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Environmental benefits resulting from the reduction of air pollution accompanying CO_2 emissions. Analysis with the use of the air quality model for Poland.

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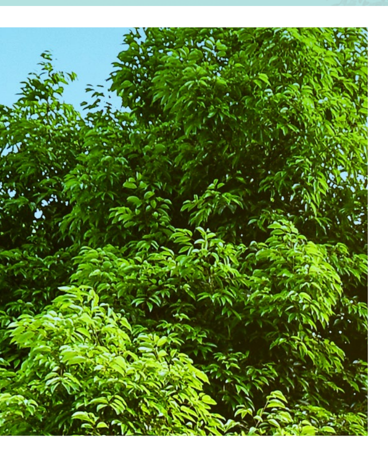

Authors

dr hab. inż. Jacek W. Kamiński, dr inż. Joanna Strużewska, mgr inż. Grzegorz Jeleniewicz, mgr inż. Paweł Durka, mgr inż. Paulina Jagiełło, mgr Aneta Gienibor, mgr inż. Tomasz Majchrzak, mgr Sylwia Kryłowicz, inż. Justyna Tomczyk, mgr inż. Przemysław Chrzan, inż. Paweł Maliński

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Introduction

Air pollution is one of the most important civilisation problems. Numerous studies corroborate the negative impact of air pollution on human health, ecosystems and infrastructure. The population is exposed to the excessive concentrations of atmospheric pollutants in urban areas, both due to the concentration of emissions and high population density. Air pollution has a direct impact on human health causing many respiratory and cardiovascular diseases. Children, the elderly and people with respiratory diseases are most at risk. Health problems caused by exposure to air pollutants result in increased social costs. For the sake of air quality, systematic observation of the state of air pollution is carried out in European countries and legal measures are taken to reduce emissions.

Emissions of substances harmful to human, animal and plant health are being reduced, and at the same time, efforts are being made to limit greenhouse gas emissions that cause global warming. Since the second half of the 20th century a systematic increase in temperature has been recorded. Since the 1990s, the observed trends in climate change, such as increase in air temperature, change in precipitation volume, reduction of ice caps and rising sea levels have been the subject of research by the Intergovernmental Panel for Climate Change (IPCC). The results of these studies are published every few years in the form of Assessment Reports, which include a detailed analysis of observed changes and climate forecasts, broadly understood aspects of adaptation to climate change, as well as recommendations for actions related to mitigation of climate change.

Based on the results of numerous and well-documented scientific studies, the 5th Assessment Report (AR5, 2013) proposes a thesis of a high probability of the dominant influence of human activity on temperature warming observed since the middle of the 20th century[1]. Projections of climate change indicate that climate change mitigation decisions taken in the nearest future will have a significant impact on the trend of changes until the end of the 21st century. At the same time, the Report indicates that none of the emission reduction scenarios considered is sufficient to halt global warming, and the effectiveness of these actions strongly depend on international cooperation in the implementation of the greenhouse gas emission reduction policy.

Both in the case of climate change limitation as well as measures taken to improve air quality, the measures focus on the reduction of pollutant emissions from various types of processes related to the combustion of fossil fuels.

Selected legal acts referring to air protection

The Directive 2008/50/EC of the European Parliament and of the Council of 21 May 2008 on ambient air quality and cleaner air for Europe (OJ L 152, 11.6.2008, p. 1) (hereinafter referred to as the CAFE Directive) indicates in Article 15(1) the National Exposure Reduction Targets for $PM_{2.5}$ for individual countries, determined on the basis of national average exposure indicators. These targets shall be achieved as of 1 January 2020.

In 2016, another piece of legislation was adopted in connection to the reduction of total emissions of air pollutants in order to strengthen measures to improve air quality: the Directive 2016/2284 of the European Parliament and of the Council of 14 December 2016 *on the reduction of national emissions of certain atmospheric pollutants, the amendment of Directive 2003/35/EC and the repeal of Directive 2001/81/EC*[2] (National Emissions Ceilings Directive - NEC). This act aims at further reduction of air pollution and related risks to human health and the environment. The Directive established national emission reduction obligations for each Member State for the following pollutants: sulphur dioxide (SO_2), nitrogen oxides (NO_x), non-methane volatile organic compounds (NMVOC), ammonia (NH_3) and fine dust ($PM_{2.5}$). The achievement of these reduction targets will also contribute to the achievement of the Union's long-term air quality objectives in line with the World Health Organisation (WHO) guidelines.

The reduction of SO_2, NO_x, NH_3 and NMVOC was covered by the repealed Directive 2001/81/EC of the European Parliament and of the Council on national ceilings for emissions of certain atmospheric pollutants[3] (Directive 2001/81/EC).

[1] 'It is extremely likely that human influence has been the dominant cause of the observed warming since the mid-20th century.' (IPCC 2013)
[2] OJ EU L 344 of 17.12.2016, p.9
[3] OJ EU L 390 of 27.11.2001, p.22

The objectives of Directive 2001/81/EC were to reduce emissions of acidifying and eutrophying substances leading to a reduction in exposure to acidifying and eutrophying deposition below a value considered harmful to the environment and to limit emissions of ozone precursors sufficient to reduce ground-level ozone concentrations to the levels recommended by the WHO for the protection of human health and the protection of plants against photochemical pollution. The directive set emission limits for the four pollutants to be met in 2010, taking into account all sources of pollution within the EU, excluding international sea shipping and emissions from aircraft, but taking into account the emissions from the landing and take-off cycles, which are included in the balance sheet.

The NEC Directive is part of the "The Clean Air Policy Package" launched in 2013, which adopted Communication from the Commission to the Council, the European Parliament, the European Economic and Social Committee and the Committee of the Regions - "A Clean Air Programme for Europe", COM(2013) 918 final, as well as Directive (EU) 2015/2193 of the European Parliament and of the Council of 25 November 2015 on the limitation of emissions of certain pollutants into the air from medium combustion plants.

Legal acts adopted in the framework of the "Clean Air Policy Package" continue the Union's long-term policy of improving air quality by achieving levels of air pollution that exclude significant negative impacts on and risks to human health and the environment. Therefore, the system of national emission ceilings laid down in the Directive 2001/81/EC has been amended in order to align the international obligations of the Union and the Member States. The NEC Directive therefore defined national emission reduction commitments for particular pollutants in reference to year the 2005 for years 2020-2029 under the revised Gothenburg Protocol[4], and for 2030 and beyond, it defined a range of individual pollutant reductions based on the estimated reduction potential of each Member State.

National context for the implementation of the NEC Directive

Poland takes an active part in the policy of reducing air pollution through ratification of international treaties and implementation of obligations arising from conventions and directives of the European Parliament.

Under the Treaty of Accession of the Republic of Poland to the European Union[5] Poland was obliged to reduce the pollutants specified in the Directive 2001/81/EC to the level specified in the Gothenburg Protocol[6] (before amendment), i.e. the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the UNECE Convention on Long-range Transboundary Air Pollution[7], drawn up at Geneva on 13 November 1979 (LRTAP). Poland has met these commitments.

Compliant to Directive 2008/50/EC, transposed into national law by the Act of 27 April 2001 Environmental Protection Law (hereinafter: "EPL"), in Poland, air quality in zones is assessed annually. Despite the continuous improvement of air quality in Poland, excessive concentrations of particulate matter PM_{10} and $PM_{2.5}$ and benzo(a)pyrene in winter and excessive levels of ground-level ozone in summer are still an important problem. In addition, there are individual cases of excessive concentrations of nitrogen dioxide, caused mainly by emissions connected to intensive vehicle traffic in the city centre and on major roads near measurement stations. The National $PM_{2.5}$ Average Exposure Index for Poland is also systematically reduced. It has decreased by almost 11% over three years. In order to achieve the National Exposure Reduction Target of 18 μg/m^3 understood as a three-year rolling average of the average of values from all measurement points measuring the average exposure indicator for $PM_{2.5}$ dust it is necessary to take additional measures that will further reduce this indicator.

The primary objective of air protection measures is to reduce emissions of pollutants into the air in a manner enabling to achieve improvements in air quality and ensure compliance with legal standards concerning air quality standards defined by the EU and national law.

In Poland until now, the main fuel used both in the energy generation and transformation sector, industry and the municipal and household sector are solid fuels, i.e. bituminous coal and lignite accounting for about 80% of the country's fuel mix. The use of solid fuels (e.g. gas) is associated with the relatively high emission of pollutants in comparison to other fossil fuels. Therefore, such a high share of solid fuels in the Polish economy is associated with its high emissions. Therefore if

[4] 1999 Protocol to Abate Acidification, Eutrophication and Ground-level Ozone, amended in 2012 (hereinafter referred to as the "Gothenburg Protocol as amended").

[5] OJ EU L 236 of 23.09.2003.

[6] On 30 May 2000 Poland signed the Protocol to Abate Acidification, Eutrophication and Ground-level Ozone to the Convention of the United Nations Economic Commission for Europe (UNECE) on Long-Range Transboundary Air Pollution, drawn up in Geneva on 13 November 1979.

[7] Journal of Laws of 1985. No 60, item 311, Journal of Laws of 1988 r. No 40, item 313 and 314.

is necessary to introduce changes in the fuels used. Poland wants to continue to use coal resources, but with altered technologies of its use and processing, e.g. coal gasification. Strong emphasis is placed on greater use of renewable energy sources and nuclear energy, as well as on the introduction of innovative technological solutions for improving energy efficiency at each stage of product manufacturing.

The planned share of energy from renewable sources is steadily increasing. It is linked, among others, to the obligations of the EU Member States, for which legislative acts lay down a commitment to achieve a target of at least 32% RES use in 2030 in the Union as a whole. Therefore, the Polish Government introduces legislative and non-legislative measures to support the development of renewable energy sources (RES) and to stabilise the reliability of RES sources, the development of dispersed energy and to support innovative solutions in the production of second generation bio-components and other renewable fuels.

