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EMISSION INVENTORY FOR LIGNITE BASED PUBLIC POWER AND ENERGY SECTOR – MERGING INFORMATION FROM VARIOUS SOURCES

15.1 INTRODUCTION

Compilation of the national emission inventory always is connected with possibilities of committing mistakes, misuse or misunderstanding the data. According to Frey's approach [1, 2], there are rarely known real values of estimated uncertainties, however his identification of main sources of uncertainties is still of the moment. Understanding of the sources of uncertainties and possibility of misusing the data is strictly connected with compilation of emission inventory accordingly to "best practices", described as IPCC guidelines (GHGs) [3, 4] or guidebook (air pollutants) [5] and should guarantee proper quality assurance and quality control (QA and QC) of used data.

The result of emission inventory, considered as a single value describing annual emission of particular compound to atmosphere is always charged with various uncertainties. Emission inventory for significant sources, like public power and energy sector merge pieces of information from: statistical surveys (Polish Main Statistical Office and EUROSTAT), data from NED, specific data on GHGs emission from EU–ETS[1], national emission factors and fuel characteristics. A large number of analysis is still based on expert knowledge. Strictly statistical calculations are used in the first step – for obtaining input data, or as final tool for quantitative assessment of uncertainties.

Polish emission inventory reports, elaborated at the National Centre for Emission Management (NCEM) (the part of Institute of Environmental Protection – National Research Institute) for the purposes of international conventions, EU directives or as another obligations, are the final link in the chain of compilation of emission inventories.

The article shows, how works merging the pieces of various (scientific and technical) data in the context of compiling of carbon dioxide emission inventory for public power and energy sector based on lignite.

15.2 HOW DOES IT WORK

In practice, the national GHGs inventory is compiled similarly to many other elaborations where merging of information from various sources is required, also with using the specific guidelines providing the proper level of QA and QC [6]. However that guidelines

1 European Union – Emission Trading Scheme

are not straightforwardly connected with experimental procedures or measurements and they are rather second step of QA and QC in the context of supplying proper result of the inventory, considered as emission of particular compound to air. Apart from meticulously following the guidelines, there is still some space for including *ad hoc* results of scientific surveys, measurements, sectoral analysis national forecasts or simulations.

The good example of that kind of data management is estimation of carbon dioxide emission from combusted lignite in public power and energy sector.

The emission of CO_2 from combusted lignite is estimated by the following formula:

$$E_{\mathrm{CO2,\ lignite}} = A_{\mathrm{lignite}} \times EF_{\mathrm{CO2,\ lignite}} \qquad (15.1)$$

where:

$E_{\mathrm{CO2,\ lignite}}$, emission of CO_2 from combusted lignite,

A_{lignite}, mass of combusted lignite,

$EF_{\mathrm{CO2,\ lignite}}$, named the emission factor, represents the mass of CO_2 created from mass of combusted lignite.

The value of emission factor comes directly from carbon content in lignite. Emission of carbon dioxide from combusted lignite comes directly from carbon content in lignite. There is assumed that total carbon content in lignite is converted to CO_2 during combustion process.

Currently published results of the scientific elaborations show using observed correlation between carbon content and net calorific value for lignite for obtaining domestic emission factor from combusted fuel [7, 8, 9]. The generated formula is linear in both approaches: by Fott [7], based on data from Czech coal and lignite and by Stefanović et al. [8, 9], based on Serbian lignite from Kolubara basin. The main difference between following approaches concerns Kolubara lignite, where the combustible part of coal (represented by 100 reduced by sum of ash and water content, all values expressed in percents) is also taken into consideration.

Polish data on lignite held by NCEM was also analyzed for obtaining emission factors from carbon and lignite. Current state of analysis, including separate formulas for hard coal and lignite is included in national emission inventory report [10]. Formulas currently used for compilation of the Polish emission inventory are a result of investigation of the linear correlation between obtained measurement data on carbon content and net calorific value for lignite.

Accordingly to Frey's elaborations [1, 2] that kind of analysis might be problematic in the context of his classification of various uncertainties. Apart from statistical uncertainties, enumerated by Frey and earlier investigation done by Jagóra and Szwed-Lorenz [11], there are also identified problems with geospatial matters on obtaining average values of the qualitative parameters of lignite [12, 13, 14, 15, 16]. Apart from problems mentioned above, there are still problems with new opencast mines in Poland till 2040 [17] and new possibly available data on qualitative parameters of lignite.

Problems listed above and also other various discrepancies might make the current analysis [10] quickly outdated.

