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Environment and health within the OECD region: lost health, lost money

Background document to the
OECD Environmental Outlook

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Abstract

This study assessed the environmental health impact within the OECD region, both in terms of lost health and lost money. 2-5% of the total Burden of Disease (BoD) was attributed to environmental factors. Environmental health loss in the OECD high income subregion was monetary valued at US$45-140 billion (or US$53-160 per capita, central estimate).

First, environment attributable fractions of the BoD of 16 diseases with high disease burdens were assessed and total environmental BoD was estimated at: OECD region 2-5% (non-OECD 8-12%, world 7.5-11%). Second, an economic valuation of the environmental health impact was performed. Applying the above percentages to the total health expenditure resulted in OECD environmental health costs of 45-110 billion US$ (40-100 $/capita). However, since health expenditures only apply to morbidity, morbidity and mortality costs were also estimated separately. Environmental *morbidity* costs were obtained using disease-specific direct costs of illness, environmental *mortality* costs were based on a monetary valuation of the years of life lost, first as GDP per capita and second by using willingness-to-pay values for death divided by lost life expectancy. This finally lead to three different estimates of environmental health costs in the OECD high income region: a lower estimate of US$30-95 billion (US$35-105 per capita), a central estimate of US$45-140 billion (US$53-160 per capita), and an upper estimate of US$215-680 billion (US$240-775 per capita).

Preface

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Samenvatting

Dit rapport schat het effect van blootstelling aan milieufactoren op de gezondheid in de OESO regio, in termen van verloren gezondheid en geld. Geschat werd dat 2-5% van de totale ziektelast gerelateerd is aan blootstelling aan milieuverontreiniging, vergeleken met 8-12% voor de niet-OECD landen. Voor de rijkste OECD landen werd dit gezondheidsverlies economisch gewaardeerd op 45-140 miljard $ of 53-160 $ per capita (centrale schatting).

Dit onderzoek vond plaats in het kader van de recente ‘Environmental Outlook’ van de Organisatie voor Economische Samenwerking en Ontwikkeling (hoofdstuk 21 Human Health and the Environment). Eerst wordt geschetst hoe economische en demografische transities gepaard gaan met transities in (volks-)gezondheid en omgevingsrisico’s, waarna enkele concepten en maten voor gezondheid, milieu effecten en monetaire waardering besproken worden. Vervolgens is eerst de totale ziektelast in de OECD-regio geschat, op basis van gegevens uit het World Health Report 1999 gecorrigeerd voor regiogrenzen en bevolkingsgroottes. Ziektelast of gezondheidsverlies (‘burden of disease’) werd uitgedrukt in ‘disability adjusted life years’ (DALYs) of ziektejaarequivalenten. De totale ziektelast per capita in de OECD regio is ongeveer de helft kleiner dan in niet-OECD landen. Daarna is voor 16 ziekte(groepe)n met hoge ziektelast op basis van literatuuronderzoek bepaald welk deel van hun ziektelast toe te schrijven is aan milieufactoren. Voor de OECD-regio werd geschat dat 2-5% van de totale ziektelast gerelateerd is aan blootstelling aan milieu-verontreiniging (1,5-4% voor landen met een hoog inkomen, 4-7% voor de lagere inkomens); voor de niet-OECD landen en de wereld werden deze percentages geschat op resp. 8-12% en 7,5-11%.

Vervolgens is gepoogd deze verliezen van gezondheid in geld uit te drukken. Wanneer de bovenstaande percentages worden toegepast op de totale gezondheidsuitgaven binnen de OECD regio, dan kunnen de milieu-gerelateerde gezondheidskosten geschat worden op US$45-110 miljard ($40-100 per capita). Echter, dergelijke uitgaven hebben vrijwel alleen betrekking op morbiditeit. Daarom zijn vervolgens de kosten van milieugerelateerde gezondheidverliezen voor morbiditeit en mortaliteit apart geschat. Voor de eerste is dit gedaan door middel van ziektegroepspecifieke kosten die echter alleen voor enkele landen met hoger inkomens beschikbaar bleken; dit resulteerde in ongeveer dezelfde kosten als bovenstaande benadering, maar nu alleen voor morbiditeit. Milieugerelateerde mortaliteit is in dit onderzoek uitgedrukt in verloren levensjaren, waarvan de monetaire waarde ten eerste is geschat door het Bruto Nationaal Product te delen door de bevolkingsgrootte, en ten tweede door ‘willingness-to-pay’ waarden voor sterfte onder en boven de 65 jaar te delen door de verloren resterende levensverwachting. Dit leidde tot drie verschillende schattingen van de kosten -en de potentiële opbrengsten van interventies- van milieugerelateerde gezondheidsverliezen in de rijkere landen van de OECD: een lage schatting van 30-95 miljard dollar ($35-105 per capita) met potentiële opbrengsten van een ziektelastreductie van 5 % van 1,5-4,5 miljard dollar ($1,7-5,3 per capita), een middenschatting van $45-140 miljard ($53-160 per capita) en $2,5-7 miljard ($2,7-8 per capita), en tot slot een hoge schatting van resp. $215-680 miljard ($240-775 per capita) en $11-35 miljard ($12-40 per capita).

Geconcludeerd wordt, na een korte bespreking van enkele *hot issues* en kosten(-baten) onderzoeken, dat de invloed van het milieu op de gezondheid zowel in gezondheidsverlies als in geld aanzienlijk is wordt, en dat potentiële opbrengsten van interventies waarschijnlijk groter zullen zijn dan de kosten ervan.

