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Geoinformation technology for spatial inventory of greenhouse gas emissions: electricity and heat generation in Poland

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Abstract. One of the main features of energy production in Poland is high dependence on consumption of coal and lignite, which results in significant emissions of greenhouse gases (GHGs) to the atmosphere. This article presents the geoinformation technology and spatial analysis of GHG emissions from fossil fuel burned by power and combined power and heat plants. These plants are considered as emission sources of a point type. As input data, official regional statistics about consumption of fossil fuel for electricity and heat production are used. In addition, main characteristics of power and power/heat plants are collected from official web-sites. Based on the developed model, numerical experiments have been carried out for the territory of Poland. The results of spatial modeling are presented in the form of thematic maps.

Key words: modeling, geoinformation technology, greenhouse gas emissions, electricity production, combined heat and power production, fossil fuel.

INTRODUCTION

Technological development moves ahead, making our life more and more comfortable. As a downside, the global temperature increases and global climate change becomes irreversible [7, 13, 27]. International scientific community has proved that the increase of greenhouse gases (GHGs) in the atmosphere is the main reason of the increase in average global temperature and significant global climate change [5, 10, 15, 16].

The energy sector is the biggest contributor of GHG emissions to the atmosphere [3, 4, 16]. In the developed countries, it accounts for almost 90% of total carbon dioxide emissions and 75% of total GHG emissions. According to the classification of emission sources created by the Intergovernmental Panel on Climate Change (IPCC), the category "*1.A.1.a. Electricity and Heat Production*" belongs to the energy sector [1]. It is further divided into three subcategories, as shown in Fig. 1.

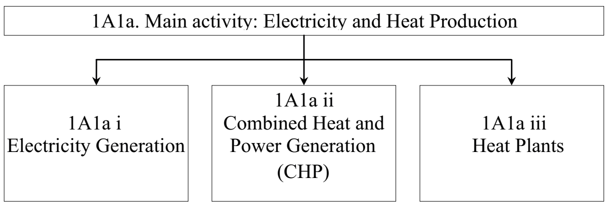


Fig. 1. Subcategories of the category "1.A.1.a"

In the modern world the majority of human activities require electricity and heat supply. Electricity and heat generation are based mainly on the combustion of fossil fuels, such as coal, natural gas or fuel oil. This leads to significant increase in GHGs emissions. Therefore, numerous incentives are introduced in order to reduce the use of fossil fuels, and instead increase a share of renewable sources in total energy production. Despite these efforts, fossil fuels remain the main source of energy.

Spatial inventory of GHG emissions improves the estimates of effectiveness of greenhouse gas emission reduction measures [2, 3, 9]. It identifies greenhouse gas sources and sinks at the level of individual regions, not only at the national (country) level. Therefore, countries are encouraged to develop their own spatial models to assess the processes of GHGs emission/absorption [17].

The first results of spatial analysis of GHGs caused by fossil fuel burned by power and power/heat plants in separate Polish regions were presented in [14]. This paper describes the mathematical model for spatial analysis of GHGs, and the experiments were carried out only for eastern Poland.

In the present paper we modify the model introduced in [14] by considering the amount of fossil fuels burned and known for each plant. This study focuses on two categories of sources: (1) Electricity Generation and (2) Combined Heat and Power Generation. We develop spatial inventory of GHGs of power and combined power and heat plants for whole Poland. For verification of results, we compared calculated emissions of point sources with corresponding data reported by each power plant.

FEATURES OF ELECTRICITY AND HEAT GENERATION IN POLAND

Poland annually produces greenhouse gas inventory reports according to the international obligations introduced by the Kyoto Protocol to the United Nations Framework Convention on Climate Change - UNFCCC. The latest inventory report [18] shows that the category "1.A.1.a. Public Electricity and Heat Production" is the largest contributor of emissions. It covers over 53.1 % of total GHG emissions in energy sector [18].

The energy sector in Poland highly depends on coal. Almost 62% of the electricity and heat production is based on combustion of coal as the main source of energy. Lignite is the second important fossil fuel used for electricity and heat production; it covers around 30% of total electricity in Poland [28]. Power plants that consume lignite usually are located close to miners of this fossil fuel.

The category "1.A.1.a" covers two types of power plants: "Zawodowe" (power/heat plants for general usage) and "Przemysłowe" (power plants for industry) [8,12]. This study is focused on power and heat plants classified as "Zawodowe". The power/heat plants which are classified as "Przemysłowe" belong to another category of emission sources (Manufacturing industries and building).

