Project No. 037005

CECILIA

Central and Eastern Europe Climate Change Impact and Vulnerability Assessment

Specific targeted research project

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D7.5: Present and future key species exceedances of the EU limits and WHO guidelines, health effects.

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Dissemination Level		
PU	Public	X
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
CO	Confidential, only for members of the consortium (including the Commission Services)	

CECILIA WP7 DELIVERABLE D51 (or D7.5)

Lead partner for deliverable: WUT

Contributing partners: WUT, BOKU, CUNI, AUTH, NIMH

1 Introduction

The main objective of WP7 was to model the interaction between climate and air quality by predictions of present and future air pollution levels and loads in the target regions on the fine scale. Key species concentrations and depositions from high resolution runs for present climate and for future projection are discussed in Deliverable D7.3, while evaluation of modelling results and comparison between high (10 km) and coarse (50 km) resolution runs is presented in Deliverable D7.4. The main goal of Deliverable D7.5 is to assess present and future key species exceedances of the EU limits and WHO guidelines as well as to assess possible health effects.

The harmful impact of air pollution on human health has been known since ancient times (Makra and Brimblecombe, 2004). Improvement in epidemiological research over the 1990s and greater sensitivity of the present studies have revealed that people's health may be affected by exposures to much lower levels of some common air pollutants than believed even a few years ago (WHO, 2000). From the ambient air pollution mixture the attention has focused especially on solid and liquid parts of air, known as particulate matter (PM) as well as on ozone (O_3).

In order to assess air pollution threat to human health and the environment, existing concentration fields have to be compared to pollution levels, above which, according to current knowledge, direct adverse effects on receptors such as human being, plants, ecosystems or materials may occur, namely limit values/critical levels. According to WHO, adverse effect means change in morphology, physiology, growth, development or life span of an organism which results in impairment of functional capacity or impairment of capacity to compensate for additional stress or increase in susceptibility to the harmful effects of other environmental influences (WHO, 2000). WHO sets non-binding air quality guidelines for Europe, with the aim to provide a basis for protecting public health from adverse effects of air pollutants and to eliminate or reduce exposure to those pollutants that are known or likely to be hazardous to human health or wellbeing. The guidelines provide a basis for setting standards or limit values for air pollutants. Although health effects were the major consideration in establishing the guidelines, evidence of the effects of pollutants on terrestrial vegetation was also considered and guideline values were recommended for a few substances. It is important to note that the numerical values of guideline values should be regarded as the shortest possible summary of a complex scientific evaluation process of risk due to air pollution (WHO, 2005). Based on WHO guidelines, standards for ambient air pollutants were set in the framework of EU legislation. The EU Directive 2008/50/EC (EC, 2008) states the following standards:

- "limit value" (LV) shall mean a level fixed on the basis of scientific knowledge, with the aim of avoiding, preventing or reducing harmful effects on human health and/or the environment as a whole, to be attained within a given period and not to be exceeded once attained;
- "critical level" (CLev) shall mean a level fixed on the basis of scientific knowledge, above which direct adverse effects may occur on some receptors, such as trees, other plants or natural ecosystems but not on humans;

By subtracting the limit values/critical levels from the existing concentrations, the so called exceedances are obtained, which are direct estimates of population and/or environmental risk. Exceedance of CLev/LV is defined as the non-negative difference between CLev/LV and the concentration (C); $Ex(CLev_t) = \max\{C_t - CLev_t, 0\}$; $Ex(LV_t) = \max\{C_t - LV_t, 0\}$, where t is the averaging time for concentration, t = 1h, 8h, 24h, year.

In the present Deliverable D7.5, the key species are ozone and PM, which are priority species regarding human health and sulphur dioxide having complex impacts on human health and the ecosystems. We compared key species concentration obtained for so-called extended control period (1991-2000) with EU limit/critical levels in order to assess present day exceedances. Next we assessed the exceedances for the end-century (2091-2100) decade. For assessing possible health effects, the case study for Poland was performed. We estimated the adverse health effects caused by $PM_{2.5}$ air pollution for present day decade as well as for future decades 2041-2050 and 2091-2100.

Simulations have been performed with Regional Climate Models (RCM) coupled to Air Quality Models (AQM). The map projection choice was Lambert conformal. The majority of partners (AUTH, BOKU, CUNI and WUT) used RegCM3(Beta)-CAMx modelling system driven by ECHAM5 Global Climate Model outputs. NIMH used ALADIN-CMAQ modelling system driven by ARPEGE Global Climate Model outputs. Longer range transport to the target regions is taken into account from simulation for the whole Europe with the resolution of 50 km x 50 km. These simulations are used to constrain nested higher resolution runs (10 km x 10 km) focusing in the selected target regions in CCE. Top boundary conditions correspond to concentrations of clean air.

The anthropogenic emission are kept constant at the values of year 2000 for all time slices. Biogenic emissions are calculated by a RCM-AQM pre-processor. Emission database for 50 km resolution runs are based on the UNECE/EMEP database (http://webdab.emep.int/). The detailed explanation of preparation of emission database for 50 km runs is given by Krüger et al. (2008). For targeted domains high resolution simulations, emission database have been prepared as follows:

- For BOKU and CUNI domains, as well as for part of WUT domain excluding Poland, emissions were calculated with the emission model of BOKU-Met based on data from the UNECE/EMEP database for the year 2000, available in 50 km x 50 km EMEP grid resolution. For the Pannonian countries (Austria, Czech Republic, Hungary, and Slovakia), a detailed 5 km x 5 km emissions inventory from the year 1995 (Winiwarter and Zueger, 1996) was used for the spatial distribution of the EMEP data. Area and point sources were treated as surface area emissions.
- For Poland, the emission model EMIL was developed for the CECILIA project, based on a detailed 1 km x 1 km emissions inventory of area and point sources for reference year 2000. For Large Combustion Plants (LCPs), with a stack height, h ≥ 100 m, a detailed emission and stack parameters database was prepared. The created point sources database contains data for 220 stacks. Finally, area sources were treated as surface area emissions, while elevated point sources were simulated individually.
- For Bulgaria emissions were prepared by interface programs AEmis and PEmis. Input to them was TNO high resolution (0.25° x 0.125°) inventory (Visschedijk and van der Gon, 2005). The inventory is produced by proper disaggregation of the EMEP 50-km inventory data base. GIS technology was applied to produce 10 x 10 km input to AEmis and PEmis. The TNO inventory is elaborated for Area Sources and Large Point Sources separately, distributed over 10 SNAPs (CORINAIR methodology). Large point sources are treated as area sources, but specific effective height of release is assigned to a given SNAP category. Finally, area sources were treated as surface area emissions, while for large point sources 3D emission file is produced with zero-values at the surface and non-zeros at the respective model levels.

2 Key species exceedances

2.1 Ozone exceedances

Ozone, the main photochemical atmospheric pollutant is known to be harmful both for human health and for vegetation. Therefore we analyzed exceedances of criteria relating to both receptors.

Protection of vegetation

When setting critical level value for O_3 it was taken into account that results of exposure–response studies with open-top chambers shows that mean concentrations are not appropriate to characterize ozone exposure. This is mainly because (a) the effect of ozone results from the cumulative exposure; and (b) not all concentrations are equally effective, higher concentrations having greater effects than lower concentrations (WHO, 2000). Vegetation ozone exposure is therefore expressed as the sum of 1-hour mean concentrations above a cut-off concentration of 40 ppb during a vegetation period. Such an exposure index is strongly related to biological responses, and hence to the degree of risk to sensitive vegetation. It is referred to as the Accumulated exposure Over a Threshold of 40 ppb, AOT40. AOT40 is calculated for a 3-month growing season in the case of crops or herbaceous semi-natural vegetation ($AOT40_c$), or a 6-month growing season for forest trees ($AOT40_f$). The calculation of the AOT40 considers only daylight hours, when stomata are open and uptake of ozone by vegetation occurs. For Europe these are 8.00 to 20.00 Central European Time (CET).

In the framework of this Deliverable the AOT40 values were calculated for the periods May to July ($AOT40_c$) and April to September ($AOT40_f$), which are considered as a measures for the impact of ozone on crops and on forests, respectively. The EU Directive 2008/50/EC sets a CLev value for the protection of crops CLev($AOT40_c$) = 9 000 ppbv h (18 000 μg/m^3 h), while WHO (2000) recommends CLev value for the protection on forests, CLev($AOT40_f$) = 10 000 ppbv h (20 000 μg/m^3 h).

At BOKU, it has been investigated, how the EU critical level of 9 000 ppb h for the $AOT40_c$ value in the crops growing season May to July is exceeded in the model calculations. The data for the control period (1991-2000) and for the end-century decade (2091-2100) from the 50 km-runs are shown in Fig.1.

