A^r	0.20	0.11
C_{fix}^r	0.50	0.39
S_u^r	0.10	0.07
C^r	0.25	0.21
H^r	0.12	0.09
S_s^r	0.07	0.04

Defining the percentage of combustible content in the raw coal sample as:

$$combustible\ (\%) = 100 - A^r\ (\%) - W^r\ (\%) \quad (16)$$

the regression analysis, performed on data set of Kolubara lignite representative samples, results in following linear dependence:

$$Q_d^r\ (\text{kJ/kg}) = 297.8\ combustible\ (\%) - 2829.6 \quad (17)$$

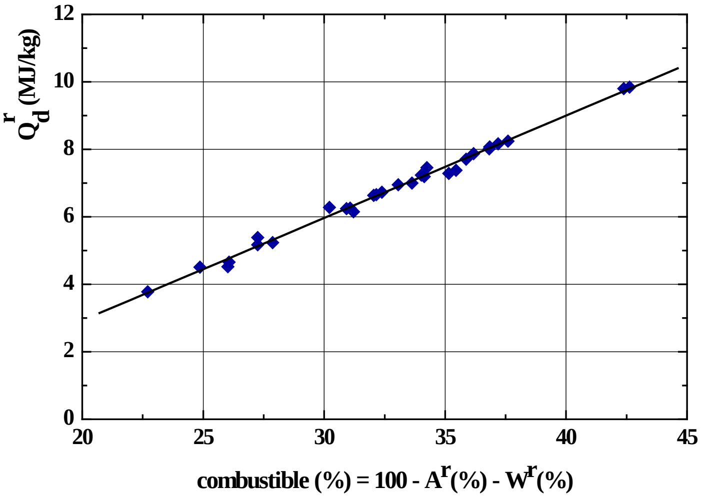

Fig. 1. Correlation between the net calorific value Q_d^r and combustible matter content in the raw lignite sample from Kolubara basin; [Q_d^r (kJ/kg) = 297.8 combustible (%) – 2829.6].

The correlation analysis indicated that a well-defined linear dependency exists between the net calorific value and content of combustible matter in the coal samples (Fig. 1.). The obtained linear correlation stands for coal samples recovered both from the eastern and western area of the Kolubara basin and similarly, could be applied to the mixture of these coals.

The regression analysis indicates a very strong linear dependence (coefficient of correlation R^2=0.9935) between the carbon content and content of combustible matter in the Kolubara raw lignite samples (Fig. 2):

$$C^r(\%) = 0.7785 \cdot combustible\ (\%) - 4.6405 \quad (18)$$

The content of carbon and hydrogen in the pure combustible matter was nearly constant in all representative coal samples investigated (C^{daf} = 63.3 % and H_d^{daf} = 5.9 %).

3. Correlation between the carbon content and the heating value

The experimentally determined dependence between the carbon content and the net calorific value of the representative raw and dry lignite samples from the Kolubara basin is shown on Fig. 3. The linear regression line describing the carbon content versus net calorific value is in the form:

$$C\ (\%) = 2.3718\ Q_d\ (\text{MJ/kg}) + 4.2637 \quad (19)$$

This correlation is in good agreement with the appropriate linear correlations obtained by regression analysis of the numerous data for Czech coals [6] given above.

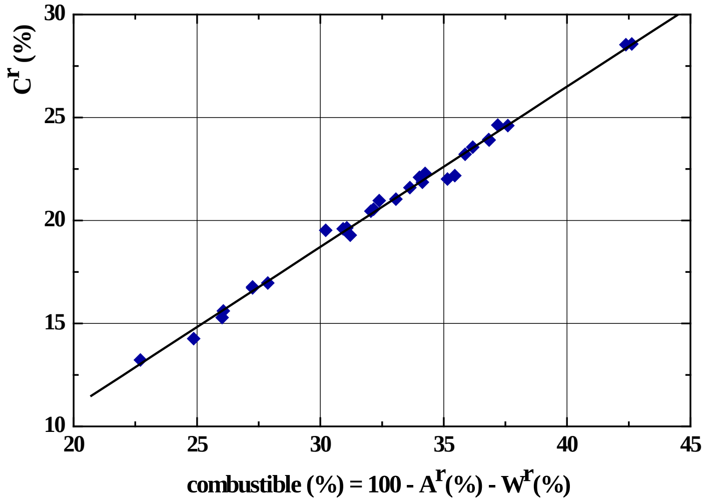

Fig. 2. Linear dependency between carbon content C^r and combustible matter in the raw lignite from the Kolubara basin; [C^r(%) = 0.7785·combustible (%) – 4.6405].