MODELLING GHG EMISSIONS FROM ELECTRICITY AND HEAT GENERATION

Input data required for spatial modeling of GHG emissions from electricity or combined power and heat generation include the following:

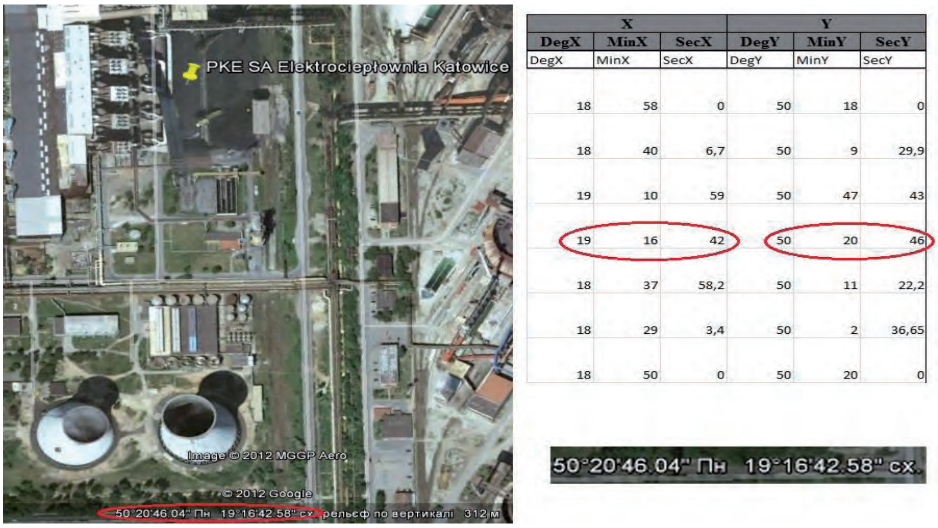
– consumption of different types of fossil fuels; this is available only on a voivodeship level,
– characteristics of plants and their coordinates.

Consumption of fossil fuels. Since 2008 the statistics data on coal consumption is reported as a total amount used by both types of plants – "Occupational" ("Zawodowe") and " Industrial" ("Przemysłowe"). To get the information only about coal consumption of "Occupational" plants, we assume that the proportion of fuel consumed by "Occupational" and "Industrial" plants remains the same as in 2007.

Figure 1 illustrates the thematic map of consumption of coal and natural gas for power and heat production by "Occupational" plants. This map was built using fuel consumption and the digital map of Polish voivodeships.

Plants as emission sources. The power plants producing electricity and heat are considered to be huge sources of a point-type [4]. We created a database with detailed information on characteristics of these plants. The database includes a set of precise geographic coordinates that were extracted from web-sources using the plug-in "Google Earth". An example of this process is shown in Fig. 2.

Fig. 1. Consumption of coal and natural gas for power and heat production at voivodeship level for the year 2010, th. TJ



X			Y		
DegX	MinX	SecX	DegY	MinY	SecY
DegX	MinX	SecX	DegY	MinY	SecY
18	58	0	50	18	0
18	40	6,7	50	9	29,9
19	10	59	50	47	43
19	16	42	50	20	46
18	37	58,2	50	11	22,2
18	29	3,4	50	2	36,65
18	50	0	50	20	0

Fig. 2. Extraction of coordinates of a power / heat plant using the plug-in "Google Earth"

Naturally, a territorial distribution of power/heat plants in Poland depends on economic activity, and thus it is uneven. For instance, Silesian voivodeship is the main industrial region of the country with numerous power plants.

Based on the coordinates of power plants, a digital map of electricity generation plants was created, using GIS tools (see Fig. 3).

Fig. 3. The created map of power / heat plants of Poland

Emission estimates. Carbon dioxide is the main GHG emitted by energy sources. Emissions of carbon dioxide are formed as a result of burning of carbon contained in fossil fuels [11, 16]. It causes also a release of a large amount of thermal energy, which is directly or indirectly used to produce mechanical energy (often to produce electricity).

For a spatial analysis, one needs to know exact fuel consumption at each point source, and this kind of information is not available from official statistics. However, with certain parameters, such as a structure of fossil fuel consumption and general power, the data on fuel consumed can be disaggregated into individual point sources within a voivodeship.