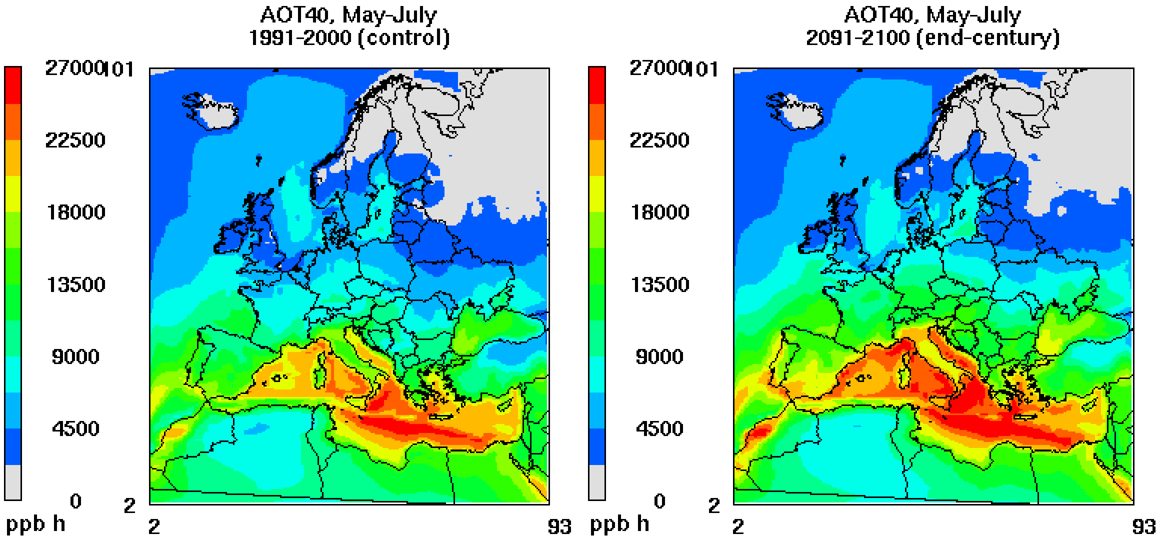

Figure 1: Average of the $AOT40_c$ for May to July in the BOKU calculation with 50 km spatial resolution for the present decade 1991-2000 (left panel), and for the end-century decade 2091-2100 (right panel). Critical level for crops (EU), $AOT40_c$ = 9 000 ppb h.

A gradient with lower values in the north and higher values in the south is observed. The highest values are found over the Mediterranean Sea. With climate change, the $AOT40_c$ values are increasing. The highest increase occurs in northern Italy and over the Iberian Peninsula. With present day conditions (1991-2000) the critical level for crops (9 000 ppb h) is not exceeded north of the Alps and the Black Sea. In the calculation with future climate (2091-2100) the $AOT40_c$ values become higher and the limiting line of 9 000 ppb h is shifted to the north causing exceedances of CLev for crops in the majority of CCE countries with no exceedances in present climate. These are: Germany, Austria, Czech Republic, Slovakia and Bulgaria.

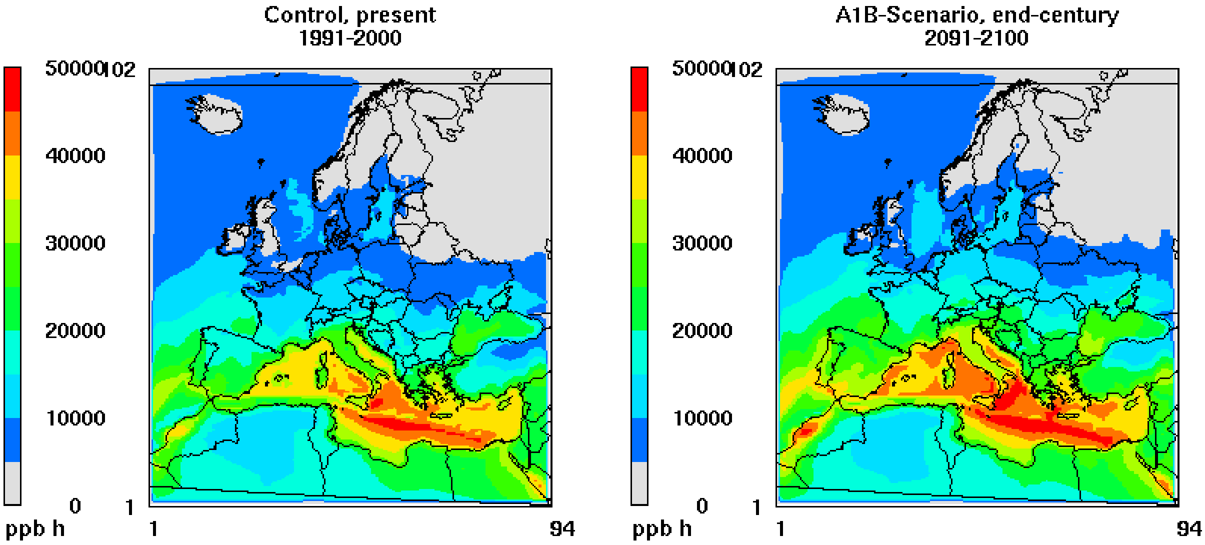

Figure 2: Average of the $AOT40_f$ for April to September in the BOKU calculation with 50 km spatial resolution for the present decade 1991-2000 (left panel), and for the end-century decade 2091-2100 (right panel). Critical level for forests (WHO), $AOT40_f$ = 10 000 ppb h.

To analyse the potential climate change impacts on forest ecosystems, the $AOT40_f$ values were calculated for the period April to September at BOKU and AUTH. The spatial distribution of $AOT40_f$ for forest protection, presented in Fig. 2, is similar to this of $AOT40_c$, with lower values in the north and higher values in the south. With climate change, the $AOT40_f$ values are increasing. The highest increase occurs in northern Italy and over the Iberian Peninsula. With present day conditions (1991-2000) the critical level for forests set as WHO AQG ($AOT40_f$ =10 000 ppb h) is exceeded for wider area than EU critical level for crops, including whole continental Europe west from Poland (with exclusion of Northern Germany). Simulations for the end-century decade (2091-2100) show higher $AOT40_f$ values and the limiting line of 10 000 ppb h is shifted to the north causing exceedances of CLev for forest also for Poland and Northern Germany. The results obtained by AUTH are similar with those illustrated in Fig. 2. For the near future decade 2041-2050 (not shown here), $AOT40_f$ goes down over most of Europe except of the Iberian Peninsula and southeast Europe, while there is a strong increase over most of Europe in the end-century decade.

Figure 3 displays the $AOT40_c$ values for the present day and the end-century decades calculated for BOKU domain in high 10 km resolution. The values are generally higher than in the coarse resolution run. With present day conditions (1991-2000) only over Poland and Ukraine the limit of 9 000 ppb h is not exceeded. The highest values are found over the Adriatic Sea and over Italy. With far future climate (2091-2100) a further increase is observed. The high increase over Southern Germany may be attributed to boundary effects of the model. In the target region of CECILIA the increase is strongest in a belt stretching from Austria over western Hungary and Serbia to Bulgaria.

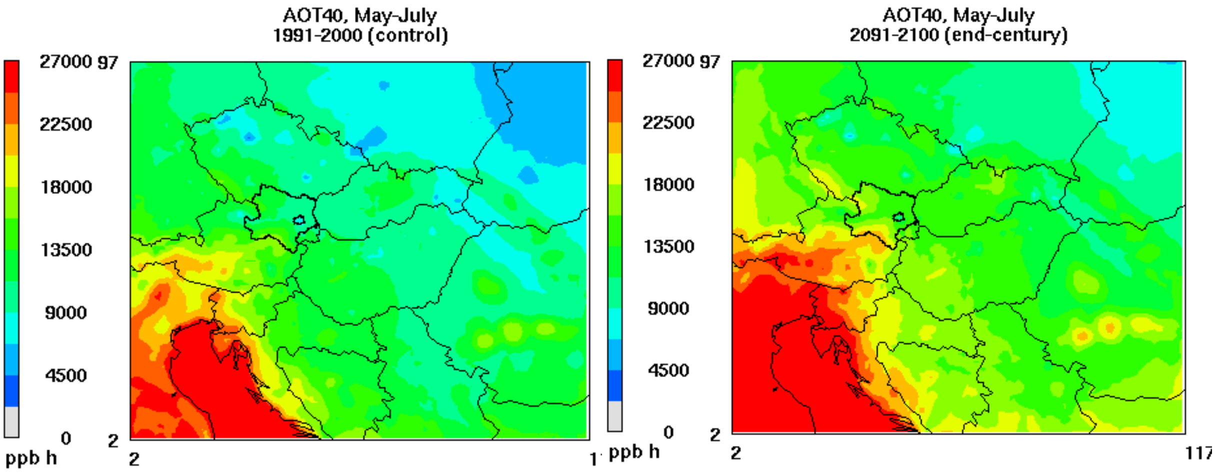

Figure 3: Average of the $AOT40_c$ for May to July for the BOKU domain with 10 km spatial resolution for the present day decade 1991-2000 (left panel), and and for the end-century decade 2091-2100 (right panel). Critical level for crops (EU), $AOT40_c$ = 9 000 ppb h.

