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Including the temporal change in $PM_{2.5}$ concentration in the assessment of human health impact: Illustration with renewable energy scenarios to 2050

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ABSTRACT

This article proposes a new method to assess the health impact of populations exposed to fine particles ($PM_{2.5}$) during their whole lifetime, which is suitable for comparative analysis of energy scenarios. The method takes into account the variation of particle concentrations over time as well as the evolution of population cohorts. Its capabilities are demonstrated for two pathways of European energy system development up to 2050: the Baseline (BL) and the Low Carbon, Maximum Renewable Power (LC-MRP). These pathways were combined with three sets of assumptions about emission control measures: Current Legislation (CLE), Fixed Emission Factors (FEFs), and the Maximum Technically Feasible Reductions (MTFRs). Analysis was carried out for 45 European countries. Average $PM_{2.5}$ concentration over Europe in the LC-MRP/CLE scenario is reduced by 58% compared with the BL/FEF case. Health impacts (expressed in days of loss of life expectancy) decrease by 21%. For the LC-MRP/MTFR scenario the average $PM_{2.5}$ concentration is reduced by 85% and the health impact by 34%. The methodology was developed within the framework of the EU's FP7 EnerGEO project and was implemented in the Platform of Integrated Assessment (PIA). The Platform enables performing health impact assessments for various energy scenarios.

Introduction

People's exposure to fine particulate matter under 2.5 μm diameter ($PM_{2.5}$) can lead to various health effects as described by scientific publications in the area of observational epidemiology (Dockery, 2009). The calculation of the health impact indicator, i.e. the Loss of Life Expectancy (LLE) from $PM_{2.5}$ concentrations is mainly based on epidemiologic studies and the dose–response equation by Pope et al. (1995, 2002) as well as work from Rabl (2003) and Vaupel and Yashin (1987).

Emissions of $PM_{2.5}$ are partly due to energy production and consumption (EEA, 2013). The European policy aimed at combating air pollution and mitigation of the climate change necessitates contemplating on low-carbon energy scenarios to further reduce emissions compared to the Baseline. For this purpose, the European Commission has funded the EnerGEO[1] project. The objective of the EnerGEO project was the development of tools in order to determine how low carbon scenarios, and in particular scenarios with a high share of renewable electricity, affect emissions of air pollutants and greenhouse gases and contribute to mitigation of negative impacts of energy systems on human health and ecosystems. The project was executed over the period 2009–2013 and included nine research groups from Europe, including MINES ParisTech, IIASA and AGH. In this paper we describe the computation of the LLE indicator that we have developed for the Platform of Integrated Assessment (PIA) which is available for decision makers and stakeholders. In our approach LLE is computed taking into account the variation of particle concentrations over the lifetime of the population as well as the evolution of the cohort's size. This dynamic method is suitable for the assessment of energy scenarios, as it considers the long-term evolution of population and pollutant concentrations. It enables the comparison of scenarios in terms of their impacts on human health, which needs to be taken into account in planning further policy efforts.

LLE assessment including the temporal change in $PM_{2.5}$ concentrations

We propose a new algorithm for the computation of LLE for people exposed to $PM_{2.5}$ based on the approach recommended by the Task

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[1] EnerGEO: Earth Observation for monitoring and assessment of the environmental impact of energy use. http://www.energeo-project.eu/.

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0195-9255/

Force on Health (TFH, 2003) described in the IIASA Report (Mechler et al., 2002) and accounting for the exposure-risk parameter proposed by Pope et al. (2002). The IIASA health indicator has been used to compare health impacts of different energy scenarios. In IIASA's method $PM_{2.5}$ concentrations are chosen for a selected year and are kept constant until the death of the population considered for which LLE indicators are calculated. Our algorithm computes the actual life expectancy for a selected population (in this study people older than 30 years in 2005) based on the survival tables which are provided for each country for five-year time-periods (United Nations, 2011). We make the hypothesis that this life expectancy includes the effect of $PM_{2.5}$ exposure. We then compute the updated life expectancy without the effect of $PM_{2.5}$ using the formulae by Pope et al. (2002), which links the mortality without $PM_{2.5}$ to the mortality due to all drivers including $PM_{2.5}$ concentration. This updated life expectancy is computed with variable mortality rates and variable $PM_{2.5}$ concentrations observed during the whole life of the selected population. Finally, we take the difference between those two life expectancies to compute days of life lost per person. Temporal evolution of 5-year cohort mortalities and relative weight of each cohort are also considered. Details of the computation are provided in Annex A.