Fuel combustion processes occur in various types of installations belonging to all categories of human economic activity, including, in particular, heat and power generation, industry, transport and the municipal and household sector and agriculture. For this reason, the planned measures must relate to particular categories responsible for the largest share of air pollutant emissions. The catalogue of national strategies and policies, as well as actions to achieve reduction targets arising from both the NEC Directive and the achievement of air quality standards set out in Directive 2004/107/EC and Directive 2008/50/EC related to energy production and transformation sectors can be found in the Polish National Energy Policy. Consultations are currently underway on the new Polish National Energy Policy until 2040, which assumes an average annual increase in electricity demand in the years 2018-2040 at the level of 1.7%, and plans to change the fuel mix, including a higher share of renewable energy and nuclear energy sources. Poland must meet the target of 27% share of RES in electricity generation by 2030 and intends to achieve this through the use of photovoltaics and offshore wind farms, and by 2035 the first unit of the nuclear power plant will be commissioned. The implementation of these assumptions will avoid producing or reduce air pollution emissions resulting from the NEC Directive and from climate policy. At the same time, legislative actions based on the implementation of the Directive 2010/75/EU of the European Parliament and of the Council of 24 November 2010 on industrial emissions[8] in reference to new emission standards for SO_2, NO_x, NMVOC, NH_3 and $PM_{2.5}$ will enable the implementation of reduction commitments and will improve air quality in Poland.

For the municipal and household sector, in which large reduction potential has been identified for the reduction of pollutants having a significant impact on air quality, a measure to improve the energy efficiency of residential buildings and to change the fuels used has been developed and implemented. The measure introduced, the so-called "Clean Air" programme, aims at improving air quality by avoiding or reducing the emission of dust and other pollutants introduced into the atmosphere by single-family houses. The programme focuses on complex measures: the replacement of old solid fuel furnaces and boilers and thermomodernisation of single-family buildings. Activities undertaken under this programme include, among others, replacement of an old, high-emission heat boiler, insulation of the house, replacement of windows and doors, installation of renewable energy sources (solar collectors and photovoltaic installations), installation of mechanical ventilation with heat recovery, installation or modernisation of central heating and domestic hot water systems.

Increasing the share of energy from renewable sources in final energy consumption, including transport electrification and an increase in the share of alternative fuels, e.g. hydrogen or natural gas in the form of LNG and CNG, in the consumption of transport, fuels constitute an opportunity to reduce emissions of air pollutants, including greenhouse gas emissions. Emissions of dust, non-methane volatile organic compounds, sulphur oxides and nitrogen oxides hazardous for health can be reduced through more intensive transport sector' efforts towards electromobility and replacement of obsolete rolling stock with that less polluting - vehicles equipped with engines meeting the highest emission standards, hybrid or electric-powered vehicles.

The transport sector, in particular, road transport, contributes significantly to air pollution and is one of the main sectors responsible for the deterioration of air quality in urban areas. Therefore, the Transport Development Strategy by 2020 (with a perspective until 2030), in addition to legislative solutions introducing fuel combustion standards in engines plans to expand the road infrastructure through the construction of city bypasses, as well as the development of motorways, which aim at transferring road traffic out of cities. The "Energy for the Future" Electromobility Development Plan, adopted by the Council of Ministers on 16 March 2017, describing main assumptions, objectives, mechanisms and effects of the introduction of electric vehicles on a large scale, with the aim of achieving the number of 1 million electric cars by 2025 is to support the reduction of emissions from transport in agglomerations.

The National Air Pollution Control Programme (NAPCP) resulting from the provisions of the NEC Directive (2016) is currently under preparation. In particular, it is necessary to maintain favourable trends in terms of improved air quality and reduced health risks coming from exposure to airborne substances harmful to health, i.e. particulate matter PM_{10} and $PM_{2.5}$, benzo(a)pyrene and ozone.

[8] OJ EU L334 of 17.12.2010, p.17

Undertaking the actions mentioned above will allow us to achieve the emission reduction obligations assumed in the NEC Directive and amounting for Poland respectively: for SO_2 in 2020 reduction by 59%, and in 2030 by 70%; in the case of NO_x reduction ceilings were set in 2020 – at the level of 30%, and in 2030 - 39%; for NMVOC – in 2020 - 25%, and 26% - in 2030, and for NH_3 - 2020 - 1%,and in 2030 - 17% and for fine dust $PM_{2.5}$ in 2020 - 16%, and in 2030 - 58%; in reference to 2005.

The implementation of national reduction commitments, as defined in the NEC Directive, in such a short time, will involve huge financial outlays, as well as undertaking legislative and non-legislative measures. In addition, it should be emphasized that only if all intervention directions and the resulting activities are implemented properly, it will be possible to achieve the reduction targets, using all necessary measures defined by the EU and national law.

As part of analyzes related to the preparation of National Air Pollution Control Programmes the IOŚ-PIB conducted a model study on the impact of the assumed reduction of atmospheric pollution emissions on the level of pollutant concentrations in Poland. This report is a pilot study of the results of calculations, focusing on the change of annual average concentrations and the assessment of the contribution of emissions from Poland to the annual background concentrations levels. The applied calculation methodology is consistent with the one adopted for the needs of IOŚ-PIB statutory tasks within the scope of supporting the national policy of air quality management with the use of mathematical modelling of transport and changes of substances in the air (Environmental Law Art. 88 par. 6).

The level of pollutant emissions reduction in Poland

in the context of the NEC Directive requirements

The NEC Directive defines the level of reduction of air pollutant emissions for the following compounds:

- particulate matter $PM_{2.5}$
- nitrogen oxides (NO_x i NO_2)
- sulphur oxides
- non-methane volatile organic compounds (NMVOC)
- ammonia

The expected reduction value is referred to the level of emissions reported for 2005.

EMEP emission inventory in the resolution 0.1° x 0.1° was used[9]. Emission dataset for 2005 (to create forecasts for 2025 and 2030) and the latest available data on emissions in 2016. The use of EMEP emission data - officially reported by individual countries under the Convention on Long-Range Transboundary Air Pollution (CLRTAP) - guarantees the coherence of the inventory methodology on a European scale. 0.1° x 0.1° resolution data is currently the only available EMEP inventory format, prepared in 2018 for the period 2000-2016. This data is currently subject to a comprehensive evaluation as part of works carried out by the Forum for Air quality Modelling (FAIRMODE), because the data values show differences with previously available data: 0.5° x 0.5° resolution, 50km x 50km stereographic polar projection.

The value of the reduction target for individual countries and particular pollutants is included in Annex No 1. The reduction level was applied proportionally to all sectors of activity.

In order to prepare emission scenarios, all the countries included in the reduction strategy were modified according to the NEC Directive coefficients. For countries not included in the NEC Directive, it was assumed that the emission stream in 2025 and 2030 is the same as reported in 2016. In the case of the coarse dust fraction, the reduction factor was assumed to be the same as for $PM_{2.5}$. Due to the lack of references in the NEC Directive to carbon monoxide, no emission reduction was assumed for this compound.

[9] http://www.ceip.at/new_emep-grid/01_grid_data

Figure 1. Total pollutant emission load reported for years 2005 and 2016 and forecasted according to the assumptions of the NEC Directive for 2025 and 2030 in Poland.

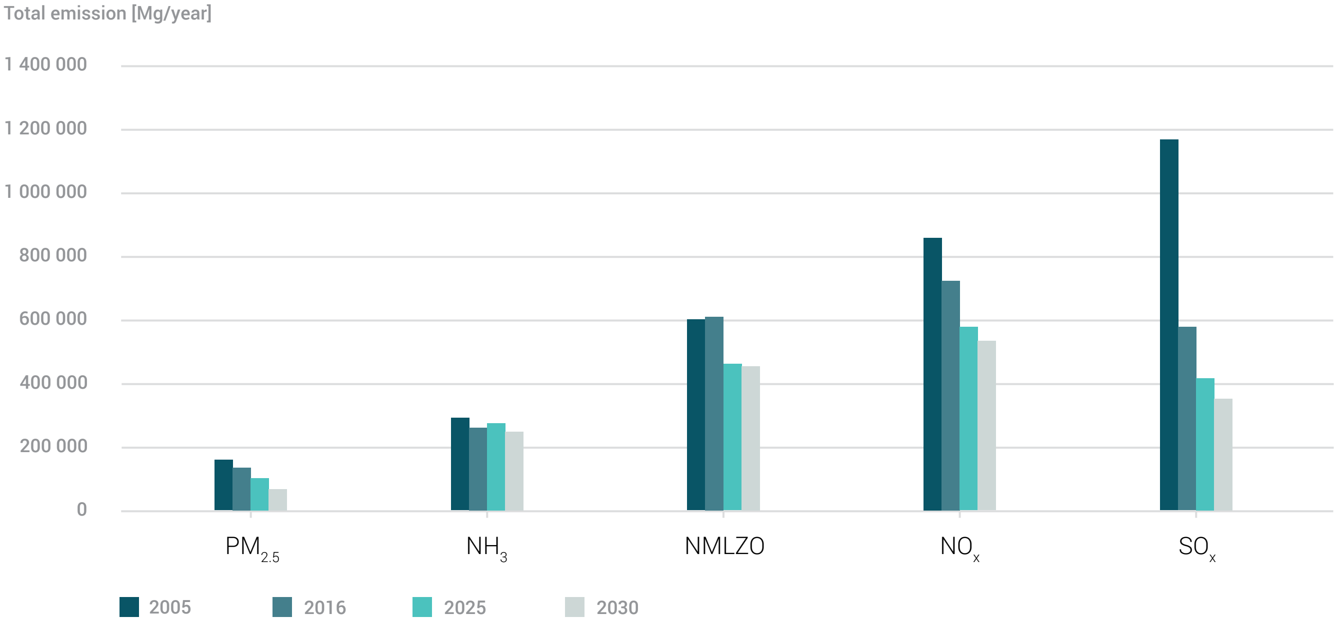


Figure 1 shows a summary of the emissions reported by Poland to EMEP for 2005 and 2016, as well as the amount of the emission load forecasted under the NEC Directive for 2025 and 2030. Depending on the pollution, large differences in terms of reduction can be observed. In the case of sulphur oxides and, to a lesser extent, nitrogen oxides, the expected reduction is very high, and the emission reduction process is progressing significantly, which can be seen when comparing emissions in 2005 and 2016. $PM_{2.5}$ reduction is characterised by a similar range, and the reduction in the horizon from 2025 to 2030 is still significant.

For volatile organic compounds, the emission level in 2005 and 2016 has not changed much and achieving 2025 and 2030 targets would require initiating changes in selected sectors.

Calculation methodology

The air quality model GEM-AQ (Kamiński et al., 2008) was used to calculate the concentrations of pollutants at the ground surface. This model is recognised at the European forum in the Copernicus service (CAMS50 Copernicus Atmosphere Monitoring Service - Regional Production) and in the framework of the European initiative FAIRMODE (Forum for Air Quality Modelling in Europe). In Poland, this model has been repeatedly used for forecasting and analysis of air pollution on a national scale. Currently, it is the basis for the modelling system implemented in IOŚ-PIB for the purposes of statutory tasks compliant to Article 88, paragraph 6 of the Act of 27 April 2001 Environmental Protection Law (i.e. Polish Journal of Laws of 2018, item 799).