Protection of human health

The EU Directive 2008/50/EC sets ozone limit value for protection of human health as the maximum daily eight-hour mean concentration, selected by examining eight-hour running averages, calculated from hourly data. The LV equals to 120 $\mu g/m^3$ (60 ppb) not to be exceeded on more than 25 days per calendar year. The recent update of WHO air quality guidelines (WHO, 2005) recommended the air quality guideline for ozone at the level of 100 $\mu g/m^3$ for daily maximum 8-hour average. According to WHO, it is possible that health effects will occur below this level in some sensitive individuals. Based on time-series studies, the number of attributable deaths brought forward can be estimated at 1-2% on days when ozone level reaches this guideline level as compared with the background ozone level (WHO, 2005).

The exceedances of LV for ozone have been calculated for CUNI domain in high 10 km resolution. Number of days with maximum daily 8-hour running O_3 average exceeding 120 $\mu g/m^3$ calculated for the present day decade as well as differences in number of exceedance days between far future and present day decades are displayed in Figure 4.

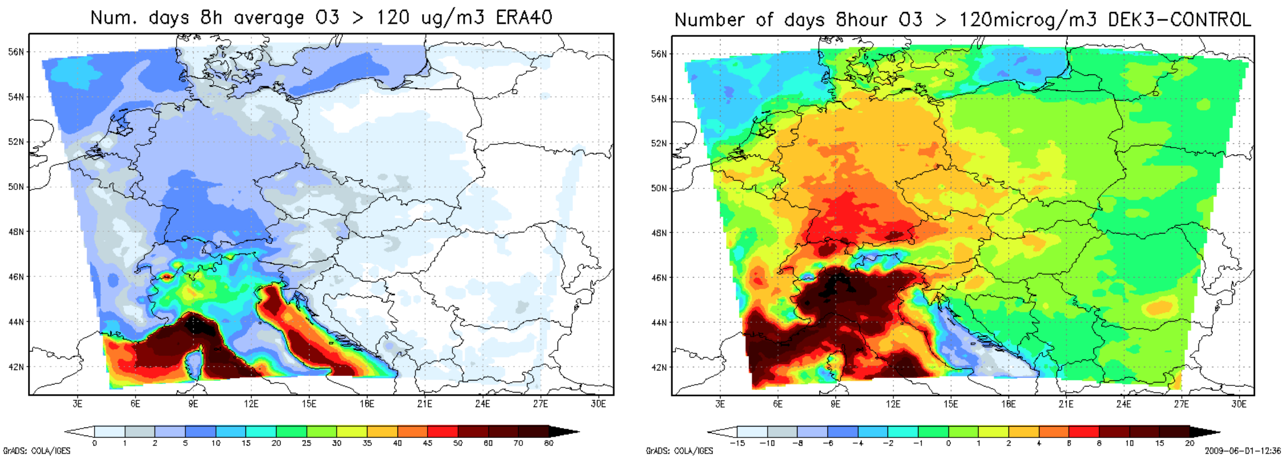

Figure 4: Number of exceedances [days] over O_3 limit value of 120 $\mu g/m^3$ at CUNI domain for the present day decade 1991-2000 (left panel) and climate change impacts on exceedances of O_3 limit value in terms of the differences [days] for the end-century decade 2091-2100 against the present day decade (right panel).

On the large part of the CUNI domain, the values lay between 1 and 5 exceedance days per year (the 25 exceedance days is allowed). The highest values occur over northern Italy, up to 50 exceedance days per year and over the Mediterranean Sea, with values up to 80 days over the Ligurian Sea (an arm of the Mediterranean Sea, between the Italian Riviera and the islands of Corsica and Elba. No exceedances are modelled on the eastern part of domain.

In the target region of CECILIA, the number of exceedance days per year is increasing in the end-century decade, however the allowed 25 exceedance days are not overshot. Northern Italy will suffer the most, being affected by an increase of 6-20 exceedance days per year, which cause that LV is not met. The reason of increasing number of exceedance days is higher frequency of extreme temperature and heat-weaves in the future climate.

2.2 PM exceedances

Protection of human health

The EU Directive 2008/50/EC sets two legally binding PM_{10} mass concentrations limit values for protection of human health. These are: annual mean PM_{10} LV of 40 μg/m^3 and daily mean PM_{10} LV of 50 μg/m^3 not to be exceeded on more than 35 days per calendar year. In addition, the Directive sets a non-binding annual $PM_{2.5}$ standard of 25 μg/m^3.

The recent update of WHO air quality guidelines (WHO, 2005) recommended the air quality guidelines (AQG) both for PM_{10} and $PM_{2.5}$. For $PM_{2.5}$ annual mean AQG is equal to 10 μg/m^3, and daily mean AQG is equal to 25 μg/m^3. For PM_{10}, AQG is equal to 20 μg/m^3 for annual mean, and 50 μg/m^3 for daily mean. The annual average guideline value of 10 μg/m^3 for $PM_{2.5}$ (two and half times lower than EU standard) was chosen as the lowest level at which total, cardiopulmonary and lung cancer mortality have been shown to increase with more than 95% confidence in response to $PM_{2.5}$ in the American Cancer Society (ACS) study (Pope et al., 2002).

The exceedances of LV for PM have been calculated for WUT domain in high 10 km resolution. Figure 5 displays the annual mean PM_{10} levels for the present day and differences in concentrations between end-century decade and present day one. The annual LV is not exceeded for present day decade (maximum value equals to 33 μg/m^3). With climate changes, the PM_{10} levels are decreasing for whole domain (up to -4.5 μg/m^3) with exception of Eastern Germany, where difference is close to zero.

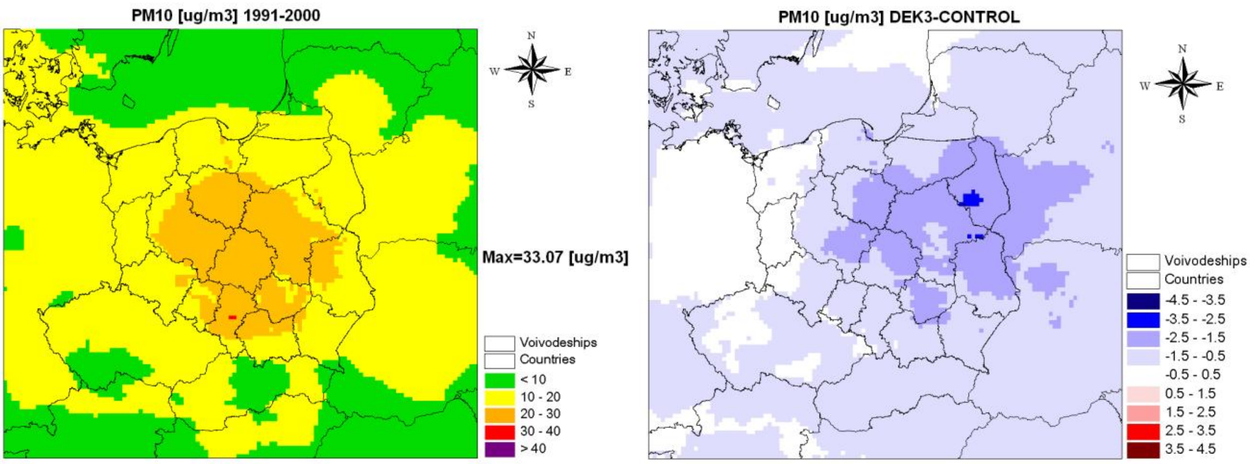

Figure 5: Annual mean PM_{10} concentrations [μg/m^3] at WUT domain for present day decade 1991-2000 (left panel) and climate change impacts on PM_{10} concentrations in terms of the differences [μg/m^3] for the end-century decade 2091-2100 against the present day decade (right panel).

Number of days with daily mean PM_{10} levels exceeding 50 μg/m^3 calculated for the present day decade and differences in number of exceedance days between the end-century and present day decades are presented in Figure 6.