The main difference compared to the method proposed by IIASA (Mechler et al., 2002) is that our method integrates the variation of $PM_{2.5}$ during the entire lifetime of people by updating the mortality rate with the variation of $PM_{2.5}$ concentration. The IIASA method answers the question: "how is life expectancy affected if $PM_{2.5}$ remains at a constant level?" whereas our method answers "how is life expectancy affected for people living in a given year, if the $PM_{2.5}$ concentrations change during their lifetime?"

EnerGEO emission scenarios

The EnerGEO project developed several low carbon (LC) energy pathways, which simulated the effects of policies to reduce emissions of CO_2 from energy production and use up to 2050 through energy efficiency improvement as well as the use of cleaner fuels and renewable energy in all sectors of the economy. The pathway with the lowest emissions of CO_2 was the low carbon scenario with the maximum share of renewable electricity (LC-MRP). The low carbon scenarios were compared with the Baseline (BL) pathway, which assumed continuation of current trends and policies regarding the development of the European energy system.

Emissions were calculated for different sets of assumptions about air pollution control policies, namely:

- the Current Legislation (CLE) case assumes implementation of all current international and national policies to control the emissions of air pollutants
- the Fixed Emission Factor (FEF) case demonstrates the (hypothetical) emissions for the situation the emission factors were frozen at a level of the year 2005
- the Maximum Technically Feasible Reduction (MTFR) case demonstrates the effects of implementation of all technical measures to reduce the emissions.

Combination of activity pathways and control policies enabled the development of several emission scenarios. Calculations were done with the IIASA GAINS model (Amann et al., 2011) and are available on-line.[2] Results are described in Cofala et al. (2012). This paper demonstrates the effects of three scenarios, namely:

- Baseline, Fixed Emission Factor (BL/FEF), which yields the highest emissions among all scenarios considered
- Low Carbon, Maximum Renewable Power, Current Legislation (LC-MRP/CLE) and
- Low Carbon, Maximum Renewable Power, Maximum Feasible Control (LC-MRP/MTFR), which defines the potential for decreasing air pollution in Europe though implementation of all available technical measures.

Application of the new algorithm for the assessment of EnerGEO energy scenarios

The new algorithm was applied to compare the health impact of the above-mentioned scenarios. Loss of life expectancy was considered over the whole lifetime of the population older than 30 years – as the exposure-risk parameter by Pope et al. (2002) concerns only such cohorts – in year 2005 and carried out for 45 European countries. Temporal evolution of 5-year cohort mortalities and relative weight of each cohort are also considered.

Calculations were performed with the following data sources:

- *Cohort Population Data:* national population in each 5-year cohort was extracted from the World Population Prospects of the 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.
- *Gridded Population Data:* the map delivered from SEDAC (2004) for year 2005 was used to disaggregate the national cohort populations into European grid cells (5 km × 5 km).
- *Mortality Rates*: for each cohort in each country, the mortality rates were calculated based on the life table of survivors at their exact age (United Nations, 2011). The study is following the population over 30 years in 2005.
- *Gridded $PM_{2.5}$ Concentration Data* delivered from GAINS model following the EMEP 2008 resolution (50 km × 50 km). Concentrations of $PM_{2.5}$ were calculated for the EnerGEO emission scenarios by the GAINS model. Both primary PM emission sources (dust) as well as secondary aerosols were taken into account. GAINS uses the so-called pollution transfer matrices, which determine to what extend emissions of PM precursors from country *x* contribute to the concentration of the pollutant in grid *y*. These "country_to_grid" matrices were obtained by the "atmospheric chemistry and transport" model from EMEP (Simpson et al., 2012). Grid resolution used in our study was 50 × 50 km. Our method of calculating health impacts required data on annual concentrations in each grid cell. Since the GAINS scenarios were only available for 2005, 2020, 2030, 2040 and 2050, the $PM_{2.5}$ values have been linearly interpolated for the years in-between. Values after 2050 were kept constant at the 2050 level.