The correlations (19) for both raw and dried Kolubara lignite are in quite a good agreement with the correlation (5) for sample series C. The same conclusion stands when comparing to correlations given by equation (8).

Based on the correlation between carbon content and the net calorific value (19), a dependency between the carbon emission factor and the net calorific value of raw Kolubara lignite can be derived:

$$CEF\ (\text{tC/TJ}) = 10\ C\ (\%)/Q_d\ (\text{MJ/kg}) = 23.718 + 42.637/Q_d\ (\text{MJ/kg}) \quad (20)$$

The dependency (20) is shown on Fig. 4, together with the experimental data for 30 representative Kolubara lignite samples.

Increasing the coal quality (i.e., increasing the net calorific value), the carbon emission factor decreases and converges to an asymptotic value of 25.42 tC/TJ for bituminous coal with lower heating value Q_d = 25 MJ/kg. This value for *CEF* is a bit lower than standard recommended one (25.8 tC/TJ). In comparison to the standard recommended value of *CEF* = 26.2 tC/TJ for brown coals, this correlation gives a more appropriate value of 17.18 MJ/kg for the net calorific value.

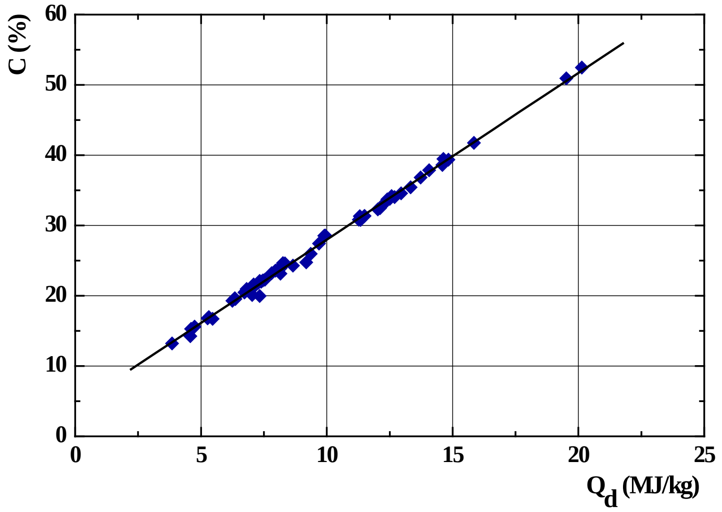

Fig. 3. Dependence between the carbon content end the net calorific value for raw and dried lignite from Kolubara basin; [C (%) = 2.3718 Q_d (MJ/kg) + 4.2637].

However, for the raw lignite with net calorific value in the range $6 \leq Q_d^r \leq 10$ MJ/kg, the correlation (11) gives significantly higher values for the carbon emission factor (30.8–28 tC/TJ) compared to the standard recommended *CEF* value for lignite of 27.6 tC/TJ.

A function derived from the correlation (6) for European coals [6] is shown on Fig. 4. It is evident that this correlation yields even higher values for the carbon emission factor than the experimentally determined values for Kolubara lignite. The correlation obtained for Velenje lignite [7] lies practically between these two curves.

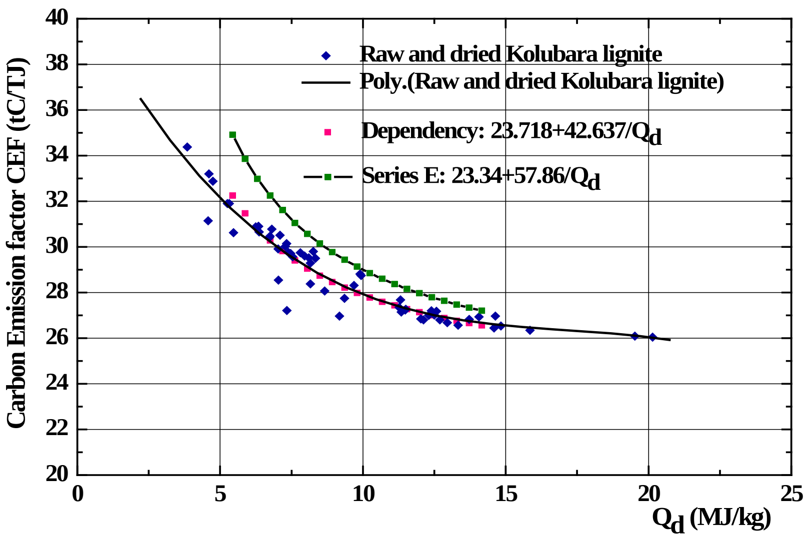

Fig. 4. Functional dependency between the carbon emission factor and net calorific value for raw and dried Kolubara lignite.

