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Energy and environment – problems of sustainable development

by

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Abstract: Ecologically sustainable economic development is one of the basic problems related to transformation of Polish economy. Violations of environmental protection standards are mainly due to energy generation and consumption sectors, which are both characterized by low efficiency and high emission of polluting species. In the paper, a computer system, designed as a decision support tool for energy planning on regional scale, is presented. The main functions of the system are: (i) to evaluate the consequences of the selected expansion scenarios of energy demand and energy supply sectors, (ii) to verify potential ability of national economy to meet the assumed scenario, (iii) to suggest the optimal strategy of new investment and technology location that minimize the negative environmental impact.

1. Introduction

Total emission of sulfur and nitrogen oxides in Poland is one of the biggest in Europe. High level of air pollution has a great impact on the environment and affects people's health not only in Poland but also in the neighbouring countries due to the transboundary pollution flows. On the other hand, emissions from major power plants in other European countries and regions (Saxony, Northern Bohemia, Central Slovakia) affect significantly western and south-western regions of Poland, see Klimont, Amann, Cofala, Gyarfas, Klaassen and Schopp (1993), Kuechler, Conredt (1994).

There are several reasons of such a situation. Hard coal and lignite are the main natural resources in Poland and will be utilized as the basic energy carriers in Polish energy sector and households for the decades to come. However, both are characterized by relatively high sulfur contents, compared with that of petroleum and gas, which implies strong environmental consequences. Moreover, most of the power and heat generating plants, as well as local heat generating stations are based on old technologies and are not equipped with desulfurization installations. Coal used to be a cheap energy carrier because in centrally planned economy its production was highly subsidized. As a consequence, low coal prices resulted in low effectiveness of its use, particularly in house-heating, due to the lack of motivation for energy conservation. On the other hand, poor buildings insulation, together with low efficiency of coal-fired home furnaces, were and still are responsible for great local contamination of the atmosphere.

In the present decade there is a strong international pressure to reduce air pollutant emissions to the atmosphere, see Commission of the European Communities (1990), Klimont, Amann, Cofala, Gyarfas, Klaassen and Schopp (1993). The factors which play the main role in investigation of this problem are: (i) availability of technologies that enable utilization of the renewable as well as non-renewable energy sources, necessary to reduce or eliminate the air pollutant emissions, (ii) availability of financial means required in order to introduce these technologies, (iii) air quality control techniques that take into account location of power plants, regional dispersion of air pollution and abatement technology cost.

In the paper, a decision support computer system, designed for investigation of the above problems is discussed, see also Ciechanowicz, Holnicki and Kałuszko (1993), Ciechanowicz, Holnicki, Kałuszko, Partyka, Uhrynowski, Żochowski (1994), Ciechanowicz, Holnicki, Kałuszko, Partyka, Uhrynowski, Żochowski (1994). It allows to analyse various scenarios of energy sector development in the framework of national economy as well as to evaluate the resulting environmental impact. The main functions of the system are:

- to evaluate consequences of the selected expansion scenarios for the energy demand and energy supply sectors,
- to verify potential ability of the national economy to meet the assumed expansion scenario,
- to suggest the optimal strategy of new investments in energy sector and location of new technologies that minimize negative environmental consequences of economy expansion.

An application of the system for analysis of economically acceptable scenarios of energy sector development in Poland for the nearest decades is discussed in the next sections. The resulting level of sulfur oxides emissions is utilized for evaluation of the predicted environmental impact.

2. General characteristics of the system

The computer system discussed is composed of two basic parts: (i) model of national economy that includes energy sector, and (ii) model of air pollution dispersion and evaluation of environmental impact. The main functional blocks of the system, presented in Fig. 1, are as follows: budget, energy demand, energy supply, new technology allocation, simulation of pollutant dispersion patterns, final environmental impact assessment and graphical presentation of the results. The main functions of the system are to determine: (i) scenario of energy sector expansion that enables reduction of energy consumption as well as abatement of environment pollution, (ii) the means necessary to realize the assumed scenario, (iii) economic conditions under which these means are available, (iv) availability of the required technologies of energy production (including renewable resources), (v) optimal location of new investments in energy sector (to minimize environment pollution), (vi) spatial pattern of environmental impact (sulfur oxides concentration and total sulfur deposition) resulting from the considered expansion scenario.

