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*Original Research*

# Environmental Challenges of the Polish Energy Sector

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## Abstract

Our paper presents the results of the integrated assessment modelling of environmental and human health impacts of emissions in Poland. The analysis was performed based on the so-called National Scenario. The estimated emission levels of $SO_2$, $NO_x$, and PMs for 2020 were used as the input data to model ambient concentrations and depositions of these pollutants. Exceedances of critical loads of acidity caused by nitrogen and sulphur depositions were calculated. External costs associated with human health impacts of air pollution were estimated. Additionally, ambient concentration of gaseous and particulate Hg were modelled based on 2005 EMEP emissions data. The main part of the analysis was carried out using the Eulerian Chemistry Transport Model POLAIR3D.

**Keywords:** energy sector, emissions, concentrations and depositions, acidification, external costs

## Introduction

During the last two decades a consensus has been reached among public health experts that air pollution, even at current ambient levels, aggravates morbidity (especially respiratory and cardiovascular diseases) and leads to premature mortality [1, 2]. Those negative health impacts are not fully compensated for by the perpetrators (i.e. those who are emitting the pollutants) and can be expressed in monetary term as “external costs.” In order to quantify numerous possible impacts, a new approach called Impact-Pathway Analysis (IPA) has been crafted by the ExternE project [3]. Depositions of nitrogen and sulphur also have harmful effects on the environment. In order to determine the sensitivity of ecosystems to the deposition of acidifying pollutants, the critical loads (CL) approach was developed. It has been defined as “the highest deposition of acidifying compounds that will not cause chemical changes leading to long-term harmful effects on ecosystem structure and function” [4].

In this paper we showed how implementation of the National Scenario (NAT) would have changed the emissions of selected pollutants from sectors in 2020 compared to 2005. These estimated values have been subsequently used to model atmospheric dispersion and resulting ambient concentrations and depositions of pollutants. Finally, we estimated the exceedances of critical levels for acidification and external costs associated with the human health impact.

### National Scenario Description

NAT was built based on the national energy development projections sent on behalf of the Polish Government

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Table 1. Emissions of selected pollutants in 2005 and 2020 according to NAT scenario.

| | $SO_2$ [kton] | | $NO_x$ [kton] | | $PM_{TSP}$ [kton] | | $CO_2$ [Mton] | Hg [kg] |
|---|---|---|---|---|---|---|---|---|
| SNAP1 category | 2005 | 2020 | 2005 | 2020 | 2005 | 2020 | 2020 | 2005 |
| Combustion in energy industries | 892.2 | 503.4 | 340.2 | 144.5 | 39.2 | 28.8 | 190.0 | 8,126 |
| Non - industrial combustion plants | 184.3 | 167.4 | 60.3 | 70.4 | 189.9 | 166.9 | 56.3 | 2,041 |
| Combustion in manufacturing industry | 112.3 | 102.2 | 84.0 | 68.4 | 18.7 | 17.3 | 40.7 | 8,399 |
| Production processes | 43.0 | 46.5 | 8.2 | 5.7 | 34.5 | 31.0 | 26.2 | 1,267 |
| Road transport | 11.6 | 0.2 | 175.5 | 74.9 | 25.3 | 32.0 | 39.9 | |
| Other mobile sources and machinery | 2.4 | 1.1 | 76.0 | 65.7 | 10.0 | 5.3 | 7.8 | |
| Waste treatment | 0.2 | 0.2 | 0.5 | 0.5 | 8.4 | 8.3 | | |
| Agriculture | 0.1 | 0.1 | 0.2 | 0.2 | 63.5 | 63.9 | | |
| Extraction and distribution | | | | | 31.1 | 26.4 | 8.3 | |
| Sum | 1,246.1 | 821.1 | 744.9 | 430.3 | 420.6 | 379.9 | 369.2 | 20,094 |