The experimental values for 30 representative Kolubara lignite samples, the fitted curve for the whole range of Q_d^r values and the fitted linear dependency of the carbon emission factor for the subset of lignite samples with net calorific value in the range of Q_d^r = 6–10 MJ/kg are shown in

Fig.5. The regression line that describes carbon emission factor of Kolubara lignite samples with Q_d^r = 6–10 MJ/kg is:

$$CEF^r \text{ (tC/TJ)} = 34.407 - 0.5891\, Q_d^r \text{ (MJ/kg)} \qquad (21)$$

The values of the intercepts and slopes of lines (10) and (21) are almost identical, resulting in relative difference of CEF^r calculated using these equations less than 0.35% in the sub range of Q_d^r = 6 ÷ 10 MJ/kg. For the same sub range of net calorific values, the relative difference between results of eq. (20) and standard recommended value [6] remains higher, decreasing from the value of 10.6% for lignite of lowest quality rank (Q_d^r = 6 MJ/kg) on the level of 3.2% for lignite with higher net calorific values (Q_d^r = 10 MJ/kg). Relative difference between values calculated using eq. (21) and (20) vary between 0.2% and 2.3% in the sub range of interest.

According to guideline [3], standard recommended net calorific value for the lignite recovered from ex-Yugoslav mines is 8.89 MJ/kg, while standard *CEF* value for lignite is 27.6 tC/TJ. The CEF^r value obtained for Kolubara lignite with recommended value of net calorific value using equations (19) and (20) is 28.52 tC/TJ and 29.17 tC/TJ correspondingly. Thus, local CEF^r value exceeds the internationally recommended one by 3.2% and 5.69% subsequently.

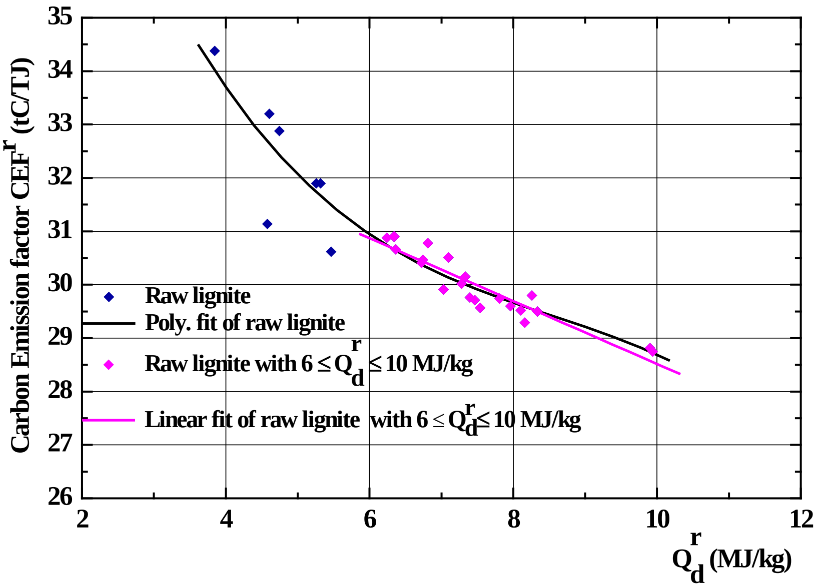

Fig.5. Functional dependency between carbon emission factor and the net calorific value for raw Kolubara lignite.

Modelling of the GHG emission by energy industry (which is the major GHG emitter in Serbia) requires detailed determination of the lignite net calorific value. When introduce values of Q_d^r into the equations (15), (20) and (21) it results in values of local carbon emission factor of Kolubara raw lignite. Results of carbon emission factor calculation for the net calorific value from the range 6–10 MJ/kg are presented in table 3.

Table 3: Comparation of carbon emission factor calculation results

Q_d^r [MJ/kg]		6	7	8	9	10
CEF^r [tC/TJ]	eq. (15)	31.78	31.05	30.50	30.07	29.73
	eq. (21)	30.87	30.28	29.69	29.11	28.52
	eq. (20)	30.82	29.81	29.05	28.46	27.98

Lignite recovered from the Kolubara open pit mine used in Thermal Power plant ''Nikola Tesla'' is usually of considerably low net calorific value of 7.0–8.0 MJ/kg [4]. The net calorific value Q_d^r of the Kolubara basin raw lignite conveyed to thermal power plants in previous period and corresponding carbon emission factors CEF^r as determined in [4] are presented in table 4.

