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Expressing air pollution-induced health-related externalities in physical terms with the help of DALYs

Till M. Bachmann [a,*], Jonathan van der Kamp [a,b]

[a] European Institute for Energy Research, Emmy-Noether-Str. 11, 76131 Karlsruhe, Germany
[b] Karlsruhe Institute of Technology (KIT), Kaiserstr. 12, 76131 Karlsruhe, Germany

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ABSTRACT

The unintended impacts of industrial activity on human health and the environment have regularly been assessed and monetised (referred to as "external costs"). External costs are, however, a rather abstract aggregate so that decision makers cannot easily relate them to tangible impacts. At the same time, physical health impact indicators have different units that cannot readily be compared and communicated in a joint way. To support better informed decisions at policy or company level, we propose and demonstrate a way to facilitate communication on non-monetized, that is, physical health indicators quantified in studies. The concept Disability-Adjusted Life Year (DALY) is chosen as metric due to its widespread use.

We establish a comprehensive and consistent set of six health endpoints caused by particles and ozone, and derive related up-to-date DALYs. Further we apply the DALY values to a French smart grid demonstration project. Owing to its size, the gains in terms of reduced DALYs are however small. In contrast to external cost assessments, in the frame of which morbidity endpoints usually contribute to around 10–15%, they are found to be insubstantial in the overall DALY score (i.e. below 1%). This is because DALYs only consider time losses weighted by severity while external costs also factor in further welfare effects, i.e. combining resource, disutility and opportunity costs of illness. As a result, methodological limitations, mainly existing for the morbidity-related DALY values, appear to be less of concern.

Overall, using the DALYs with and without morbidity impacts is justifiable. Either choice in the communication of health-related physical externalities induces the need to explain the limitations in terms of the treatment of morbidity endpoints (notably their definition and the disability weights used) or their complete disregard.

1. Introduction

Air pollution in general and that specifically related to fossil fuel-based combustion processes causes impacts on human health and the environment (Bachmann and van der Kamp, 2014; Lelieveld et al., 2015; Machol and Rizk, 2013; Nieuwenhuijsen and Khreis, 2016; OECD, 2016; Oxley et al., 2013; Rabl et al., 2014; West et al., 2016; Zhou et al., 2006). When expressing these externalities in monetary terms they are referred to as "external costs" (European Commission, 2005). While convenient in the communication of aggregated results and in social cost-benefit analyses (CBAs), external costs are a rather abstract aggregate so that decision makers cannot easily relate them to tangible impacts. Beyond climate change, human health-related impacts contribute the largest share in currently quantifiable external costs of fossil fuel-based combustion processes (Bachmann and van der Kamp, 2014; U.S. Environmental Protection Agency, 2011; Watkiss et al., 2005). At the same time, a multitude of different physical health impact indicators are quantified for which aggregation is not straightforward, as they are typically expressed in different units (e.g. cases, days, years, cf. Rabl and Spadaro, 1999; Sonnemann et al., 2002; van der Kamp and Bachmann, 2015).

Different methods exist which allow for the aggregation of morbidity and mortality endpoints. Most notably the concepts Disability-Adjusted Life Years (DALYs) and Quality-Adjusted Life Years (QALYs,

Abbreviations: ADEME, French Energy and Environment Agency; CAFE, Clean Air For Europe (programme); CASES, Costs Assessment for Sustainable Energy Systems co-ordination action (project); CBA, cost-benefit analysis; DALY, Disability-Adjusted Life Year; DW, disability weight; ExternE, Externalities of Energies (project series); GBD, Global Burden of Disease; GHE, Global Health Estimates; HEIMTSA, Health and Environment Integrated Methodology and Toolbox for Scenario Development (project); IHME, Institute for Health Metrics and Evaluation; INTARESE, Integrated Assessment of Health Risks of Environmental Stressors in Europe (project); LRS, Lower Respiratory Symptoms; MRAD, Minor Restricted Activity Day; NEEDS, New Energy Externalities Developments for Sustainability (project); PACA, French Provence-Alpes-Côte d'Azur; PM, particulate matter; PV, photovoltaic; QALY, Quality-Adjusted Life Years; RAD, Restricted Activity Day; ReCiPe, Life Cycle Impact Assessment methodology; VOLY, Value of a Life Year; WHO, World Health Organization; WLD, Work Loss Day; WTP, willingness to pay; YLD, years (of healthy life) lost due to disability; YLL, years of life lost; YOLL, years of life lost.