to IIASA[1] in 2006. It was used by IIASA as a baseline in the process of revising the National Emission Ceiling Directive (NECD). It reflects the national policies as laid down at that time, in the governmental environmental and energy plans. Furthermore, it includes all necessary measures to comply with the Kyoto targets on greenhouse gas emissions. In this scenario, the total primary energy consumption in 2020 equals ca. 4,772 PJ. The total electricity gross generation and heat production in the power sector and district heating plants are 217 TWh and 383 PJ, respectively. The shares of different fuels in total primary energy consumption are: lignite 10%, hard coal 32%, other solids 8%, gas fuels 23%, liquid fuels 26%, and hydro and renewables 1%.

## Estimation of Future Emissions

Emission levels of selected pollutants were estimated with the use of the RAINS model [5], used for several years to support the European Commission and UNCLRTAP in preparation of strategies to combat air pollution. By using Eq. 1 it was possible to estimate emissions based on activity data, uncontrolled emission factors, the removal efficiency of emission control measures and the extent to which such measures are applied.

$$E_p = \sum_k \sum_m A_k \cdot ef_{k,m,p} \cdot x_{k,m,p} \qquad (1)$$

...where:

$E_p$ – emissions of pollutant $p$,

$k, m, p$ – activity type, abatement measure, pollutant, respectively,

$A_k$ – activity level of type $k$ (e.g. coal consumption in power plants),

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

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

The assumed emission abatement measures were proposed by IIASA to fulfil the national environmental policies as laid down in 2006. The estimated emission levels are presented in Table 1.

The last column in Table 1 presents the emissions of mercury as reported in EMEP inventory [6]. Hg was not taken into consideration in the process of NECD revision. We decided to include it in our analysis as the European Commission proposed in 2005 a comprehensive strategy against mercury pollution, which most likely would lead to the necessity of implementation of additional mercury emission controls in coal power plants.

## Dispersion Modelling

The estimated levels of pollutant emissions were then used as input data to the POLAIR3D software to model the way they are dispersed in the atmosphere. The emissions of other pollutants that are not listed in Table 1 but which were necessary to run the model had been taken from EMEP [6]. Polair3D is the chemistry-transport-model that is part of the full modelling system for air quality – Polyphemus. Polair3D tracks multiphase chemistry:

(i) gas,
(ii) water, and
(iii) aerosols.

Gas-phase chemical scheme is RACM. Aerosol chemistry is treated twofold:

(i) inside clouds, aqueous-phase chemical reactions are modelled using the variable size-resolution model (VSRM),
(ii) otherwise, a size-resolved aerosol model (SIREAM) treats the effects of condensation, evaporation, coagulation and nucleation [7].

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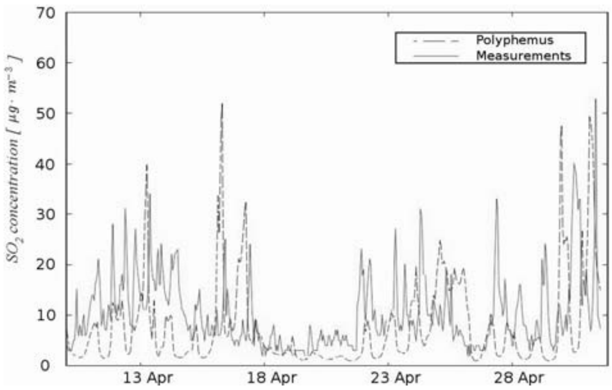


Fig. 1. Comparison of modelled and measured $SO_2$ concentration in April 2005 (Krowodrza measurement station).

A new model for mercury that was developed with the involvement of the authors was applied. The main possible mercury transformations in the aqueous and gaseous phases are presented in [8]. The model was run with a spatial resolution of 0.25º x 0.25º. Each time, i.e. for 2005 and 2020, meteorological data for 2005 was used.

