Chapter 47
Environmental Burden of Diseases

Otto Hänninen

Abstract Environmental exposures are associated with a large variety of human diseases ranging from headaches and annoyance to cancer and premature death. Comparison of such risks and prioritization of preventive measures therefore cannot be based on incidence or prevalence rates. Environmental burden of disease methodology, developed by World Health Organization, accounts for both years of life lost due to mortality as well as years lived with various disabilities. The latter are quantified using, besides the duration of the condition, a severity weight. Such weights are inherently value-loaded, but in practice the resulting environmental burden of disease estimates have been found very useful.

Improved population health registries and harmonization of disease codes together with statistical methods such as population attributable fraction that can be estimated from epidemiological data, allow for rapid and comparable international assessments as demonstrated e.g. by the Institute of Health Metrics and Evaluation.

Recent estimates suggest that fine particles (PM2.5) are the leading environmental health risk in European countries by causing up to 10,000 non-discounted lost years of health per million people annually in the EU.

Keywords Burden of disease • Health risk characterization • Population attributable fraction • Disability adjusted life year • DALY

47.1 Introduction

Environmental indicators are designed to describe the state of the environment and its impact on human beings, ecosystems and materials, the pressures on the environment, and the driving forces and the responses steering the system. Indicators have gone through a selection and often an aggregation process to enable them to steer action (EEA 2012). First order environmental indicators focus on the state of the environment. However, comparison of the importance of the state descriptors across a wide range of indicators is not directly supported. Therefore, a second order of indicators is needed to translate the state into the magnitude of impacts.

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This section of the book covers indicators that focus on impacts on human beings and especially on population health. This is achieved by combining information on the state of the environment, determining the population exposures to risk factors, with population characteristics, including age and gender distributions and health status, to generate a ranking of environmental stressors based on their population health importance. One of these approaches is called environmental burden of disease (EBD) and is the topic of this chapter.

47.2 Background

Prevention and control of disease and injury require information about the leading medical causes of illness and the associated exposures and risk factors (Murray and Lopez 1997). Assessment of the public-health importance of various risk factors involves comparisons of highly variable health conditions ranging from relatively mild diseases, such as the common cold or sleep disturbance, to serious life threatening and fatal conditions. Up to the 1990s, mortality statistics were used as a crude metric for serious health hazards and they have served quite well over the decades for tackling the most important causes of death. However, mortality counts can hardly be compared with less severe outcomes when investigating the overall burden over a wide range of diseases and risk factors.

The World Bank sponsored the first global burden of disease study in collaboration with the World Health Organization (WHO) in 1993. As well as generating a comprehensive and consistent set of estimates of mortality and morbidity by age, sex and region for the world, the study also introduced a new metric to measure the loss of health to quantify the burden of disease: disability adjusted life year (DALY) (Mathers et al. 2004). Burden of disease (BoD), measured in DALYs, combines health losses from premature mortality and from morbidity into a metric that allows comparisons of the health losses due to a wide range of different causes, accounting for morbidity as well as mortality. Moreover, also the quantification of deaths is enhanced from body counts to quantify the years of life lost due to mortality. Figure 47.1 depicts some examples of disability weighted health conditions.

47.3 Methods

Burden of disease is a measure of sickness and death in a population. The burden of disease methodology is based on making years lived with a disability (YLD) comparable with years of life lost (YLL) due to premature mortality. Summing