Six simulations covering a period of one calendar year were performed:

- three simulations reflected subsequent emission reduction scenarios - 2016 reference scenario and 2025 and 2030 - as a forecast based on the guidelines of the NEC Directive;
- In order to determine the share of domestic emissions in the development of ozone concentration levels in Poland and the impact on pollution in neighbouring countries, as well as to estimate the impact of pollutants from cross-border transport on the observed excessive values over the limits, three additional simulations were performed with all anthropogenic emissions over the territory of Poland excluded. All other elements of model configuration and input data remained unchanged (so-called brute force for sensitivity analysis method for source oriented models).

GEM-AQ Model

The GEM-AQ model is based on the GEM (*Global Environmental Multiscale Model*) numerical weather forecast model operated by the Canadian Meteorological Centre (Côté et al., 1998a, 1998b). In the MAQNet project, the meteorological model was extended with the introduction of a comprehensive tropospheric chemistry module (Kamiński et al., 2008). The GEM-AQ model can be used in a wide range of spatial scales: from global to meso-γ scale. The description of transport and physical processes in GEM-AQ comes from the meteorological model.

Air quality modules are introduced *on-line* into the meteorological model. As far as the gaseous phase chemistry is concerned, it has 35 gaseous compounds transported by advection, deep convection and turbulence diffusion and 15 gaseous compounds not subject to transport due to their short lifespan. The mechanism describing chemical properties of the gaseous phase in the GEM-AQ model is based on the modification of the ADOM model [Acid Deposition and Oxidants Model (Lurmann et al., 1986)]. This model was extended by 4 additional compounds (CH_3OOH, CH_3OH, CH_3O_2, CH_3CO_3H) and 22 reactions. The modified mechanism contains 50 compounds, 116 chemical and 19 photochemical reactions.

The calculation of three-dimensional concentration fields is achieved by solving a system of mass behaviour equations for each of the modelled chemical substances. Advection and vertical diffusion of chemical substances is calculated inside the GEM according to the algorithm used for water vapour advection and diffusion - the semi-Lagrangian scheme has been used. For some chemicals, it is required to calculate additional values depending on current meteorological parameters, i.e. dry deposition velocity, photolysis coefficients.

An integral part of the GEM-AQ model is the aerosol module, which allows the simulation of atmospheric aerosol and its interaction with chemical compounds of the gaseous phase. In particular, it allows to simulate the heterogeneous reaction of N_2O_5 hydrolysis leading to the formation of HNO_3. This reaction takes place on the surface of the atmospheric aerosol and has a very strong impact on the concentration of tropospheric ozone (Jacob, 2000; Thornton et al., 2003). The intensity of the reaction depends on both the concentration and the surface of the aerosol.

Aerosol processes are represented by parameters of nucleation, coagulation, intra-cloud processes, including liquid phase chemistry for sulphur compounds and leaching inside the cloud, as well as sedimentation and dry and wet deposition. Transport processes include advection, turbulence diffusion and deep convection.

Mass distribution is represented in 12 aerosol particle size ranges describing the logarithmic increase in particle radius (Table 1). The modelled values of PM_{10} and $PM_{2.5}$ dust concentrations are calculated as the sum of respective fractions of individual chemical components.

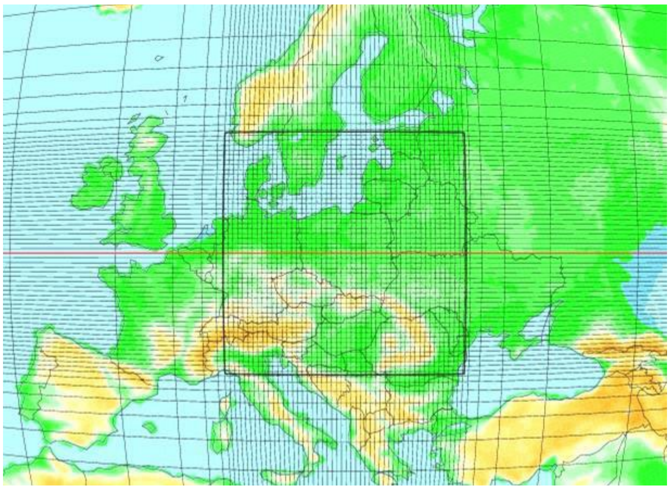
Table 1. Aerosol size distribution in the CAM model.

Range of variability	0.005 - 0.01	0.01 - 0.02	0.02 - 0.04	0.04 - 0.08	0.08 - 0.16	0.16 - 0.32	0.32 - 0.64	0.64 - 1.28	10.28 - 2.56	20.56 - 5.12	55.12 - 10.24	110.24 - 20.48
Average aerodynamic radius	0.0075	0.015	0.03	0.06	0.12	0.24	0.48	0.96	10.92	30.84	70.68	15.36

Configuration of the GEM-AQ model

Calculations with the GEM-AQ model were performed on a variable resolution global grid, with approximately 10 km resolution over Central Europe (Figure 2). This configuration ensures a proper reconstruction of the cross-border inflow. The time step used in the calculations was 600 seconds. For the purpose of this analysis, the 2017 meteorological fields were used for all model simulations.

Figure 2. Variable resolution global grid configuration: the black square covers the high (10 km) resolution area, the red line represents the equator in a rotated coordinate system.



Emission data

With regard to anthropogenic emissions, the latest available data reported by the Member States under the LRTAP Convention were used for Europe.

Since 2018, the EMEP emission base has been released at the resolution, i.e. 0.1° x 0.1° (approx. 10 km). SO_2 and SO_4 emissions were calculated based on emission data for sulphur oxides, whereas NO_x and NO_2 emissions were calculated based on emission data for NO_x. Emissions of non-methane volatile organic compounds (NMVOC) have been disaggregated into substances and groups of substances relevant for modelling of chemical transformations.

Outside Europe, ECLIPSE emissions prepared by IIASA were used (http://www.iiasa.ac.at/web/home/research/researchPrograms/air/ECLIPSEv5.html).

Archiving the results

All meteorological and chemical fields were archived at 1-hour intervals for the following variables:

1) meteorological variables:
- temperature (°C);
- specific humidity (kg/kg);
- pressure (hPa);

2) chemical variables:
- O_3 concentration;
- NO_2 concentration;
- SO_2 concentration;
- PM_{10} concentration;
- $PM_{2.5}$ concentration;

Pollutants' concentration values for the lowest layer of the model, which is to represent values "near the ground", have been converted to μg/m^3 units, taking into account the molecular masses of pollutants and air density calculated on the basis of temporary values of meteorological parameters.

The calculated diagnostics for individual pollutants covered the scope identical to the one performed for the annual assessment of air quality, contained in the Regulation of the Minister of the Environment *on the scope and manner of providing information on air pollution* of 6 June 2018 (Appendix no. 6, point 3), i.e.:

- O_3
  - the number of days on which the maximum daily 8-hourly rolling averages exceeded the target value of 120 μg/m^3;
  - number of days with a maximum daily concentration exceeding 180 μg/m^3 (public information threshold);
  - the number of days with a maximum daily concentration exceeding 240 μg/m^3 (alert threshold);
  - 93.2 percentile in an annual series of daily maximum eight-hour rolling concentration;
  - AOT40 counted in hours between 8:00–20:00 of the Central European Time in the period 01.05–31.07;

- NO_2
  - the number of hours with one-hour values exceeding 200 μg/m^3 in a calendar year;
  - 99.8 percentile of an annual series of one-hour concentration;
  - annual average concentration;

- NO_x
  - annual average concentration;

- SO_2
  - the number of hours with the one-hour value exceeding 350 µg/m^3 in a calendar year;
  - the number of days with daily values exceeding 125 µg/m^3 in a calendar year;
  - 99.7 percentile from an annual series of one-hour concentrations;
  - 99.2 percentile from an annual series of one-hour concentrations;
  - average concentration in the winter period (01.10–31.03);
  - annual average concentration.
- PM_{10}
  - the number of days with daily values exceeding 50 µg/m^3 in a calendar year;
  - 90.4 percentile of the annual series of daily concentrations;
  - annual average concentration;
- $PM_{2.5}$
  - annual average concentration.

In this report, the preliminary analysis focuses only on the change in annual average concentrations of $PM_{2.5}$, PM_{10}, NO_2, NO_x, SO_2 and the level of exposure due to health and plant protection for ozone.

Analysis of results

On the basis of the results of modelling for 1-hour values, the following have been carried out for the area of Poland:

- maps of the analysed diagnostics (in the case of this analysis, annual averages of NO_2, NO_x, SO_2, PM_{10} and $PM_{2.5}$ and the level of exposure due to health and plant protection for ozone);

- maps of concentration differences between the base year emission status (2016) and emission scenarios (2025 and 2030). Relative differences were calculated as averaged values for the whole year, expressed by the mathematical formula:

$$RD = \frac{C_{2025\,|\,2030} - C_{2016}}{C_{2016}} \; 100\%$$

where: C – the 1-hour concentration value for the pollutant in the relevant emission scenario.

Positive values of the measure defined in this way indicate an increase in pollution in a given scenario, while negative values indicate a decrease in relation to the scenario on the basis of emissions for 2016.

- maps of the share of emissions from Poland in the development of pollution concentration in the region. Relative differences were calculated as averaged values for the whole year, expressed by the mathematical formula:

$$TRD = \frac{C_{noPL} - C}{C} \; 100\%$$

Positive values of a measure defined in this way may occur for secondary pollutants and indicate an increase in pollution as a result of emission reductions over Poland, while the level of negative values indicates the level of impact of emission reductions from Poland on the level of pollution.

The preliminary evaluation of the reference scenario based on the concentration data from National Monitoring System network (PMŚ) indicate an underestimation of the calculated annual average concentrations. Using the same emission dataset, similar tendencies were obtained with the EMEP model, which underestimated annual concentrations over Europe, especially for PM_{10} and $PM_{2.5}$ (EMEP Status Report 1/2018). The EMEP report also points to doubts regarding the spatial distribution of Poland's emissions from road transport sector (at 0.1° x 0.1° resolution), which may affect the spatial distribution of nitrogen oxides and ozone. Also, concentrations similar to the reference scenario for the area of Poland were obtained using a different inventory and 7 other models used in Europe. These results are published as Copernicus Atmosphere Monitoring Service reanalysis products. This may indicate a wider problem with the correct representation of emissions in Poland, which has not been correctly diagnosed due to the lack of verification of reported emissions using European-scale and country scale modelling.