## Validation of Dispersion Model

In order to validate the results of Polyphemus with real measurements, a series of calculations was performed by the authors. For instance, the results of comparison of modelled concentration of $SO_2$, with the measurement recorded by Krowodrza monitoring station of the Regional Inspectorate of Environmental Protection in Kraków, are presented in Fig. 1.

The results of more detailed comparison of modelled and measured annual concentration of main pollutants for EMEP and AirBase measurement stations are presented in [9]. The obtained concentration and deposition levels were subsequently used to calculate the exceedances of critical loads for acidity and to estimate the external costs.

## Environmental and Human Health Impacts

Both sulphur and nitrogen contribute to acidification and no unique acidity critical load can be derived. Therefore, the critical load function was used to calculate exceedances of critical loads of acidity. The updated database of critical loads of acidity in 1x1 km spatial resolution was used [10]. Each cell represented one ecosystem for

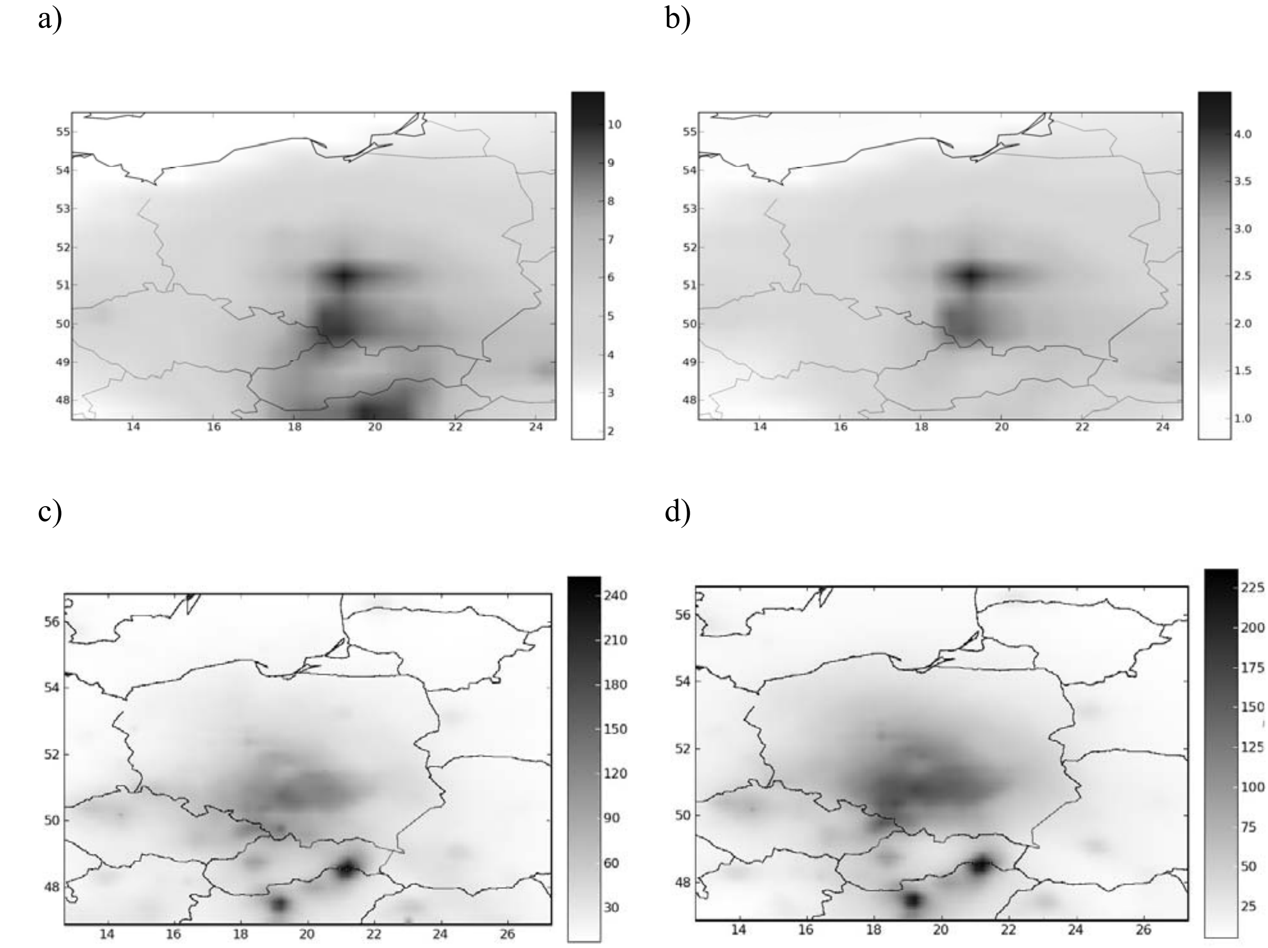


Fig. 2. Annual mean $SO_2$ concentration [μg/m$^3$] due to emissions from the energy sector in 2005 (a) and 2020 (b) and the annual mean concentration [pg/m$^3$] of gaseous mercury $Hg^{++}$ (c) and particulate mercury $Hg_P$ (d) over Poland in 2005.

which the minimal nitrogen deposition and maximal nitrogen and sulphur depositions were given to make the critical load function. The exceedance was calculated with the use of the methodology described in [11].