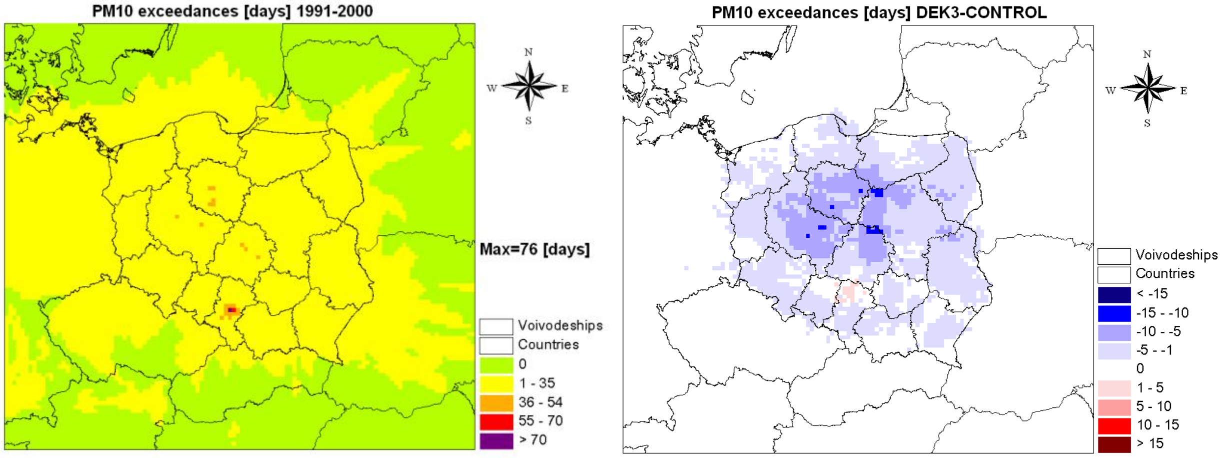

Figure 6: Number of exceedances [days] over PM_{10} limit value of 50 μg/m^3 at WUT domain for present day decade 1991-2000 (left panel) and climate change impacts on PM_{10} limit value exceedances in terms of the differences [days] for the end-century decade 2091-2100 against the present day decade (right panel).

On the majority of the WUT domain, the number of exceedance days is less than 35 per year, thus LV is not overshot. The highest values occur in the hot spot areas in Poland - surroundings of densely populated urban areas. The maximum value of 76 days with daily mean PM_{10} levels exceeding 50 μg/m^3 was calculated for Upper Silesia Metropolitan area. For the end-century decade the PM_{10} levels are decreasing. The number of PM_{10} exceedance days is the same as for the present day decade for the majority of domain, except of Polish territory, where the number of exceedance days is decreasing. For future climate, only in Silesia Metropolitan area, the number of exceedance days is bigger than allowed in EU legislation. The decrease of PM_{10} concentration is most probably due to increase of mixing height, wind speed and precipitation in future climate in the region under concern.

Figure 7 shows the distribution of calculated annual mean levels of $PM_{2.5}$ for the WUT domain and differences in concentrations between end-century decade and present day one.

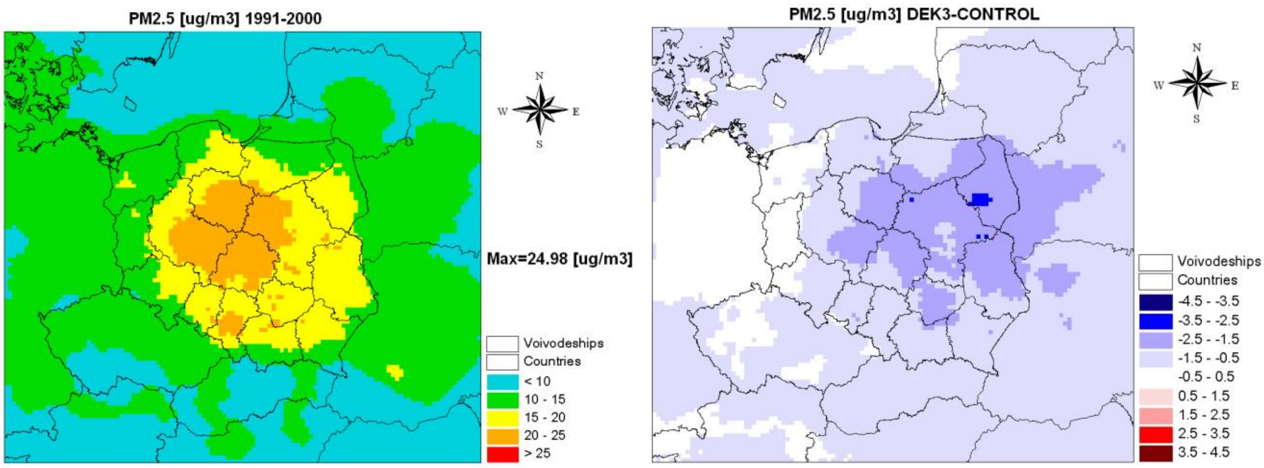

Figure 7: Annual mean $PM_{2.5}$ concentrations [μg/m^3] at WUT domain for present day decade 1991-2000 (left panel) and climate change impacts on $PM_{2.5}$ concentrations in terms of the differences [μg/m^3] for the end-century decade 2091-2100 against the present day decade (right panel).

For the present day decade the annual EU non-binding $PM_{2.5}$ standard (25 μg/m^3) is not exceeded. However, the AQG set by WHO (10 μg/m^3) is exceeded for the majority of the domain. With climate changes, also $PM_{2.5}$ levels are decreasing for whole domain (up to -4.5 μg/m^3) with exception of Eastern Germany, where difference is close to zero.

2.3 SO_2 exceedances

The atmospheric SO_2 is causing adverse effects both for human health and the environment as a whole. These include direct impact on respiratory track diseases as well as on growth and yield of plants. SO_2 is also known from changing plant sensitivity to other environmental stresses. In addition, SO_2 is a precursor of particulate sulphate (SO_4^{-2}), formed in the air as secondary $PM_{2.5}$. It directly affects people's health, reduces visibility and is also a component of the acid mists, which have a direct impact on vegetation, especially in mountain regions. Finally, SO_2 is causing sulphur deposition, which is one of the principal contributors to acidification, especially affecting aquatic ecosystems and forest soil and having indirect effects on vegetation and human health (Juda-Rezler, 2004). For the results of sulphur deposition modelling under climate change in Poland see Deliverable D7.3, and for the resulting impacts on critical loads exceedances for the selected forest ecosystems in Poland see Deliverable D6.6.

Protection of human health

The EU Directive 2008/50/EC sets two legally binding SO_2 limit values for protection of human health: 125 μg/m^3 for daily mean SO_2 levels and 350 μg/m^3 for hourly mean SO_2 levels not to be exceeded on more than 3 and 24 times per calendar year, respectively. Reported in the literature short-term (day-to-day) changes in health status related to daily mean SO_2 concentrations are based on epidemiological studies in which people are exposed to a mixture of pollutants. Separating the contributions of each pollutant is very difficult, especially for SO_2 and PM. In the revision of WHO guidelines (WHO, 2000), it was noted that epidemiological studies showed separate and independent adverse public health effects for SO_2. In the recent update of guidelines (WHO, 2005), the AQG for daily mean SO_2 concentration was set at a prudent precautionary, very low level of 20 μg/m^3. In spite of this, there is still considerable uncertainty as to whether SO_2 is the pollutant responsible for the observed adverse effects or, rather, a surrogate for ultra-fine particles or some other correlated substance (WHO, 2005).

The excedances of LV for SO_2 have been calculated for WUT domain in high 10 km resolution. Number of days with daily mean SO_2 levels exceeding 125 μg/m^3 calculated for the present day decade and differences in number of exceedance days between the end-century and present day decades are presented in Figure 8.

