ARCHIVES OF ENVIRONMENTAL PROTECTION

vol. 36 no. 1 pp. 41 - 48 2010

PL ISSN 0324-8461

TOWARDS AN INTEGRATED ASSESSMENT OF ENVIRONMENTAL AND HUMAN HEALTH IMPACT OF THE ENERGY SECTOR IN POLAND

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Keywords: Energy sector, emissions, human health and environmental impacts, external costs.

Abstract: The paper presents the results of the integrated assessment of environmental and human health impacts of emissions released from different sectors in Poland. The analysis was performed with the use of the eurelian emissions transport model POLAIR 3D and the Regional Air Pollution Information and Simulation model RAINS. The models are briefly described. At present, this hybrid system can operate in a simulation mode and enables estimation of the emission and concentration/deposition levels of main air pollutants, emission control costs, environmental impacts and external costs associated with different energy scenarios. Emission levels of main air pollutants in 2005, 2010 and 2020 are presented for the selected energy scenario. Associated external costs and impacts on acidification have been estimated.

INTRODUCTION

The human development needs entail the increase of energy demand. Unfortunately, the increasing number of cars, industrial facilities and the growth in domestic energy consumption result in more emissions. The emitted substances directly or through chemical reactions damage human health and the environment. The impact of air pollution on human health ranges from minor respiratory effects to reduced lung function, asthma, chronic bronchitis, cancer and, in consequence, reduced life expectancy. Acidification (caused by emissions of SO_2, NO_x and ammonia) damages forests, rivers, lakes and other ecosystems. Eutrophication (an excess input of nitrogen nutrients nitrogen oxides and ammonia) disturbs the structure and function of land-based and aquatic ecosystems and leads to nitrogen leaching into water courses and biodiversity. Additionally, both acidification and particulate emissions, cause damage to buildings and historical monuments. At present, those negative effects remain uncompensated by the perpetrators. However, this situation is due to be changed in the future by internalization of external costs into the price of goods they produce. There is a need to assist the decision-making processes, specifically when energy development scenarios are prepared, and consider all the factors that have impacts on environment, health, climate change, social and economical development.

SYSTEM DESCRIPTION

The approach is to combine the integrated assessment model RAINS with the chemistry transport model POLAIR 3D. In principle, integrated assessment modeling enables identification of the emission reduction scenarios, providing information on how to optimally allocate the emission reduction investments. RAINS make it possible to estimate the present and future levels of pollutant emissions. In this study, emission results of RAINS have been implemented as the input data in the air pollution dispersion model POLAIR 3D. Thus, it was possible to calculate also the atmospheric transport of air pollutants, at local and transboundary distances and subsequently related ground level concentrations and depositions. The obtained deposition levels were then confronted with the threshold values, i.e. critical loads of acidity. In the case of human health, the physical impacts of a dose of pollutant that affects population at the receptor have been estimated with the use of concentration-response functions (CRF). These functions relate changes in the occurrence of a particular impact (loss of life, asthma attack, loss in crop yield, etc.) to an incremental change in ambient concentration of a particular pollutant. The simplified information flow in the system considered is illustrated in the Figure 1.

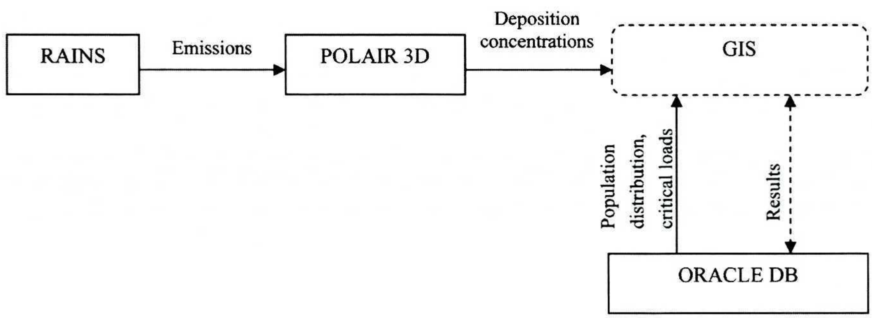

Fig. 1. The simplified information flow in the considered system

RAINS MODEL

The RAINS model, developed at the International Institute for Applied Systems Analysis (IIASA), combines information on economic and energy development, emission control potentials and costs, atmospheric dispersion and environmental sensitivities towards air pollution [8]. The model has been used for several years to support European Commission and UNCLRTAP in preparation of strategies to combat air pollution. For each of the pollutants listed in Table 1, RAINS estimates emissions based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied, as presented below:

$$E_{i,p} = \sum_{k} \sum_{m} A_{i,k} ef_{i,k,m,p,} x_{i,k,m,p}$$

where: $E_{i,p}$ – emissions of pollutant p (for SO_2, NO_x, PM_{TSP}) in region i;
i, k, m, p – region, activity type, abatement measure, pollutant, respectively;
$A_{i,k}$ – activity level of type k (e.g., coal consumption in power plants) in country i;