The analysis of human health impacts was limited to negative effects due to exposure to $SO_2$ and $PM_{10}$ concentrations. Concentration values of these pollutants were put together with population densities, concentration-response functions and unit monetary values for particular impacts. Analyzed external effects 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 effects present more than 85% of all external costs related to human health. Slopes and unit values of aforementioned functions were taken from [12]. For simplicity, it was assumed that the unit costs of impacts in 2020 will be approximately the same as at present. One should bear in mind that both monetary values and CRFs are constantly revised and updated in the ExternE follow-up projects. It should be underlined that besides the pollutants and end points (i.e. YOLL, CB, RAD considered in this study) additional external costs exist. They arise from losses in agricultural production, damage to buildings, negative health effects due to $NO_x$ and – above all – global warming. Analysis of these additional costs will be the subject of our future work.

## Results

The change in ambient $SO_2$ concentration due to emissions from the energy sector between 2005 and 2020 and the calculated annual mean concentration of mercury in 2005 in Poland are presented in Fig. 2.

The estimated sulphur and nitrogen deposition levels in 2005 and 2020 were used to calculate the exceedances of critical loads of acidity. The corresponding results together with the estimated level of external costs per capita are presented in Fig. 3.

## Discussion of Results

Realization of the National Scenario will lead to reducing emission of major air pollutants. As presented in Table 1 the