Results and discussion

We analyze here the estimation of the Loss of Life Expectancy in terms of Days of Life Lost (DOLL) per person over his or her whole lifetime due to exposure to $PM_{2.5}$ concentrations. The results for the low carbon scenarios are compared with the BL/FEF scenario, which served as a reference.

Fig. 1 presents the $PM_{2.5}$ concentrations averaged over Europe for each scenario. In the worst case (BL/FEF), concentrations tend to slightly increase compared to 2005. On the contrary, concentrations in the LC-MRP/CLE scenario decrease by 58%. They decline further down to 15% of the 2005 level in the LC-MRP/MTFR scenario. Fig. 2 shows the map with Days of Life Lost (DOLL) for the BL/FEF scenario. Figs. 3 and 4 present maps with relative reduction of the DOLL indicator compared to BL/FEF for the LC-MRP/CLE and LC-MRP/MTFR scenarios, respectively. Mean DOLL values for Europe are weighted according to the country area. Values for 45 countries are presented in Table 1.

[2] GAINS: Greenhouse gas–Air pollution INteractions and Synergies model. http://www.iiasa.ac.at/web/home/research/researchPrograms/GAINS.en.html.

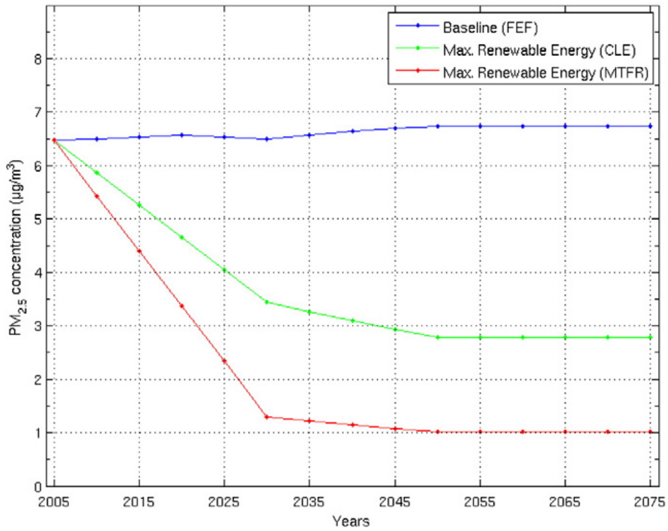

Fig. 1. The average $PM_{2.5}$ concentrations in Europe for the EnerGEO scenarios from the GAINS model. The years not covered by GAINS values have been linearly interpolated.

The LC-MRP/CLE scenario is inducing, on average for European countries, a DOLL reduction of 21%. A reduction of 34% is reached in the case of the LC-MRP/MTFR scenario.

DOLL ranges between 24 days/person (Norway) and 228 days/person (Belgium and The Netherlands), which indicates a wide dispersion across Europe. Surprisingly, this dispersion remains valid in the renewable energy scenarios, as the most polluted countries in 2005 do not present the best reduction rates. Albania, Turkey and Cyprus have the highest DOLL reduction resulting from an increase of the use of renewables for power generation. One can see that the DOLL indicator (per capita loss of life expectancy) for the Benelux countries is higher than for Poland and Romania. Numbers presented in the table are national averages. In the Benelux countries high concentrations of $PM_{2.5}$ occur over a high share of the total area of those countries, which, combined with high population density, gives a high per capita DOLL value. In Poland and Romania the concentrations of $PM_{2.5}$ in hot spots (e.g., Upper Silesia in Southern Poland) are even higher. However, there are regions, which are relatively clean. Thus the national averages of DOLL are lower.