* Corresponding author.
E-mail addresses: bachmann@eifer.org (T.M. Bachmann), vanderkamp@eifer.org (J. van der Kamp).

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cf. Hofstetter and Hammitt, 2002) have been used for this purpose. Even though it is possible to link QALYs to specific health effects (Hammitt and Haninger (2017) referring to Lawrence et al. (2006)), the DALY indicator allows for the immediate assessment of specific health endpoints (Gold et al., 2002) relevant in air quality-related health impact assessments. Despite issues related to monetising mortality risks and health metrics in general, further discussed in the conclusions of this paper, DALYs have also already been used in external cost-related studies (Bachmann, 2006; Lvovsky et al., 2000; Narain and Sall, 2016; Nedellec et al., 2016; Rabl et al., 2010, 2011; Torfs and Bossuyt, 2006). As further explained in Section 2, the DALY indicator has therefore been chosen as the preferred aggregation metric.

Aiming to support decision-making by facilitating the quantification of and communication on physical health indicators, the main objective of this study was to identify and define up-to-date DALYs for a consistent set of air quality-related health endpoints that avoid double-counting. The prioritised endpoints were those used within the NEEDS project,[1] i.e. the latest project in the tradition of the European Externalities of Energies (ExternE) project series. These endpoints were implemented in the online tool EcoSenseWeb (Preiss and Klotz, 2008), establishing a causal relationship between a given source of pollution and health endpoints among other effects, following the so-called impact pathway approach (cf. European Commission, 1995, 1999, 2005; Holland, 2014b; Rabl and Spadaro, 1999; Sonnemann et al., 2002; van der Kamp and Bachmann, 2015). Similarly, we also defined DALYs or the endpoints recommended by WHO's Health Risks of Air Pollution In Europe (HRAPIE) project (WHO, 2013), as used in the impact assessment of the 2013 EU Clean Air Policy Package (European Commission, 2013).

The health endpoints of interest are listed in Table 1. Related impacts were due to ozone or (primary or secondary) particulate matter (PM) with either an aerodynamic diameter of 10 or 2.5 μm. The associated DALYs reflect recent (preferably European) evidence and were applicable for the whole of Europe in current and future years.

The paper is organized as follows. In Section 2, the DALY concept is introduced. The results of the literature review (Section 3) provide the basis for the definition of a comprehensive and consistent set of air pollution-related DALYs (Section 4). In Section 5, DALY reduction opportunities are explored for a French smart grid demonstrator. Section 6 presents the conclusions.

2. The DALY concept

Originally co-developed by the World Bank and building on the earlier work on Quality Adjusted Life Years (QALYs), the Disability-Adjusted Life Year (DALY) concept was adopted in the frame of the Global Burden of Disease (GBD) studies (GBD 2013 Mortality and Causes of Death Collaborators, 2015; Lozano et al., 2012; Mathers, 2017; Mathers et al., 2008; Mathers and Stevens, 2013; Murray and Lopez, 1996; Wang et al., 2016). Since the GBD 2010 and even more so with the GBD 2013 and GBD 2015 updates, the GBD has developed into a large multi-national collaboration project, coordinated by the Institute for Health Metrics and Evaluation (IHME). While the World Health Organization (WHO) co-developed the GBD methodology since the 1990s, the methodology used in the WHO's Global Health Estimates (GHE) deviates from the GBD methodology since the GBD 2010 study (Mathers, 2017), further detailed below.

