Estimating particulate matter health impact related to the combustion of different fossil fuels

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Abstract

Exposure to particulate matter (PM) in ambient air leads to adverse health effects. To design cost effective mitigation strategies, a thorough understanding of the sources of particulate matter is crucial. We have successfully generated a web map service that allows to access information on fuel dependent health effects due to particulate matter. For this purpose, the LOTOS-EUROS air pollution model was equipped with a source apportionment module that tracks the origin of the modelled particulate matter distributions throughout a simulation. Combined with a dedicated emission inventory PM2.5 maps specified by fuel type were generated for 2007-2009. These maps were combined with a health impact calculation to estimate Lost of Life Expectancy for each fuel categories. An user friendly web client was generated to access the results and use the web mapping service in an easy manner.

1. Introduction

Exposure to particulate matter (PM) in ambient air leads to adverse health effects (Dockery et al., 1993). Deposition of secondary inorganic aerosol and its precursors leads to a loss of biodiversity through acidification and eutrophication of soils and surface waters. Moreover, particulate matter components play a key role in climate change affecting the radiation balance of the earth. To limit the effects of PM pollution, efforts are made to reduce emissions of particles and its precursors. To design cost effective mitigation strategies, a thorough understanding of the sources of particulate matter is crucial. As PM consists of a host of components with different sources and atmospheric behaviour, establishing the origin of PM remains a challenge. Complementary to experimental data, a chemical transport model (CTM) can be used to obtain a more detailed source apportionment. Chemical transport models provide calculations of the evolution of the air pollution situation across a region based on emission inventories and atmospheric process descriptions. Hence, they implicit contain the information to perform a source apportionment. Moreover, these models can be used to evaluate mitigation strategies.

Within the EnerGEO project the improved assessment of source apportionment for PM is a focus point. For this purpose, a dedicated source apportionment module was developed and evaluated. The new system is used to evaluate the health impact of different fuels used in Europe as well as the evaluation of scenarios for energy transitions. Here we report on the first topic.

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2.1 Emission data

To be able to look at the contribution of fuel combustion to air pollution using a chemistry transport model, the underlying emission database is required to include detailed information about the fuel use in all sectors and associated emissions. To be able to calculate modeled fuel contributions to PM the high resolution (1/8° longitude x 1/16° latitude) European TNO-MACC emission dataset for 2005 (Kuenen et al., 2011) was disaggregated in such a way that the contributions of the different sectors and fuels are recognized separately. The adapted emission database contains 20 (sub)sectors and 7 fuel types for 43 countries and 5 international seas.

2.2 Model description

The LOTOS-EUROS model (Schaap et al., 2008) is used to calculate the PM10 distributions over Europe. for 2005. The LOTOS-EUROS model is a 3D chemistry transport model aimed to simulate air pollution in the lower troposphere. In the vertical the model has four layers up to 3.5km following the dynamic mixing layer approach. ECMWF meteorology is used to force the model simulations for the years 2007-2009. The horizontal resolution used here is 25x25Km. The model is suitable to calculate the transport of primary (combustion) particles (EC, OC), sea salt, dust and secondary inorganic aerosols (SIA: SO4, NO3, NH4). Previous versions of the model have been used for the assessment of (particulate) air pollution (e.g. Schaap et al., 2004; Manders et al., 2009). For a detailed description of the model v1.8 we refer to Hendriks et al. (2012) and references therein.

A source apportionment module for LOTOS-EUROS was developed to be able to track the origin of the components of particulate matter (Kranenburg et al., 2012). This module uses a labeling approach, tracking the source contribution of a set of predefined sources through the model system from emission to concentration of carbon, nitrogen and/or sulfur containing air pollutants. The source apportionment module for LOTOS-EUROS provides a source attribution valid for current atmospheric conditions as all chemical conversions occur under the same oxidant levels. To limit the amount of sources to be tracked in the simulation and thereby save computer time, not all fuel types were traced separately for all sectors. For each fuel type, the sectors contributing most to emissions originating for that fuel were given a label and the other sectors were lumped together in the labeling. This resulted in 27 labels, including labels for natural emissions and for emissions from outside the model domain (see Table 4).