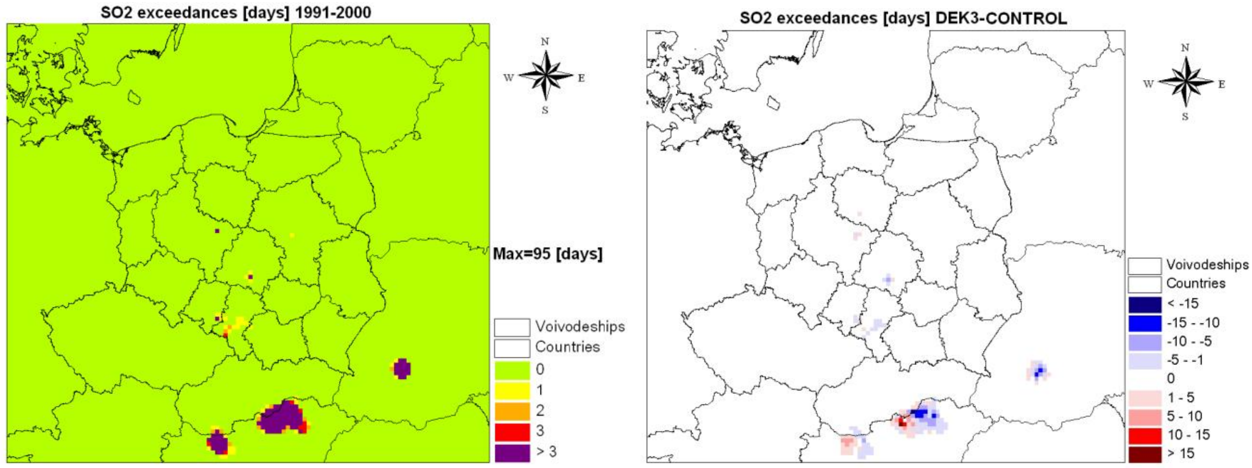

Figure 8: Number of exceedances [days] over SO_2 daily limit value of 125 μg/m^3 at WUT domain for the present day decade 1991-2000 (left panel) and climate change impacts on SO_2 limit value exceedances in terms of the differences [days] for the end-century decade 2091-2100 against the present day decade (right panel).

On the majority of the WUT domain, there is no exceedances of the daily LV for SO_2 for the present day decade (no days with daily mean concentration exceeding 125 μg/m^3). The exceedances occur in the surroundings of large combustion plants (LCP) where the limit value is not met (number of days with daily mean levels over 125 μg/m^3 is bigger than 3). The maximum number of days with average concentration exceeding 125 μg/m^3 equals to 95 and was estimated for Northern Hungary. However, as it was described in the Introduction, the LCP sources were simulated individually only for Poland, while for the rest of the WUT domain the LCP were treated as surface area sources. These resulted in significant overestimation of SO_2 concentrations in the vicinity of LCP in Northern Hungary and Ukraine. For the end-century decade there is also no exceedances of the daily LV for SO_2 on the majority of the WUT domain (no days with daily mean concentration exceeding 125 $\mu g/m^3$). Only in the surroundings of LCP the number of exceedance days is slightly decreasing in Poland and is increasing/decreasing in Hungary and Ukraine. The highest differences were calculated for the vicinity of Mátra Power Plant in Hungary (from -18 to +17 exceedance days).

Number of hours with hourly mean SO_2 concentrations exceeding 350 $\mu g/m^3$ calculated for the present day decade and differences in number of exceedance hours between the end-century and present day decades are presented in Figure 9.

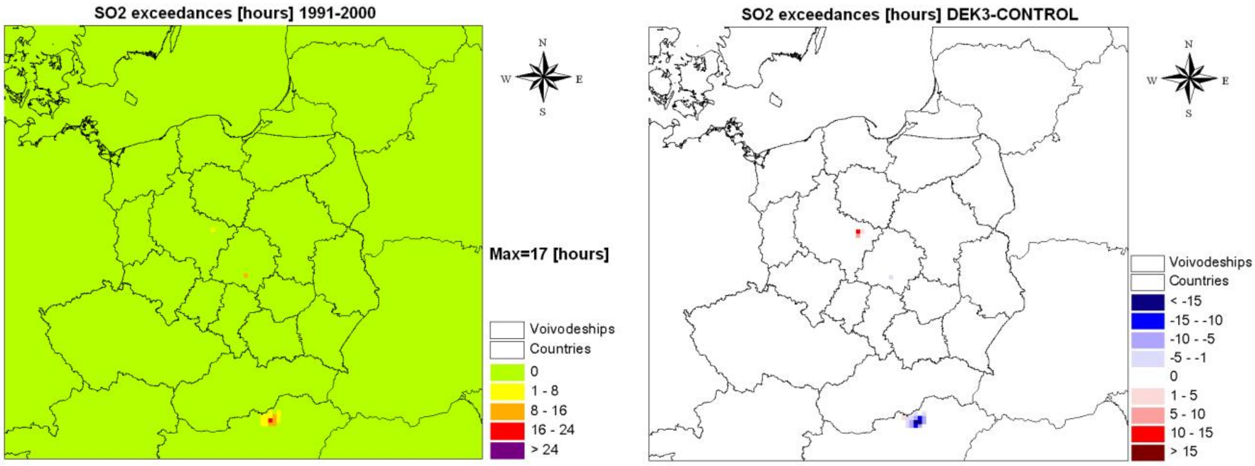

Figure 9: Number of exceedances [hours] over SO_2 hourly limit value of 350 $\mu g/m^3$ at WUT domain for the present day decade 1991-2000 (left panel) and climate change impacts on SO_2 limit value exceedances in terms of the differences [hours] for the end-century decade 2091-2100 against the present day decade (right panel).

Again, on the majority of the WUT domain, there is no exceedances of the hourly LV for SO_2 for the present day decade (no hours with hourly mean concentration exceeding 350 $\mu g/m^3$). The exceedances occur in the surroundings of LCP in Hungary and in Poland, however the number of hours with mean levels over 350 $\mu g/m^3$ is not bigger than 24, thus the LV is met. For the end-century decade there is also no exceedances of the hourly LV for SO_2 on the majority of the WUT domain. The climate impact on the number of hours with mean concentration over 350 $\mu g/m^3$ is seen only in few grid points. The number of exceeding hours is increasing in one grid in Poland (up to 14 hours) and decreasing in the vicinity of Mátra Power Plant in Hungary.

Protection of vegetation

Due to well known impacts of SO_2 on vegetation (especially for natural vegetation and forests), the EU Directive 2008/50/EC sets also SO_2 critical level for the protection of vegetation: 20 $\mu g/m^3$ for annual mean SO_2 levels. Figure 10 displays the annual mean SO_2 levels calculated for the WUT domain for the present day and differences in concentrations between end-century decade and present day one.

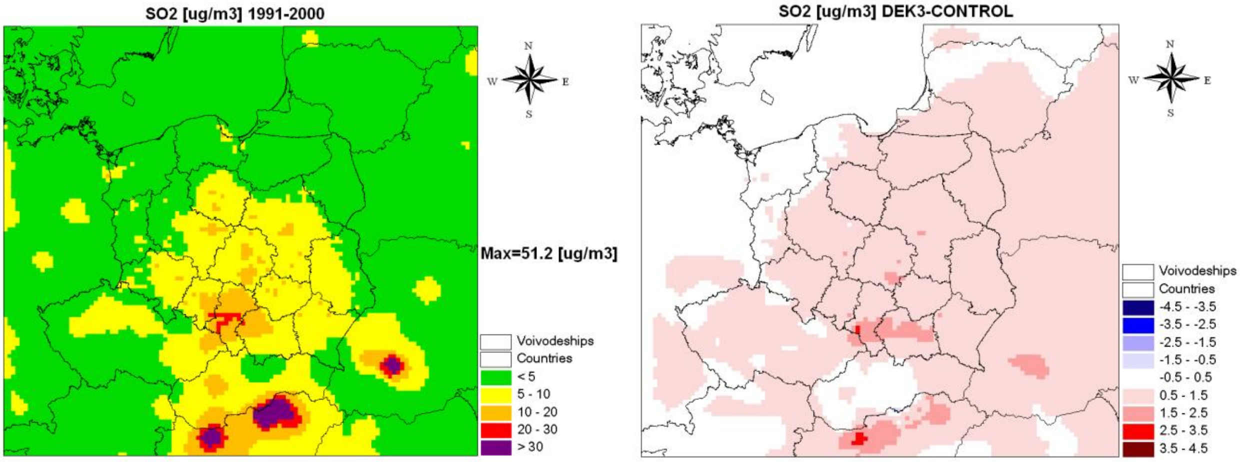

Figure 10: Annual mean SO_2 concentrations [$\mu g/m^3$] at WUT domain for the present day decade 1991-2000 (left panel) and climate change impacts on SO_2 concentrations in terms of the differences [$\mu g/m^3$] for the end-century decade 2091-2100 against the present day decade (right panel).

For the present day decade, the annual CLev is exceeded only in Upper Silesia industrial region in Poland and for vicinity of LCP in Northern Hungary and Ukraine (maximum value equals to 51 $\mu g/m^3$). As was already explained, the high values calculated for Hungary and Ukraine are overestimated due to emission treatment in the AQ model. Predictions for end-century decade show increase in annual mean concentrations (up to 4.5 $\mu g/m^3$) with the exception of Eastern Germany, Austria and Slovakia, where difference is close to zero.

Figure 11 presents the calculation results for the WUT domain in terms of exceedances solely. It can be noticed that exceedances area in Poland is slightly wider for end-century decade in comparison to present day decade.