The emission of g-th gas from an elementary object (a single plant) is calculated based on its usage of fuels accounting for respective calorific values and emission factors, in accordance with the formula:

$$E_g^{En}\left(\xi_{En,n_p}\right) = \sum_{f\in F} Q_f^{En}\left(\xi_{En,n_p}\right) K_{g,f}^{En}\ C_f\left(\xi_{En,n_p}\right), \quad (1)$$

where: $E_g^{En}\left(\xi_{En,n_p}\right)$ is the emission of the g-th GHG from fuel burning of a point source ξ_{En,n_p}, $n_p = \overline{1, N_{En,p}}$; $N_{En,p}$ is the number of emission sources in an administrative unit R_{1,n_1}, $R_{1,n_1} \in \tilde{R}_1$, and R_{1,n_1} is an administrative unit of the "first level" (voivodeship); $\tilde{R}_1$ is the set of administrative units; f is a fuel type, $f \in F$; F is a set of fuel types (coal, lignite, natural gas, mazut); ξ_{En,n_p} is a point-type emission source (power/heat plant), $\xi_{En,n_p} \in \Xi_{En}$; Ξ_{En} is a set of point-type emission sources on the administrative unit R_{1,n_1}; $K_{g,f}^{En}$ is the emission factor of the g-th gas from burning the f-th fuel type in Energy sector (1.A.1.a "Main Activity Electricity and Heat Production"); $C_f\left(\xi_{En,n_p}\right)$ is the calorific value of the f-th fuel type for point-type source (these parameters differs for each point source; the main reason of it is a technological process of plants [26]), $Q_f^{En}\left(\xi_{En,n_p}\right)$ is the amount of the f-th fuel type consumed by a point-type source ξ_{En,n_p} in R_{1,n_1} administrative unit.

The parameter $Q_f^{En}\left(\xi_{En,n_p}\right)$ is calculated for each power/heat plant with the formula:

$$Q_f^{En}\left(\xi_{En,n_p}\right) = \frac{D_f^{En} - \sum_k D_{k,f}^{En}}{\sum_{i=1}^{N_{En,p}} W\left(\xi_{En,i}\right) - \sum_{n_k} W\left(\xi_{En,n_k}\right)} W\left(\xi_{En,n_p}\right),$$

$$n_p = \overline{1, N_{En,p}}, \quad (2)$$

where: D_f^{En} is the amount of the f-th fuel for electricity and heat production in administrative unit (voivodeship)

R_{1,n_1}; $D^{En}_{k,f}$ is the known amount of fuel used by a point-type source ξ_{En,n_k}; $W(\xi_{En,i})$ is the overall power of a power/heat station; $W(\xi_{En,n_k})$ is the overall power of power/heat station with known amount of fuel used. Overall power of a plant is the main parameter used for fossil fuel disaggregation, since power (combined power and heat) plants cannot produce more electricity (electricity and heat) than it is technically feasible.

For the ξ_{En,n_p}-th plant, the total GHG emissions in CO_2 equivalent are calculated as a sum of the g-th gas emissions multiplied by their respective global warming potential:

$$E^{En}_{\Sigma}(\xi_{En,n_p}) = \sum_{g\in G} E^{En}_{g}(\xi_{En,n_p})\, W_g,\; n_p = \overline{1, N_{En,p}}, \quad (3)$$

where: $E^{En}_{\Sigma}(\xi_{En,n_p})$ is the GHG emission in CO_2 equivalent by point-type source ξ_{En,n_p}; W_g is the global warming potential [6].

COMPUTER REALIZATION

Geoinformation tools were developed using MapInfo and corresponding programming language MapBasic. Calculations are based on the mathematical model (1)-(3) to provide spatial analysis of GHG emissions from power/heat plants of Poland.

For computer modeling, a specialized database was created as input data. It includes the following components: (i) consumption of fossil fuel by power and heat plants at voivodeship level [28]; (ii) list of public power plants and their characteristics; (iii) coordinates of public power plants with additional statistical data [25]; (iv) emission factors [26]; (v) remarks and references.

The results are presented in the form of thematic maps. As an example, Fig. 4 demonstrates the total emission from electricity and heat production in Poland at the level of separate plants. It includes a sum of emissions of all GHGs multiplied by global warming potentials. The same results but aggregated to the level of voivodeships are presented in Fig. 5.