15.3 METHODOLOGY AND ANALYSIS

Part of previously analyzed dataset [10], held by NCEM, concerning data on measured

carbon content and net calorific value of lignite combusted by Pątnów power plant.
The following analysis presents the characteristics of the held sample (further named: "Pątnów" sample, where Ctr is carbon content in lignite, expressed in % and Qir is net calorific value in lignite).

Summary statistics

Following table presents summary statistics for Ctr and Qir of "Pątnów" sample (table 15.1):

Table 15.1 Summary statistics of the Pątnów sample

Parameter	Ctr [%]	Qir [MJ/kg]
Minimum	23.40	8.005
1st Quartile	25.28	8.967
Median	25.90	9.136
Mean (average value)	25.92	9.127
3rd Quartile	26.57	9.295
Maximum	30.07	9.961
Shapiro – Wilk normality test result (α = 0.05)	+ (p-value: 0.0661)	- (p-value: 0.0052)

Further analysis

Following the analysis, conducted by Fott [7] also partly analysis by Stefanović et al. [8, 9], there are scatter-plot presenting dependency between Ctr and Qir in "Pątnów" sample. The look of plot shows that is highly probable that combusted lignite from "Pątnów" sample came from 2 independent sources and it is not possible to describe the Ctr (Qir) dependency in simple way, with using only one linear formula (fig. 15.1):

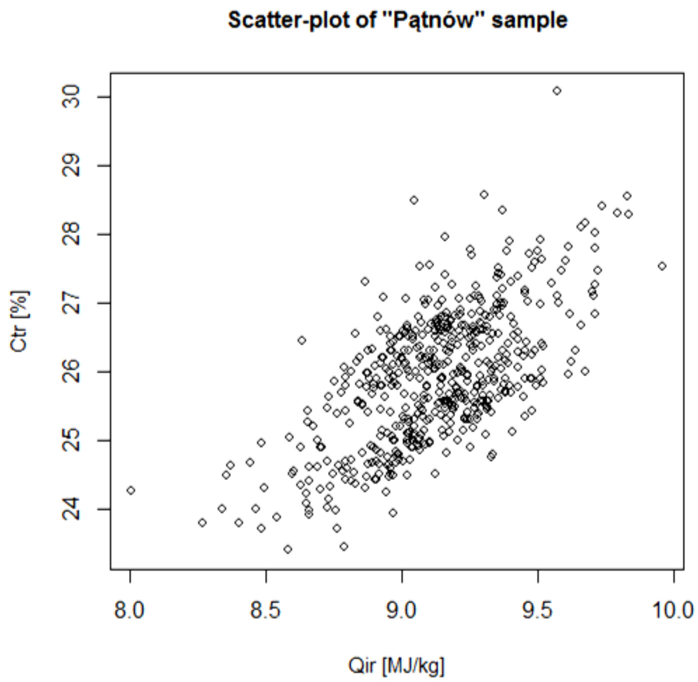

Fig. 15.1 Scatter-plot. Dependency between Ctr and Qir in "Pątnów" sample

For more detailed analysis there is presented, histogram of auxiliary factor *a*, (table 15.2), expressed in: % × kg × $(MJ)^{-1}$, derived by following formula:

$$a = Ctr \times (Qir)^{-1} \tag{15.2}$$

Table 15.2 Summary statistics of the factor *a*

Parameter	***a* [% × kg × $(MJ)^{-1}$]**
Minimum	2.654
1^{st} Quartile	2.774
Median	2.835
Mean (average value)	2.840
3^{rd} Quartile	2.906
Maximum	3.148
Shapiro – Wilk normality test result (α = 0.05)	- (p-value: 2.607×10^{-7})

Histogram of factor *a* is made for 100 breaks within the interval, between minimum and maximum of *a*.

Shape of histogram of the *a* factor (fig. 15.2), confirms probability of mixing 2 independent sub-samples within "Pątnów" sample. The split point of "Pątnów" sample was identified by using "stem and leaf" (fig. 15.3), plot of factor *a*.

