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

Mireille Lefevre¹, Benoit Gschwind¹, Isabelle Blanc¹, Thierry Ranchin¹, Artur Wyrwa², Kamila Drebszok², Janusz Cofala³, Sabine Fuss¹

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/Hoeoglund-Isaksson/Klimont/Nguyen/Posch/Rafaj/Sandler/Schöpp/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),
- 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). 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:

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

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

Where:

---

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

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

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

Where:

$\Delta t$ is the length of considered ranges.

$a_\infty$ 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:

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

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:

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

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$_2$O), 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](image1.png)

**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.

<table>
<thead>
<tr>
<th>Country</th>
<th>Baseline scenario</th>
<th>Maximum Ren. Power scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DOLL (days/person)</td>
<td>YOLL (10^3 years)</td>
</tr>
<tr>
<td>Albania</td>
<td>81.6</td>
<td>347</td>
</tr>
<tr>
<td>Armenia</td>
<td>56.2</td>
<td>266</td>
</tr>
<tr>
<td>Austria</td>
<td>83.0</td>
<td>1384</td>
</tr>
<tr>
<td>Azerbaijan</td>
<td>47.6</td>
<td>483</td>
</tr>
<tr>
<td>Belarus</td>
<td>128.9</td>
<td>2161</td>
</tr>
<tr>
<td>Belgium</td>
<td>178.3</td>
<td>3497</td>
</tr>
<tr>
<td>Bosnia Herzegovina</td>
<td>93.0</td>
<td>582</td>
</tr>
<tr>
<td>Bulgaria</td>
<td>126.3</td>
<td>1736</td>
</tr>
<tr>
<td>Croatia</td>
<td>110.8</td>
<td>912</td>
</tr>
<tr>
<td>Cyprus</td>
<td>92.5</td>
<td>127</td>
</tr>
<tr>
<td>Czech Republic</td>
<td>140.5</td>
<td>2549</td>
</tr>
<tr>
<td>Denmark</td>
<td>110.6</td>
<td>1068</td>
</tr>
<tr>
<td>Estonia</td>
<td>81.3</td>
<td>194</td>
</tr>
<tr>
<td>Finland</td>
<td>37.5</td>
<td>475</td>
</tr>
<tr>
<td>France</td>
<td>88.5</td>
<td>10980</td>
</tr>
<tr>
<td>Georgia</td>
<td>53.4</td>
<td>428</td>
</tr>
<tr>
<td>Germany</td>
<td>130.4</td>
<td>21378</td>
</tr>
<tr>
<td>Greece</td>
<td>83.8</td>
<td>1788</td>
</tr>
<tr>
<td>Hungary</td>
<td>164.1</td>
<td>2981</td>
</tr>
<tr>
<td>Ireland</td>
<td>47.0</td>
<td>329</td>
</tr>
<tr>
<td>Italy</td>
<td>78.0</td>
<td>10375</td>
</tr>
<tr>
<td>Kazakhstan</td>
<td>51.3</td>
<td>1216</td>
</tr>
<tr>
<td>Latvia</td>
<td>92.7</td>
<td>383</td>
</tr>
<tr>
<td>Lithuania</td>
<td>114.8</td>
<td>673</td>
</tr>
<tr>
<td>Luxembourg</td>
<td>149.3</td>
<td>122</td>
</tr>
<tr>
<td>Montenegro</td>
<td>82.8</td>
<td>79</td>
</tr>
</tbody>
</table>
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 maps¹. 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](http://viewer.webservice-energy.org/energeo_pia/index.htm)
Bibliography