$ef_{i,k,m,p}$ – emission factor of pollutant p for activity k in region i after application of control measure m;

$x_{i,k,m,p}$ – share of total activity of type k in region i to which a control measure m for pollutant p is applied.

The emission levels presented in Table 1 are calculated based on the official national energy projections up to 2020, which have been used as a baseline for the revision of the national emission ceilings directive. The projections reflect the national policies (as laid down, e.g., in the governmental energy plans). Furthermore, they include all necessary measures to comply with the Kyoto targets on greenhouse gas emissions and with the burden sharing agreement for 2012. For 2020, it is assumed that the Kyoto emission caps remain unchanged.

Table 1. SO_2, NO_2 and TSP emission levels [Mg/yr] estimated for the energy scenario considered

	SO_2			NO_x			PM_{TSP}		
SNAP1 codes	2005	2010	2020	2005	2010	2020	2005	2010	2020
Combustion in energy industries	892.2	798.3	503.4	340.2	324.1	144.5	36.89	28.77	25.45
Non-industrial combustion plants	227.1	220.9	204.5	60.25	64.34	70.35	188.6	182.3	150
Combustion in manufacturing industry	111.4	105.3	101.3	83	71.04	67.65	18.01	17.08	16.62
Production processes	43.05	38.54	46.47	8.212	7.49	5.712	33.85	30.71	30.3
Road transport	11.61	0.179	0.236	178.7	139.8	76.67	27.73	29.29	37.52
Other mobile sources and machinery	2.448	1.051	1.094	76.01	75.87	65.69	7.96	7.208	4.405
Waste treatment	0.21	0.21	0.21	0.481	0.481	0.481	8.374	8.348	8.274
Agriculture	0.1	0.1	0.1	0.228	0.228	0.228	64.18	64.65	64.55
Extraction and distribution							31.08	28.77	26.33
Sum	1288	1165	857.4	747.1	683.3	431.2	416.7	397.1	363.5

These results were then used as input emissions to the POLAIR 3D model. The emission of other pollutants that were necessary to run the model was taken from [4].

POLYPHEMUS/POLAIR 3D

The atmospheric transport of air pollution is calculated with the use of full modeling system for air quality – POLYPHEMUS. POLYPHEMUS is composed of the chemistry-transport-model POLAIR 3D, the library of physical parameterizations called AtmoData and a set of programs using AtmoData designed to generate data needed by POLAIR 3D (deposition velocities, vertical diffusion coefficients, emissions, etc.) [2]. POLAIR 3D tracks multiphase chemistry (gas / water / aerosols). Gas-phase chemical scheme is RACM and aerosol chemistry is treated differently depending on the cloud liquid water content. Inside clouds, aqueous-phase chemical reactions are modeled using the Variable Size-Resolution Model (VSRM). Otherwise, a size-resolved aerosol model (SIREAM) treats the effects of condensation/evaporation (including the inorganic aerosol thermodynamics, ISORROPIA), coagulation and nucleation upon the particle size distribution. [5].

The model was run with 0.25° x 0.25° spatial resolution. Each time, i.e. for 2005, 2010 and 2020 meteorological data for 2005 was used. To check the model performance, the modeled concentration values were compared with measurements from monitoring stations of the Regional Inspectorate of Environmental Protection in Krakow. These are provided every 1 hour.