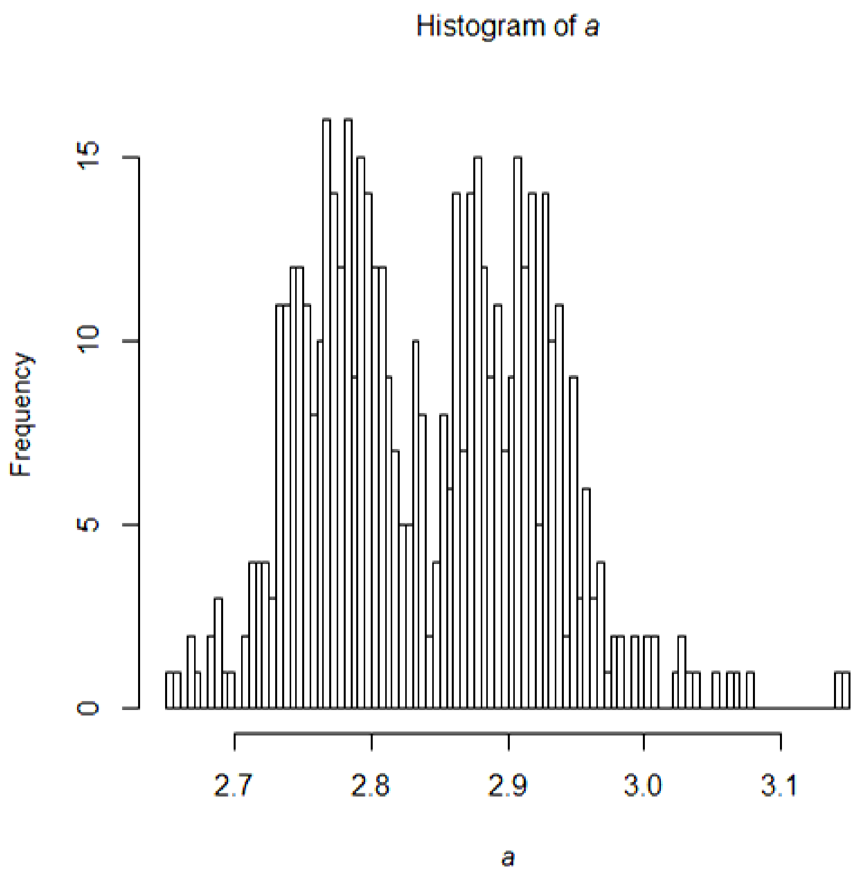

Fig. 15.2 Histogram of factor a

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264 | 46
266 | 891
268 | 0266049
270 | 7803456679
272 | 34556780122233444467778899
274 | 000112222344456667788999000111233333447799999
276 | 00011222445555666668888999901111233344444555677889999
278 | 0000011122333445566678888800111112222335556666678888999
280 | 001222223444555667778889911233334456789999
282 | 11235556900112333555566677779
284 | 2366800011244466667
286 | 001112222334445578890011222223334455556666778899
288 | 000011233344445558999999901111333444457888899
290 | 01133444556666667778888990001111222335666678889999
292 | 0012335566666677778891111122345666667788889
294 | 013666677890445577889
296 | 1245888177
298 | 2422
300 | 1167
302 | 36026
304 | 2
306 | 208
308 |
310 |
312 |
314 | 28
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Fig. 15.3 Stem and leaf plot of factor *a*
(The assumed split point is bolded, the probable outlier values is marked *italic*)

Analysis of sub-samples

Splitting "Pątnów" sample to 2 independent sub-samples created possibility of create 2 independent linear formulas describing dependency between carbon content and net calorific value in lignite. Following table 15.3 presents basic statistics for split "Pątnów" sample:

Table 15.3 Summary statistics of the "Pątnów" sample and derived sub-samples

Parameter	Pątnów sample		1st sub-sample		2nd sub-sample	
	Ctr [%]	Qir [MJ/kg]	Ctr [%]	Qir [MJ/kg]	Ctr [%]	Qir [MJ/kg]
Minimum	23.40	8.005	23.40	8.401	23.80	8.005
1st Quartile	25.28	8.967	24.89	8.993	26.05	8.942
Median	25.90	9.136	25.43	9.170	26.51	9.105
Mean (average value)	25.92	9.127	25.39	9.157	26.49	9.095
3rd Quartile	26.57	9.295	25.86	9.325	26.91	9.262
Maximum	30.07	9.961	27.53	9.961	30.07	9.836
Shapiro – Wilk normality test result (α = 0.05)	+ (p-value: 0.0661)	- (p-value: 0.0052)	+ (p-value: 0.6162)	+ (p-value: 0.6913)	- (p-value: 0.0003)	- (p-value: 0.0027)

Similar technique was used for analysis of 2nd sub-sample. Results are presented below.