Table 4: Kolubara raw lignite net calorific and carbon emission value

YEAR	**1990**	**1998**	**2000**	**2004**	**2005**	**2006**	**2007**	**2008**
Q_d^r **[MJ/kg]**	7756	7905	8076	7918	7957	7936	8018	8033
CEF^r **[tC/TJ]**	29.838	29.750	29.649	29.742	29.719	29.732	29.683	29.675

Knowing the exact quantity of the burned coal, it is possible to estimate CO_2 emission levels with higher confidence. It is expected that further investigations of the sets with higher number of Kolubara lignite samples (more than 30), should result in more accurate determination of Kolubara lignite carbon emission characteristics.

4. Conclusion

One of the main responsibilities of the Republic of Serbia to the UNFCCC is reporting national communications. According to the UNFCCC directives, GHG Inventories have to follow UNFCCC guidelines. Internationally recommended methodology recognises the standardised net calorific values and carbon emission factors for all fossil fuels. However, it is also suggested that more precise values obtained from analysis of local fossil fuels should be used for modelling GHG emission, if such data is available. This paper presents the results of analysis of carbon emission characteristics of the local low-calorific lignite recovered from the Kolubara basin. Data set extracted from the results of the laboratory analysis of the representative coal samples recovered from the Kolubara basin was used for regression analyses. The experimentally determined characteristics of the raw coal, such as ash content, water content and net calorific value were taken into consideration. There was a series of raw lignite samples gathered from the Kolubara mine field. Each coal sample was carefully selected to ensure the coverage of the broad spectrum of the quality of lignite usually supplied to the TPP "Nikola Tesla".

The correlation analysis indicated that a well-defined linear dependency exists between the net calorific value and the content of combustible matter in the raw coal samples. The regression analysis indicates a strong linear dependence between the content of carbon and combustible matter in the samples (coefficient of correlation R^2=0.9935). The linear regression line describing the carbon content versus net calorific value was derived. This correlation is found to be in the good agreement with the appropriate linear correlations obtained by regression analysis of the numerous data for Czech coals of different quality. Based on correlation between carbon content and the net calorific value for lignite from Kolubara basin, a dependency between the carbon emission factor and the net calorific value was derived. For the raw lignite from Kolubara basin with net calorific value in the range $6 \leq H_d^r \leq 10$ MJ/kg, this correlation gives significantly higher values for the carbon emission factor compared to the standard recommended *CEF* value for lignite.

Nomenclature

A	ash content, %
W	water content, %
C	carbon content, %
V	volatile content, %
H	hydrogen content, %
S	sulphur content, %

CEF	carbon emission factor, tC/TJ
X_C	mass fraction of carbon
m	mass
Q_g	total calorific value, kJ/kg
Q_d	net calorific value, kJ/kg
R^2	coefficient of correlation

Superscripts

r	*raw lignite sample*
d	*dry lignite sample*
daf	*dry and ash free sample*

References

[1] Official Gazette of the Federal Republic of Yugoslavia: "International Arrangements'' no. 2/97, 1997

[2] The Law on Ratification of the Kyoto Protocol as an Addendum to the UNFCCC (Official Gazette of the Republic of Serbia, no.88/07), 2007

[3] The Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories, Tier 1, 1996

[4] Serbia's First National Communication Under the United Nations Framework Convention on Climate Change, http://www.ekoplan.gov.rs/src/

[5] Fott, P., Svítilová, J., Kolár, F.,: Acta Montana B 101 (6), 1996, pp. 79-94

[6] Pavel Fott: Carbon Emission Factor of Coal and Lignite: Analysis of Czech Coal Data and Comparisation to European Values, Environmental Science&Policy 1999; 2: 347-354

[7] Andrej Šušteršić et al., Paper No. 1686: National CO_2 Emission Factor for Lignite from Velenje Coalmine, Elektroinštitut Milan Vidmar, Odelek za elektrarne, Ljubljana, April 2004.