THE BUDGET MODULE simulates the basic econometric parameters of economy. The main goal of this module is: (i) to determine the global production prognosis of all the branches of economy, utilized next as an input to energy demand module, (ii) to verify potential ability of national economy to meet the assumed expansion scenario. The scenarios are created by the respective modification of future behaviour trends of the input variables, such as: materials, energy and fuel costs, financial accumulation of branches, employment, payments, taxes. The main inputs constitute export and domestic consumption forecasts, while the main outputs – global production and financial potential of national economy, see Ciechanowicz, Holnicki and Kałuszko (1993), Ciechanowicz, Holnicki, Kałuszko, Partyka, Uhrynowski, Żochowski (1994).

The main goal of ENERGY DEMAND MODULE is to estimate the consequences of energy sector expansion. The main outputs are: energy demand, predicted costs of primary and secondary energy carriers and pollutant emissions.

The main inputs for ENERGY SUPPLY MODULE are: energy demand forecast, the set of energy generation technologies available, non-renewable and renewable energy sources that can be utilized in expansion scenarios and the forecast of energy carrier prices. The module generates prognosis of energy carrier supply, for liquid and gaseous fuels, electricity and heat, as well as pollutant emissions.

ENVIRONMENTAL IMPACT MODULE generates spatial distribution patterns of air pollution concentration/deposition as a result of the assumed expansion scenario. It is represented by three blocks indicated in Fig. 1: dispersion generation, final environmental impact assessment and the graphical output conversion. The first model calculates year-averaged (or season-averaged) spatial distributions of polluting factors (concentration/deposition) per unit emission, for power installations under consideration. The input data set consists of structural characteristics of the area (geometry, topography, aerodynamical roughness), meteorological data (wind field, precipitation, mixing height, atmospheric stability conditions). The unit dispersion pattern (transfer matrix) for each emission source is pre-processed off-line by a Lagrangian trajectory model. In the next block, for a given expansion scenario, the matrices are multiplied by the respective (for each source) emission intensity and superimposed to form the resulting pollution field. It is presented in the form of isoline concentration/deposition maps by the graphical output block.

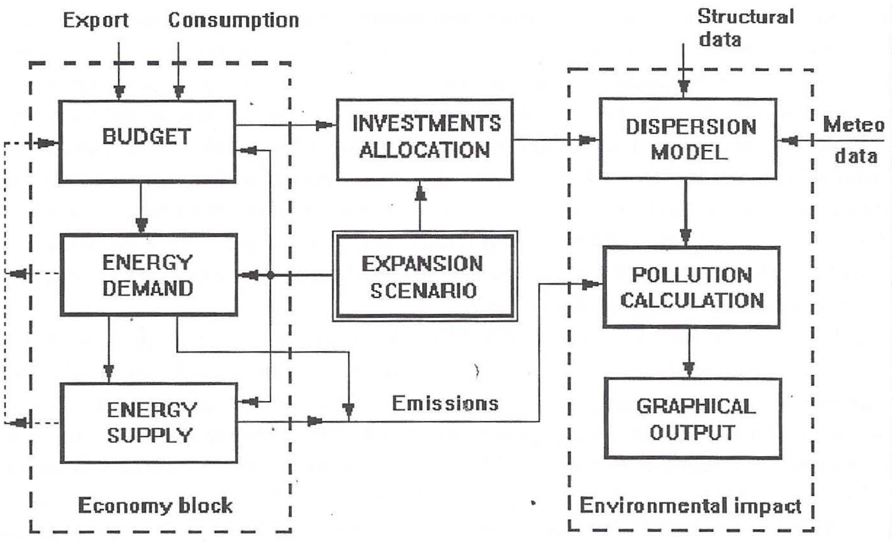


Figure 1. The block diagram of the computer simulation system

3. Selected results of economy expansion simulation

The system has been applied for analysis of economic and environmental consequences of the selected expansion scenarios of energy demand and energy supply sectors in Poland. The simulation was performed for the period 1989 – 2030, discretized with 2.5 year intervals. It is assumed that ability of energy conservation in industry is 10 – 30% of the one of conventional technology, depending on the branch of industry. Moreover, it is assumed that the unit heat demand in residential buildings will decrease within the period of simulation, from 190 – 340 kWh/(m^2·year) to about 50 kWh/(m^2·year).