Conclusions

A new method has been developed for calculation of the Loss of Life Expectancy caused by fine particles in ambient air. This method can be applied for a comparative analysis of health impacts of energy scenarios. It takes into account the change in pollutant concentrations resulting from energy and air pollution control scenarios and the evolution of the exposed population in the time period from 2005 to 2050. The results show that compared to the BL/FEF scenario in which an energy system develops according to the Baseline assumptions and the emission factors are frozen at the 2005 level, low carbon growth and implementation of the current legislation on air pollution (LC-MRP/CLE case) result in a 58% reduction of $PM_{2.5}$ concentrations in Europe. Consequently, the loss of life expectancy is reduced by 21%. A reduction by 85% of the $PM_{2.5}$ concentrations and by 34% of health impact can be achieved if – in addition – all technically feasible emission reduction measures are applied (LC-MRP/MTFR case).

We found out that applying the feature of the temporal evolution of $PM_{2.5}$ instead of using constant values (as is currently the common practice) is of great interest for assessing the potential impacts of scenarios (Lefevre et al., 2013). It is a realistic approach to assess scenarios and should be a good support for stakeholders within the current energy transition debate.

Within the EnerGEO project we used this model over 10 different scenarios, and results for all EnerGEO scenarios are provided online on the Platform of Integrated Assessment[3] in the form of tables and maps for individual indicators (Blanc et al., 2013; Gschwind et al., 2012). This platform is available for decision-makers and stakeholders. It enables comparison of scenarios in terms of their impacts on human health, which needs to be taken into account in planning further policy efforts.

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Annex A

Within this annex we detail the computation of Loss of Life Expectancy, and in the Life expectancy computation, Computation of survivability function, Computation of LLE due to $PM_{2.5}$ and Introduction of location, age base and time base sections we formalize the computation with continuous functions. For the Discretization and computational algorithm and Final computation of LLE sections we make a discretization of those functions using Riemann sums for integral computation to enable the computation from available data.

Life expectancy computation

The life expectancy of a population is computed as the probability to reach a given age. This can be written with the following formula:

$$l_e(t) = \int_0^\infty a\, f(t+a, a)\, da \qquad (1)$$

where:

- a represents the current age in the integral.
- $f(t+a, a)$ is the probability to reach age a at time $t+a$ and die at this moment and can be written as:

$$f(t, a) = l(t, a)\, \mu(t, a) \qquad (2)$$

where:

- $l(t, a)$ is the survivability function defined as the ratio of the population reaching at least the age a at time t to the whole population born at $t-a$.
- $\mu(t, a)$ is the mortality rate defined as the probability to die at age a at time t.

Computation of survivability function

For each cohort in each country, the mortality rates are calculated based on the life table of survivors at that exact age (United Nations, 2011).

The mortality rate $\mu(t, a)$ can be expressed in terms of $p(t, a)$ the population size over time of a given population, and its derivative

[3] PIA: Platform of Integration Assessment. http://viewer.webservice-energy.org/energeo_pia/index.htm.