[8] Miloljub Grbović: Technological process of increasing energy efficiency in system of coal production in stratified deposits Kolubara and producing electricity in power plants "Nikola Tesla", UDC 622.23/.7.004, ENERGIJA, EKONOMIJA EKOLOGIJA, Broj 1, Godina XIII, Mart 2011., pp. 189-194

[9] Predrag Stefanović et al., "The Results of the Laboratory Analysis of the Representative Coal Samples Recovered from the Kolubara Basin", Internal report NIV ITE-369, Vinča, June 2008

Reviewers comment:
==

a) A general comment refers to the use of emission factor expressed as tC/TJ. The use of values of tC/TJ are expressing the carbon content while as emission factor is stated tCO2/TJ.
b) It should be mentioned that the requirements according to the guidelines for monitoring of GHG according to the Directive 2003/87/EC and more specifically the compliance of the described methodology with the relevant EN, ISO and DIN standards. Does the laboratory where the work dealing with identification of lignite parameters and low heating value is operated according to ISO 17025 ? In any case the standards used should be mentioned.
c) The evolution of the calculated factor tC/TJ through time is needed in order to present the changes of the mean value in annual basis. According to the raw data available it is proposed to cover at least the period 2005 – 2008.

--- Editor's additional comment: ---

5. I agree with reviewer, but I nor sure that it is possible to give data in such long period 2005-2008. Authors can avoid this comment.

==

The changes that have been made according to reviewer and editor's comments:

a) This is a subsequent of the fact that carbon content in fuel per unit of energy shows less variation than the carbon content per unit of mass and that total carbon is released during process of combustion, oxidised or non oxidised. We hope that footnote given on the page 3 should help to clarify this issue.

b) Yes, the laboratory where the work dealing with identification of lignite parameters and low heating value is operated according to ISO 17025. The name of the testing laboratory (added in footnote 2) is ''Department for the fuel characterization, Laboratory for Thermal Engineering and Energy, Institute of Nuclear Sciences Vinca''. The laboratory is accredited according to ISO/IEC 17025 standard for the testing and calibration laboratory, with accreditation certificate number 01-264 issued from the Accreditation body of Serbia in the year 2008. The sentences in the first paragraph on the page 4: ''Sampling of coal and preparation of representative samples were taken out according the ISO 5069-1 (1983) and ISO 5069-2 (1993) standards.'' and in the second paragraph on the page 4: '' Water content W^r (%), ash content A^r (%), gross calorific value Q_g^r (kJ/kg) and net calorific value Q_d^r (kJ/kg) according to ISO/R 1928 (2009) standard, coke percentage (%), fixed carbon content C_{fix}^r (%), volatile content V^r (%), combustible **(**%), total sulphur S^r (%), sulphur in the ash S_A^r (%) and combustible sulphur S_c^r (%) levels were established through the ultimate analysis (according to ISO 17247 (2005) standard).'', were changed by adding information about relevant standards.

The list of the standardised methods accredited and implemented are given below:

1. ISO 5069-1: Brown coals and lignite - Principles of sampling, Part 1: Sampling for determination of moisture content and general analysis (1983)
2. ISO 5069-2- Brown coals and ignites -- Principles of sampling -- Part 2: Sample preparation for determination of moisture content and for general analysis (1993)
3. ISO 589- Hard coal -- Determination of total moisture (1981)
4. ISO 579 - Coke -- Determination of total moisture content (1981)
5. ISO 687 - Solid mineral fuels -- Coke -- Determination of moisture in the general analysis test sample (1974)

6. ISO 5068- Brown coals and lignite -- Determination of moisture content -- Indirect gravimetric method (1983)
7. ISO 1171 - Solid mineral fuels. Determination of ash (1981)
8. ISO 562 - Hard coal and coke -- Determination of volatile matter (1981)
9. ISO 334- Solid mineral fuels -- Determination of total sulphur -- Eschka method (1992)
10. ISO 157 - Coal -- Determination of forms of sulphur (1996)
11. ISO/R 1928- Solid mineral fuels -- Determination of gross calorific value by the bomb calorimetric method and calculation of net calorific value (2009)
12. ISO 17247 - Coal -- Ultimate analysis (2005)
13. ISO 602 - Coal -- Determination of mineral matter (1983)
14. ISO 540- Hard coal and coke -- Determination of ash fusibility (2008)
15. ISO 1953 - Hard coal -- Size analysis by sieving (1994)

c) We agree with the comment of the reviewer. Lignite from Kolubara coal field is of very uneven quality. In order to accurately estimate annual CO_2 emission from the energy sector, it is necessary to track the Kolubara lignite carbon content on the annual basis. In that sense, we are preparing a project of continually tracking a characteristics of lignite conveyed to thermal power plants.