Human health impacts for Renewable Energy scenarios from the EnerGEO Platform of Integrated Assessment (PIA)

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Abstract

This article reports impact results from running the EnerGEO Platform of Integrated Assessment (PIA) related to human health for different scenarios in Europe. The scenarios were prepared within the EnerGEO project. The idea of this European project is to determine how low carbon scenarios, and in particular scenarios with a high share of renewable energy, affect concentrations of air pollutants and as a consequence affect human health. $PM_{2.5}$ concentrations were estimated with the IIASA Greenhouse Gas and Air Pollution Interactions and Synergies (GAINS) model on a time horizon up to the year 2050 for different scenarios. We analyse here the estimation of the Loss of Life Expectancy due to $PM_{2.5}$ concentrations for the *Baseline* scenario taken as a reference and the *Maximum renewable power* scenario.

1. Introduction

People exposure to fine particulate matter ($PM_{2.5}$) can have various health effects as described in scientific publications in the area of observational epidemiology (Dockery 2009) (Pope/Thun/Namboodiri/Dockery/Evans/Speizer 1995) (Pope/Burnett/Thun/Calle/Krewski/Ito 2002). Within the EnerGEO Platform of Integrated Assessment (PIA) (Blanc/Gschwind/Lefevre/Beloin-Saint-Pierre/Ranchin/Menard/Cofala/Fuss/Wyrwa/Drebszok/Stetter/Schaap 2013), impacts on human health from $PM_{2.5}$ are investigated. We now report how is performed the estimation of the Loss of Life Expectancy (LLE) related to $PM_{2.5}$ concentrations time series corresponding to different scenarios derived from the GAINS model (Amann/Bertok/Borken-Kleefeld/Cofala/Heyes/Hoeglund-Isaksson/Klimont/Nguyen/Posch/Rafaj/Sandler/Schoepp/Winiwarter 2011).

A reference scenario, the *Baseline* scenario considers current policies with regard to mitigation of climate change, as taken into account in various studies available for Europe. The EnerGEO *Maximum renewable power* scenario assumes the highest possible electricity generation from renewable sources.

All scenarios were compiled by IIASA (Cofala/Bertok/Heyes/Rafaj/Sander/Schöpp 2012) using the following sources:

- PRIMES scenarios up to the year 2050 (Capros 2010),
- Scenarios up to 2035 prepared by the International Energy Agency with the use of the World Energy Model for the World Energy Outlook 2009, Organization for Economic Co-operation and Development (OECD/IEA 2009),
- The POLES scenarios up to 2050 (Russ/Ciscar 2009).

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Unlike the assumption where the $PM_{2.5}$ concentrations remain constant at a fixed level (implemented in GAINS for example), this study accounts for the temporal evolution of $PM_{2.5}$ concentrations along the time frame from 2005 till 2075. LLE was considered over the whole life time of the population older than 30 years in year 2005. The analysis was carried out for 45 European countries.

2. Methodology

The LLE computation is based on the difference between the life expectancy with no exposure to particulates and life expectancy with exposure to observed particulates in each scenario. We propose an algorithm for the computation of LLE for population exposed to $PM_{2.5}$ based on the approach recommended by the Task Force on Health (TFH 2003) described in IIASA's Report (Mechler/Amann/Schöpp 2002) and accounting for the Pope exposure-risk parameter (Pope/Burnett/Thun/Calle/Krewski/Ito 2002).
We found out that applying a new feature of temporal evolution of $PM_{2.5}$ instead of constant values with time is of great interest for assessing the potential impacts of scenarios (Lefevre/Blanc/Gschwind, Ranchin/Drebszok/Wyrwa 2013). Thus $PM_{2.5}$ values have been linearly interpolated each five years between 2005 and 2050. We also considered the temporal evolution of population mortalities.

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 (United Nations 2011) – data are related to the population of the entire country, not individual grid cells, from 1950 to 2100.
- *Mortality Rates* – for each cohort in each country, the mortality rates were calculated based on the life table survivors at exact age (United Nations 2011).
- *Gridded Population Data* – national population in each grid cell (5 km * 5 km) were delivered from SEDAC for years 2005, 2010, 2015 (SEDAC 2004).
- *Gridded $PM_{2.5}$ Concentration Data* delivered from GAINS model following the EMEP 2008 resolution 50 km * 50 km (Cofala/Bertok/Heyes/Rafaj/Sander/Schöpp 2012)[1]. GAINS model outputs for 2005, 2030, 2040 and 2050 were interpolated each five years to provide $PM_{2.5}$ time series. Values after 2050 were kept constant.