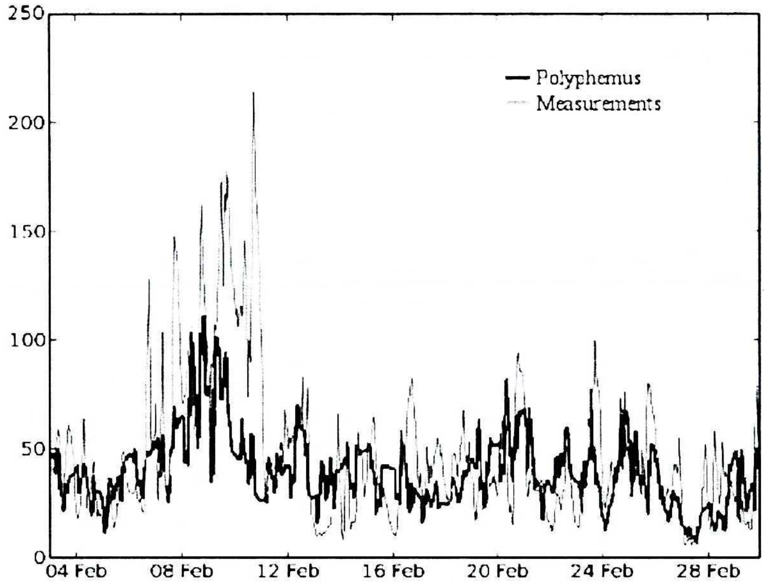

Fig. 2. Comparison of modeled and measured NO_2 concentration [$\mu g/m^3$] for February 2005 (Krowodrza station)

The table below shows comparison of modeled and measured concentration results for other stations monitoring stations in Krakow.

Table 2. Comparison of results from POLYPHEMUS and measurements from different stations

	Measurement station					
	Krasińskiego	Krowodrza	Nowa Huta	Skawina	Summary	
SO_2	28.5	18.4	16.0	29.6	24.7	Meas_mean
	31.0	19.3	26.8	22.4	26.7	Sim_mean
	39.1	25.9	31.8	33.7	34.9	RMSE
	54.5	46.7	51.7	31.6	45.9	correlation [%]
NO_2	42.5	36.7	26.9	31.1	34.3	Meas_mean
	41.3	39.1	40.9	30.0	37.8	Sim_mean
	17.7	15.8	20.6	19.9	18.5	RMSE
	57.1	60.1	33.5	36.0	46.7	correlation [%]
PM_{10}		79.0	71.2	73.8	74.3	Meas_mean
		34.9	34.2	31.8	33.6	Sim_mean
		89.4	84.1	85.6	86.3	RMSE
		44.0	21.8	22.6	29.5	correlation [%]

For each year, the obtained concentration and deposition levels were used to calculate the exceedences of critical loads for acidity and to estimate the external costs.

CRITICAL LOADS FOR ACIDITY

To determine the sensitivity of ecosystems to the deposition of atmospheric pollutants the Critical Loads (CL) approach was developed, defined as a quantitative estimate of the exposure to one or more pollutants below whose significant harmful effects on specified sensitive elements of the environment do not occur according to present knowledge [7]. In the analysis, the critical load function of acidity was used, because sulfur and nitrogen both contribute to acidification and no unique acidity critical load can be derived. The updated database of critical loads of acidity in 1 x 1 km spatial resolution was used [6]. Each cell represented one ecosystem for which the minimal nitrogen deposition and maximal nitrogen and sulphur depositions were given to make the critical load function. The exceedance was calculated using methodology described in [3].

EXTERNAL COSTS

Formally, externality is defined as an uncompensated side effect of one agent's action that directly affects the welfare of another agent [1]. Since externalities have not been reflected yet in market prices, there is a need to assist decision-making processes by assigning to them monetary values and, in this way, to internalize them into private cost.

In the analysis external costs related only to human health were considered. Additionally, only negative effect due to change of SO_2 and PM_{10} concentrations were taken into account. Concentration values of these pollutants were put together with population densities, concentration-response functions and unit values for particular impacts. CRF chosen were: chronic mortality (YOLL), chronic bronchitis (CB) and restricted activity days (RAD). Chronic mortality refers to loss in life expectancy in the population affected by increased air pollution. Chronic bronchitis counts the newly diagnosed cases of chronic bronchitis in the population over 18 years of age. Restricted activity days correspond to days when daily activity routines of adult individuals are disrupted due to reasons resulting form air pollution. Taken together, these functions present over 85% of all external costs related to human health. Slopes and unit values of the aforementioned functions are presented in the Table 3.