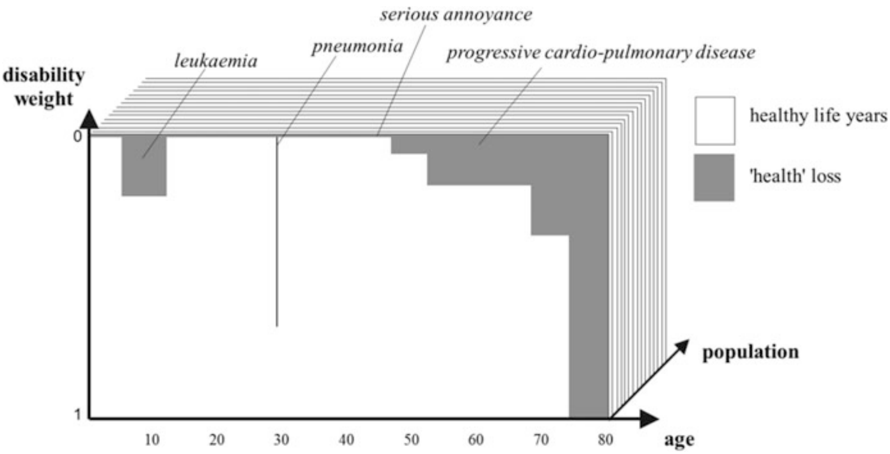

Fig. 47.1 Examples of disability adjusted life-year losses due to various diseases (*grey* areas) (Modified from de Hollander et al. 1999)

these two components produces disability adjusted life years (DALY) (Murray and Lopez 1997):

$$BoD = YLL + YLD \tag{47.1}$$

Years of life lost (YLL) in a case of premature mortality are calculated as the age-specific remaining life expectancy at the age of death. Mortality numbers, ages of death by causes, incidences of acute and chronic diseases and corresponding mean durations available in health registries are supplemented with disability weights.

Disabilities caused by various types of diseases are calculated by accounting for both the duration of the disease (L) and the disease severity expressed as a disease specific disability weight (DW):

$$YLD = DW \times L \tag{47.2}$$

The value of the time lived in non-fatal health states, in comparison with life lost due to premature mortality, is estimated using health state weights reflecting social preferences for different states of health.

Although the disability weights used in DALY calculations quantify societal preferences for different health states, the weights do not represent the lived experience of any disability or health state, or imply any societal value for the person in a disability or health state. Rather, they quantify societal preferences for health states in relation to the societal ideal of good health. The term "disability" is used broadly to refer to departures from good or ideal health in any of the important domains of health. These include mobility, self-care, participation in usual activities, pain and discomfort, anxiety and depression, and cognitive impairment (Prüss-Üstün et al. 2003). Examples of disability weight values, collected from dedicated

Table 47.1 Examples of disability weights (Adopted from Murray and Lopez 1996)

Disease	Disability weight	
	Untreated disease	Treated disease
AIDS	0.50	0.50
Infertility	0.18	0.18
Diarrhoea disease, episodes	0.11	0.11
Measles episode	0.15	0.15
Tuberculosis	0.27	0.27
Malaria, episodes	0.20	0.20
Trachoma, blindness	0.60	0.49
Trachoma, low vision	0.24	0.24
Lower respiratory tract infection, episodes	0.28	0.28
Lower respiratory tract infection, chronic	0.01	0.01
Cancers, terminal stage	0.81	0.81
Diabetes mellitus cases (uncomplicated)	0.01	0.03
Unipolar major depression, episodes	0.60	0.30
Alcohol dependence syndrome	0.18	0.18
Parkinson disease cases	0.39	0.32
Alzheimer disease cases	0.64	0.64
Post-traumatic stress disorder	0.11	0.11
Angina pectoris	0.23	0.10
Congestive heart failure	0.32	0.17
Chronic obstructive lung disease, symptoma	0.43	0.39
Asthma, cases	0.10	0.06
Deafness	0.22	0.17
Benign prostatic hypertrophy	0.04	0.04
Osteoarthritis, symptomatic hip or knee	0.16	0.11
Brain injury, long-term sequelae	0.41	0.35
Spinal cord injury	0.73	0.73
Sprains	0.06	0.06
Burns (>60 %) – long term	0.25	0.25

questionnaire panels, are shown in Table 47.1. Treatment of diseases further modifies the diseases and the disabilities. In many cases a treated disease is substantially less disabling than a non-treated disease. These differences are highlighted in the table, too. More data on disability weights can be found in Opasnet 2014.

47.4 Population Attributable Fractions

In practice, burden of disease estimates describe the overall burden in a population and generally only a small fraction of this is attributable to given environmental and other risk factors.

Burden of disease can be estimated using a bottom-up approach described in Eqs. 47.1 and 47.2. However, the mathematical properties of relative risks offer a lucratively easy way to estimate the fraction of disease burden associated with a given risk factor when epidemiological data are available. In 1953, Levin first proposed the concept of the population attributable fraction. Since then, the phrases "population attributable risk," "population attributable risk proportion," "excess fraction," and "etiologic fraction" have been used interchangeably to refer to the proportion of disease risk in a population that can be attributed to the causal effects of a risk factor or set of factors (Rockhill et al. 1998).