The presented annual average concentrations differ from the results of the annual assessment published by the Chief Inspectorate of Environmental Protection (GIOŚ), which results not only from the use of different emission inventory but also a different modelling approach and spatial resolution of computation grid (1 km over the voivodeship, 0.5 km over urban agglomerations and cities with a population above 100 thousand vs. 10km for NEC analysis). Higher resolution modelling allows for much more accurate capture of areas characterized by high concentrations of pollutants.

Despite the uncertainty of modelling results for the base year, the values of relative differences of pollutants concentrations obtained for emission reduction scenarios can be the used as a basis to conclude on relative the decrease in environmental exposure related to air quality.

Annual average PM_{10} concentrations

In the northern, eastern and western parts of the country, in the reference scenario 2016, the annual average concentration values of PM_{10} dust ranged from 5.2 to 10 µg/m^3. On the other hand, in central and southern parts of Poland higher concentrations, from 10 to 15 µg/m^3, were recorded, and in small areas, they reached as much as 20 µg/m^3. As mentioned before, these values are lower than observed, which is due to the uncertainty related to the new and not fully verified EMEP emission inventory. The forecast for 2025 and 2030 shows a decrease in dust concentration. In 2030, practically all over Poland, the concentration values of PM_{10} dust will not exceed 10 µg/m^3, except for small areas in the south of the country, where concentrations of up to 15 µg/m^3 are forecasted. The percent differences from the baseline status are described below.

In the analysis of the impact of cross-border pollution, the forecasted changes present an increase in the impact of pollution from outside Poland. In 2016, in the west of the country and in the north-eastern part of Poland, the value of the index of the impact of emissions from Poland on the level of PM_{10} dust ranges from -24.9 to -10, while in the remaining part of the country ranges -49.9 to -25. In 2030, in the centre and in the south of the country, the values of the coefficient of average daily concentration levels for dust are forecasted in the range from -49.9 to -25, and in the remaining part of Poland from -24.9 to -10.

Figure 3. presents spatial distribution of the annual average concentration of PM_{10} dust (left side) and the spatial distribution of Poland's emissions in the 24-hour average concentration level for PM_{10} dust (right side) in 2016, 2025 and 2030.

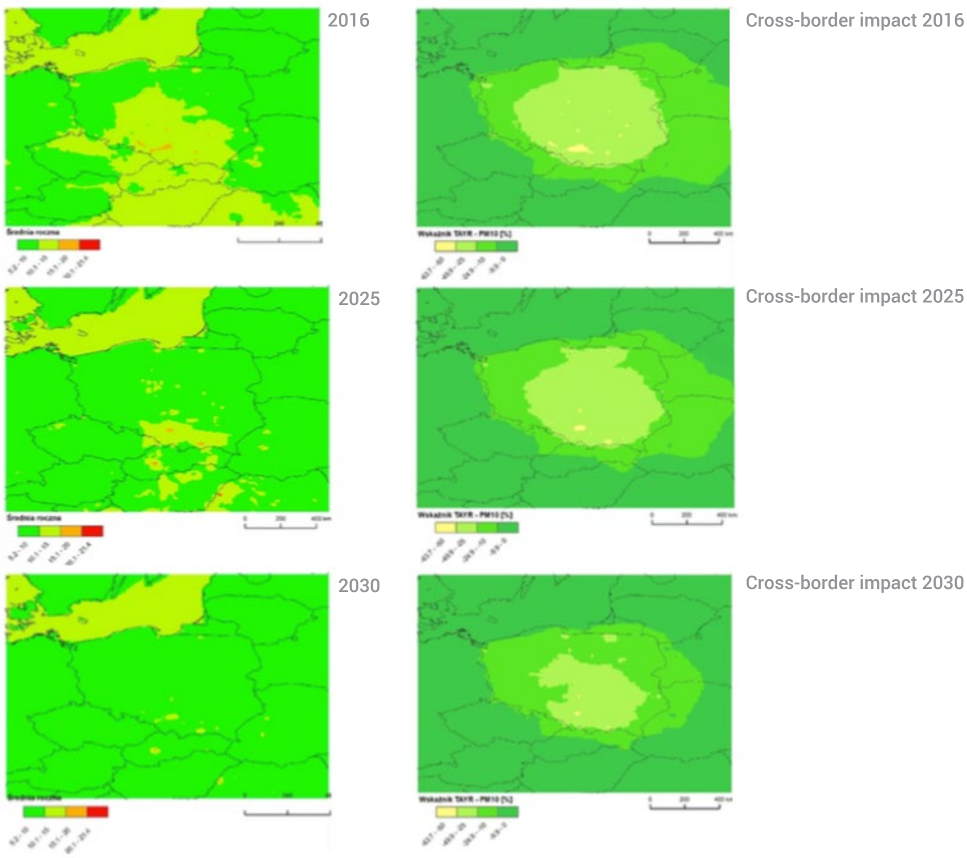
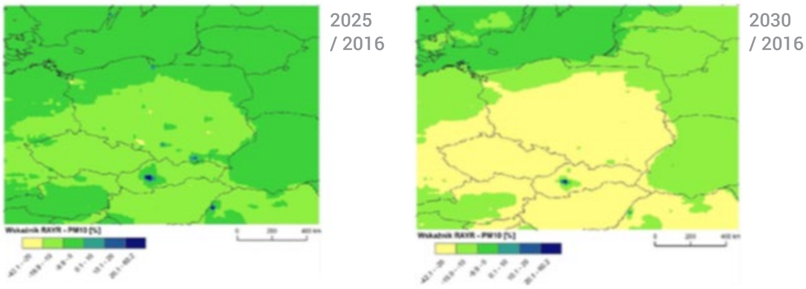


Figure 4 shows a decrease in the average annual concentration of PM_{10} dust in 2025 and 2030 compared to 2016. In 2025, in the north of the country an improvement of at most up to 10% is forecasted, and in the remaining territory of the country: up to 10-20%. In 2030, further improvement of annual average concentration levels by 10-20% is forecasted in the north of the country and by 20-40% in the remaining territory of Poland.

Figure 4. Relative change in average annual concentration of PM_{10} in 2025 (left panel) and 2030 (right panel) compared to 2016.

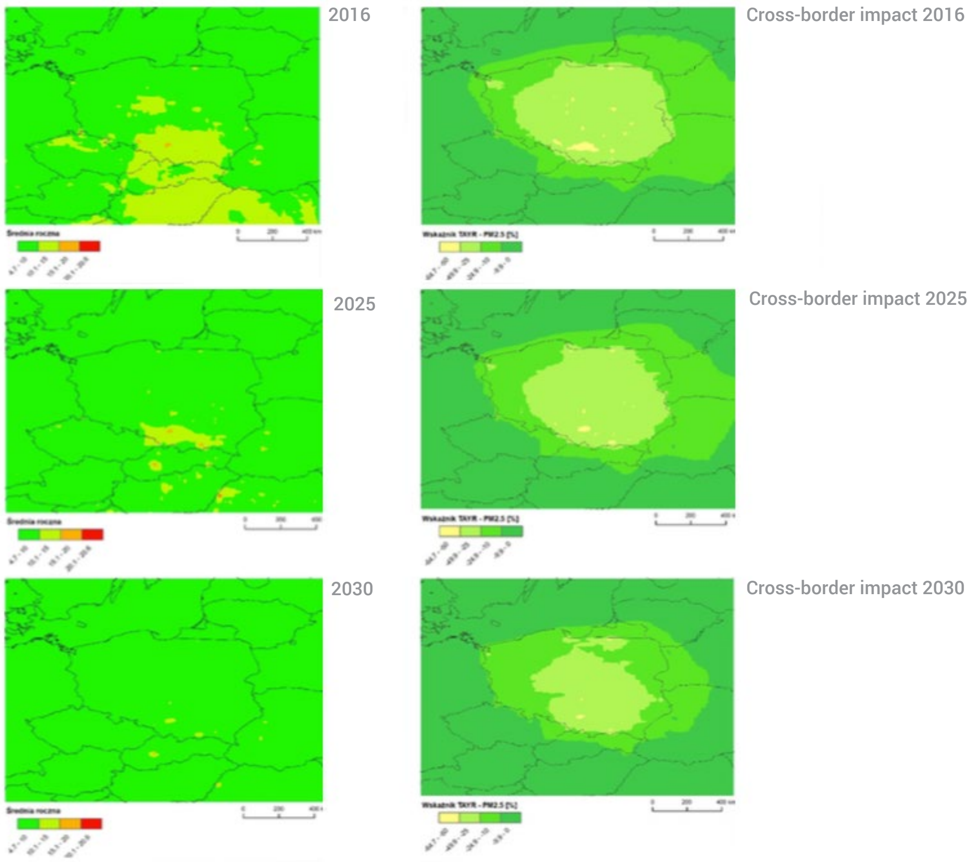


Annual average $PM_{2.5}$ concentrations

In 2016, the highest concentrations of $PM_{2.5}$ dust were recorded in Silesian, Małopolskie, Podkarpackie and Świętokrzyskie Voivodships and in the centre of the country. Concentration values ranged from 10 to 15 µg/m^3, but there were small areas where concentrations reached 15-20 µg/m^3 (Silesian Voivodship). In the remaining territory of Poland $PM_{2.5}$ concentrations ranged from 4.7-10 µg/m^3. As in the case of PM_{10}, the modelled values are lower than the concentration levels obtained using data from the measurements at the stations. In 2025 a significant improvement can be observed. Increased concentrations are forecasted for the Silesian and Małopolskie Voivodships. However, in 2030, the average annual concentration of $PM_{2.5}$ dust will not exceed 10 µg/m^3 throughout the country. The percent differences from the baseline status are described below.