The following scenarios of energy sector expansion are considered:
Scenario 1. No technological changes are introduced in the energy system,
Scenario 2. Major technological modernization in residential sector is applied: (i) building insulation technologies leading to reduction of the unit heat demand, (ii) central solar heating plants with seasonal storage, assisted by an electric, gas or oil driven heat pump,
Scenario 3. As in Scenario 2, plus energy conservation technologies in all the branches of industry,
Scenario 4. As in Scenario 3, plus the following unconventional technologies: (i) offshore located wind generator farms, (ii) short rotation forestry culture for wood production, utilized then as energy carrier, (iii) chemical conversion of wood to liquid fuels.

Coal demand for four scenarios considered is presented in Fig. 2(a).

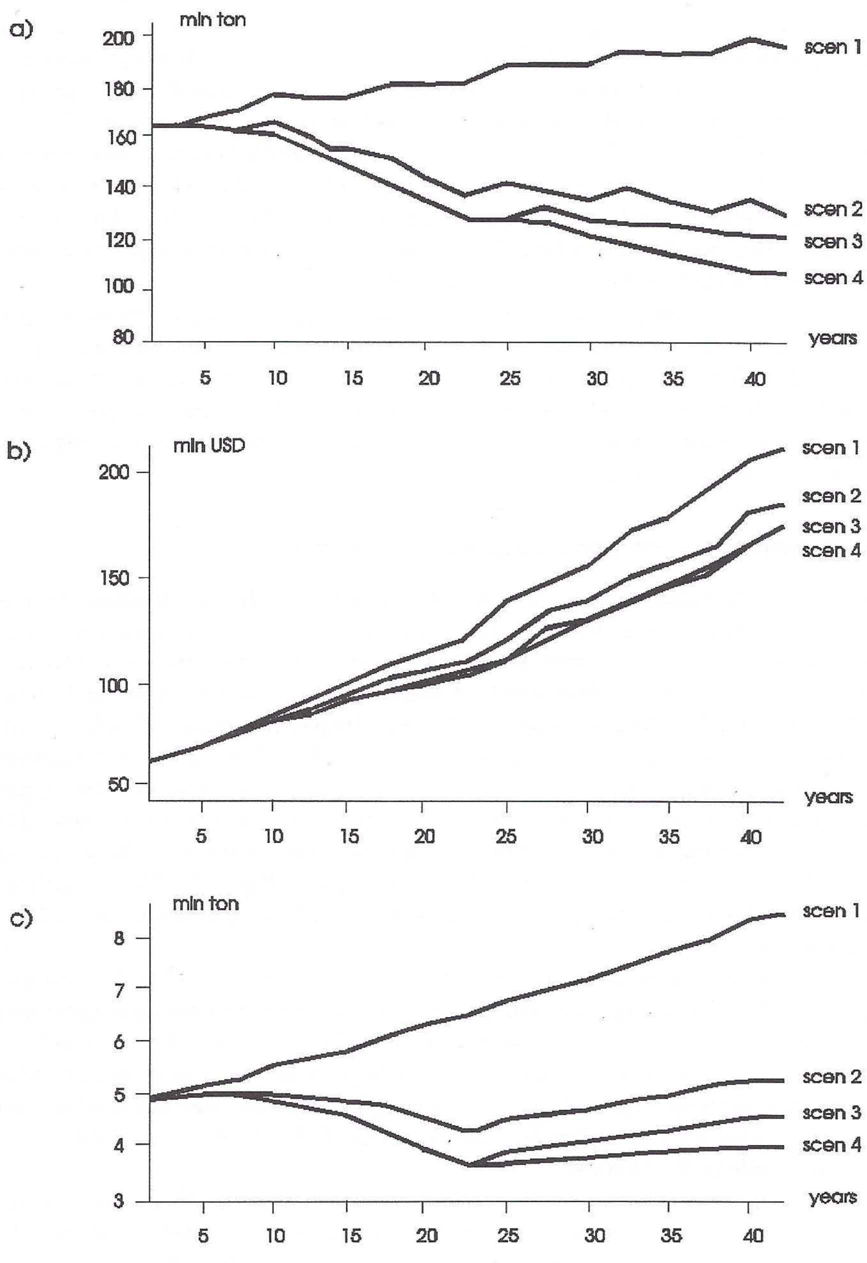


Figure 2. Simulated forecasts of coal demand (a), coal prices (b) and SO_2 emissions (c) for four expansion scenarios (1989)

The figures show the potential possibilities of energy conservation policy. It is evident that the most significant energy savings can be achieved in residential sector, particularly when the suitable building insulation technology would be applied. This is a result of low energy prices (highly subsidized energy production) in centrally planned economy in the past decades. The high level of gas demand in Scenario 2 is due to the assumption of utilizing central solar heating plants, assisted by the gas driven heat pump. Total predicted costs of coal as a primary energy carrier are presented in Fig. 2(b). Observe that the financial profit for Scenarios 2 – 4 can be achieved by energy conservation policy applied in residential sector as well as in the industry.