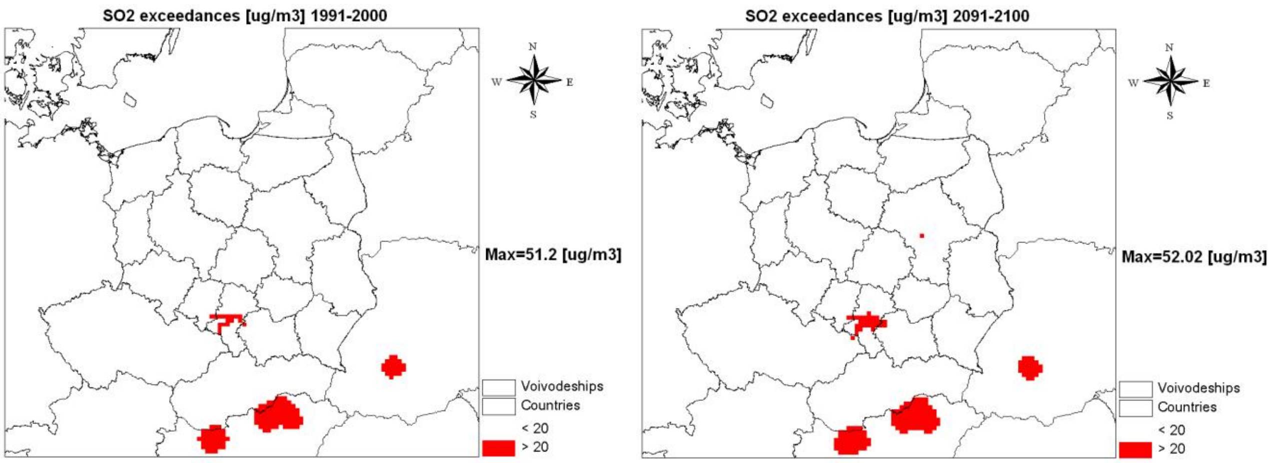

Figure 11: Exceedances [$\mu g/m^3$] of SO_2 annual critical level of 20 $\mu g/m^3$ at WUT domain for the present day decade 1991-2000 (left panel) and for the end-century decade 2091-2100 (right panel).

Exceedances of SO_2 critical level were analysed also for Bulgaria in the NIMH domain. Results presented in Figure 12 show that exceedances can be observed only in two regions, around the thermal power plants Mariza-Iztok and Bobov dol. There is no relevant change of the shape and area of these regions between the time slices. The change of the concentrations is also not relevant, however the exceedance area, similar as in Poland, is slightly wider for the end-century decade.

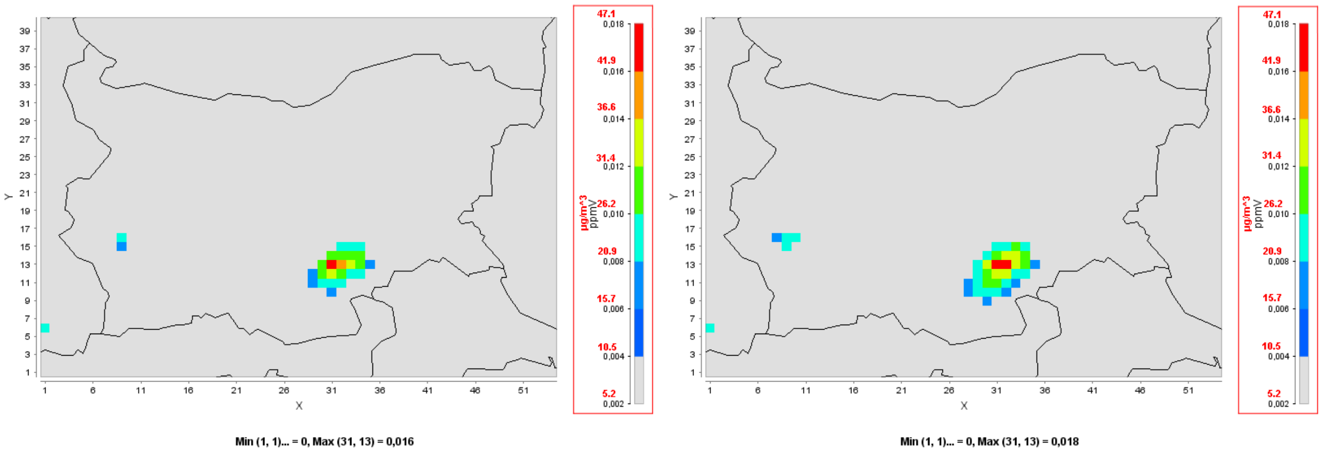

Figure 12: Exceedances [µg/m^3] of SO_2 annual critical level of 20 µg/m^3 (~ 0.008 ppmv) at NIMH domain for the present day decade 1991-2000 (left panel) and for the end-century decade 2091-2100 (right panel).

Finally, Figure 13 presents the calculation results for the WUT and CUNI domains in terms of exceedances solely.

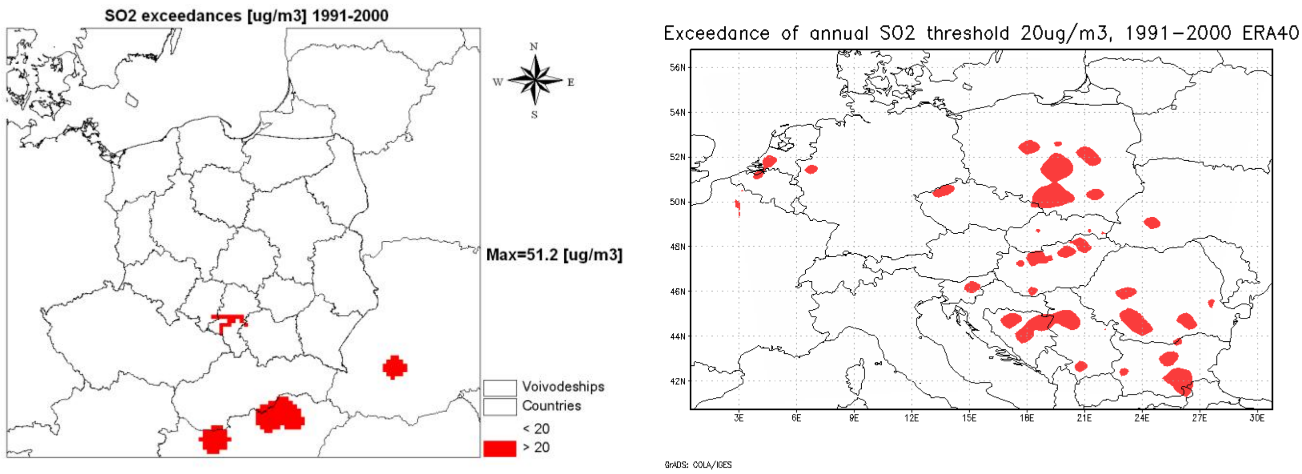

Figure 13: Comparison of the exceedances [µg/m^3] of SO_2 annual critical level of 20 µg/m^3 for the present day decade 1991-2000 calculated for the WUT domain (left panel) and for the CUNI domain (right panel).

The comparison between exceedances of SO_2 critical level calculated for the present day decade at NIMH (Fig 12, left panel), WUT (Fig. 13, left panel) and CUNI (Fig. 13, right panel) domains, highlights the differences in the set up of modelling systems. The Polish and Bulgarian large point sources were treated individually (Poland) and as elevated area sources (Bulgaria) in the simulations (see Introduction), while for all countries in the CUNI domain point sources were treated as surface area sources, thus causing significant overestimation in the vicinity of the LCP. The differences in estimated exceedance areas obtained in CUNI and WUT runs for Poland are exclusively due to differences in emission input, as both CUNI and WUT use the same modelling system (RegCM3(Beta)-CAMx). The differences obtained in CUNI and NIMH runs for Bulgaria are additionally due to different modelling systems applied (ALADIN-CMAQ in NIMH simulations).

3 Health effects – the case study for Poland

3.1 Introduction

Hundreds of new epidemiological studies in 1990's and 2000's have indicated that the current air pollution levels are capable of harming public health. From the ambient air pollution mixture the attention has focused especially on particulate matter (PM). Out from the entire PM mass, it is especially the fine particulate matter ($PM_{2.5}$) that has been associated with a number of adverse health effects (e.g. Pope and Dockery, 2006). The impact assessments have estimated that $PM_{2.5}$ causes annually over 800 000 premature deaths worldwide (Cohen et al., 2005); 350 000 in Europe alone (Watkiss et al., 2005). $PM_{2.5}$ air pollution is one of the major environmental health problems in the developed world.