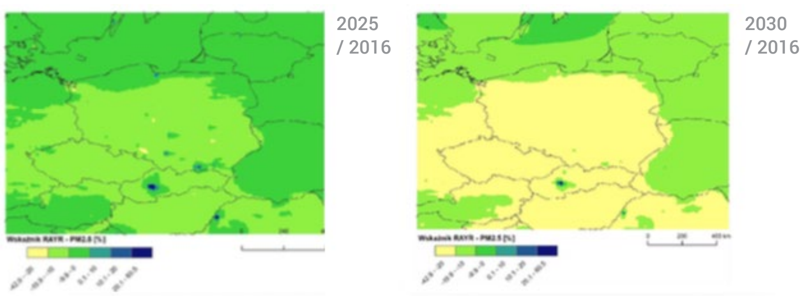
The analysis of the impact of cross-border pollution shows forecasted increase in the impact of incoming pollution. In 2016, in the eastern and central parts of Poland, the share of emissions from Poland in the average annual level of emissions for $PM_{2.5}$ dust reached values ranging from -50 to -25. In the western part of the country, the value of the index reached levels from -25 to -10. In the following years 2025 and 2030, the impact of cross-border pollution is expected to increase. The index is forecasted to increase in the eastern and western part of the country, while in the central part of Poland the values will not change until 2030.

Figure 5. Spatial distribution of annual average $PM_{2.5}$ dust concentration (left side) and TAYR indicator distribution for $PM_{2.5}$ dust concentration (right side) in 2016, 2025 and 2030.



Forecasts until 2025 and 2030 show a reduction in the average annual concentration of $PM_{2.5}$ dust compared to 2016 (Figure 11). In 2025, the concentration of $PM_{2.5}$ dust in the north of the country will decrease by 0-10%, while in the remaining part of the country it will drop by 10-20%. In 2030, in the north of the country the concentration of $PM_{2.5}$ will drop by 10-20%, and on the remaining territory of Poland: by 20-42% compared to 2016.

Figure 6. Relative change in average annual concentration of $PM_{2.5}$ in 2025 (left panel) and 2030 (right panel) compared to 2016.

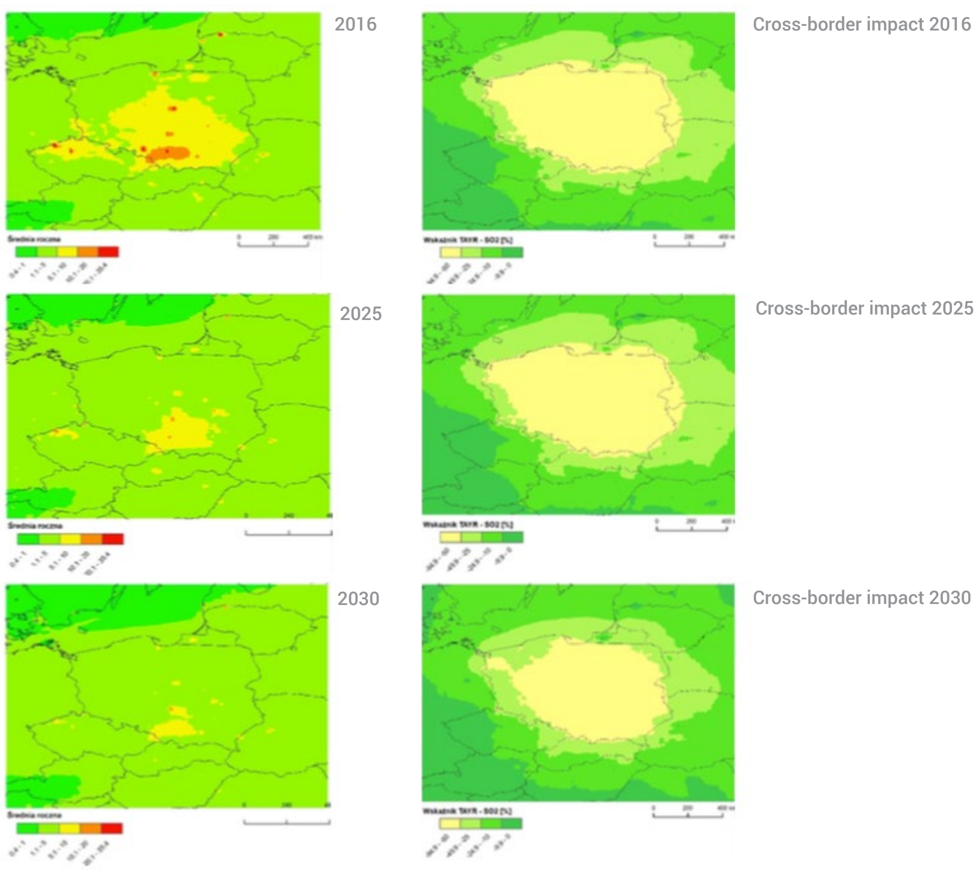


Annual average SO_2 concentrations

In 2016, the highest average annual concentrations of sulphur dioxide, even up to 35.4 μg/m^3, were recorded in the Silesian and Małopolskie Voivodships, as well as in the centre of the country and the Gdańsk Bay. Lower values, up to 5 μg/m^3, were recorded in the northeast and north-west of the country. In contrast to particulate matter concentrations, annual average SO_2 concentrations indicate overestimation. The forecast for 2030 shows a decrease in concentrations of sulphur dioxide. In 2030, almost all over the country SO_2 concentrations will not exceed 5 μg/m^3, with the exception of the Silesian Voivodship, where concentrations will reach the values of up to 10 μg/m^3.

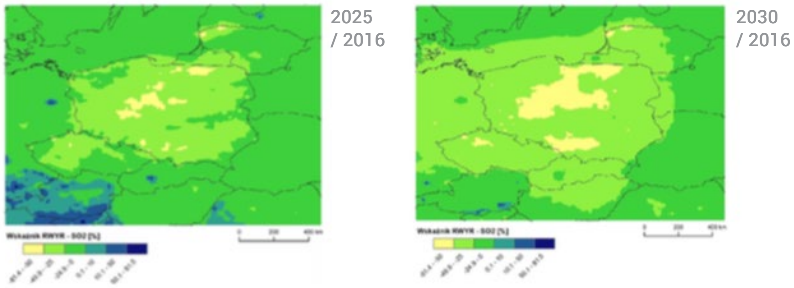
The impact of cross-border pollution in 2016 was very low. On almost the whole territory of Poland, the index values ranged from -100 to -50% with the exception of the area near the western border, where the cross-border impact of SO_2 concentrations resulted in values ranging from -49.9 to -25%. The forecast until 2030 shows a very slight deterioration of this indicator. The impact of incoming pollution will increase at the western extremities of the country, at the Baltic Sea shores and in Suwałki - the value of the index of the share of emissions from Poland in the average annual level varies from -49.9 to -25. The percent differences from the baseline status are described below.

Figure 7. Spatial distribution of the average annual concentration of sulphur dioxide (left side) and spatial distribution of the impact index of the share of emissions from Poland for sulphur dioxide (right side) in 2016, 2025 and 2030.



Forecasted changes in the average annual concentration of SO_2 resulting from the reduction in emissions of this pollutant (Figure 6) show an improvement of up to 82% in 2025. The largest difference is forecasted in the centre of the country and in the Mazurian Lake District, while the smallest - in the east and north-west. In 2030, as in 2025, the largest changes, up to 82%, will occur in the centre and in the Mazurian Lake District and in the Silesian Voivodship. On the remaining territory of Poland forecasted changes will amount to 25 up to 50%.

Figure 8. Relative change in average annual SO_2 concentration in 2025 (left panel) and 2030 (right panel) compared to 2016.



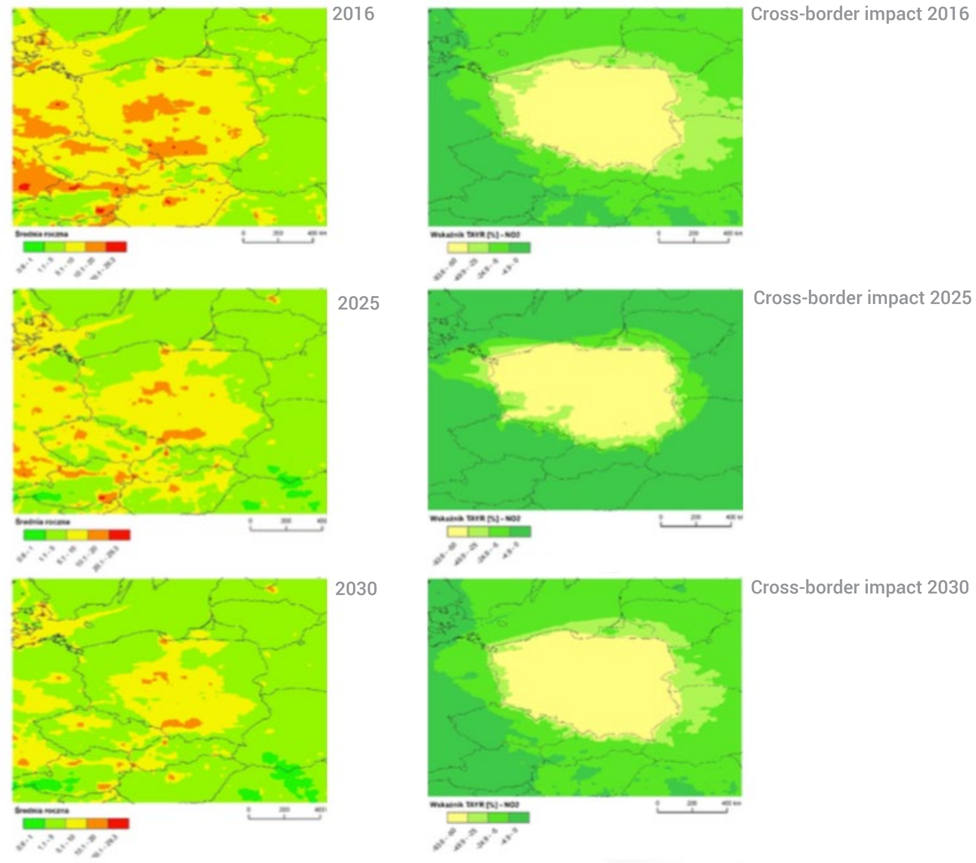
Annual average NO_2 concentrations

In 2016, the highest concentrations of nitrogen dioxide were recorded in the central and southern parts of the country, particularly in the Silesian, Małopolskie and Wielkopolskie Voivodships. Concentrations in these areas ranged from 10 to 20 μg/m^3, but there are also places where concentrations reached 29 μg/m^3. The lowest concentrations, up to 5 μg/m^3, were recorded in the coastal territory and in the north-eastern part of the country. On the remaining territory of Poland, NO_2 concentrations ranged from 5 to 10 μg/m^3. The concentrations of nitrogen oxides reported in Poland's annual air quality assessment are higher. These discrepancies between model results and the observations are most probably related to the uncertainty of the EMEP inventory, as other European models e.g. EMEP model were also unable to reproduce nitrogen oxides' concentrations based on this emission dataset.