Silesia (Śląskie) voivodeship is a region with the largest GHG emissions from energy production[21, 23, 24]. Two out of ten biggest Polish power plants (Elektrownia Rybnik, Elektrownia Jaworzno) are located there, see Fig. 6 and Fig. 7,a. In terms of GHG emissions from power plants, Mazowieckie voivodeship [20, 22, 24] is one of the biggest emitters. In Mazowieckie voivodeship there are eight power plants, and two of them are in the list of the largest emitters (Kozienice Plant, Siekierki Power Plant), see Fig. 6 and Fig. 7 b.

Fig. 4. Total emissions from electricity and heat production at the level of plants (2010, th. tones CO_2-equivalent)

Fig. 5. Total emissions from electricity and heat production at the level of voivodeships (2010, th. tones CO_2-equivalent)

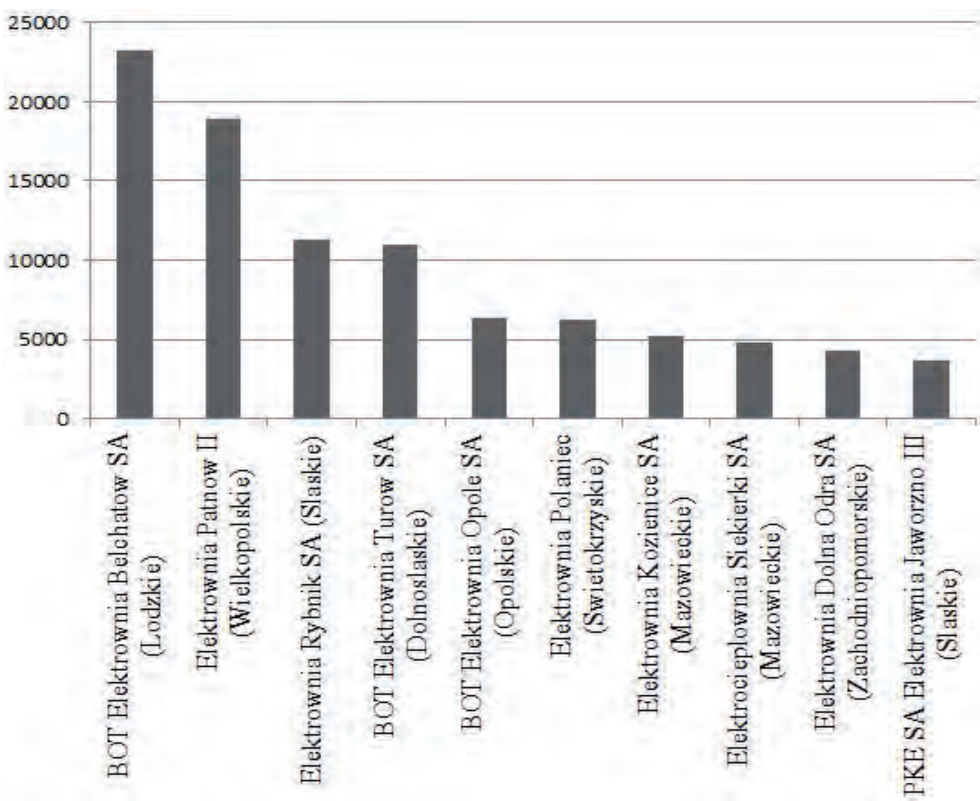
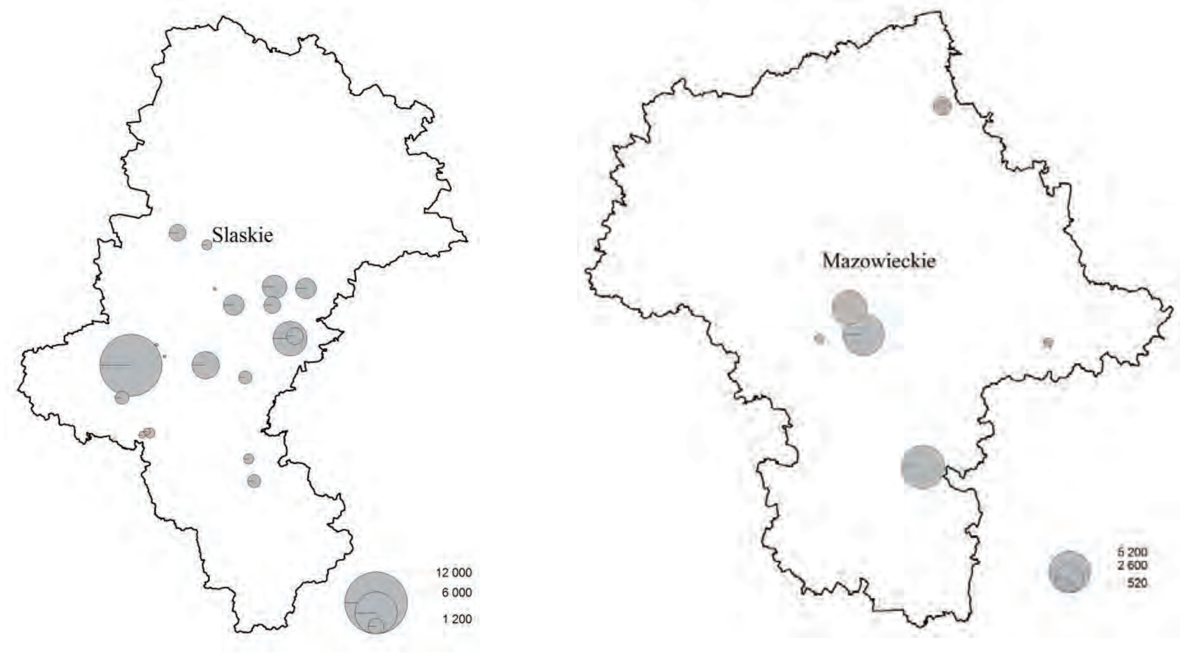