Figure 2(c) shows the forecasts of the total sulfur dioxide emissions (per year) for the scenarios considered. It can be observed that the energy conservation policy for the residential sector (Scenario 2) can play an important role in emission reduction in comparison to other sectoral policies. Importance of energy conservation is also related to the dominating role of coal combustion in energy generation in Poland.

4. Simulation of environmental effects

Inventory of the existing and planned power plants and district heating stations is applied to characterize the emission field for the current expansion scenario. It is utilized as an input data set to assess the resulting environmental impact. Calculation of the transport of sulfur oxide pollution was carried out by a dynamical, Lagrangian-type, single-layer trajectory model, Ciechanowicz, Holnicki, Kałuszko, Partyka, Uhrynowski, Żochowski (1994), Kuechler, Conredt (1994). The technique was applied to all the individual sources and the aggregated groups of sources to compute the resulting, unit transfer matrices. The rectangular area considered is defined by the coordinate ranges of the longitude $14^o - 24^o$ E and the latitude $49^o - 55^o$ N (compare Fig. 3). Computational domain was discretized by 60 x 60 square grid, with an increment of 11.5 km approximately.

Model calculates year- or season-averaged concentrations of sulfur dioxide and total sulfur deposition, including effects of dry and wet deposition processes. Time horizon of the forecast is discretized with 12h intervals. This is the basic resolution of all the time-dependent meteorological data: mixing height, wind components, atmospheric stability, precipitation intensity. The horizontal wind field trajectories are calculated by interpolation of the observation data from 4 basic meteorological stations.

Basic dispersion computations have been performed for 70 major existing power and heating plants and 10 planned installations (conventional and renewable), resulting from scenarios considered. Also, the transboundary pollution inflow from the neighbouring countries is taken into account. The emissions from residential sector are considered in aggregated form as the background field. The sequence of meteorological data for the year 1989 was assumed as the representative, reference set. The transfer matrices, *emission* $\longrightarrow$ *concentration* (obtained for all the sources for unit emission intensity) were then utilized to calculate the final concentration maps that characterize specific expansion scenario. The final pollution map is then obtained as the superposition of the respective unit matrices, where the coefficients follow from the scenario considered.

In Fig. 3 the initial distribution of SO_2 concentration caused by domestic, public power plants for the year 1989 is presented. Figure 4 shows the transboundary inflow of sulfur dioxide from major power plants in the neighbouring countries. They represent the public power plants in Saxony (Germany), Northern Bohemia (Czech Republic) and Central Slovakia. The respective background SO_2 concentration field, resulting from the residential sector in the initial year 1989 is presented in Fig. 5.

Total SO_2 concentration map for the initial year of simulation presented in Fig. 6 is calculated as a superposition of component maps, Fig. 3 – Fig. 5, respectively. The maps that illustrate environmental impact of Scenario 4, for the years 2010 and 2030, respectively, are presented in Fig. 7. General decrease of concentration observed is a result of energy conservation policy and emission reduction by utilizing "clean" technologies (compare Fig. 2). The decrease of the maximum concentration area in 2030 in comparison with that in 2010 is also a result of the limited share of the major, lignite-based power plants in total emission field.