The calculation of LLE from PM2.5 concentrations (Gschwind/Lefevre/Blanc 2012) is mainly based on epidemiologic studies and dose-response equation from (Pope 2002) and (Pope 1995) as well as work from (Rabl 2003) and (Vaupel/Yashin 1986). The result is the following formulae:

$$le_0(t_0, l, a_0) = -\int_0^{\infty} e^{-\int_0^y \mu_e(t_0+x, a_0+x, l)\cdot e^{-\beta\cdot(pm(t_0+x,l))}\cdot dx} \cdot dy$$

$$le(t_0, l, a_0) = -\int_0^{\infty} e^{-\int_0^y \mu_e(t_0+x, a_0+x, l)\cdot dx} \cdot dy$$

Where:

[1] GAINS Model : http://www.iiasa.ac.at/web/home/research/researchPrograms/GAINS.en.html

$le(t_0, l, a_0)$ is the life expectancy for a group of people that reach the age a_0 at time t_0 in location l,

$le_0(t_0, l, a_0)$ is the life expectancy *without* effect of $PM_{2.5}$ for a group of people that reach the age a_0 at time t_0 in location l,

$\mu_e(t, a, l)$ is the actual mortality rate at time t and location l,

$pm(t, l)$ is $PM_{2.5}$ concentration at time t and location l.

Because we do not have continuous values for $PM_{2.5}$ and mortality rates, we made the assumption that $PM_{2.5}$ and mortality rates are constant by range of 5 years . The result is the following formulae:

$$le_0(t_0, l, a_0, \Delta t) = -\sum_{k=0}^{a_\infty/\Delta t} e^{-\sum_{i=0}^{k} \mu_e(t_0+i\cdot\Delta t, a_0+i\cdot\Delta t, l)\cdot e^{-\beta\cdot(pm(t_0+i\cdot\Delta t, l))}}$$

$$le(t_0, l, a_0, \Delta t) = -\sum_{k=0}^{a_\infty/\Delta t} e^{-\sum_{i=0}^{k} \mu_e(t_0+i\cdot\Delta t, a_0+i\cdot\Delta t, l)}$$

Where:
Δt is the length of considered ranges.
a_∞ is a maximum age were we consider that no one can survive.

The difference between these two life expectancies, $\Delta le(t_0, l, a_0, \Delta t)$, gives the YOLL (Years Of Life Lost) in each cohort due to $PM_{2.5}$:

$$\Delta le(t_0, l, a_0, \Delta t) = le(t_0, l, a_0, \Delta t) - le_0(t_0, l, a_0, \Delta t)$$

This formula has been integrated over the cohorts considered :

$$\Delta le_c(t_0, l, \Delta t, C) = \frac{\sum_{\forall a \in C} \Delta le(t_0, l, a, \Delta t) \cdot p_a(t_0, l, a, \Delta t)}{\sum_{\forall a \in C} p_a(t_0, l, a, \Delta t)}$$

Where $p_a(t_0, l, a, \Delta t)$ is the population of age in $[a, a + \Delta t[$ at time t_0 at location l.

Finally we can compute the loss of life expectancy for an area L like a country by spatial integration:

$$\Delta le_{c,l}(t_0, \Delta t, L, C) = \frac{\sum_{\forall l \in L} \Delta le_c(t_0, l, \Delta t, C) \cdot p_l(t_0, l)}{\sum_{\forall l \in L} p_l(t_0, l)}$$

Where $p_l(t_0, l)$ is the population of the given location l.

3. Results and discussion

Although European emissions of air pollutants importantly decreased over the last 25 years, in 2005 they were still high: 3.6 millions tons of $PM_{2.5}$ (Cofala/Bertok/Heyes/Rafaj/Sander/Schöpp 2012). Future emissions in the *Baseline* scenario are much lower: in 2050 they decrease to 3.1 millions tons for $PM_{2.5}$ (-13%). Low carbon (climate) policies cause further reduction of emissions compared to the *Baseline* scenario. These reductions are pollutant-specific (more than 7% for $PM_{2.5}$ in 2050). The three low carbon scenarios developed within EnerGEO, do not reveal large differences for the $PM_{2.5}$ pollutant concentrations between them (Figure 1), which is not the case for other pollutants : NO_x, SO_2, volatile organic compounds (VOC), ammonia (NH_3), carbon monoxide (CO), greenhouse gases (CO_2 and CH_4), nitrous oxide (N_2O), etc... Thus we focus on the *Maximum renewable power* scenario, where results can stand for the two other low carbon scenarios, namely Island Europe and Open Europe.