2.3 Health impact calculation

The Lost of Life Expectancy (LLE) computation is based on the difference between the life expectancy with no exposure to particulate matter and life expectancy with exposure to observed particulate matter in each scenario. We have used an algorithm for the computation of LLE for population exposed to PM2.5 derived by Lefèvre et al. (2013) based on the approach recommended by the Task Force on Health (TFH, 2013) described in IIASA's Report (Mechler et al., 2002) and accounting for the Pope exposure-risk parameter (Pope et al., 1995). Calculations were performed with the use of the following data sources:

- *Cohort Population Data* – national population in each cohort every 5 years were extracted from the World Population Prospects of United Nation Population Division – data are related to the population of the entire country, not individual grid cells, from 1950 to 2100.
- *Baseline Mortality Rates* – for each cohort in each country, the mortality rates were calculated based on the cohort population data.
- *Gridded Population Data* – national population in each grid cells (5 km * 5 km) were delivered from SEDAC for years 2005, 2010, 2015. Values after 2015 were kept constant.
- *Gridded $PM_{2.5}$ Concentration Data* delivered by LOTOS-EUROS model as described above.

3. Results

In Figure 1 the modelled fractional contribution of the combustion of the separate fuels to the modelled annual average PM2.5 concentrations are shown. The model allocates about 70 % of the modelled particulate mass to the combustion of fuels. The remainder is associated with (industrial) process emissions, wear processes (transport) and agricultural ammonia emissions. From the different fuels the gaseous and light liquid fuels (e.g. gasoline) do not contribute much to PM2.5 across Europe. These contributions are mostly secondary material formed from NOx. In western Europe and large cities medium liquid fuels (i.e. Diesel from transport) dominate the fuel related PM2.5 mass with contributions of about 20%. In eastern Europe and isolated areas elsewhere, solid fuels and especially wood and coal combustion in the energy sector as well as households cause the largest contribution to fine particulate matter levels. Heavy fuel oil combustion in international shipping is important in coastal areas and especially in southern Scandinavia where it contributes most.

The health impact assessment shows that for PM2.5 the calculated loss of life expectancy maximises over the Po Valley, the Benelux and south eastern Europe. In these regions the LLE is about 8-10 months. Across most of central Europe the value is about half a year, whereas the impact is lower towards Scandinavia and the Iberian peninsula. In general, the fraction maps shown in Figure 1 can be used to the assess the fuel dependent health impact. However, in terms of totals across the population the contributions of Diesel is higher than for solid fuels due to the higher population density in western Europe. Per unit emission, the surface sources are about twice as important as stack emissions.

The total LLE in days per person is shown in Figure 2. The figure shows the DOLL (average days of life lost per person) for the total European domain. It is shown that solid fuels are the largest contributing fuel to LLE in days per person. However, the first analysis shows that the combination of combustion with unknown fuel and non-combustion processes contribute even more to the LLE. These processes include for instance industrial process emissions and wear emissions from transport. The category “Other” represents natural emissions, and model initial/boundary conditions which are also an important parameter to the LLE on the European scale.

Figure 3 shows the DOLL per country, only from the combustion of coal in power plants for Europe in a map. The graph shows higher DOLL in Eastern European countries. These countries typically have older technologies and less abatement installed, which means that PM emissions are higher per unit of coal-fired electricity generated. Also, countries like Poland and the Czech Republic have high shares of coal in their fuel mix for electricity generation.