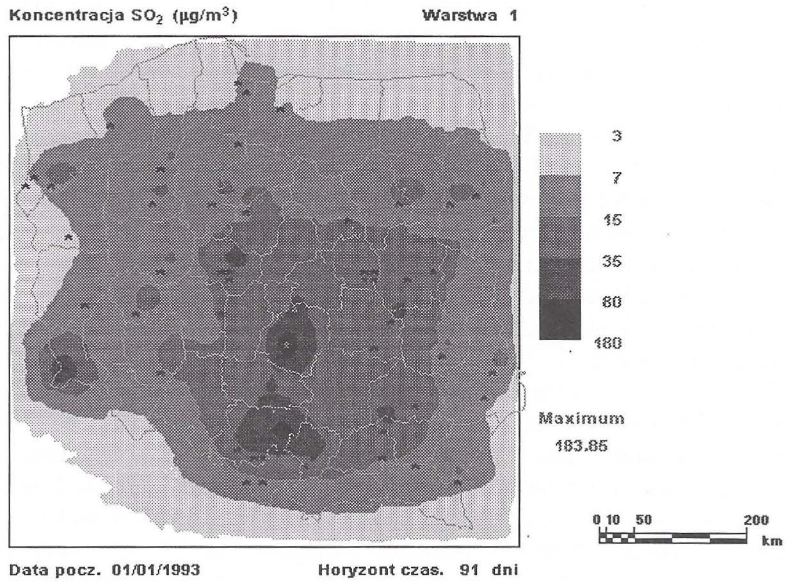


Figure 3. A year-averaged SO_2 concentration from energy sector in Poland (1989)

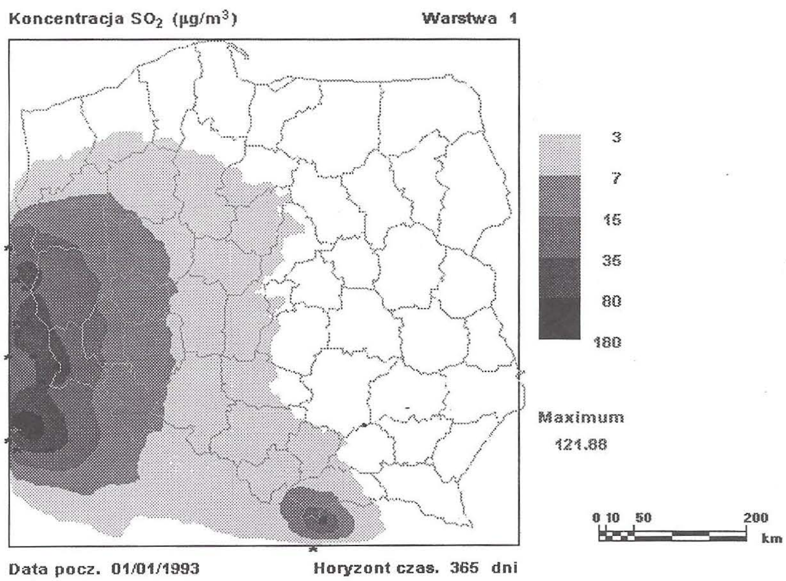


Figure 4. Initial, year-averaged transboundary SO_2 inflow (1989)