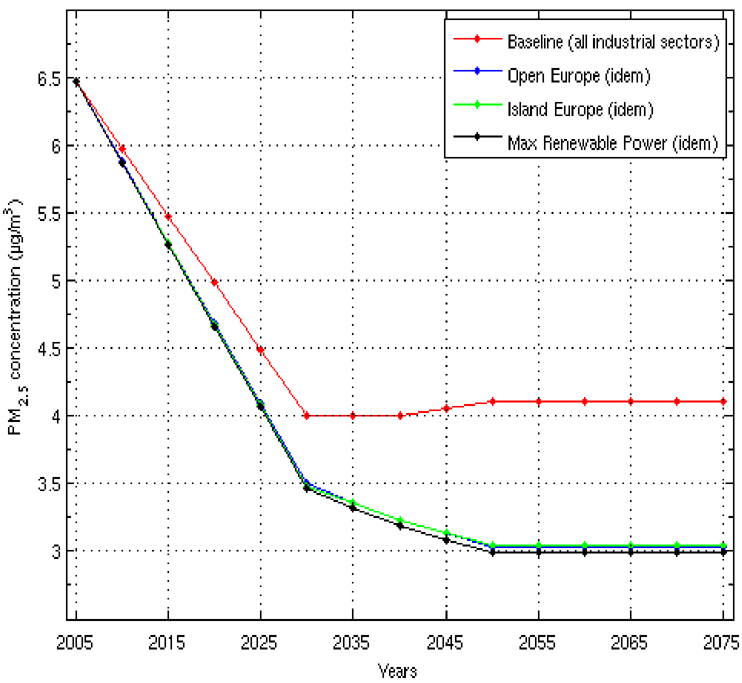

Figure 1
Evolution of $PM_{2.5}$ concentrations for the EnerGEO scenarios (time interpolation between GAINS outputs).

Figure 2 presents LLE results map in terms of days lost per person, while Figure 3 presents LLE map in terms of millions years lost per country, considering a population over 30 years in 2005 for the baseline scenario. Table 1 presents for European countries the comparison between LLE for the *Baseline* scenario and for the *Maximum renewable power* scenario.

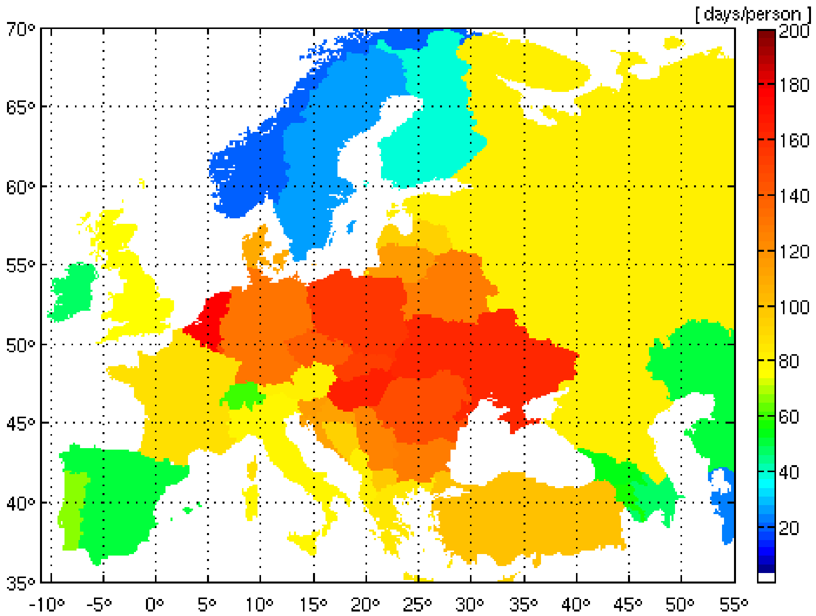

Figure 2
Mean loss of life expectancy in days per person following the *Baseline* scenario.