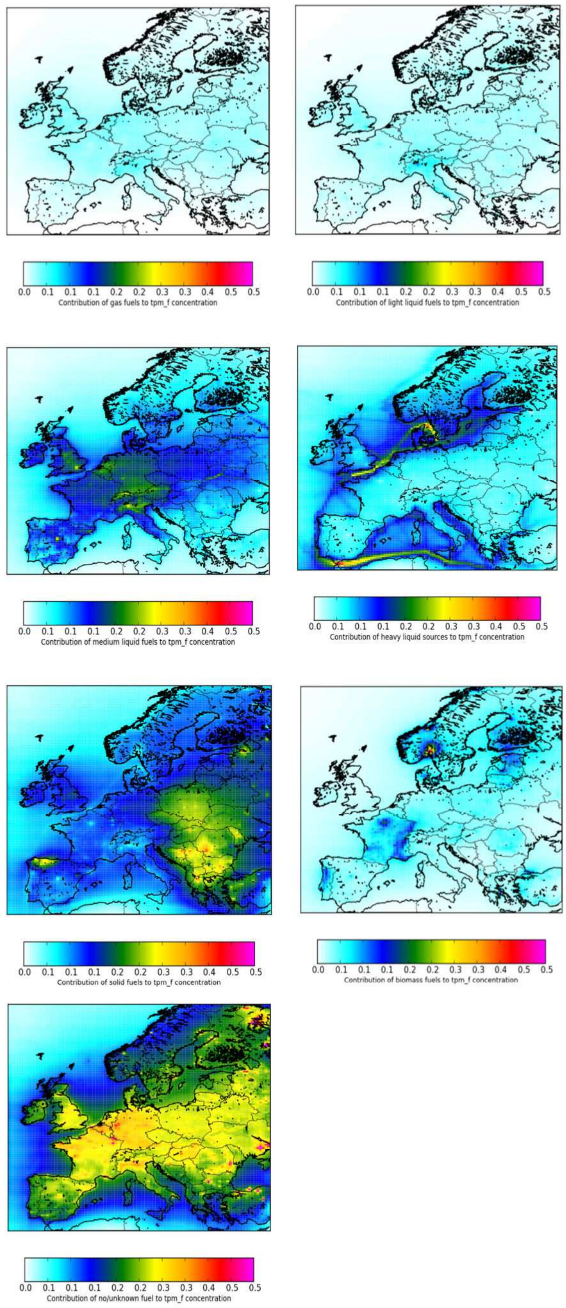

Figure 1. From left to right and top to bottom: Modelled contribution of combustion of gas fuels, light liquid fuels, medium liquid fuels, heavy liquid fuels, solid fuels and biomass fuels as well as other anthropogenic sources to PM2.5 concentration in Europe for 2007-2009.

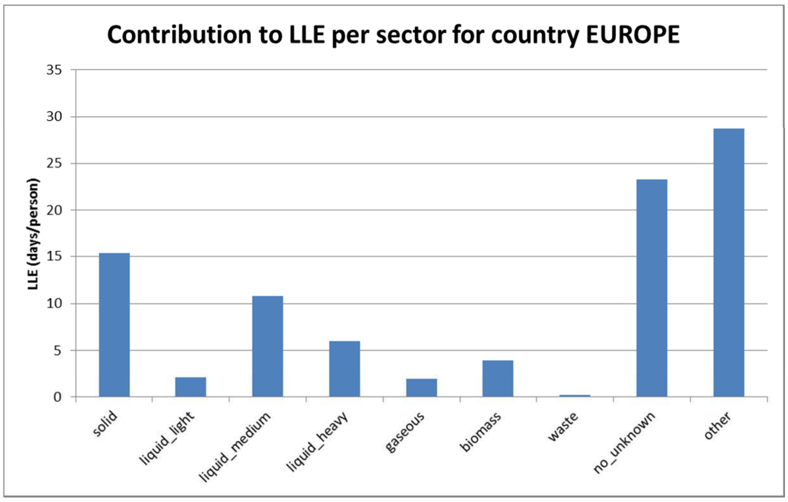

Figure 2. Contribution to loss of life expectancy (in average number of days lost per person) in Europe, per fuel for the year 2005.

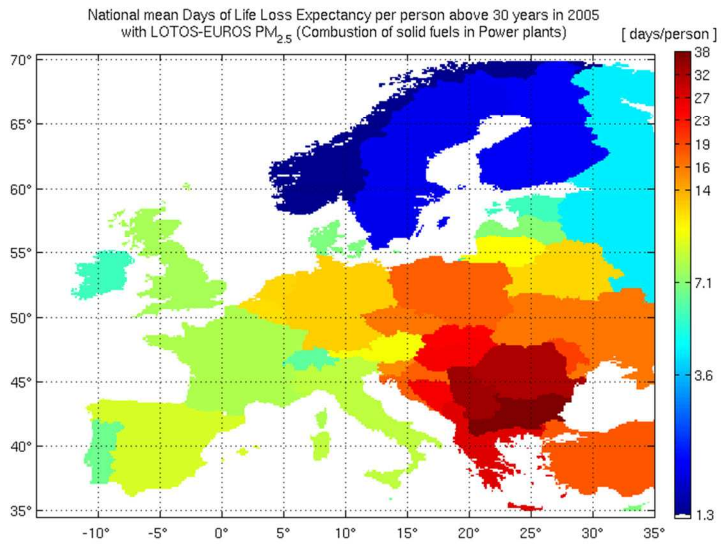

Figure 3. National mean days of life expectancy lost in Europe in 2005 resulting from coal-fired power plants.