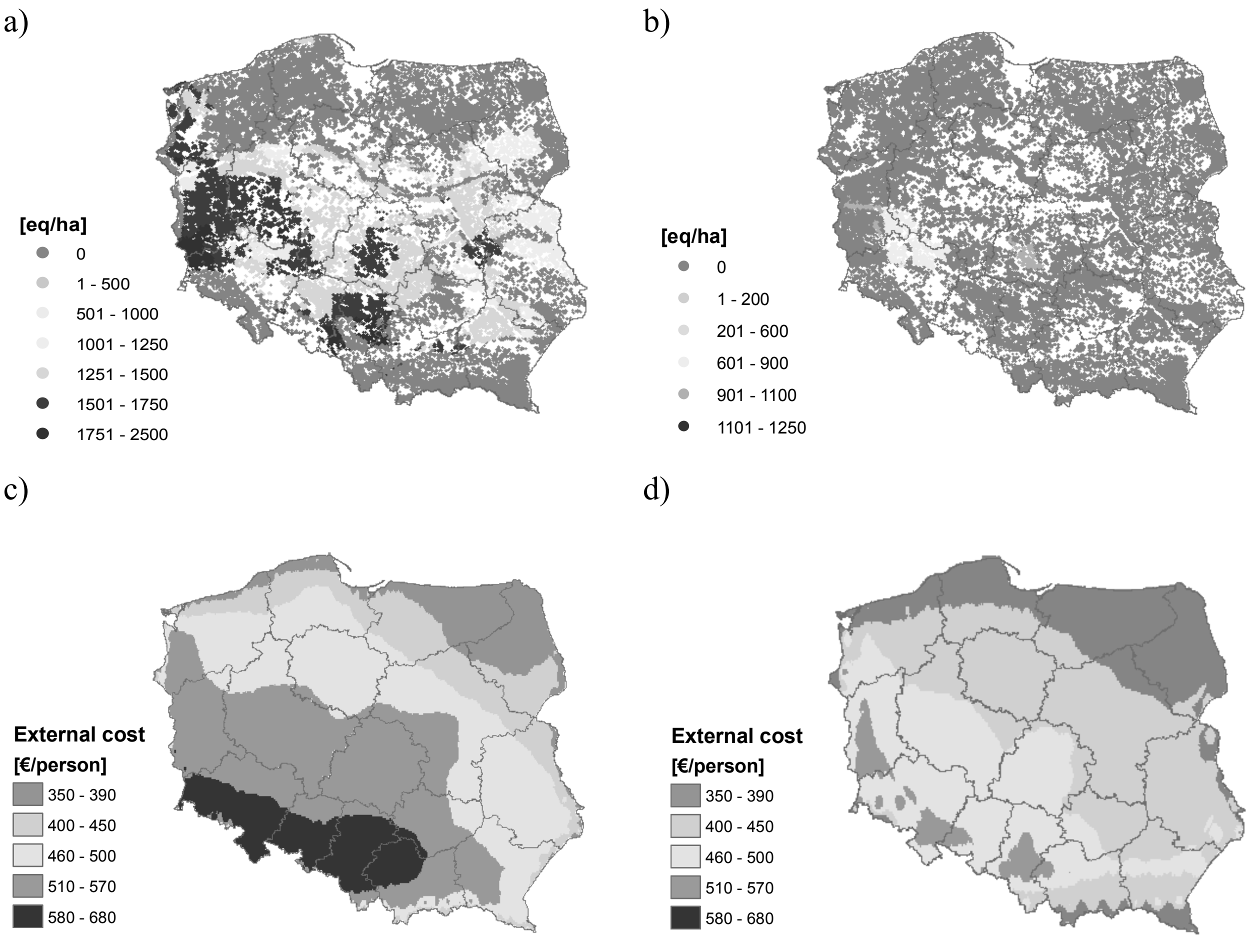


Fig. 3. Excess critical loads of acidity caused by deposition of oxidized and reduced N and S for 2005 (a) and 2020 (b) and external costs estimated for 2005 (c) and 2020 (d).

greatest reduction is expected to take place in the power sector. Increasing numbers of power plants are being equipped with desulphurization systems. As a consequence, one can expect that the $SO_2$ ambient concentration will also be reduced (as presented in Fig. 2a). No prediction on future mercury emission was made. Even though the gaseous metallic part of mercury Hg(0) can be considered a global pollutant due to its long residence time in the atmosphere, its reactive gaseous form $Hg^{++}$ and particulate mercury $Hg_p$ have significant local impact as presented in Figs. 2c, d. One should note, however that reactive gaseous and particulate forms of mercury are water-soluble and deposit by wet and dry deposition. After mercury moves through the water chain it can be transformed by aquatic microorganisms into methyl-mercury (MeHg), which is much more toxic than the other forms. Subsequently, MeHg is concentrated particularly in predatory fish and enters the human food chain and could result in neurotoxic impacts.