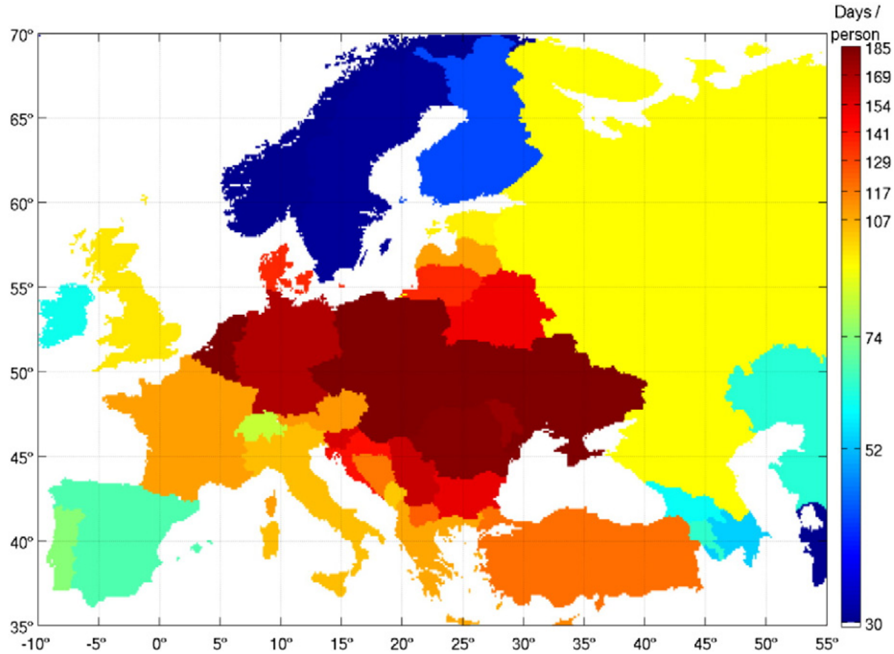

Fig. 2. National mean Days of Life Lost (DOLL) per person in 2005 for the BL/FEF scenario.

$\frac{\partial p}{\partial t}(t,a)$ with respect to time:

$$\mu(t,a) = -\frac{\frac{\partial p}{\partial t}(t,a)}{p(t,a)}. \quad (3)$$

There is a relation between the survivability function and the mortality rate, because there is a relation between $p(t, a)$ and $l(t, a)$:

$$p(t,a) = l(t,a)\, p(t-a,0). \quad (4)$$

From those formulae we can differentiate $p(t, a)$ as follows:

$$\frac{\partial p}{\partial t}(t,a) = \frac{\partial l}{\partial t}(t,a)\, p(t-a,0). \quad (5)$$

Then, from Eqs. (3), (4) and (5) we derive the following relation between $l(t, a)$ and $\mu(t, a)$:

$$\mu(t,a) = -\frac{\frac{\partial l}{\partial t}(t,a)}{l(t,a)}. \quad (6)$$

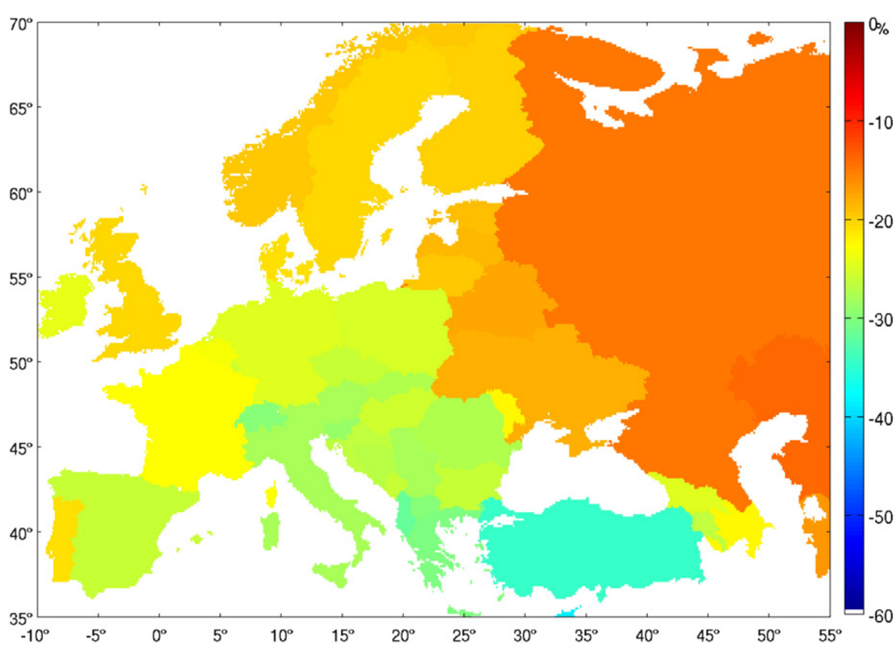

Fig. 3. Relative change (in %) of DOLL indicator for the LC-MRP/CLE scenario compared to the BL/FEF scenario. Negative values mean a reduction of health impacts.