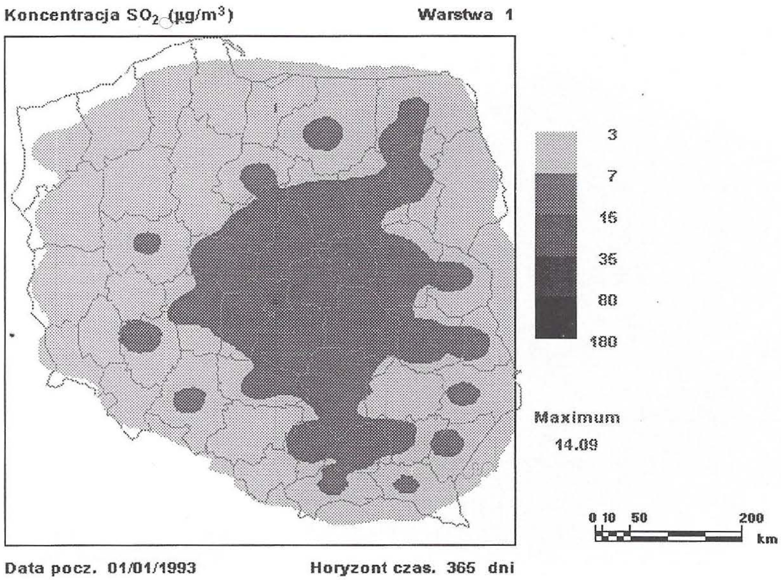


Figure 5. Initial SO_2 concentration from residential sector

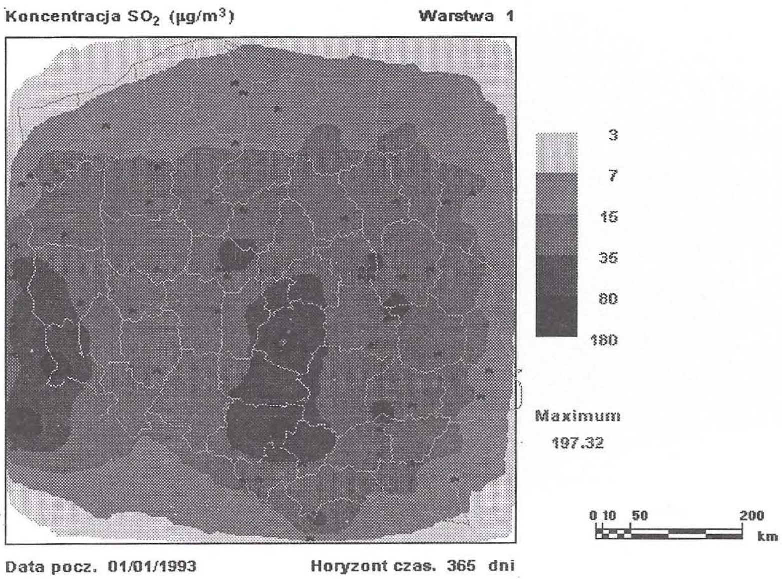
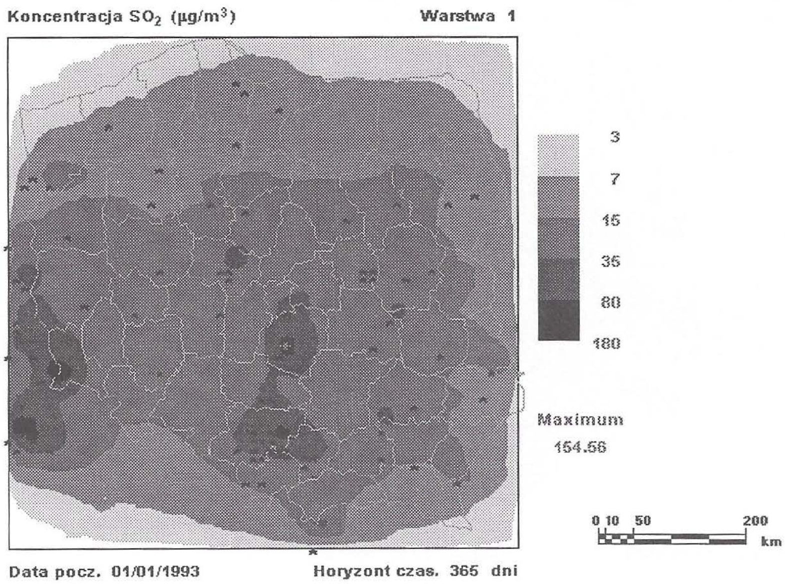


Figure 6. Total, year-averaged SO_2 concentration for initial year



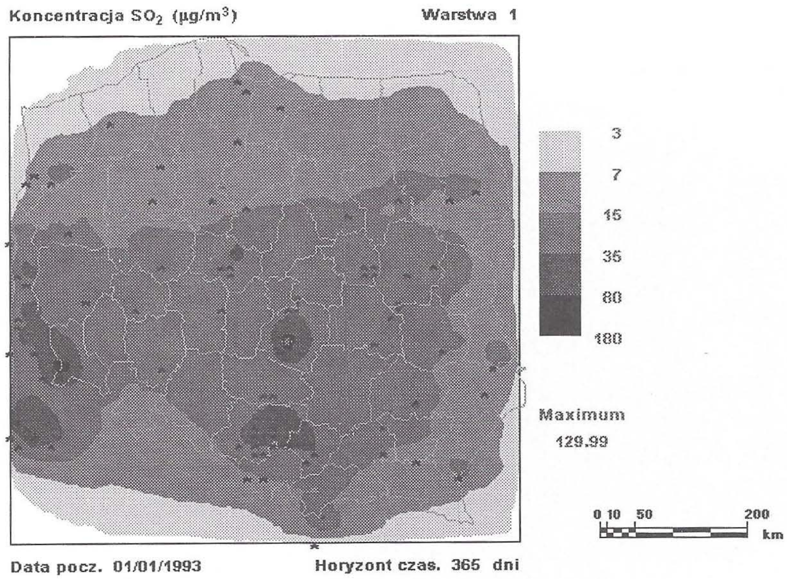


Figure 7. Simulated SO_2 concentration distributions for the years 2010 (top) and 2030 (bottom) for Scenario 4

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