Fig. 6. The biggest point sources of emissions – power/heat plants (2010, th. tones of CO_2-equivalent)



a b

Fig. 7. Total emissions from electricity production in Silesia (a) and Mazowieckie (b) voivodeships (2010, th. tones of CO_2-equivalent)

The next step after computer realization is a verification of obtained results. Some power plants and combined power/heat plants publish data on their annual emissions on web-sites. We compared the results of our model with the official data published by plants. For example, in Lower Silesian voivodeship there are three power and heat stations. One of them “BOT Turow SA Power Plant” is the biggest emitter that covers more than 70% of all GHG emissions in the voivodeship [19]. In this case, the difference between the model results and official numbers from the environment report does not exceed 4 %, see Fig. 8.

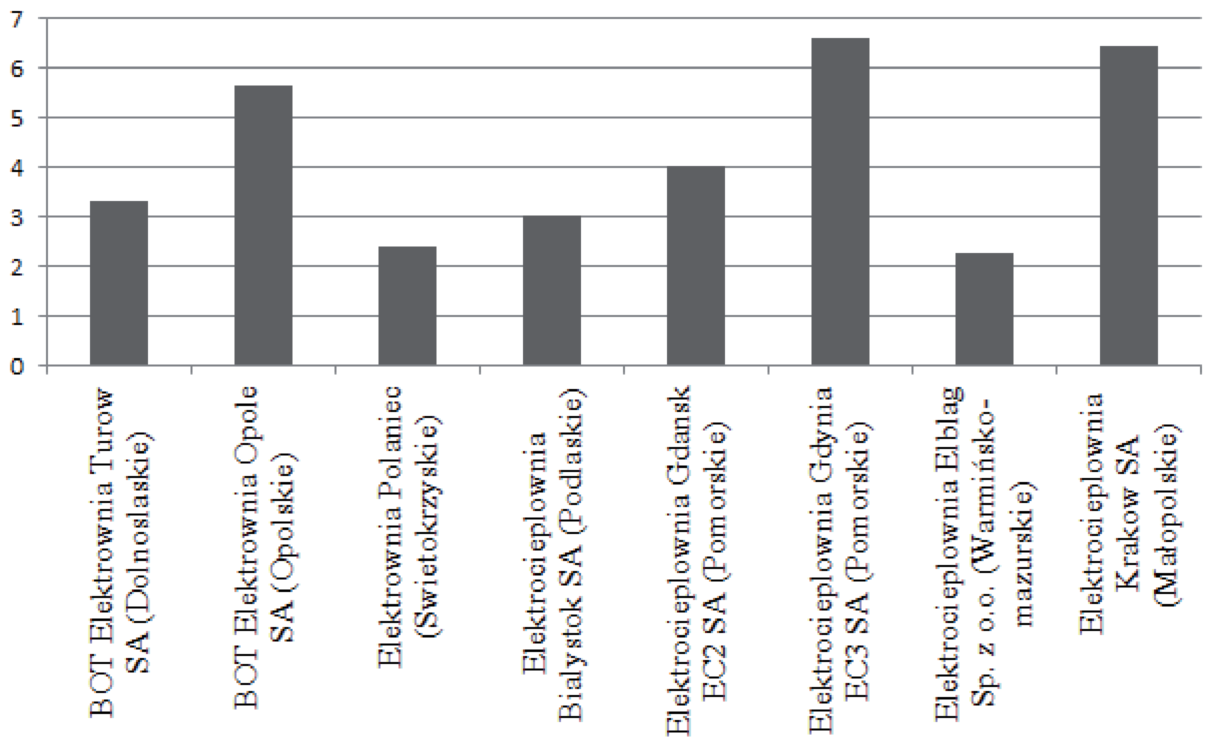


Fig. 8. Difference between official data that are published on power / heat plant sites and calculated from distributed data (2010, %)

CONCLUSIONS

Electricity and heat generation is one of the main energy categories in Poland, accounting for 43.5 % of total GHG emissions. This paper provides the spatial analysis of annual GHG emissions from fossil fuel burning in power and power/heat plants. The emission estimates are based on official statistics about consumption of fossil fuels for electricity, power/heat production, and data on electricity, electricity/heat generation by each plant. In order to spatially allocate the emission sources, geographical location of the main power and power/heat plants as point-type emission sources have been identified, and corresponding digital map of power plants has been created using GIS tools. The numerical experiments on spatial modeling of GHG emissions were carried out by implementing the developed geoinformation technology. Obtained results can be presented in the form of digital maps with georeferrenced information on sources of emissions. For example, spatially resolved carbon dioxide emissions and corresponding thematic map clearly emphasize that the largest emitter of CO_2 is the power plant – BOT Elektrownia Bełchatów SA located in Lodz voivodeship. Nevertheless, Silesian voivodeship is an unquestionable leader of GHG emissions from electricity production. The difference between the model results and official numbers included in the environment report does not exceed 3-7 %.