The reduction in emissions of acidifying substances will limit the areas where the critical loads of acidity will be exceeded in 2020 compared to 2005 as presented in Fig. 3 a, b. It was estimated that the external costs due to air pollution in the most polluted places in Poland in 2005 equaled to approx. 580 to 680 EUR per capita. Another important consequence of emissions reduction is the decrease of the level of the external costs as presented in Fig. 3d.

## Conclusions

In this study we analyzed the range of positive effects that the adopted emission control legislation, in particular related to the power sector, is expected to have on the environment and human health. Even though the assumed coal consumption in NAT scenario in 2020 is significant, it is possible to mitigate air pollution related problems by implementation of efficient emission reduction technologies. Obviously, the application of such emission controls will increase the internal costs of utilities. On the other hand, it should be taken into account that the external cost will be reduced as well. Such a costs-benefits analysis of different energy scenarios can be carried out with the use of integrated assessment modelling. One should remember that NAT was the baseline scenario, a starting point for establishment of the new emission ceilings in the EU member countries for 2020. Part of our study was devoted to mercury, which is an emerging pollutant. Works on preparation of mercury-related legislation at the EU level are ongoing. Results of first studies on external costs of mercury emissions have been recently published [13]. Further investigation of this issue will be the subject of our future work.

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## References

1. FREDRICH R., BICKEL P. ExternE. Externalities of energy. Methodology 2005 Update, Ed.; Directorate-general for Research. Sustainable Energy Systems: Brussels EUR 21951, **2005**.
2. WHO. Quantification of the health effects of exposure to air pollution. Report. Bilthoven: Ed.; World Health Organization, **2000**.
3. KREWITT W. External costs of energy – do the answers match the questions? Looking back at 10 years of ExternE. Energy Policy **30**, 839, **2002**.
4. NILSSON J., GRENNFELT P. Critical Loads for Sulphur and Nitrogen. Report from a workshop held at Skokloster, Sweden. Miljorapport 15, ISBN 87-7303-248-4, pp. 1-418, **1988**.
5. SCHOPP W., AMANN M., COFAŁA J., HEYES C., KLIMONT Z. Integrated assessment of European air pollution emission control strategies. Environmental Modelling & Software **14**, 1, **1999**.
6. EMEP. http://www.emep.int/.
7. BOUTAHAR J., LACOUR S., MALLET V., QUELO D., ROUSTAN Y., SPORTISSE B. Development and validation of a fully modular platform for numerical modeling of air pollution: Polair3D. Int. J. Environment and Pollution, **22**, (1/2), 17, **2004**.
8. ROUSTAN Y. Modelling of the atmospheric dispersion of mercury, lead and cadmium at European scale. PhD thesis; École nationale des ponts et chaussées, (http://cerea.enpc.fr/fich/these-roustan.pdf), Paris, **2005**.
9. ZYŚK J., STĘŻAŁY A., PLUTA M., WYRWA A., ROUSTAN Y., SPORTISSE B. Air quality modeling system Polyphemus – validation of results. Current problems in air protection. Collective work / Ed. Anna Musialik-Piotrowska and Jan D. Rutkowski; PZITS: Wrocław, pp. 191-194, **2008** [In Polish].
10. MILL W. Update of Database of Critical Loads of Acidity and Eutrophication based on 1x1km spatial resolution. Internal Report of ENVIRO AGH-EDF Project. **2007**.
11. LRTAP Manual on Methodologies and Criteria for Modelling and Mapping Critical Loads & Levels and Air Pollution Effects, Risks and Trends. UNECE Convention on Long – range Transboundary Air Pollution. **2004**.
12. STĘŻAŁY A., WYRWA A., PLUTA M., ZYŚK J., ŚLIŻ B. Externalities of energy production – the hot issue, Ed.; Kiadja az Interregionális Megújuló Energiaklaszter Egyesület: Pecs, pp. 196-206, **2006**.
13. SPADARO J.V., RABL A. Global Health Impacts and Costs Due to Mercury Emissions. Risk Analysis. **28**, (3), 603, **2008**.