By default, a DALY associated with a disease or condition consists of two additive elements that are specific to cause, sex, age and year (Mathers and Stevens, 2013). DALYs are computed as follows:

$$DALY = YLL + YLD$$

[1] New Energy Externalities Developments for Sustainability, www.needs-project.org, last accessed on 2016-10-04.

Table 1
List of health endpoint indicators used in the NEEDS or the WHO HRAPIE projects and associated pollutants.

Indicators	NEEDS 2009	WHO HRAPIE project 2013
Asthma symptom day, asthmatic children of age 5–19	–	PM_{10}
Bronchitis prevalence, children 6–12	–	PM_{10}
Bronchodilator usage, asthmatics older than 20 (ozone) and asthmatic children between 5 and 14 according to PEACE study criteria (PM_{10})	PM_{10}, O_3	–
Cardiovascular hospital admission due to PM, all ages	PM_{10}	$PM_{2.5}$
Cardiovascular hospital admission (excluding stroke) due to ozone, older than 65 years	–	O_3
Chronic bronchitis case	PM_{10} (older than 27)	PM_{10} (older than 18)
Cough day, children 5–14	O_3	–
Lower respiratory symptoms (LRS), children between 5 and 14 (ozone and PM) and adults older than 15 (PM)	O_3 (excluding cough), PM_{10}	–
Minor Restricted Activity Day (MRAD)	O_3 and $PM_{2.5}$ (adults between 18 and 64 years old)	O_3 (all ages)
Mortality (acute) due to ozone, all ages	O_3	O_3
Mortality (chronic) due to $PM_{2.5}$, adults	$PM_{2.5}$ (adults, older than 30)[a]	$PM_{2.5}$ (adults, older than 30)[a]
Mortality due to PM_{10}, infants (0–1 years)	PM_{10}	PM_{10}
Respiratory hospital admission due to ozone, older than 65 years	O_3	O_3
Respiratory hospital admission due to PM, all ages	PM_{10}	$PM_{2.5}$
Restricted Activity Day (RAD), all ages	$PM_{2.5}$	$PM_{2.5}$
Work Loss Day (WLD)	$PM_{2.5}$ (between 15 and 64 years)	$PM_{2.5}$ (between 20 and 65 years)

[a] Irrelevant difference between the NEEDS project and WHO's HRAPIE project given that YOLLs are quantified considering differences in life expectancy losses, while having the same disability weights.

where YLL is "*years of life lost*" from premature death (mortality) and YLD is "*years (of healthy life) lost due to disability*" for non-fatal (i.e. morbidity-related) health outcomes.

The GBD studies sought to assess total DALYs worldwide at population level. In calculating DALYs, the annual number of incident cases per disease and the number of premature deaths were considered. By contrast, the current study only seeks to define DALY values per case of selected health endpoints and this for a European setting. This has a number of implications.

In contrast to previous GBD studies, YLL estimates since the GBD 2010 study and GHE studies were not based on the longest life expectancy observed globally (i.e. that of Japanese men, 80, and women, 82.5). Instead, the WHO, in its GHE studies, chose to use life expectancy at birth projected for the year 2050, amounting to 91.9 years (Mathers, 2017; Mathers and Stevens, 2013). In the GBD 2010 and following studies, a reference life expectancy of 86 years for males and females has been used (Wang et al., 2016). Given that it is questionable whether these life expectancies are a realistic benchmark for all people worldwide, we propose an alternative approach to quantifying YLLs that is region specific (Section 4.3).

The YLDs we present result from multiplying the average duration of a case of a health impact until remission or death or average duration of disability (D in years) with a so-called disability weight (DW): $YLD = DW \times D$.

DWs reflect the severity of a given disease or condition on a scale from zero (perfect health) to one (equivalent to death, cf. Mathers and Stevens, 2013). The issue of representativeness of the globally applied DWs in the calculation of YLDs in the GBD studies is the same as for YLLs since regional differences can be expected.