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REFERENCES

1. 2006 IPCC Guidelines Versus the Revised 1996 IPCC Guidelines: Implications for Estimates of CO2 Emission from Fuel Combustion / IEA, Paris, France, 2009, 22.
2. **Bun R., Gusti M., Kujii L., Tokar O., Tsybrivskyy Ya. and Bun A. 2007.** Spatial GHG inventory: Analysis of uncertainty sources. A case study for Ukraine, Water, Air, & Soil Pollution: Focus. Springer Netherlands, vol. 7, Is. 4-5, 483-494.
3. **Bun R., Hamal Kh., Gusti M. and Bun A. 2010.** Spatial GHG inventory on regional level: Accounting for uncertainty, Climatic Change. Springer Netherlands, vol. 103, Is. 1, 227-244.
4. **Bun R., HamalKh., Gusti M., Bun A. and Savchyn O. 2007.** Spatial inventory of greenhouse gases on regional level, Information Technologies in Environmental Engineering "ITEE 2007": Third International ICSC Symposium, Oldenburg, Germany, Springer, 271-280.
5. **Busko E.C., Pazniak S.S., Kostukevich S.B. and Dudkina L.A. 2012.** Perspectives of the use of renewable energy sources in enhancement of environmental and energy security of Belarus, Econtechmod, Poland, vol. 1, n. 2, 9-16.
6. Climate Change Connection – CO_2 equivalent. Available online at: http://www.climatechangeconnection.org/emissions/CO2_equivalents.htm
7. **Gorobets V. and Mendeleyev V. 2012.** Influence of pollutions on the thermal characteristics, heat efficiency and optimal dimensions of tubes with londitudinal fins, Econtechmod, Poland, vol. 1, n. 1, 35-40.
8. Gospodarka paliwowo-energetyczna w latach 2009, 2010, Warszawa, Poland, Główny Urząd Statystyczny, 2010. Available online at: http://www.stat.gov.pl/cps/rde/xbcr/gus/pbs_gosp_paliw_energ_2009-2010.pdf
9. **Hamal Kh. 2008.** Carbon dioxide emissions inventory with GIS, Artificial Intelligence, Ukraine, N. 3, 55-62.
10. **Horynski M., Pietrzyk W. and Boguta A. 2012.** A model of an energy efficient building automation system, Econtechmod, Poland, vol. 1, n. 1, 41-46.
11. IPCC 2006, 2006 IPCC Guidelines for National Greenhouse Gas Inventories, Prepared by the National Greenhouse Gas Inventories Programme, Eggleston H.S., Buendia L., Miwa K., Ngara T., and Tanabe K. (eds). Published: IGES, Japan.
12. Kotły – kraj – elektrownie zawodowe, elektrociepłownie **i** ciepłowni, Raport RAFAKO S.A., Poland, Available online at: http://www.rafako.com.pl/pub/File/Referencje/01_kotly_kraj_El_zawodowe.pdf
13. **Kovalyshyn B. 2012.** Theoretical and experimental ground of the fuel energy efficiency improvement by an activation of the burning reaction molecules-reagents, Econtechmod, Poland, vol. 1, n. 1, 63-66.
14. **Lesiv M., Bun R., Shpak N., Danylo O. and Topylko P. 2012.** Spatial analysis of GHG emissions in eastern polish regions: energy production and residential sector, Econtechmod, Poland, vol. 1, n. 2, 17-23.