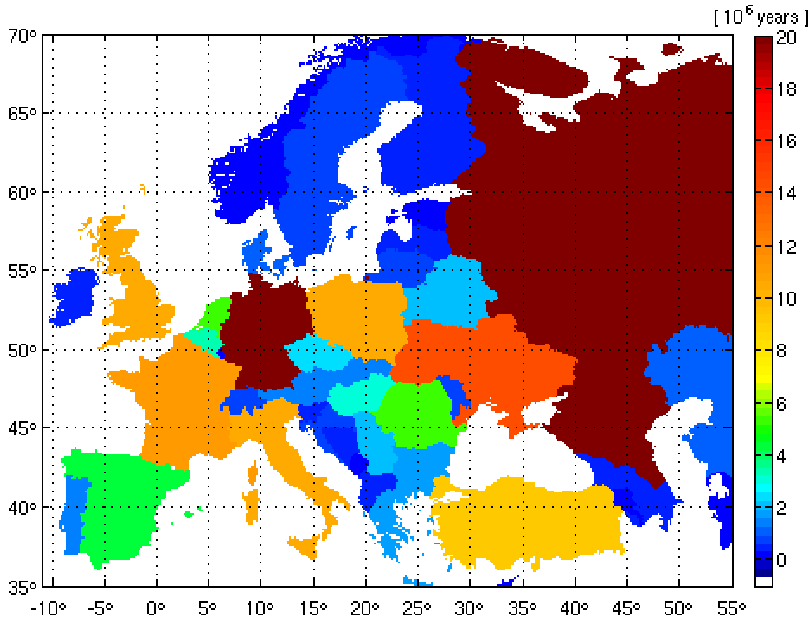

Figure 3
Mean loss of life expectancy in years per country following the *Baseline* scenario.

Table 1. Mean loss of life expectancy per country.

	Baseline scenario		Maximum Ren. Power scenario	
Country	DOLL (days/person)	YOLL (10^3 years)	DOLL (days/person)	YOLL (10^3 years)
Albania	81.6	347	76.0	323
Armenia	56.2	266	45.9	214
Austria	83.0	1384	79.6	1327
Azerbaijan	47.6	483	41.0	420
Belarus	128.9	2161	125.6	2111
Belgium	178.3	3497	172.8	3389
Bosnia Herzegovina	93.0	582	87.4	547
Bulgaria	126.3	1736	121.1	1666
Croatia	110.8	912	105.5	870
Cyprus	92.5	127	68.4	94
Czech Republic	140.5	2549	135.5	2458
Denmark	110.6	1068	107.8	1040
Estonia	81.3	194	78.4	187
Finland	37.5	475	35.3	456
France	88.5	10980	86.4	10729
Georgia	53.4	428	45.6	368
Germany	130.4	21378	125.9	20636
Greece	83.8	1788	78.6	1682
Hungary	164.1	2981	158.6	2884
Ireland	47.0	329	45.6	319
Italy	78.0	10375	75.2	10025
Kazakhstan	51.3	1216	49.4	1171
Latvia	92.7	383	89.9	372
Lithuania	114.8	673	111.5	654
Luxembourg	149.3	122	144.7	118
Montenegro	82.8	79	78.2	74

Netherlands	177.1	5232	170.7	5042
Norway	19.8	283	19.1	279
Poland	156.8	10620	151.6	10269
Portugal	66.0	1428	65.1	1412
Republic of Moldova	147.1	837	140.9	801
Romania	146.4	5437	140.5	5221
Russian Federation	82.7	40315	79.6	39615
Serbia	125.7	1947	118.1	1829
Slovakia	153.0	1332	147.4	1284
Slovenia	116.2	426	111.7	409
Spain	50.8	4382	49.7	4293
Sweden	25.9	778	24.9	753
Switzerland	59.7	911	57.3	874
TFYR Macedonia	96.9	299	91.3	281
Turkey	99.2	9307	76.4	7379
Turkmenistan	24.5	0.27	22.8	0.25
Ukraine	162.4	14341	157.1	13896
United Kingdom	76.7	10384	74.8	10133
Uzbekistan	25.3	90	23.7	84
EUROPE	**85.8**	**174859**	**81.6**	**167989**

LLE range between 20 days/person (Norway) up to 178 days/person (Belgium and The Netherlands) which is a wide dispersion across Europe. It would be worth analyzing the difference induced by the assumptions for each scenario.

DOLL values for Europe are means weighted according to the country size. The *Maximum renewable power* scenario is inducing, in average for European countries, a reduction of 5% which is fairly small. Discussions on the relevance of such difference compared to the uncertainty range needs to be discussed further.

All these results are provided on line on the EnerGEO PIA in numerical form as well as in form of LLE maps[1]. This platform is demonstrating the availability for potential decision makers to enquire about scenarios results in terms of impact assessment.