In this context, the environmental burden of disease associated with a given risk factor can be calculated simply from the overall population burden of a given disease by multiplying it by the epidemiological estimate of the population attributable fraction. National background burden of disease data are directly available from the World Health Organization (2013).

$$EBD = PAF \times BoD \tag{47.3}$$

As described in more detail in Hänninen and Knol (2011), the population attributable fraction (*PAF*) can be derived from relative risk (RR) as

$$PAF = \frac{f \times (RR - 1)}{f \times (RR - 1) + 1} \tag{47.4}$$

where f is the fraction of population exposed to a given factor and RR is the relative risk of the exposed population.

In the case of environmental exposures, the relative risk is commonly expressed per a standard increment of exposures, e.g., 10 μg m^{-3} as in the case of fine particles (in this case, exposure to e.g., 15 μg m^{-3} would be expressed as E = 1.5). The needed relative risk at the current exposure level can be directly calculated as

$$RR = e^{(E \ln RR^{\circ})} = RR^{\circ E} \tag{47.5}$$

47.5 Assessments

Murray and Lopez (1997) developed the first global burden of disease study. At that time, they considered two environmental risk factors: (i) poor water, sanitation, and hygiene, and (ii) air pollution. In the updates of the global burden of disease project for 2002 (World Health Report 2002) and 2004 (World Health Organization 2009), additional environmental risk factors included: (iii) lead, (iv) indoor air pollution from solid fuels, and (v) climate change.

One of the first more comprehensive analyses of environmental burden of diseases from a number of risk factors was conducted by de Hollander et al. (1999) in the Netherlands. The 19 environmental risk factors covered are

Table 47.2 Estimated health impacts of selected environmental risk factors in the Netherlands (Hollander et al. 1999), demonstrating that the population level health risks are dominated by a few risk factors (particulate matter and accidents in this case)

	Environmental factor	Included health end-points	Total health impact	Relative contribution (%)
			DALY/ a/M	
1	Particulate air pollution (long-term exposures)	Total and cardiopulmonary mortality, lung cancer, chronic respiratory symptoms in children, chronic bronchitis	15,482	52
2	Domestic accidents	Hospital admissions, disability, mortality	6,390	21
3	Traffic accidents	Hospital admissions, disability, mortality	4,640	16
4	Noise	Severe annoyance, sleep disturbance	1,774	5.9
5	Lead (drinking-water pipes)		469	1.6
6	Foodborne	Acute gastroenteritis, symptoms and mortality	266	0.89
7	ETS	Lung cancer and ischemic heart disease mortality and morbidity, asthma aggravation, lower respiratory tract symptoms, otitis media, sudden infant death	262	0.88
8	Particulate air pollution (short-term exposures)	Respiratory, coronary heart disease, pneumonia, and other mortality, respiratory and cardiovascular hospital admissions, respiratory emergency room visits, asthmatic attacks, use of bronchodilators, upper and lower respiratory tract symptoms	172	0.58
9	Radon (indoor)	Lung cancer mortality and morbidity	114	0.38
10	Damp houses	Lower respiratory disease, asthma	109	0.37
11	Ozone air pollution	Respiratory, cardiovascular, pneumonia, and other mortality	87	0.29
12	UV-A/UV-B exposure	Melanoma mortality and morbidity	30	0.10
13	B(a)P	Respiratory disease hospital admissions and emergency room visits	16	0.053
14	Benzene	Leukemia mortality and morbidity	7.9	0.026
15	Large industrial accidents	Mortality	1.3	0.0044
16	Vinyl chloride	Hepatoangiosarcoma mortality and morbidity	0.79	0.0027
17	Ethylene oxide	Leukemia mortality and morbidity	0.11	0.0004
18	1,2-Dichloroethane	Cancer mortality and morbidity	0.10	0.0003
19	Acrylonitrile	Lung cancer mortality and morbidity	0.09	0.0003
	Total		**29,821**	**100**

listed in Table 47.2, with a leading contribution from long-term exposures to ambient particulate matter and domestic and traffic accidents. These results demonstrated that, while environmental concerns are presented regarding a large number of pollutants, the public health impacts are driven by a relatively small number of factors and that these factors may not receive as much attention as the disease burden associated with them would justify.