15. **Lesiv M., Bun R. and Topylko P. 2011.** Geoinformation technologies and models for spatial analysis of GHC emissions: energy production in eastern Polish regions, Proceedings of the International Workshop "Methods and Applications of Artificial Intelligence", 22-23 September 2011, CIM, Bielsko-Biała, Poland, 38-48.
16. **Marland G., Brenkert A. and Olivier J. 1999.** CO_2 from fossil fuel burning: A comparison of ORNL and EDGAR estimates of national emissions, Environmental Science and Policy, USA, Vol.2, Is. 3, 265-273.
17. **Maududie A., Handoko I. and Seminar K. 2002.** The development of Geographic information system for inventory and publication of greenhouse gas emissions from Energy sector, Journal of GIS, Remote Sensing and Dynamic Modelling, USA, Vol. 2, 59−80.
18. Poland's National Inventory report 2011. Greenhouse Gas Inventory for 1988-2010. National Centre for Emission Management at the Institute of Environmental Protection, National Research Institute, Warszawa, Poland, 2012. Available at: http://unfccc.int/national_reports/annex_i_ghg_inventories/national_inventories_submissions/items/6598.php.
19. Raport o stanie środowiska w województwie dolnośląskim w 2010 roku. –Wrocław, Poland. Available online at: http://www.wroclaw.pios.gov.pl/index.php?id=publikacje&sub=raporty&rok=2010
20. Rocznik Statystyczny Województwa Mazowieckiego [CD-ROM], Warszawa, Poland, Urząd Statystyczny w Warszawie, 2010.

21. Rocznik Statystyczny Województwa Śląskiego [CD-ROM], 2010: Katowice, Poland, Urząd Statystyczny w Katowicach.
22. Stan środowiska w województwie mazowieckim w 2010 roku. Warszawa, Poland. Available online at: http://www.wios.warszawa.pl/portal/pl/17/608/Stan_srodowiska_w_wojewodztwie_mazowieckim_w_2010_roku.html
23. Stan środowiska w województwie śląskim w 2010 roku. Katowice, Poland. Available online at: http://www.katowice.pios.gov.pl/monitoring/raporty/2010/raport2010.pdf.
24. State of the environment in Poland. 2011 signals, Warsaw, Poland, 2011. Available online at: http://www.gios.gov.pl//zalaczniki/artykuly/Signals%20calosc_ang2011.pdf.
25. Symbole terytorialne GUS. Warszawa, Poland. Available online at: http://wipos.p.lodz.pl/zylla/ut/kody-GUS.html
26. Wartości opałowe (WO) i wskaźniki emisji (WE) w roku 2007. Warszawa, Poland. Available at: http://www.kashue.pl/materialy/download/WE_i_WO_do_HE_2007.pdf
27. Zużycie paliw i nośnikow energii w 2010 r., Główny Urząd Statystyczny, Warszawa, Poland, 2011. Available at: http://www.stat.gov.pl/cps/rde/xbcr/gus/PUBL_se_zuzycie_paliw_nosnikow_energii_2010.pdf
28. **Żotkiewicz Z. and Karwinski A. 2012.** Effect of temperature on the volume of gas emissions, Econtechmod, Poland, vol. 1, n. 2, 75-84.