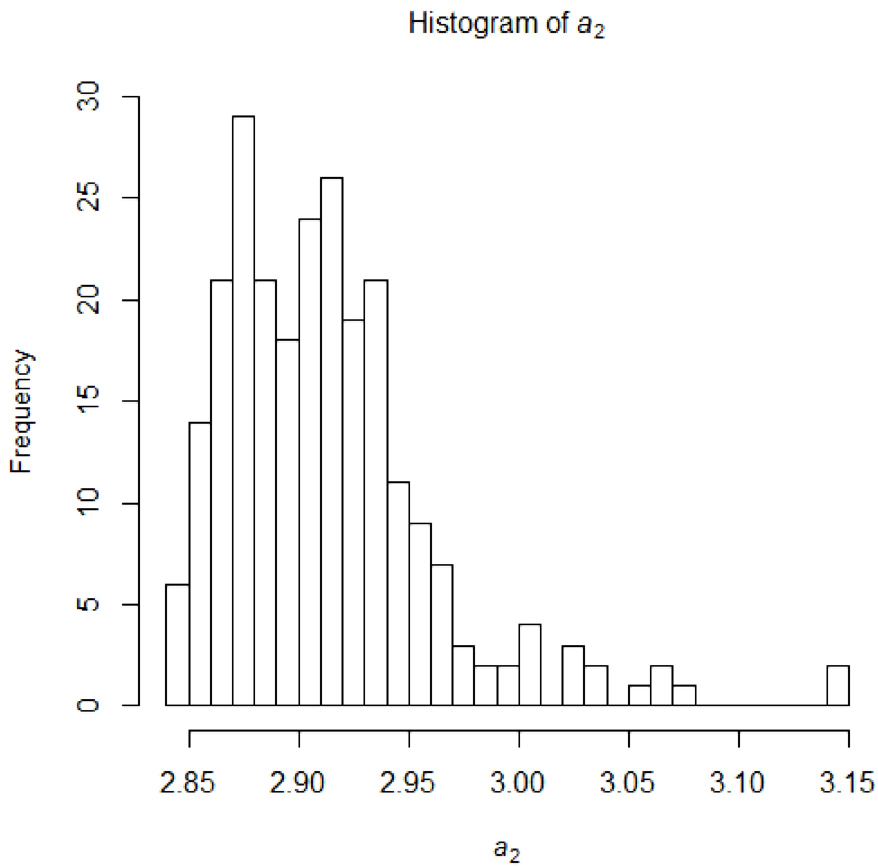

Fig. 15.4 Histogram of factor a_2

Table 15.4 Summary statistics for fator a_2, derived by using formula (13.2)

Parameter	**a_2 [% × kg × (MJ)$^{-1}$]**
Minimum	2.842
1st Quartile	2.877
Median	2.906
Mean (average value)	2.913
3rd Quartile	2.933
Maximum	3.148
Shapiro – Wilk normality test result ($\alpha = 0.05$)	- (p-value: 1.107×10^{-12})

Presented histogram (built for 25 classes) and parameters in table below suggest that combusted lignite ("Pątnów" sample) came from more than 2 independent sources. Also the shape of histogram on the figure 15.4 suggests existence of 2 independent samples or bimodal distribution of sample. Independent source of coal could be separate mining plant in the neighborhood of power plant or separate bed in the same mine.

Further analysis and splitting of sample is rejected due to constantly decreasing number of elements in sample and possibility of committing significant mistakes.

Dependency between carbon content and net calorific value

The empirical formulas of dependency were built for "Pątnów" sample and 1st sub-sample, using investigation of Pearson's correlation coefficient (cor) and least square method (for fitting linear function of regression). Below there are presented results of analysis and little comparison between applying approaches of: Fott [7], Stefanović et al. [8, 9] and currently used in Poland [10].

Table 15.5 Results of analysis – empirical formulas describing investigated dependency

Sample	cor (Ctr, Qir)	Formula
Pątnów sample	0.6448	Ctr = 2.339 × Qir + 4.546
1st sub-sample	0.8835	Ctr = 2.547 × Qir + 2.064

For comparison between formulas there are assumed combustion of 10.000 tons of lignite with net calorific value 8 MJ/kg and amount of carbon dioxide produced during combustion. There is also assumed that all amount of carbon in lignite is converted to CO_2 during combustion.