In the following years, a decrease in NO_2 concentration can be observed. In 2025, the forecasted values will not exceed 5 μg/m^3 in most of the northern part of the country: West Pomeranian and Pomeranian Voivodships and in the eastern and southern parts of the country. On the other hand, in areas of the country with the highest forecasted concentrations, the values will reach maximum levels of 20 μg/m^3. In 2030, in the eastern and western territory of Poland, the forecasted values of NO_2 concentrations will not exceed 5 μg/m^3. A significant reduction of nitrogen dioxide is forecasted throughout the country. The percent differences from the baseline status are described below.

The analysis of the indicator of the share of emissions from Poland in the average annual level of NO_2 emissions for the 2016-2030 shows a reduction in the impact of cross-border pollution. A small impact of cross-border pollution was recorded in 2016 in the western part of Poland and at the Baltic Sea coast, while in 2020 the impact of this pollution is forecasted in the southern part of Poland. In 2030, only at the western border of Poland, a small impact of cross-border pollution is forecasted, and in the remaining part of the country, the values of the national emission share index are forecasted to range from -100 to -50%.

Figure 9. Spatial distribution of average annual concentration of nitrogen dioxide (left side) and spatial distribution of TAYR index for NO_2 (right side) in 2016, 2025 and 2030.

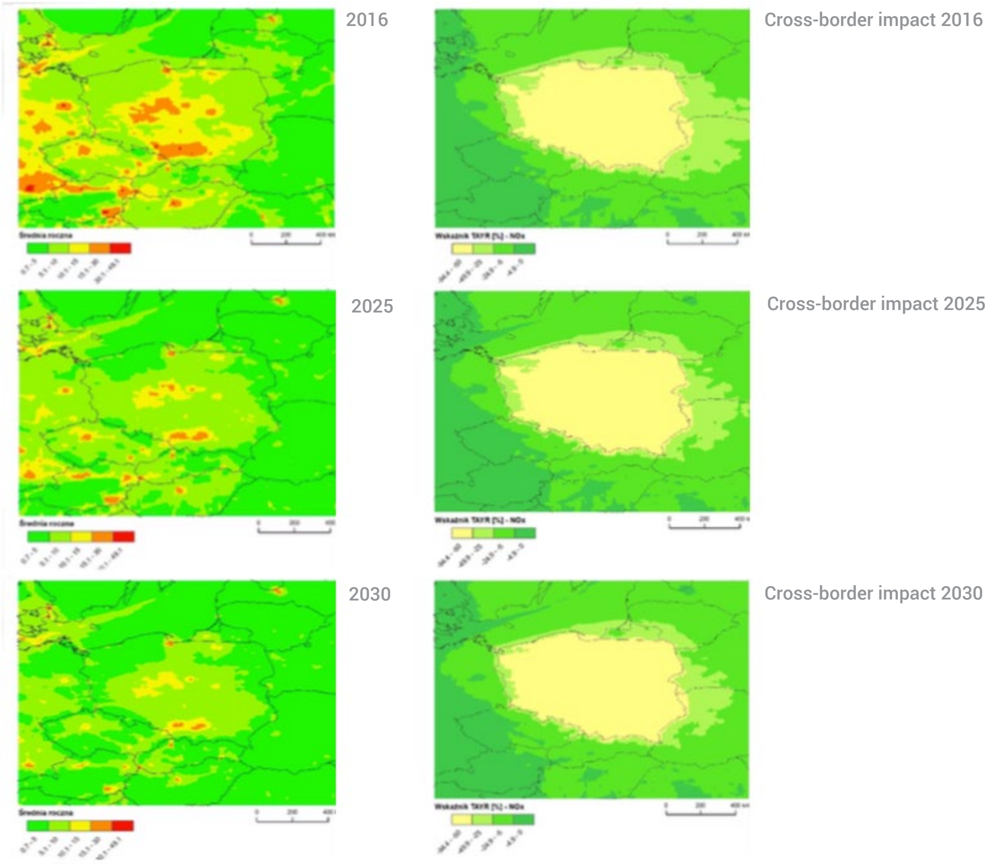


Annual average NO_x concentrations

In 2016, the highest concentrations of nitrogen oxides were recorded in the central and southern territory of the country, particularly in the Silesian, Małopolska and Wielkopolska Voivodships. Concentrations in these areas ranged mainly from 15 to 30 μg/m^3, but there are also places where concentrations reached 49 μg/m^3. The lowest concentrations, from 5 to 10 μg/m^3, were recorded in the western and eastern part of Poland. In 2025, the highest concentrations, up to 30 μg/m^3 are forecasted in the Silesian Voivodship and in the central part of the country. In the east of Poland and in Baltic Sea shore areas, the forecasted NO_x concentrations will not exceed 5 μg/m^3. In 2030, the forecasted NO_x concentrations are significantly lower on the whole territory of Poland. According to the forecast, over small areas in the Silesian Voivodship the concentration of nitrogen oxides will reach the maximum value of 30 μg/m^3. The percent differences from the baseline status are described below.

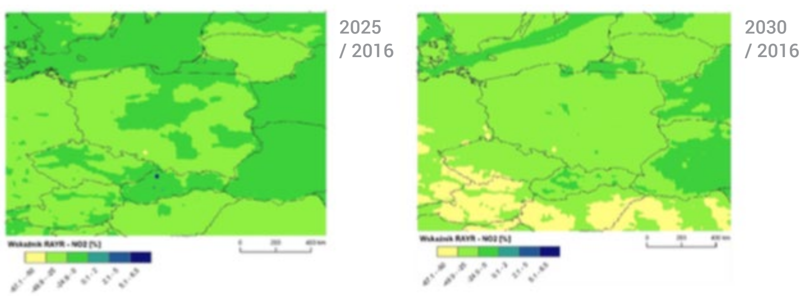
The analysis of the share of emissions from Poland in the average annual NO_x emission level for years 2016-2030 shows a decrease in the impact of cross-border pollution in the area near the western border of Poland. In the remaining part of the country, the impact of these pollutants is small, ranging from -100 to -50%.

Figure 10. Spatial distribution of average annual concentration of nitrogen oxides (left side) and spatial distribution of the share of emissions from Poland in average annual emission levels for NO_x (right side) in 2016, 2025 and 2030.



In 2025 and 2030, the forecasted change in the average annual concentration of NO_2 indicates a decrease in concentrations as a result of emission reductions compared to the level in 2016 r. In 2025, in the south, in the centre and in the Świętokrzyskie and Lubelskie Voivodships, an improvement of 0-25% is forecasted, and in the rest of the country, the value amounts to 25-50%. In 2030, an improvement of 25-50% is forecasted for nearly the entire territory of Poland, with minor exceptions in the north and centre of the country, where the improvement will be at the level of 0-25%.

Figure 11. Relative change in average annual NO_2 concentration in 2025 (left panel) and 2030 (right panel) compared to 2016.



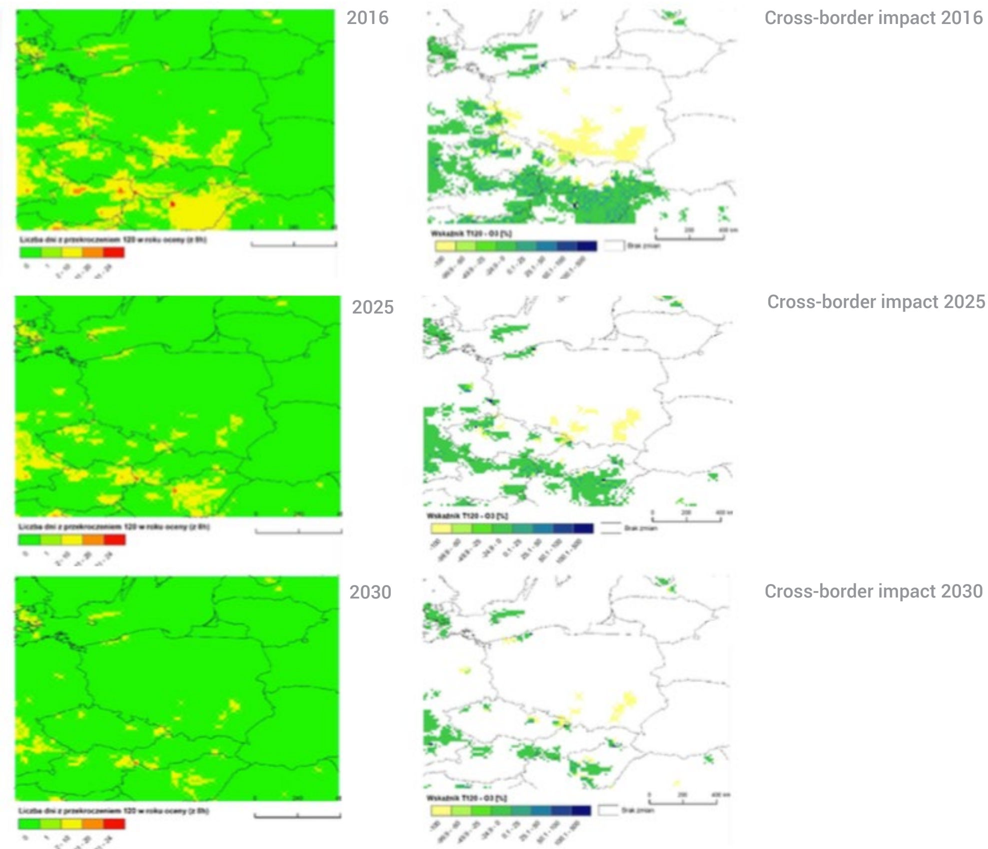
Annual average O_3 concentrations

In 2016, the highest number of days, up to 10 days, with an 8-hour average for ozone exceeding 120 µg/m^3 was recorded in Silesian and Małopolskie Voivodships, on the Baltic Sea coast and at the western border of Lubuskie Voivodship. In the remaining territory of Poland there were not more than one such analysed day. These values are lower than those resulting from the annual air quality assessment published by the Chief Inspectorate of Environmental Protection (GIOŚ). This is probably due to emission uncertainties in terms of the spatial distribution NO_x sources as well as emission flux estimations over the territory of Poland, presented in the EMEP0.1 inventory. The forecast for 2030 shows a decrease in the number of these days. In 2030, almost all over the country, there will be at most 1 day with 8-hour average above 120 µg/m^3 with the exceptions of small areas in the Świętokrzyskie and Silesian Voivodships. The percent differences from the baseline status are described below.