47.6 WHO Environmental Burden of Disease Programme

World Health Organization Headquarters in Geneva has continued to promote the environmental burden of disease methodologies actively for more than a decade. As part of their activities, they continue pushing the methodologies forward in the Environmental Burden of Disease series, with the latest contributions for inadequate housing (WHO 2011a) and environmental noise (WHO 2011b). These and other related WHO reports are available at http://www.who.int/quantifying_ehimpacts/publications/en/.

47.7 European EBoDE -Study

A more recent approach compared the environmental burden of disease over six European countries. The EBoDE-study (Hänninen and Knol 2011; Hänninen et al. 2014) covered nine environmental risk factors based on their presumed public health impact (e.g., particulate matter, second hand smoke, radon, traffic noise), individual high risk (several carcinogens), public concern (e.g., benzene, dioxins), and economic values (e.g., formaldehyde).

The overall annual environmental burden of disease was estimated to be 11,324 DALY/million, or 2.6 million DALY in total in the participating six countries. Fine particles were by far the dominating source of burden (Fig. 47.2), followed by second hand smoke, traffic noise, and radon. Fine particles were the leading cause in all countries, but the order of the following factors varied between countries due to the national conditions. E.g., in Finland, radon was the second most important factor due to the relatively high occurrence of uranium in the soil, producing radon in the radiological decay chain. In contrast, Finland had clearly the lowest impacts from second hand smoke due to proactive tobacco legislation already developed in the 1970s (Hänninen and Knol 2011; Hänninen et al. 2014).

Finland also had the highest formaldehyde exposures, but the associated health impacts were estimated to be almost negligible. However, formaldehyde very well demonstrates the various magnitudes of uncertainties in the estimates. Formaldehyde has been shown to be carcinogenic in occupational settings, where exposure levels range from 2 to 5 mg m^{-3}. However, later systematic reviews by WHO and others on studies in general populations rarely exposed to over 100 μg m^{-3} have

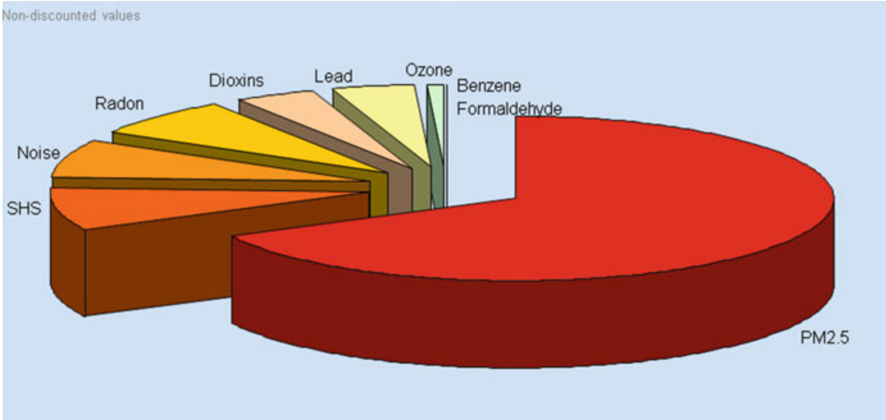

Fig. 47.2 Relative contributions of selected environmental factors on the environmental burden of disease in six European countries (Hänninen and Knol 2011; Hänninen et al. 2014)

concluded that nasal carcinogenic risk occurs only at substantially higher exposures, such as in occupational settings. Thus, the formaldehyde estimate did not include cancer as an outcome.

Uncertainties of the various environmental burden of disease estimates were evaluated in an expert panel, supported by a number of quantitative simulations of model and parameter uncertainties. Uncertainties for stressors like fine particles, for which the estimates were based on epidemiological data from large real populations at existing range of exposures were considered the smallest (Table 47.3). Pollutants for which even the selection of health end points contained substantial uncertainties, such as dioxins and formaldehyde, were classified as having the lowest certainty of the overall assessment.