[1] http://viewer.webservice-energy.org/energeo_pia/index.htm

Bibliography

Amann, M., Bertok. I., Borken-Kleefeld. J., Cofala. J., Heyes. C., Hoeglund-Isaksson. L., Klimont. Z., Nguyen. TB., Posch. M., Rafaj. P., Sandler. R., Schoepp. W., Winiwarter. W. (2011): Cost-effective control of air quality and greenhouses gases in Europe : Modeling and policy applications, in : Environmental Modelling & Software, 26(12) pp. 1489-1501.

Blanc, I., Gschwind. B., Lefevre. M., Beloin-Saint-Pierre. D., Ranchin. T., Ménard. L., Cofala. J., Fuss. S., Wyrwa. A., Drebszok. K., Stetter. D., Schaap. M. (2013): The EnerGEO Platform of Integrated Assessment (PIA): environmental assessment of scenarios as a web service, in : Proceedings of EnviroInfo 2013 - 27th International Conference on Informatics for Environmental Protection, September 2013, Hamburg, Germany.

Cofala, J., Bertok. I., Heyes. C., Rafaj. P., Sander. R., Schöpp. W. (2012): Emissions of air pollutants and air pollution impacts for the EnerGEO scenarios, EnerGEO Draft report.

Capros, P. (et al.) (2010): EU Energy Trends to 2030 — UPDATE 2009. EUROPEAN COMMISSION Directorate-General for Energy in collaboration with Climate Action DG and Mobility and Transport DG, Brussels, Belgium.

Dockery, D.W (2009): Health Effects of Particulate Air Pollution, in: Annals of Epidemiology, 19, Issue 4, pp. 257-263.

Gschwind, B., Lefevre. M., Blanc. I. (2012): Documentation for the Web Service for composite environmental indicator, EnerGEO report, October 2012.

Lefevre, M., Blanc, I., Gschwind, B., Ranchin, T., Drebszok, K., Wyrwa, A. (2013): Loss of Life Expectancy related to temporal evolution of PM2.5 considered within energy scenarios in Europe, in: 23rd SETAC Europe annual meeting, 12-16 May 2013, Glasgow.

Mechler, R., Amann, M., Schöpp, W. (2002): A methodology to estimate changes in statistical life expectancy due to the control of particulate matter air pollution. IR-02-035, International Institute for Applied Systems Analysis, Laxenburg, Austria.

OECD/IEA (2009): World Energy Outlook 2009. OECD, International Energy Agency, Paris, France.

Pope, C. A., Burnett, R. T., Thun, M. J., Calle, E. E., Krewski, D., Ito, K. (et al.) (2002): Lung cancer,cardiopulmonary mortality, and long-term exposure to fine particulate air pollution, in: Jama-Journal of the American Medical Association, 287, pp. 1132-1141.

Pope, C. A., Thun, M. J., Namboodiri, M. M., Dockery, D. W., Evans, J. S., Speizer, F. E. (et al.) (1995): Particulate air-pollution as a predicator of mortality in a prospective study of US adults. American Journal of Respiratory and Critical Care Medicine, 151, 669-674.

SEDAC (2004): Socio Economic Data and Applications Center, Center for International Earth Science Information Network (CIESIN), Columbia University. Gridded Population of the World (v3) : Future Estimates for 2005 2010 2015 with 2004 data.

Rabl, A. (2003): Interpretation of Air Pollution Mortality: Number of Deaths or Years of Life Lost?, Journal of the Air & Waste Management Association, Volume 53, pp. 41-50, doi: 10.1080/10473289.2003.10466118.

Russ, P., Ciscar, J. C. (et al.) (2009): Economic Assessment of Post-2012 Global Climate Policies – Analysis of Greenhouse Gas Emission Reduction Scenarios with the POLES and GEM-E3 models. Brussels, JRC IPTS: 70.

TFH (2003): Modelling and assessment of the health impact of particulate matter and ozone.EB.AIR/WG.1/2003/11, United Nations Economic Commission for Europe, Task Force on Health, Geneva.

United Nations (2011): Department of Economic and Social Affairs, Population Division : The 2010 Revision of the World Population Prospects.

Vaupel, J.W., Yashin, A. I. (1987): Targeting lifesaving: Demographic linkages between population structure and life expectancy. European Journal of Population/Revue européenne de Démographie Volume 2, Springer Netherlands, pp. 335-360, ISSN: 0168-6577, DOI: 10.1007/BF01796596.