In 2016, on the Baltic Sea coast, the indicator of exposure to excessive ozone concentrations due to plant protection reached the highest values, from -24.9 to 0%.

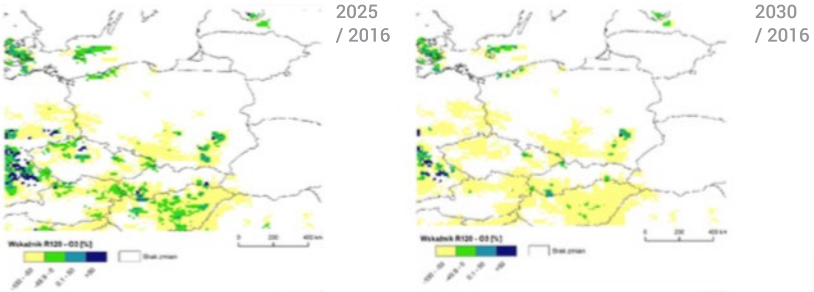
In the Silesian and Małopolskie Voivodships, there was a very small impact of cross-border pollution. However, in the remaining part of the country, the incoming pollution did not show any impact on the analysed index. The forecast until 2030 shows that the incoming pollution will not affect the occurrence of average 8-hour ozone concentration values over 120 µg/m^3.

Figure 12. Spatial distribution of days when the 8-hour average of ozone is higher than 120 µg/m^3 (left) and spatial distribution of cross-border pollution impacts for days when the 8-hour average for ozone is higher than 120 µg/m^3 (right), in 2016, 2025 and 2030.



As shown in Figure 13, the number of days with ozone values exceeding 120 µg/m^3 for the highest 8-hour rolling average concentration of ozone per day has been significantly reduced. Opolskie, Silesian, Małopolskie and Świętokrzyskie Voivodships and the Baltic Sea coast constitute exceptions. In 2025 and 2030, there will be a similar improvement compared to 2016. In the north of the country there will be an improvement within the limits of 0-50%, while in the south: from 50 to 100%.

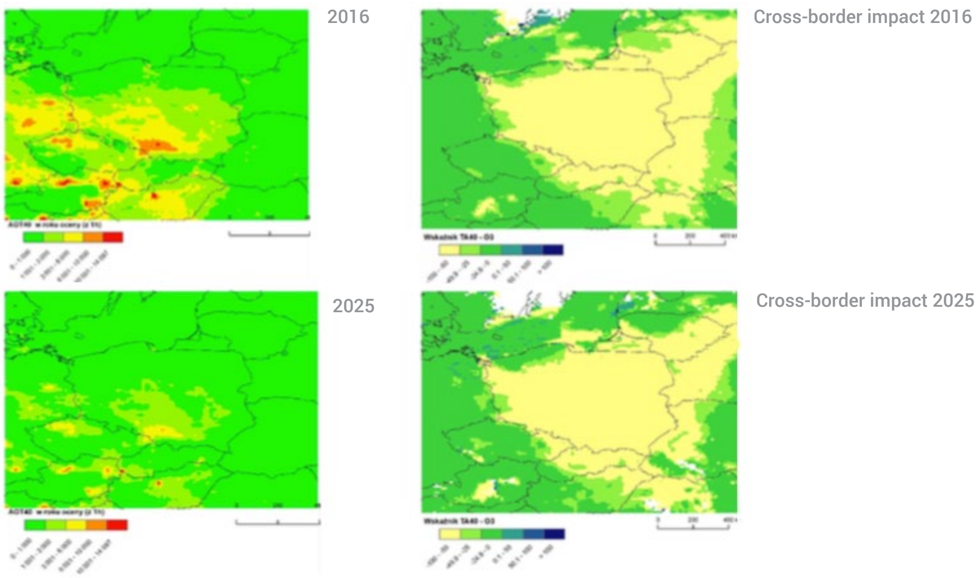
Figure 13. Number of days with values exceeding 120 µg/m^3 for the highest 8-hour rolling average daily ozone concentration.

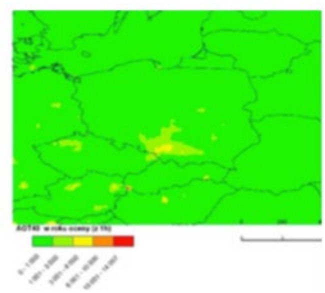


In 2016, the AOT40 index reached its highest values in the Silesian Voivodship - the values ranged from 10 001 to 14 097 µg/m^{3}h. In the central part of the country, the index values ranged from 3 001 to 6 000 µg/m^{3}h. The lowest values, up to 1 000 µg/m^{3}h, were recorded in the north of the country and in the lake district. The results of the modelling show that the value of the analysed indicator will decrease in the following years. The highest values will still be recorded in the Silesian Voivodship; however, in 2025 the highest values will reach 10 000 µg/m^{3}h, and in 2030 only up to 6 000 µg/m^{3}h in a small area of the voivodship. In the remaining part of the country AOT40, will not exceed 1000 µg/m^{3}h.

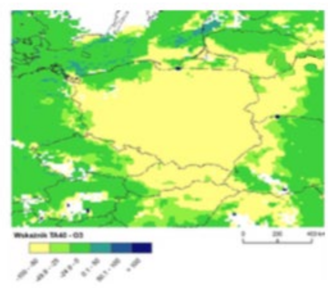
The AOT40 index for ozone in the majority of the country in each analysed year shows values in the range from -100 to -50. This means a very small share of pollutants coming from abroad in ozone concentrations recorded in Poland. A small impact of cross-border pollution occurs in areas near the western border of Poland and coastal areas.

Figure 14. Spatial distribution of AOT40 index (plant protection index) in 2016, 2025 and 2030 (left side) and spatial distribution of TA40 index (cross-border pollution impact) for ozone pollution in 2016, 2025 and 2030 (right side).





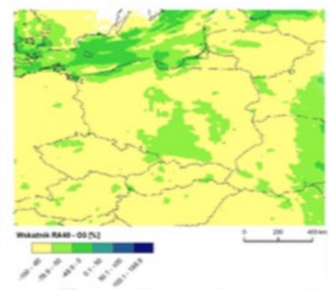
2030



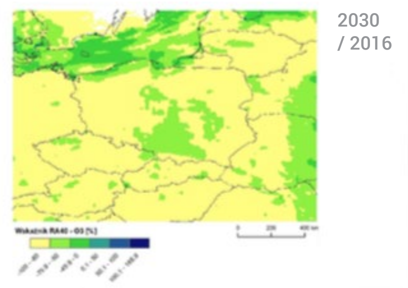
Cross-border impact 2030

The analysis of relative changes of the AOT40 index values (Figure 15) for 2025 compared to 2016 in the centre and south of Poland and at the Baltic Sea coasts, shows future reduction in the exposure levels by 50 to 80%, while in the rest of the country, the drop will amount to values from 80 to 100%. In 2030, plant protection exposure will be close to 2025 value.

Figure 15. Relative change in AOT40 in 2025 (left panel) and 2030 (right panel) compared to 2016.



2025 / 2016



2030 / 2016

Emission reduction impact

on health exposure and ecosystems

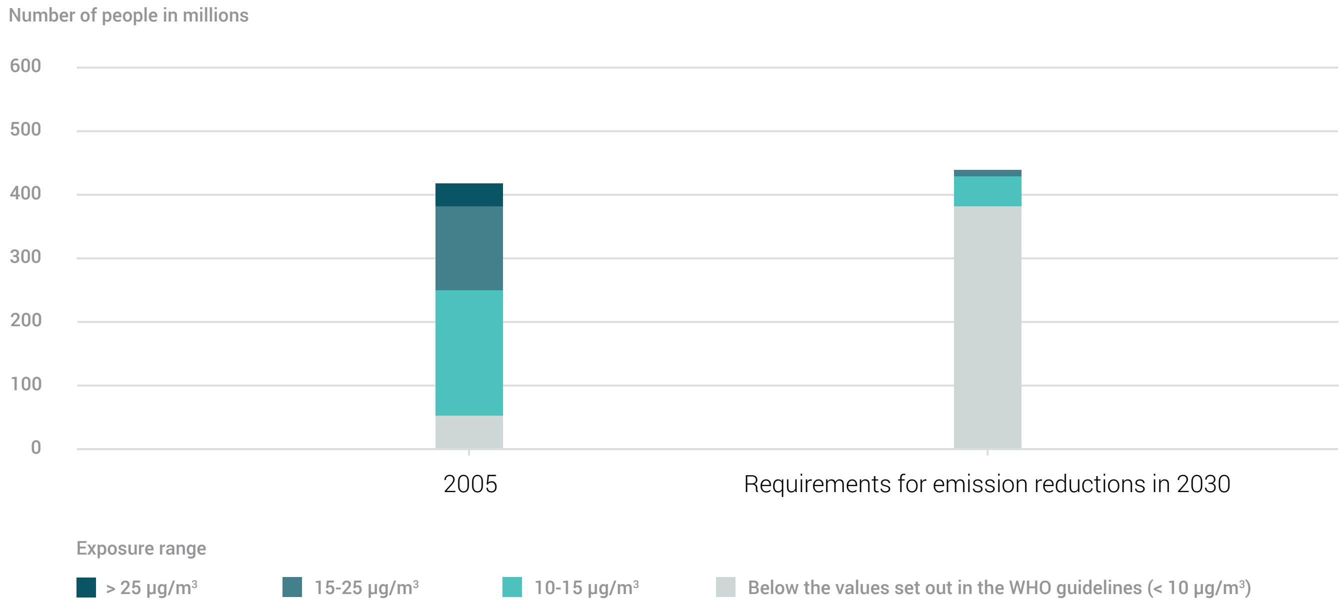
One of the objectives of the NEC Directive implementation is to improve air quality in Europe, due to the negative health impact and harmful effects of high concentrations of pollutants on ecosystems.

According to estimates by the European Environment Agency, in 2015 82% of the EU population was exposed to concentrations of $PM_{2.5}$ above the WHO guidelines' threshold of 10 µg/m^3. Compliant to the European Commission's document titled: "First Clean Air Forecast", the implementation of the reduction policy will result in a significant reduction of negative health and environmental impacts (Table 2). From 88% of the population exposed in 2005 to concentrations above the WHO guidelines' value, a decrease to 13% is expected in 2030 and values exceeding the desired levels are expected to be limited to only a few areas in Europe, most of them are to be within the acceptable 5 µg/m^3 limit value (Figure 16).