Estimation of adverse health effects caused by $PM_{2.5}$ air pollution is usually based on combination of outdoor concentrations of pollutant with exposure-response functions. Most of the published studies use ambient concentrations of $PM_{2.5}$ at different home addresses as a proxy of exposure. The exposure to $PM_{2.5}$ has been associated with a number of health effects all over the world in hundreds of epidemiological and toxicological studies. The integrated assessment studies for $PM_{2.5}$ has focused on long-term mortality impact because the major part of adverse health and economical impacts of PM are due to long-term mortality (e.g. EPA, 1999) in comparison to other adverse health effects (e.g. morbidity). Long-term mortality is the adverse health effect caused by chronic exposure to $PM_{2.5}$ air pollution and it has usually been described in $PM_{2.5}$ assessment studies by estimating the annual average $PM_{2.5}$ concentrations. The exposure-response functions used in these studies are based on epidemiological cohort studies or on the results of expert elicitation studies.

In the framework of this Deliverable, we estimated the adverse health effects caused by $PM_{2.5}$ air pollution in Poland for the present day 1991-2000, near future 2041-2050, and end-century 2091-2100 decades. The aim of the sub-project was to estimate how climate change will impact the exposure for $PM_{2.5}$ air pollution. The following chapters will describe the data, methodology and results.

3.2 Data

The following calculations are based on $PM_{2.5}$ concentrations calculated at WUT with RegCM3(Beta)-CAMx modelling system. For the basic year (2000) calculations, regional climate model RegCM3(Beta) was driven by the ERA40 reanalysis fields of ECMWF (Reading, UK). For the three selected time slices RegCM3(Beta) was driven by ECHAM5 Global Climate Model outputs. The results obtained for the present day decade are presented in Figure 14. The background mortality data are from the Polish National Institute for Health. Analytica, a Monte-Carlo simulation program, was used to estimate uncertainties for premature death estimates. The average exposure levels for different provinces (Voivodeships) were calculated with ESRI ArcMap version 9.3. Exposure-response functions are based on literature.

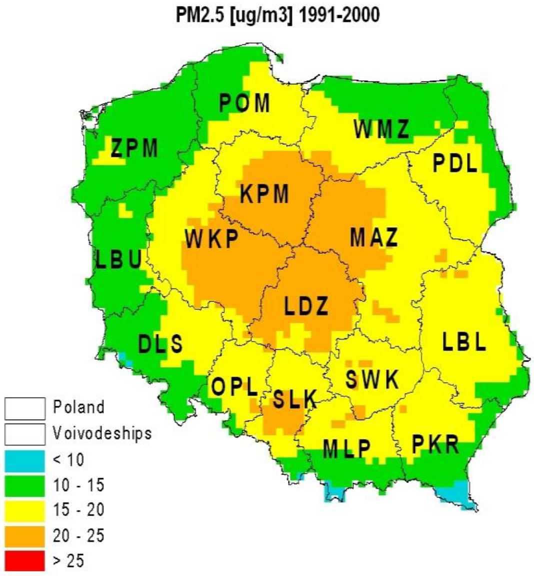

Figure 14: Annual mean $PM_{2.5}$ concentrations [$\mu g/m^3$] in Poland calculated for present day decade 1991-2000.

The background mortality data are presented in Table 1.

Table 1: Background mortality estimates for different provinces in Poland for year 2000.

Acronym	Area	Total non-accidental mortality	Together	Death with no cause specified	Other causes	External causes of illness and death - total
POL	**Poland**	**338 950**	**368 028**	**1 678**	**1 637**	**25 763**
DLS	DOLNOŚLĄSKIE	26 019	28 287	76	111	2 081
KPM	KUJAWSKO-POMORSKIE	18 388	19 727	1	102	1 236
LBL	LUBELSKIE	21 454	23 228	268	127	1 379
LBU	LUBUSKIE	8 170	8 894	2	49	673
LDZ	ŁÓDZKIE	29 620	31 961	46	234	2 061
MLP	MAŁOPOLSKIE	26 563	28 503	6	35	1 899
MAZ	MAZOWIECKIE	47 687	52 064	303	249	3 825
OPL	OPOLSKIE	8 751	9 378	3	1	623
PKR	PODKARPACKIE	16 843	18 129	41	49	1 196
PDL	PODLASKIE	10 836	11 802	3	107	856
POM	POMORSKIE	16 750	18 083	4	45	1 284
SLK	ŚLĄSKIE	41 996	45 989	557	138	3 298
SWK	ŚWIĘTOKRZYSKIE	12 459	13 377	6	62	850
WMZ	WARMIŃSKO-MAZURSKIE	10 688	11 777	1	51	1 037
WKP	WIELKOPOLSKIE	29 427	31 811	4	158	2 222
ZPM	ZACHODNIOPOMORSKIE	13 299	15 018	357	119	1 243

3.3 Exposure assessment

In the following calculations we assume that exposure = outdoor concentration of $PM_{2.5}$ in the location of population.

The average exposure of the population to $PM_{2.5}$ was estimated with two different methods:

(i) Average exposure over the grids

(ii) Population average exposure

The population average exposure was calculated with following equation:

$$E = \sum_i C_i \frac{Pop_i}{Pop}$$

In this equation, E is exposure for $PM_{2.5}$ (unit: $\mu g/m^3$), C is $PM_{2.5}$ concentration (unit: $\mu g/m^3$), Pop is number of population. In this case population average exposure have been estimated separately for (i) Poland and for different provinces and (ii) for different years. The results for Poland are presented in Figure 15 and for different provinces in Figure 16.

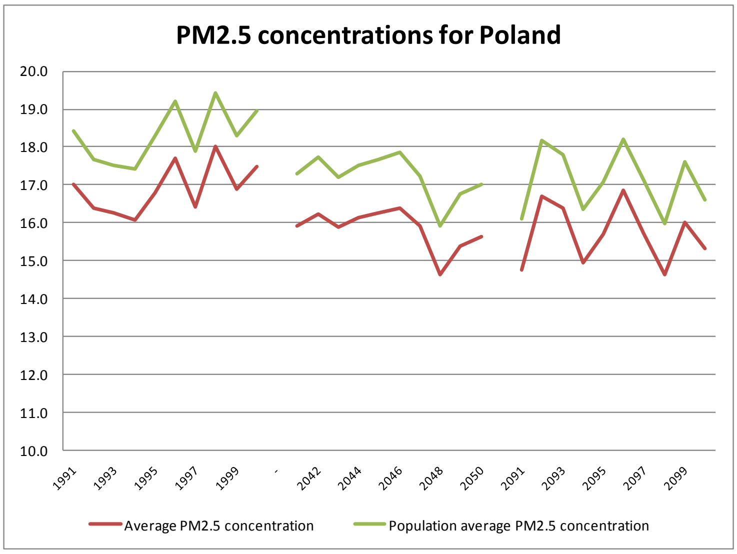

Figure 15: Average and population average exposure for $PM_{2.5}$ in Poland for the time slices 1991-2000, 2041-2050, and 2091-2100. For statistical tests see Table 2.

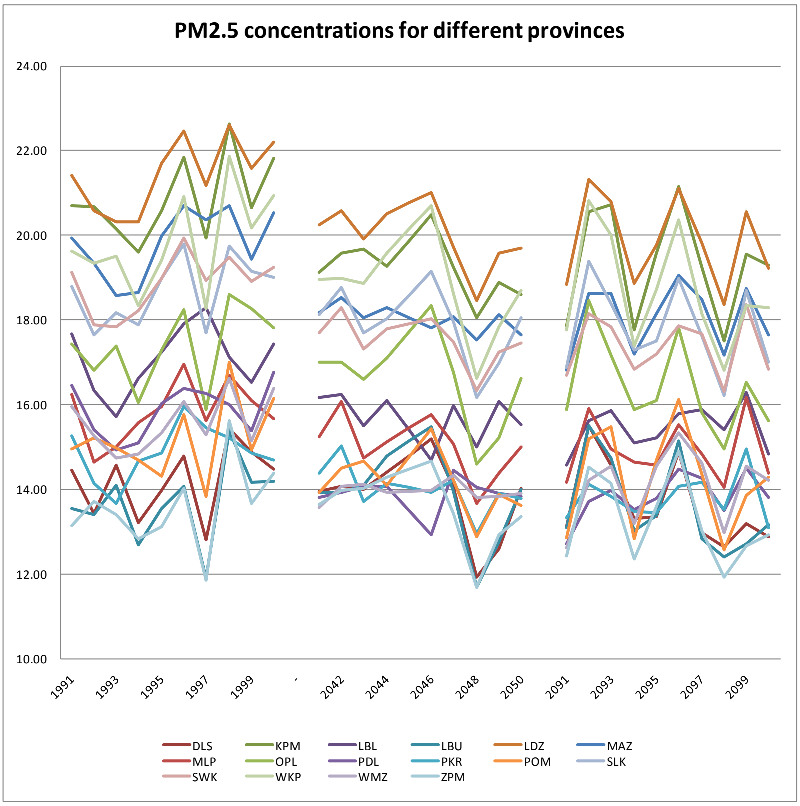

Figure 16: Average exposure for $PM_{2.5}$ in different provinces for the time slices 1991-2000, 2041-2050, and 2091-2100. Province acronyms are described in Table 1, their localisation is shown in Figure 14.