More recently, environmental burden of disease methodology has been applied specifically to exposures in indoor spaces. Logue et al. (2012) combined the methodology with toxicological estimation of the dose-response coefficients. While the uncertainties of such estimates are much wider than when using epidemiological data, their results provided fresh insights into significant pollutants potentially missing from previous estimates, including acrolein, ozone, and acetaldehyde. Hänninen and Asikainen (2013) refined a similar assessment toward evaluating the effectiveness of ventilation and other risk management actions. They found that ventilation alone is not capable of reducing the burden much. However, combining ventilation with filtration of intake air and indoor source controls, over two million DALY could be saved annually in the European Union.

One of the advantages of environmental burden of disease methodology is that it can be readily used to compare also various endpoints against each other. Hänninen and Asikainen (2013) estimated the burden of disease of indoor exposures by endpoints in 26 European countries (EU27 excluding Malta), showing that cardiovascular diseases dominate the total impacts (Fig. 47.3).

Table 47.3 Relative uncertainties in the EBoDE estimates (Hänninen and Knol 2011; Hänninen et al. 2014)

Uncertainty level	Stressor	Sources of uncertainties
High	Dioxins	Endpoint uncertainty (total cancer)
	Formaldehyde	Endpoint uncertainty (limited evidence on asthma)
Medium	Traffic noise	Exposure data from early phase of European Noise Directive data collection
	Lead	Limited exposure data since abandoning tetraethyl lead additive
	Ozone	Loss of life uncertain (1 year assumed per death)
Low	$PM_{2.5}$	Strong evidence from large number of epidemiological studies in real human populations
	Second hand smoke	
	Radon	
	Benzene	

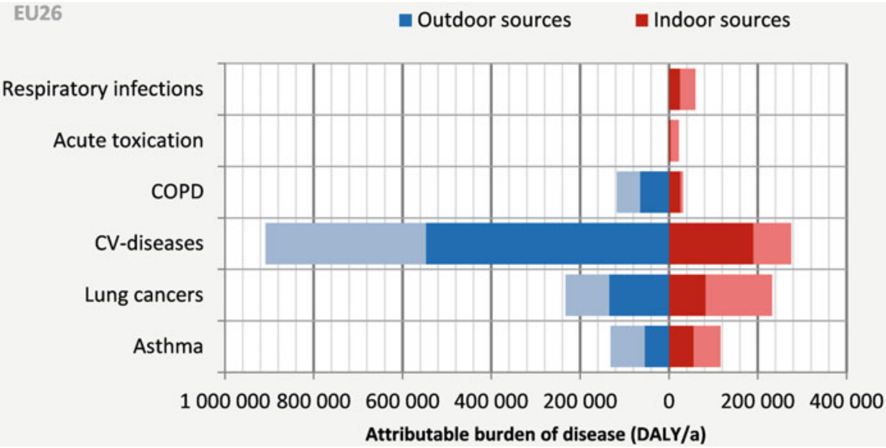

Fig. 47.3 Contribution of main disease categories to the burden of disease in EU26 caused by indoor exposures to pollutants originating from outdoor (*blue*) and indoor (*red*) air (Hänninen and Asikainen 2013). The estimated maximum reduction is shown in the *lighter shade* by disease category. *COPD* chronic obstructive pulmonary disease, *CV* cardiovascular diseases

47.8 Global Burden of Disease 2010 -Study

A recent major update of the global burden of disease study was coordinated by the Seattle-based Institute of Health Metrics, funded by the Bill Gates Foundation and published in a special issue of Lancet in December 2012. Lim et al. (2012) investigated the national and continental risks of 67 risk factors, now adding ambient ozone, residential radon, and a number of occupational risks to the palette of previous GBD assessments. Important methodological updates included dropping discounting and age weighting earlier used as a standard approach, and switching from incidence-based assessment to prevalence, i.e., focusing on current symptoms and not on the onset in the case of chronic diseases. The Institute for Health Metrics also developed impressive web-based tools to browse the results available at http://www.healthmetricsandevaluation.org/ numerically and graphically.