Table 15.6 Comparison between various approaches (by literature)

Formula by:	Formula	Calculated Ctr [%]	Amount of CO_2 [t]
Fott [7] (wet coal and lignite)	Ctr = 2.400 × Qir + 4.1232	23.32	8551.84
Fott [7] (dry and ash-removed coal and lignite)	Ctr = 2.333 × Qir + 5.511	24.18	8864.17
Fott [7] (selected country specific values)	Ctr = 2.334 × Qir + 5.5786	24.25	8891.89
Fott [7] (set A+B)	Ctr = 2.344 × Qir + 5.056	23.81	8729.70
Stefanović et al. [8] (Slovenia, "Šoštanj" power plant)	Ctr = 2.2477 × Qir + 5.8216	23.80	8727.84
Stefanović et al. [8] (Velenje)	Ctr = 2.3878 × Qir + 4.6548	23.76	8710.97
Stefanović et al. [8] (Kolubara)	Ctr = 2.3718 × Qir + 4.2637	23.24	8520.64
Poland [10] (current analysis)	Ctr = 1.9272 × Qir + 9.3856	24.80	9094.51
Pątnów sample (own analysis)	Ctr = 2.339 × Qir + 4.546	23.26	8527.93
1st sub-sample (own analysis)	Ctr = 2.547 × Qir + 2.064	22.44	8228.00

CONCLUSIONS

Presented results, taking into consideration number of investigated linear dependencies between carbon content and net calorific values, referred to different countries, coal reservoirs, mining fields, power plants (in the context of combustion of lignite) or lignite state could be significant in compilation of emission inventory.

Because of large diversification of qualitative parameters as: carbon content, net calorific value, ash and water content, also other, summary analysis on the level of separate country seems to be quite difficult. As a result, estimated emission of carbon dioxide from lignite-based public power and energy sector [7, 8, 9, 10, 11] might be charged with significant uncertainties. Additionally, taking into consideration geospatial variability of parameters of lignite (various resources, beds and other) [12, 13, 14, 15, 16], there is created the possibility that linear dependency between carbon content and net calorific value is not enough for effective compilation of emission inventory.

In the context of intensive development of brown coal industry in Poland [17] is worth to estimate "stepping" (year by year) formula of dependency between carbon content and net calorific value also make the national emission inventory data more reliable.

Observed facts confirm assumptions [7, 8, 9, 10] concerning existence of dependency between carbon content in lignite and net calorific value. This dependency could be observable as a linear function.

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EMISSION INVENTORY FOR LIGNITE BASED PUBLIC POWER AND ENERGY SECTOR – MERGING INFORMATION FROM VARIOUS SOURCES

Abstract: *The purpose of this article is presentation of emission inventory as a field, where integration of information from various sources is widely used. One of tasks of emission inventory is combining pieces of information about any significant source of emission of air pollutants or greenhouse gases (GHGs) to estimate value of emission in the most reliable way. Sources of used information are not only environmental studies. They are elaborations from completely various fields as e.g.: mining, metal casting, agricultural sciences or forestry.*
National emission inventory merge data from: statistical surveys, scientific elaborations, interior and international analysis, National Emission Database (NED) and specific international statistical questionnaires on energy sector. Emission inventory in public power and energy sector is the good example of using data from different sources. There are possibility of encounter data on: combusted fuels (type and amount), composition and calorific value of fuels, average emission factors, parameters of particular systems of air pollution control and many other.

Key words: *data-integration, carbon dioxide, emission inventory, statistics*

INWENTARYZACJA EMISJI Z WĘGLA BRUNATNEGO PUBLICZNEGO SEKTORA ENERGETYCZNEGO – SCALANIE INFORMACJI Z RÓŻNYCH ŹRÓDEŁ

Streszczenie: *Celem artykułu jest prezentacja możliwości zastosowania integracji danych w inwentaryzacji emisji. Jednym z zadań inwentaryzacji emisji jest wykorzystanie informacji charakteryzujących każde istotne źródło emisji (zanieczyszczeń powietrza albo gazów cieplarnianych) tak, aby oszacować wielkość emisji zanieczyszczeń z w/w źródła w sposób jak najbardziej miarodajny. Źródła wykorzystywanych informacji nie dotyczą jedynie nauk o środowisku, ale są opracowaniami dotyczącymi np.: górnictwa, odlewnictwa metali, nauk rolniczych, czy też leśnictwa. Krajowe inwentaryzacje emisji integrują dane z (m.in.): opracowań statystycznych, prac naukowych, analiz krajowych i międzynarodowych, baz danych (o emisjach) oraz międzynarodowych kwestionariuszy statystyki energetycznej.*
Inwentaryzacja emisji sektora energetyki zawodowej stanowi dobry przykład integracji danych z różnych źródeł: o charakterystyce zużytego paliwa, składzie, wartości opałowej, średnich wskaźnikach emisji, danych o zastosowanych systemach oczyszczania powietrza i wielu innych.

Słowa kluczowe: *integracja danych, dwutlenek węgla, inwentaryzacja emisji, statystyka*

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