Table 3. Slopes and unit values of considered CRF's

CRF function	CRF's slope [cases/(year·person·$\mu g \cdot m^3$)]	Unit value [€/case]
PM_{10} – mortality YOLL	2.90E-04	50 000
Sulfates – mortality YOLL	4.83E-04	50 000
Sulfates – restricted activity days	3.32E-02	110
Nitrates – mortality YOLL	1.45E-04	50 000
SO_2 – mortality YOLL	5.34E-06	75 000
Nitrates – restricted activity days	9.89E-03	110
Chronic bronchitis : adults over 18; PM_{10}	1.86E-05	169 330
Chronic bronchitis : adults over 18; sulfates	2.96E-05	169 330
PM_{10} – restricted activity days	1.98E-02	110
Chronic bronchitis – adults over 18; nitrates	1.86E-05	169 330

RESULTS

According to the model, approx. 2.5 billion EURO/yr was spent on emission control in all sectors in 2005. More than 1.1 billion EURO/yr was spent in the energy sector itself. In order to obtain the forecasted emission levels presented in the Table 1 approx. 3.6 billion EUROS/yr. and 6.3 billion EURO/yr will have to be spent in 2010 and 2020, respectively. The costs include mainly the installation and operation of new depollutioning systems, e.g. selective catalytic reduction for NO_x.

Table 4. SO_2, NO_2 and PM_{TSP} control costs [MEuro/yr] for the energy scenario considered

	SO_2			NO_x			PM_{TSP}		
SNAP1 codes	2005	2010	2020	2005	2010	2020	2005	2010	2020
Combustion in energy industries	606.3	688.3	733	36.37	52.78	322.9	467	489.5	457.1
Non-industrial combustion plants	28.81	59.4	92.63				125.3	169.7	254.7
Combustion in manufacturing industry	28.15	35.21	37.55	4.964	9.991	12.81	73.33	72.77	70.88
Production processes	2.72	5.544	5.964	0.58	0.97	1.972	154.9	165.3	159.6
Road transport	121.3	201.1	263.4	708.4	1295	2651			
Other mobile sources and machinery	44.6	77.49	103.7	17.82	163.4	1019			
Extraction and distribution							121	110.7	99.91
Agriculture							8.07	8.07	8.07
Sum	831.8	1067	1236	768.1	1522	4008	949.5	1016	1050

The significant decrease in SO_2 emissions from large combustion sources will have a positive impact on air quality. The annual mean SO_2 concentration due to emissions from the energy sector in 2005 and 2020 is presented in Figure 3.

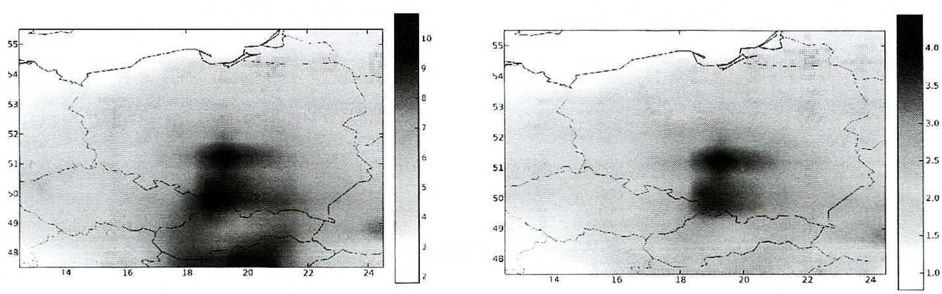

Fig. 3. Annual mean SO_2 concentration [$\mu g/m^3$] due to emissions from the energy sector in 2005 (left) and 2020 (right)

Naturally, the decrease in emissions will impact also the value of the estimated external costs. For the aforementioned assumptions, the external costs in 2020 are lower approx. by 12% and 14.5% than in 2010 and 2005, respectively. This is because more sharp decrease in emissions is forecasted between 2010 and 2020. In general, one can observe that the area with the highest change in the external costs is southern-east part of Poland. One should note that this is highly populated and industrialized area.