47.9 Discounting and Age-Weighting

Interesting methodological details debated actively in the past include discounting and age weighting. Originally Murray and Lopez (1996) used discounting to estimate the economic present values of future assets, such as lost life years. In the case of premature mortality, a substantial loss of life years may take place. According to economic models, the present value of lost life years needs to be adjusted by appropriate discounting. The World Health Organization adopted the approach and used a 3 % annual discounting rate. The present value (*pv*) of a future asset (*fv*) obtained after *n* years, using a given discount rate, is calculated as

$$pv = fv \times (1 + rate)^{-n} \tag{47.6}$$

In the case of multiple years of life lost, the cumulative sum of the present value of lost future years (the future value of each being 1) can be calculated, marking $q = 1 + rate$ as the geometric sum:

$$cpv(n) = \frac{1 - q^n}{1 - q} \tag{47.7}$$

As an example, using a 3 % discount rate ($rate = 0.03$), a year of healthy life gained 10 years from now is worth 24 % less than a year gained immediately.

Further, also an age weighing approach was developed by Murray (1996). BoD calculations involve judgments about standard life expectancy, severity (disability) weights, age weighting, and discounting over time. Murray (1996) also found originally that a year of healthy life lived at younger and older ages was weighted lower than that at middle age. In other words, Murray et al. chose to value a year of life in young adulthood more than a year in old age or infancy. This choice was based on a number of studies that have indicated there is a broad social preference to value a year lived by a young adult more highly than a year lived by a young child or at older ages (Fig. 47.4).

Both discounting and age weighting were heavily debated. For example, children's health has been given high priority in various international policies (e.g., WHO 2010), contrasting the age weights applied. In addition, discounting

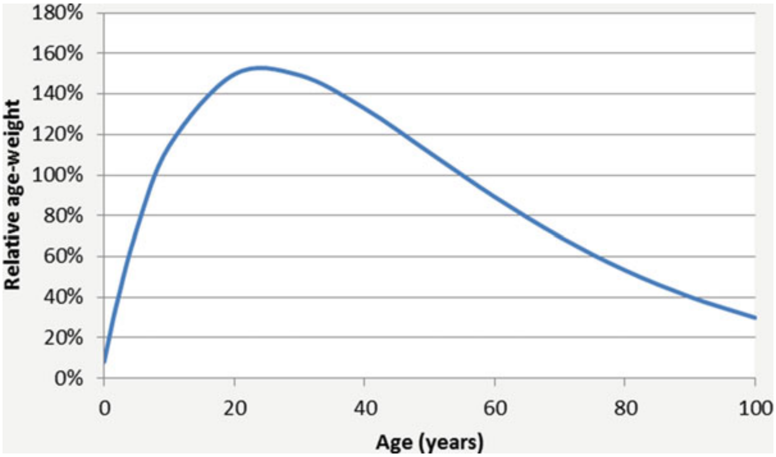

Fig. 47.4 Weights shown for 1 DALY as function of loss age

leads to the fact that childhood mortality, leading to up to 70–80 life years lost, is accounted for less than a similar amount of life years lost during a shorter period. As a reaction to the criticism, the Global Burden 2010 study (Lim et al. 2012) decided to drop both discounting and age weighting, giving equal values to the health of old and young and life saved now or later.

Conclusions

Environmental burden of disease is a useful indicator to quantify the population level health impacts of environmental factors, including chemical pollutants and noise. It allows quantitative comparisons of public health impacts associated with a wide range of environmental risk factors and targeting research and especially risk management to the major issues. However, the environmental burden of disease cannot directly be interpreted as a reducible burden. In many cases, exposures to natural sources of pollution or the existence of overlapping risk factors lead to the fact that exposures cannot be completely eliminated.

Further analysis may also be applicable for the cost effectiveness of various risk management actions. In some cases, reduction in exposures may require complex legislative changes as demonstrated, e.g., by removing lead from fuels, water pipes, canned foods, paints, and so on, over the past decades. Currently, similar challenges are being experienced, e.g., in controlling exposure to fine particles, which also have widely spread and have very heterogeneous sources. However, combining environmental burden of disease estimates with cost-effectiveness methodologies allows societies to target their environmental control efforts as efficiently as possible.

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