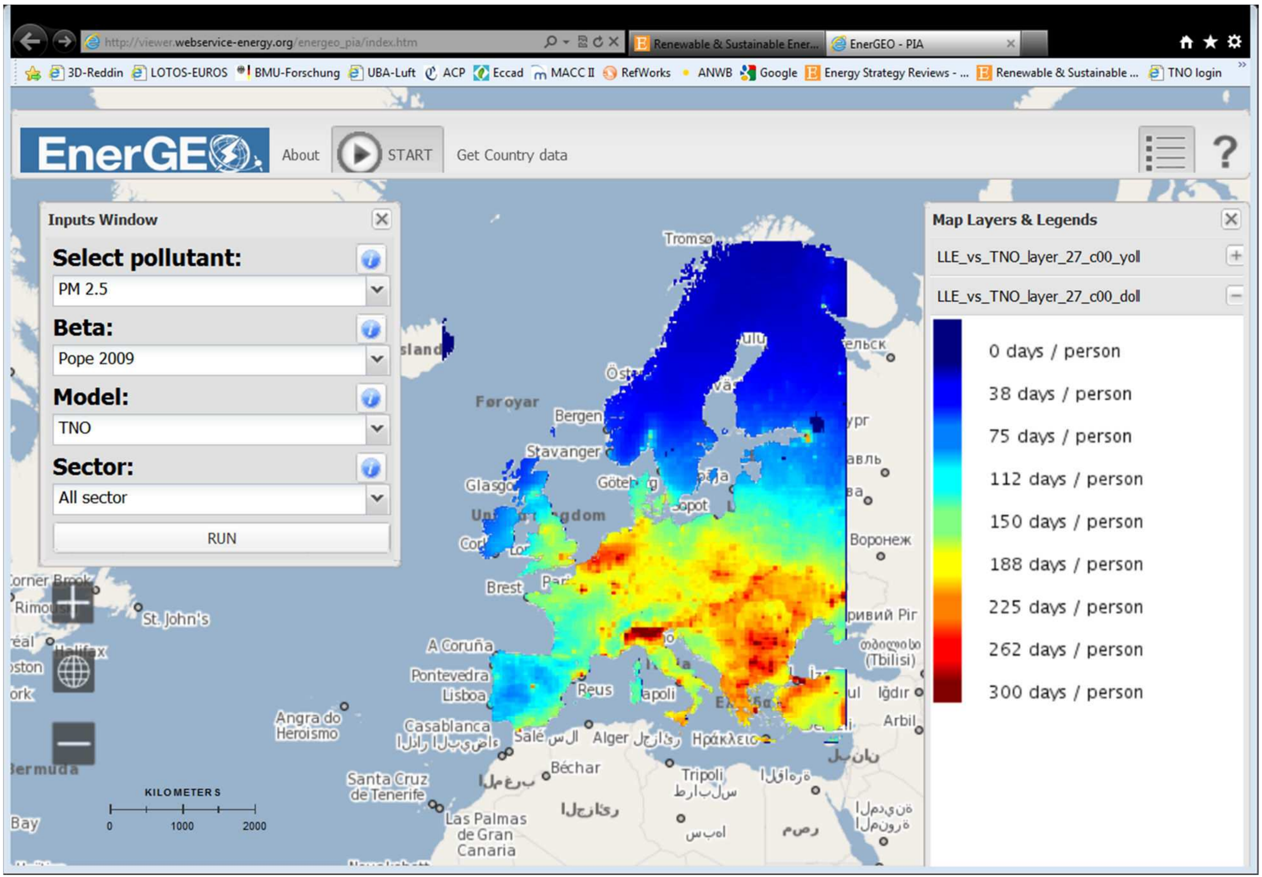

Figure 4. Screen shot of the web map service.

4. Web service

The web service implementation is composed by a Web Processing Service (WPS) as a front-end that allows the user to select all desired parameters and Web Map Services (WMS) that serve generated maps. In the background maps are pre-computed with a code that implements algorithms described in previous section. This code is mainly a MatLab™ code. The results are GeoTiff file in float, and are served by WMS. The web service has the following inputs:

- *pollutant*, a character string that can be pm2.5 or ozone;
- *beta*, a character string that can be pop2009, pop2002 or none if not needed;
- *scenario*, a character string that can be baseline, trans-csp, renewable or island-europe or none if not needed;
- *sector*, a character string that can be sc00 to sc26 which represent the different activity sectors or none if not needed;

The service provides maps of Lost of Life expectancy per person and absolute Lost of Life expectancy for Europe per country.

The web client allows users to use the web service easily. The user can fill a request to the web service by selecting each parameter in an user-friendly interface. He has access to the content of the result of his request. The client is reachable to the following URL: http://viewer.webservice-energy.org/energeo_pia/index.htm, The client is based on Javascript with OpenLayer, ExtJs, on html and on OGC standards with WMS, WPS and WFS. The request interface and an example of result are show in Figure 4.

5. Conclusions

We have successfully generated a web map service that allows to access information on fuel dependent health effects due to particulate matter. For this purpose, the LOTOS-EUROS air pollution model was equipped with a source apportionment module that tracks the origin of the modelled particulate matter distributions throughout a simulation. Combined with a dedicated emission inventory PM2.5 maps specified by fuel type were generated for a three year period. These data were combined with a health impact calculation to estimate Lost of Life Expectancy for these categories. An user friendly web client was generated to access the results and use the web mapping service in an easy manner.

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