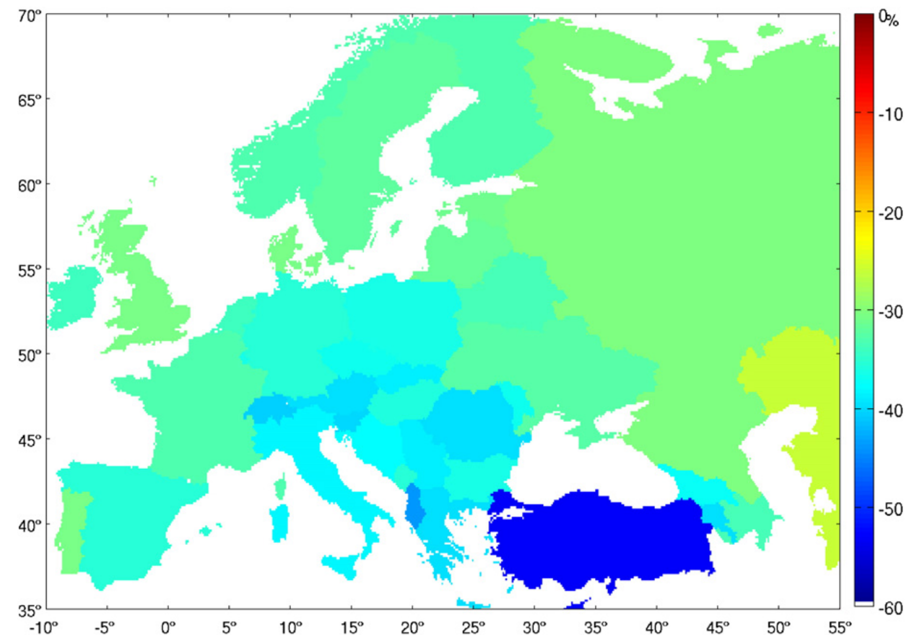

Fig. 4. Relative change (in %) of DOLL for the LC-MRP/MTFR scenario compared to the BL/FEF scenario. Negative values mean a reduction of health impacts.

This differential equation allows us to express $l(t, a)$ as follows, knowing that$l(t, 0) = 1$:

$$l(t,a) = e^{-\int_0^a \mu(t-a+x,x)\,dx}. \quad (7)$$

This result is already known as Rabl (2003) or Beltrán-Sánchez and Soneji (2011).

Equation of $l_e(t)$ can be simplified by introducing Eq. (6):

$$l_e(t) = -\int_0^\infty a\,\frac{\partial l}{\partial t}(t+a,a)\,da. \quad (8)$$

The technique of integration by parts gives:

$$l_e(t) = -[a\ l(t+a,a)]_0^\infty + \int_0^\infty l(t+a,a)\,da. \quad (9)$$

Since we do not have eternal life, $l(a)$ reaches zero before infinity then $[a \cdot l(a)]_0^\infty$ equals zero. As a result, life expectancy can be written as:

$$l_e(t) = \int_0^\infty l(t+a,a)\,da. \quad (10)$$

And finally we introduce Eq. (7) into Eq. (10) resulting in Eq. (11):