The results of T-test for the difference between considered time slices for both average and population average exposure are given in Table 2.

Table 2: T-test results. A two sample location test of the null hypothesis was used to test if the means of two different time blocks results are equal. T-test value less than 0.05 means that the means of two samples are different. According to T-test, for both average and population average exposure the difference between the present day decade 1991-2000 and the both future decades is statistically significant. The difference between the near future decade 2041-2050 and the end-century decade 2091-2100 was statistically insignificant for both average and population average $PM_{2.5}$ exposure.

	Average $PM_{2.5}$ concentration	Population average $PM_{2.5}$ concentration
1991-2000 vs. 2041-2050	0.001	0.001
1991-2000 vs. 2091-2100	0.002	0.003
2041-2050 vs. 2091-2100	0.652	0.712

3.4 Adverse health effects

The premature mortality was calculated with following equation:

$$M = M_b \times E \times (ER/100)$$

In the equation, M is premature death due to $PM_{2.5}$ air pollution, M_b is background non-accidental mortality in Poland in year 2000, E is exposure level, and ER is exposure-response function (% change in mortality due to 1 $\mu g/m^3$ $PM_{2.5}$ exposure). For value of ER, we used the estimates from European expert elicitation study that evaluated exposure-response function for $PM_{2.5}$ air pollution (Tuomisto et al. 2008). Tuomisto et al. (2008) study provided two different mean values (EDM and PDM) for E and the results have been estimated with both of these. In addition the premature deaths were estimated with Monte Carlo simulation using both of these estimates. Figure 17 shows the estimated premature deaths for different provinces for year 2000, while the premature deaths estimates for present day and future climate are presented in Table 3.

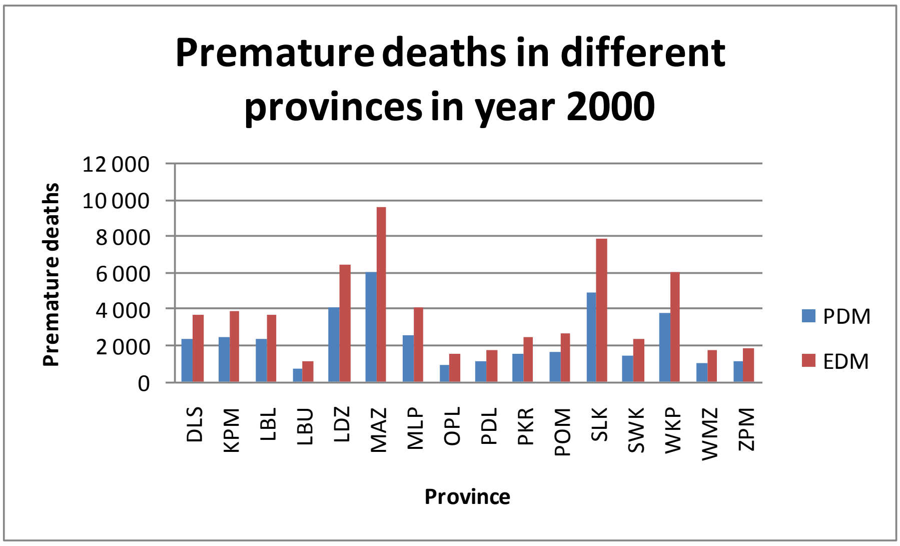

Figure 17: Premature deaths in different provinces in Poland estimated for year 2000. The premature deaths have been estimated by using both EDM and PDM exposure-response functions. See Table 1 and Figure 14 for province acronyms and localisation.

Table 3: Premature death estimates for Poland for the time slices 1991-2000, 2041-2050, and 2091-2100.

	Premature death estimates					
	Based on average PM2.5 concentration			**Based on population average PM2.5 concentration**		
Year	**PDM**	**EDM**	**Combination, mean (0.025-0.975 fractiles)**	**PDM**	**EDM**	**Combination, mean (0.025-0.975 fractiles)**
1991	35 773	56 545	70.29K (1684-265.4K)	38 739	61 232	76.11K (1824-287.4K)
1992	34 430	54 421	67.65K (1621-255.4K)	37 121	58 674	72.93K (1748-275.4K)
1993	34 141	53 965	67.08K (1607-253.3K)	36 791	58 154	72.29K (1732-273K)
1994	33 759	53 361	66.33K (1589-250.5K)	36 623	57 887	71.95K (1724-271.7K)
1995	35 278	55 762	69.31K (1661-261.7K)	38 476	60 817	75.6K (1811-285.5K)
1996	37 166	58 746	73.02K (1750-275.7K)	40 330	63 747	79.24K (1899-299.2K)
1997	34 491	54 518	67.77K (1624-255.9K)	37 586	59 411	73.85K (1770-278.9K)
1998	37 862	59 846	74.39K (1783-280.9K)	40 831	64 539	80.22K (1922-302.9K)
1999	35 483	56 087	69.72K (1671-263.3K)	38 461	60 793	75.57K (1811-285.4K)
2000	36 760	58 104	72.22K (1731-272.7K)	39 807	62 920	78.21K (1874-295.3K)
-						
2041	33 449	52 871	65.72K (1575-248.2K)	36 369	57 487	71.46K (1712-269.8K)
2042	34 121	53 934	67.04K (1606-253.2K)	37 279	58 924	73.24K (1755-276.6K)
2043	33 389	52 777	65.6K (1572-247.7K)	36 139	57 123	71K (1701-268.1K)
2044	33 938	53 644	66.68K (1598-251.8K)	36 798	58 165	72.3K (1732-273K)
2045	34 193	54 047	67.18K (1610-253.7K)	37 149	58 719	72.99K (1749-275.6K)
2046	34 448	54 450	67.68K (1622-255.6K)	37 500	59 274	73.68K (1765-278.2K)
2047	33 433	52 846	65.69K (1574-248.1K)	36 202	57 222	71.13K (1704-268.6K)
2048	30 717	48 553	60.35K (1446-227.9K)	33 473	52 909	65.77K (1576-248.3K)
2049	32 337	51 113	63.53K (1522-239.9K)	35 201	55 641	69.16K (1657-261.2K)
2050	32 853	51 928	64.55K (1547-243.7K)	35 749	56 507	70.24K (1683-265.2K)
-						
2091	30 986	48 979	60.88K (1459-229.9K)	33 824	53 463	66.46K (1592-251K)
2092	35 081	55 450	68.92K (1652-260.3K)	38 211	60 398	75.08K (1799-283.5K)
2093	34 460	54 469	67.71K (1622-255.7K)	37 379	59 083	73.44K (1760-277.3K)
2094	31 433	49 685	61.76K (1480-233.2K)	34 362	54 314	67.51K (1618-254.9K)
2095	32 998	52 159	64.83K (1554-244.8K)	35 879	56 712	70.49K (1689-266.2K)
2096	35 391	55 941	69.54K (1666-262.6K)	38 238	60 441	75.13K (1800-283.7K)
2097	33 032	52 212	64.9K (1555-245.1K)	35 996	56 897	70.72K (1695-267.1K)
2098	30 755	48 613	60.43K (1448-228.2K)	33 548	53 028	65.91K (1579-248.9K)
2099	33 658	53 201	66.13K (1585-249.7K)	37 031	58 534	72.76K (1743-274.7K)
2100	32 187	50 876	63.24K (1515-238.8K)	34 883	55 138	68.54K (1642-258.8K)

3.5 Discussion

Estimated population average exposures to $PM_{2.5}$ in Poland were 18.3 μg/m^3, 17.2 μg/m^3 and 17.1 μg/m^3 for three considered time slices 1991-2000, 2041-2050, and 2091-2100, respectively. Corresponding values for average $PM_{2.5}$ concentrations over Poland were 16.9 μg/m^3, 15.8 μg/m^3 and 15.7 μg/m^3, respectively. The difference between the average concentration of the present day decade 1991-2000 in comparison to two future climate decades was statistically significant. Results indicate that climate change might reduce the exposure to PM air pollutants and resulting premature death estimates in the region under concern. However impact of emission and population changes were not taken into account in our study.

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