Table 2. Air policy benefits foreseen for 2030 to be achieved under the NEC Directive and all source legislation adopted from 2014 onwards compared to the proposals under the „Clean Air for Europe" programme (2005 as reference year). Source: COM/2018/446 final.

	Expected reduction in negative health effects compared to 2005 (premature deaths due to particulate matter and ozone presence)	Expected reduction in ecosystem areas exceeding the reduction in eutrophication compared to 2005
The "Clean Air for Europe" programme (December 2013) applying a baseline that does not include the source legislation adopted since 2014.	52%	35%
Impact of the NEC Directive as estimated at the time of its adoption (December 2016) using the same baseline as above.	49.6%	-
The impact of the NEC Directive using a baseline that takes into account the impact of the source legislation adopted from 2014 onwards.	54%	27%

Figure 16. Distribution of EU population exposure to $PM_{2.5}$ levels in 2005 and in 2030 assuming full implementation of the emission reduction requirements of the NEC Directive and all source legislation. Source: COM/2018/446 final.



According to the estimates of the European Environment Agency (EEA), the number of premature deaths related to poor air quality in Poland in 2012-2015 remained at a similar level (Table 3).

Table 3. Number of premature air quality related deaths in Poland. Source: EEA 2015, 2016, 2017, 2018.

Year	Population (*1 000)	$PM_{2.5}$			NO_2			O_3	
		Average annual concen-tration	Number of premature deaths		Average annual concen-tration	Number of premature deaths		SOMO 35	Number of premature deaths
			C_0=0	C_0=2.5		C_0=20	C_0=10		
2015	38 006	21.6	44 500	-	15.6	1 700	-	4 530	1 300
2014	38 018	23	46 020	41 300	15.1	1 700	10 020	3 425	970
2013	38 062	22.8	48 270	-	16.1	1 610	-	3 792	1 150
2012	38 103	23.9	44 600	-	16.72	1 600	-	4 045	1 100

The assessment of the effects of exposure to abnormal concentrations of pollutants in the context of public health is an extremely important issue. The World Health Organisation (WHO/Europe) provides AirQ+ software, which allows calculations of the health effects associated with exposure to high concentrations of pollutants, taking into account the estimated reduction in life expectancy.

A change in the number of premature deaths due to the annual average concentrations of PM_{10}, $PM_{2.5}$ and NO_2 has been calculated with the use of AirQ+, based on simulation results for emission reduction scenarios compliant with the NEC Directive for the years of 2025 and 2030. Assuming that the size of the exposed population would be the same as in 2016 and average concentrations across the country would be reduced, the number of premature deaths associated with poor air quality would decrease significantly (Table 4). The largest reduction is related to NO_2 exposure: up to 29% for the reduction scenario in 2025 and 8.6% for the 2030 scenario. Exposure to high particulate matter levels is also decreasing, although the reduction level is slightly lower and compared to 2016, it amounts to 65.9% for PM_{10} and 74.2% for $PM_{2.5}$ in 2025 and respectively 44.7% and 43.8% in 2030.

Table 4. Relative change of the number of premature air quality related deaths compared to 2016 based on modelling results calculated on the basis of AirQ+.

	2025	2030
PM_{10}	65.9%	44.7%
$PM_{2.5}$	74.2%	43.8%
NO_2	29.2%	8.6%

Moreover, on the basis of the results of the simulation, the size of the area subject the exposure of ecosystems and the size of the population exposed to excessive concentrations of pollutants was calculated.

For plant protection reasons, the size of non-urban areas exposed to excessive concentrations of ozone (expressed as AOT40) and nitrogen oxides (annual average) was analysed (Table 5). For ozone, the exposure reduction is very significant and for the 2025 reduction scenario it is only 8.7% of the risk area in 2016, while for the 2030 scenario it is only 1.6%. For nitrogen oxides, organic concentration levels reduction result in a reduction of the area at risk up to 18% in 2025 and 5.5% in 2030, compared to 2016.

Table 5. Relative change of the number of the non-urban areas subject to excessive concentrations for plant protection reasons compared to 2016, based on modelling results (zones without agglomeration zones and cities with a population > 100 thousand).

	2025	2030
AOT40 (O_3)	8.7%	1.6%
NO_x	18.0%	5.5%

The introduction of emission reductions according to the requirements of the NEC Directive will also significantly reduce the size of the population exposed to excessive concentrations of pollutants (Table 6). Changes in the size of the population exposed to annual average NO_2 concentrations and annual average $PM_{2.5}$ concentrations were analysed. In the case of NO_2 already in the horizon of 2025 there are no excess concentrations, consequently there will be no long-term exposure. In the case of $PM_{2.5}$ for the emissions forecasted for 2025, the size of the exposed population will be reduced by half (on average for the whole Poland up to 47.9%, while the exposure in urban areas will be slightly higher, 52.3% of the population as compared to 2016).

Table 6. Relative change in the size of population subject to excessive concentrations for health reasons compared to 2016 based on modelling results.

	In agglomerations and cities with population >100 thousand		Whole territory of Poland	
	2025	2030	2025	2030
NO_2	-	-	-	-
$PM_{2.5}$	52.3%	8.9%	47.9%	5.1%

The reduction in health exposure to $PM_{2.5}$, dust concentrations, estimated by two methods, shows good compliance and indicates a reduction by two of the size of the exposed population and a twofold decrease in the number of premature deaths associated with long-term exposure to high concentrations of this compound if emission reductions are applied in compliance with the requirements of the NEC Directive for the horizon of 2030.

Summary

The calculations lead to a conclusion that with regard to both primary pollutants and ozone, assuming a proportional reduction of emission levels for the main sectors of activity, as a result of the implementation of the NEC Directive in the horizon of 2025 and 2030, air quality in Poland will significantly improve, both for primary and secondary pollutants.

Ozone is the only secondary pollutant subject to analysis
Exposure to excessive ozone concentrations for plant protection reasons, expressed in the AOT40 index, decreases significantly with the assumption of emission reduction to the level specified in the Directive by 2025, with a further decrease in exposure taking place by 2030. A significant decrease in this index is also observed in neighbouring countries. For reasons of health protection, the values exceeding 120 µg/m³ level for the highest 8-hour rolling average of daily ozone concentration were subject to analysis (TV - Target Value), the number of days with values exceeding the target value has been significantly reduced.

Nitrogen oxides
The highest annual average nitrogen dioxide concentrations reported by the model based on 2016 emissions in the central and southern parts of the country have decreased significantly in subsequent calculation horizons. The territory covered by concentrations above 20 µg/m³ is limited to small areas in the south and centre of Poland.

Significant reductions in concentrations are also expected in neighbouring countries with the exception of the zones along the Baltic Sea, where no emission reductions have been applied, due to the lack of guidelines in the text of the Directive.

In the distribution of the annual average NO_x ($NO_x = NO_2 + NO$) the spatial distribution is similar. For emission levels in the years 2025 and 2030, NO_x concentrations are significantly lower throughout the country than in the case of simulation based on currently reported emissions. The highest concentrations of nitrogen oxides, assuming emission reductions at the level required by the NEC Directive, are forecasted in the southern part of the country.

Sulphur dioxide
A forecast of the average annual concentrations of sulphur dioxide indicates a significant reduction in both the highest values and the area covered by the elevated concentrations of this compound.

Particulate matter pollution
With regard to the average annual concentration of $PM_{2.5}$ dust, the results of the calculations based on forecasted emissions in 2025 show a significant decrease in concentrations compared to the current situation. If the reductions required by the Directive for 2030 were applied, the concentrations would not exceed 10 µg/m³ on the whole territory of the country.

The average annual concentrations of PM_{10} dust calculated for 2016 emissions indicate the highest concentrations in the central and southern part of Poland. The forecast of concentrations for 2025 and 2030 indicates a significant decrease in the concentration of PM_{10} dust.

The analysis of the impact of cross-border emissions from outside the country shows differences depending on pollution, emission reductions and source distribution in Poland:

- For the AOT40 indicator, the share of precursor concentrations from Poland exceeds 50% in most of the country, it is slightly lower along the western and north-western borders. National emissions of precursors are also primarily responsible for the occurrence of values exceeding the target value for health protection reasons.

- The share of pollutants from Poland influencing annual average concentrations of NO_2 and NO_x exceeds 50%. A slightly higher cross-border impact is observed along the western and south-western borders.

- For SO_2, the impact of emissions from Poland corresponds to more than 50% in annual average concentration. In the horizon of 2030, in the western part of the country, it has the predominant impact is the cross-border inflow, which indicates a significant reduction in concentrations of this pollutant in Poland.

- In relation to the average annual concentrations of $PM_{2.5}$ and PM_{10} dusts in the predominant area of Poland, the model shows that the impact of foreign pollution on dust concentrations in Poland exceeds 50%. In the horizon of 2030, as a result of a significant reduction of dust emissions in Poland, the share of concentrations from outside the country's borders is increasing.

The introduction of emission reductions according to the requirements of the NEC Directive will significantly reduce the number of premature air quality related deaths. Assuming that the population of the same size is exposed, the number of premature deaths due to PM_{10} and $PM_{2.5}$ dust pollution will decrease by more than 50%, and due to oversized NO_2 concentrations by more than 90%. Assuming a smaller range of oversize concentrations, and thus a reduction in the number of inhabitants exposed to high concentrations of pollutants, the reduction in health exposure will be even more significant.

The areas of ecosystems exposed to excessive concentrations of pollutants will also be reduced. In the case of ozone concentrations the reduction will reach only about 1.6% and in the case of nitrogen oxides to about 5.5% of the exposed areas at the current emission level. Presented analysis indicate the the need to verify national emissions reported to EMEP with the use of modelling, to ensure correct spatial distribution and levels of emission concentrations over Poland's area. The accomplishment of modelling synergy with respect to the implementation of the EPL Act and activities under the CLRTAP, as well as the implementation of the NEC Directive, will certainly bring added value to comprehensive analyzes of air quality in Poland as well as transboundary transport of air pollution.

Environmental benefits resulting from the reduction of air pollution accompanying CO_2 emissions.
Analysis with the use of the air quality model for Poland.

IOŚ-PIB
INSTITUTE OF ENVIRONMENTAL PROTECTION
NATIONAL RESEARCH INSTITUTE

Institute of Environmental Protection - National Research Institute

ADDRESS
Krucza 5/11D
00-548 Warsaw

PHONE
+48 22 37 50 511
+48 22 37 50 556

E-MAIL
sekretariat@ios.edu.pl
www.ios.edu.pl

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