$$l_e(t) = \int_0^\infty e^{-\int_0^a \mu(t+x,x)\,dx}\,da. \quad (11)$$

Computation of LLE due to $PM_{2.5}$

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. The effect of $PM_{2.5}$ was analyzed in the epidemiological research conducted by Pope et al. (2002). Pope et al. (2002) studied the effect of $PM_{2.5}$ over approximately 1.2 million of people (or adults) living in the US from 1982 to 1998. Volunteers were older than 30 and data were collected by the American Cancer Society. A link between concentrations of fine particles and loss of life expectancy has been confirmed by recent studies performed under the auspices of the World Health Organization (compare Lim et al., 2012; WHO, 2013). These studies suggest even higher relative risk factors than Pope. Thus estimates using Pope (2002) are on a conservative side. He used dose–response analyses from Cox (1972) and he found that the relation between the mortality rate without exposure $\mu_b(t, a)$, and the mortality with exposure $\mu_e(t, a)$ is the following:

$$\mu_b(t,a) = \mu_e(t,a)\,e^{\beta\,(pm_b(t)-pm_e(t))} \quad (12)$$

where:

- $pm_e(t)$ is the actual particle concentration at time t.
- $pm_b(t)$ is the particle concentration that has no effect on mortality at time t.
- β is a constant value computable from the results of Pope et al. (2002). Rabl (2003) states the following relation: $RR = e^{\beta\,\Delta pm}$ where RR is the relative risk found by Pope et al. (2002), in our case RR is 1.06 per 10 $\mu g/m^3$.

At this point, we make the assumption that since the $PM_{2.5}$ always has an effect on mortality, $\forall\ t$, $pm_b(t) = 0$, and we denote $\mu_0(t, a)$, the mortality rate with $pm_b(t) = 0$, and for simplification of notation, $pm_e(t)$ is now simply named $pm(t)$:

$$\mu_0(t,a) = \mu_e(t,a)\,e^{-\beta\ pm(t)}. \quad (13)$$

Therefore, by using this equation in Eq. (11), we get the following expression for the life expectancy with no particles $le_0(t)$ at time t:

$$le_0(t) = \int_0^\infty e^{-\int_0^a \mu_e(t+x,x)\,e^{-\beta\ pm(x)}\,dx}\,da. \quad (14)$$

In the same way, the life expectancy with actual fine particle concentration $le(t)$ can be written as follows:

$$le(t) = \int_0^\infty e^{-\int_0^a \mu_e(t+x,x)\,dx}\,da. \quad (15)$$

The difference between Eqs. (14) and (15) gives the LLE.

Table 1
Mean of loss of life expectancy (days per person — DOLL) by country for the BL/FEF scenario and relative reduction of DOLL for the low carbon scenarios compared to Baseline. Negative values indicate a reduction of health impacts.

	Baseline	Maximum Renewable Power	
Countries	FEF (days)	CLE (%)	MTFR (%)
Albania	108	−32	−44
Armenia	63	−26	−40
Austria	111	−28	−39
Azerbaijan	54	−22	−33
Belarus	150	−18	−33
Belgium	228	−23	−33
Bosnia and Herzegovina	118	−27	−38
Bulgaria	153	−26	−36
Croatia	143	−27	−38
Cyprus	115	−39	−53
Czech Republic	182	−26	−37
Denmark	135	−21	−31
Estonia	95	−19	−31
Finland	42	−20	−33
France	110	−23	−33
Georgia	60	−25	−37
Germany	168	−25	−35
Greece	109	−30	−40
Hungary	209	−25	−36
Ireland	60	−24	−34
Italy	104	−28	−38
Kazakhstan	62	−14	−26
Latvia	109	−19	−31
Lithuania	137	−19	−31
Luxembourg	191	−26	−36
Montenegro	102	−26	−35
Netherlands	222	−25	−34
Norway	24	−20	−33
Poland	202	−25	−36
Portugal	75	−21	−31
Republic of Moldova	176	−22	−37
Romania	180	−28	−40
Russian Federation	92	−15	−30
Serbia	160	−28	−39
Slovakia	199	−27	−39
Slovenia	158	−29	−40
Spain	67	−26	−36
Sweden	31	−20	−32
Switzerland	84	−30	−41
TFYR Macedonia	123	−30	−40
Turkey	120	−35	−53
Turkmenistan	28	−17	−26
Ukraine	186	−18	−32
United Kingdom	96	−20	−31
Europe	103	−21	−34
EU-27	107	−24	−35
Non-EU	100	−19	−34