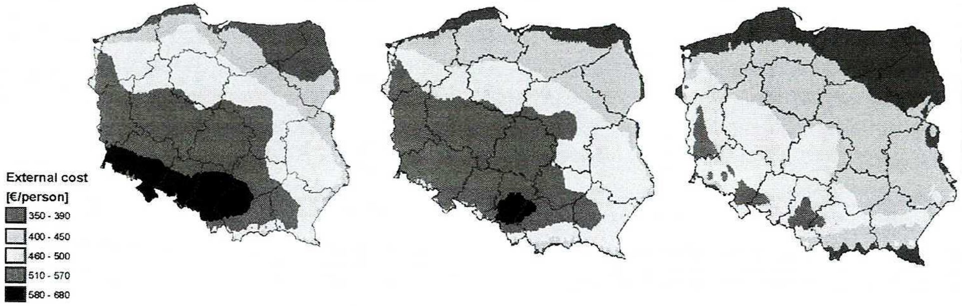

Fig. 4. Estimated external costs for 2005 (left), 2010 (center) and 2020 (right)

Decrease in SO_2 and NO_x emissions will result in lower sulfur and nitrogen depositions (ammonia emissions are planned to stay at nearly the same rate as today). As a consequence the total area of ecosystems with critical loads of acidity exceeded will decrease in forthcoming years.

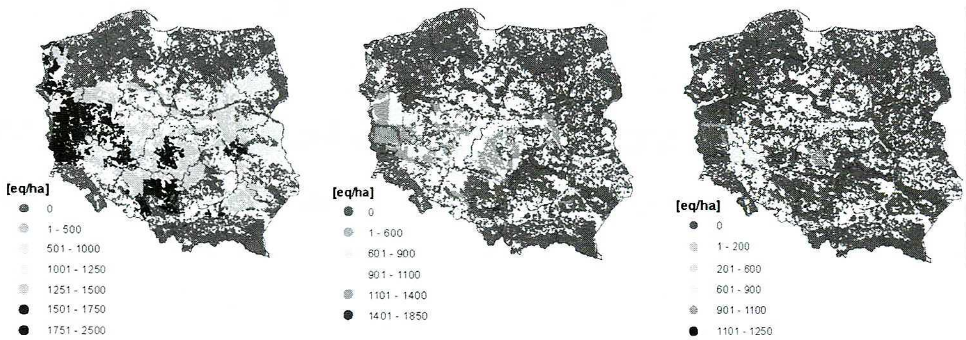

Fig. 5. Exceedances of critical loads of acidity caused by deposition of oxidized and reduced N and S for 2005 (left), 2010 (center) and 2020 (right)

CONCLUSIONS

The results presented in this paper should be treated as preliminary. This notwithstanding, the calculations show that the emissions of air pollutants in Poland will further decrease in the coming two decades. This is a consequence of the current legislation as well as of ongoing structural changes in the energy system. The most significant decrease is foreseen for large combustion installations, in particular for SO_2 and NO_x. Emissions from agriculture are anticipated to remain almost unchanged. It should be highlighted that small non-industrial installations will remain the substantial contributor to air pollution, in particular when PM emissions are considered. In general, however, for the analyzed energy scenario, the number of people negatively affected by air pollution will be reduced. However, one should bear in mind that the calculations were performed at the regional scale, and more precise studies are necessary to analyze situation inside cities. The total area of ecosystems with critical loads of acidity exceeded will decrease in forthcoming years.

The work has been partly financed within the statutory funding of the Faculty of Fuels and Energy AGH #11.11.210.156.

Acknowledgments

I would like to thank Prof. Louis Jestin from EDF Polska and Prof. Adam Gula from AGH UST for giving me technical remarks on the Polish energy sector.

I also acknowledge Prof. Wojciech Mill from the Institute of Environmental Protection and Mr. Ryszard Twarowski from the Institute of Meteorology and Water Management for their support and cooperation on the update of database of critical loads of acidity and eutrophication.

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Received: July 30, 2008; accepted: May 11, 2009.

ZINTEGROWANA ANALIZA ODDZIAŁYWANIA SEKTORA ENERGETYCZNEGO NA ZDROWIE LUDZKIE I ŚRODOWISKO

W artykule przedstawiono rezultaty zintegrowanej analizy oddziaływania emisji z sektorów gospodarczych na życie ludzkie i środowisko. Szczególną uwagę poświęcono sektorowi energetycznemu. Analiza została przeprowadzona przy wykorzystaniu eulerowskiego modelu transportu zanieczyszczeń POLAIR 3D oraz modelu do zintegrowanych badań energetyczno-ekologicznych RAINS. Przedstawiona została wielkość emisji z sektorów w latach 2005, 2010, 2020 dla wybranego scenariusza energetycznego oraz wpływ sektora energetycznego na jakość powietrza. Oszacowano koszty zewnętrzne związane z realizacja scenariusza oraz ukazano regiony, w których ładunki krytyczne dla zakwaszania są przekroczone.