Introduction of location, age base and time base

In the previous equation, the location was omitted but since the mortality rate does depend on location (i.e. mortality rate is not the same if you live in France or in Germany), we introduce location into the equations now. In previous definition of life expectancy we also implicitly computed the life expectancy of people from age 0, but in our study we need to compute the life expectancy of people older than 30, i.e. already born people. For this reason, we introduce the age base a_0 and a time base t_0 where a_0 is the age of people that we will compute the life expectancy at time t_0.

The mortality rate depends on time t, location l and age a:

$$\mu_e(t, a, l).$$

Particle concentration depends on time and location:

$$pm(t, l).$$

We obtain the following formulae:

$$le_0(t_0, l, a_0) = a_0 + \int_0^{\infty} e^{-\int_0^y \mu_e(t_0+x, a_0+x, l)\, e^{-\beta\, pm(t_0+x, l)}\, dx}\, dy \quad (16)$$

$$le(t_0, l, a_0) = a_0 + \int_0^{\infty} e^{-\int_0^y \mu_e(t_0+x, a_0+x, l)\, dx}\, dy \quad (17)$$

where

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

Discretization and computational algorithm

To compute the two integrals of Eqs. (16) and (17), we applied Riemann sums with interval equals to Δt as follow:

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

For implementation consideration we cannot compute these Riemann sums with infinite bound, but we can make the assumption that at some age nobody survives and the mortality rate drops to zero, no more people alive, no more death. If we consider that no people can live after the age a_{max} we obtain the following formulae:

$$le_0(t_0, l, a_0, \Delta t) = a_0 + \sum_{k=0}^{k_{max}} \Delta t\, e^{-\sum_{i=0}^{k} \Delta t\, \mu_e(t_0 + i\,\Delta t, a_0 + i\,\Delta t, l)\, e^{-\beta\, m(t_0 + i\,\Delta t, l)}}$$
$$le(t_0, l, a_0, \Delta t) = a_0 + \sum_{k=0}^{k_{max}} \Delta t\, e^{-\sum_{i=0}^{k} \Delta t\, \mu_e(t_0 + i\,\Delta t, a_0 + i\,\Delta t, l)}$$

where $k_{max} = ceil(\frac{a_{max}}{\Delta t})$ where $ceil(x)$ is the round of x toward positive infinity.

Final computation of LLE

Loss of life expectancy Δle at time t_0 at location l for age a_0 is written as follows:

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

This function can be integrated over ages at t_0 over a set of cohort C:

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

where:

- C is a set of cohorts where a cohort is a group of people of a given age range, for example people between 30 (included) and 35 (excluded) years old. In our case cohort of age a denotes people whose ages are greater or equal to a and strictly less than $a + \Delta t$.
- $p_a(t_0, l, a, \Delta t)$ is the number of people in the cohort of age a, at time t_0, at the location l.

Finally we can compute the LLE for an area L like a country with spatial integration:

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

where:

- $p_l(t_0, l)$ is the population of given area l.
- C is a set of cohorts.

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Glossary

$PM_{2.5}$: fine particles with an aerodynamic diameter of 2.5 μm or less.
PIA: Platform of Integrated Assessment
DOLL: Day(s) of Life Loss
LLE: Life Loss Expectancy
FEF: Fixed Emission Factor
MTFR: Maximum Technically Feasible Reduction
CLE: Current Legislation
LC-MRP/CLE: Low Carbon, Maximum Renewable Power/Current Legislation
LC-MRP/MTFR: Low Carbon, Maximum Renewable Power/Maximum Technically Feasible Reduction
BL/FEF: Baseline/Fixed Emission Factor.

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