Summary

This study assessed the environmental health impact of environmental factors in the OECD region, both in terms of lost health and lost money. 2-5% of the total Burden of Disease was attributed to environmental factors, compared to 8-12% in non-OECD countries. The environmental health loss in the high income region was monetary valued at US$45-140 billion or US$53-160 per capita (central estimate).

The study took place within the framework of the recent Environmental Outlook of the Organisation for Economic Co-operation and Development (OECD; chapter 21 ‘Human Health and the Environment’). First a short description is given of major economic and demographic transitions and corresponding transitions in health and environmental risks, followed by a concise discussion of concepts and measures of (environmental) health, attributable risk and economic valuation. Secondly, the impact of environmental exposures upon population health within the OECD region was assessed, both in terms of lost health as well as lost money. The total burden of disease (BoD) in the OECD regions was estimated using data from the World Health Report 1999 adjusted for region differences in regions and population. Burden of disease or health loss or was expressed in disability-adjusted life years (DALYs). The total BoD per capita within the OECD region is approximately half that of non-OECD countries. Subsequently environment attributable fractions (lower and upper estimates) of the burden of disease of 16 diseases causing high disease burdens were assessed based on the literature. Within the OECD region it was estimated that 2-5% of the total BoD is associated with environmental factors (high income countries 1.5-4%, lower income 4-7%), for non-OECD countries this is 8-12% and for the world 7.5-11%.

Thirdly, an economic valuation of the environmental health loss was performed. Applying the above environment attributable percentages of the total burden of disease to the total health expenditure, we estimated that within the OECD region environmental health costs range between 45-110 billion US$ (40-100 $/capita). However, health expenditures concern morbidity only. Therefore we divided the (environmental) burden of diseases into their morbidity and mortality parts. Environmental morbidity costs were estimated using disease-specific direct costs of illness (available for some OECD higher income countries only), resulting in only slightly different costs compared to the first approach, but now for morbidity alone. Environmental mortality had been expressed as lost years of life, of which the monetary value was estimated first as OECD high income region GDP per capita, and second by using willingness-to-pay values for death under and over 65 divided by lost life expectancy. This finally lead to three different estimates of OECD high income region environmental health costs -and potential intervention benefits-: a lower estimate of US$30-95 billion (US$35-105 per capita) with potential benefits of a 5% reduction in environmental BoD of US$1.5-4.5 billion (US$1.7-5.3 per capita); a central estimate of US$45-140 billion (US$53-160 per capita) with a 5% reduction benefits of US$2.5-7 billion (US$2.7-8 per capita); and an upper estimate of US$215-680 billion (US$240-775 per capita) and 5% benefits of US$11-35 billion (US$12-40 per capita).

Finally, after a brief discussion of selected environmental issues (chemicals, specific groups, global environmental change) and cost(-benefit) studies, it is concluded that the health impact of environmental factors appears to be quite substantial, both in terms of health as well as in monetary terms, and that the potential benefits of intervention policies may well exceed costs.

1. Introduction

Health is regarded by many as one of the most important assets of the human life. Health concerns have therefore traditionally underlain much of the political priority given to environmental issues in countries taking part in the Organisation for Economic Co-operation and Development (OECD). The threat of global warming, decreasing biodiversity and the urgency for sustainable growth constitute other reasons for political involvement, even though the immediate effects of these developments on health might be less visible. In the recent OECD Environmental Outlook[1] ample attention is given to the human health dimension of environmental issues, to which this document provides background information.

The relation between environmental conditions and human health has since long been established. As early as the seventeenth century, the considerable influence of sanitary conditions on human mortality was demonstrated by Sir William Petty in his investigations on 'Political Arithmeticks'[2]. The removal of the Broad Street pump handle in 1854 by John Snow to stop the outbreak of cholera is a story of nearly mythical proportions amongst epidemiologists[3], marking the beginning of current public health practices in which environmental factors are regarded as major determinants for the health status of a population. Ranging from e.g. lung cancer mortality to aggravation of asthma to wide spread severe noise annoyance, the impact of environmental risk factors upon health shows a large and complex variety in severity and clinical significance. At the same time, the concepts of environment and (public) health reflect social and cultural beliefs and values and therefore differ from era to era and from region to region.

The OECD Environmental Outlook starts with describing the underlying drivers of environmental change, such as economic development, globalisation, demography, consumption patterns and technological change. It then depicts a number of production sectors and environmental issues, and subsequently the integration with social and economic issues, amongst which is human health. Such a sequence might suggest a causal chain from economy to environment to health. Although not untrue, the relation between economy, environment and health is complex and certainly not unidirectional. Environmental quality is just one of the many determinants of health, other important factors being water supply and sanitation, food quantity and quality, public hygiene, socio-economic status, literacy, life-style etc. Also, health itself can be a key determinant for economic circumstances and progress, both on the individual and community level.

Within an economic perspective, health can be viewed as a return from investments in environmental and human capital, but also as capital itself, returning e.g. happiness and healthy time to be used for production, recreation etc[4]. Health as capital goes well with recent thinking on sustainable development, defined as leaving future generations at least as many opportunities as we have had ourselves[5]. Developing social and human, rather than material, resources will contribute towards sustainability. Expenditures on environmental interventions and in health care are therefore not only costs, but also investments with valuable and worthwhile returns, both in health and money. Moreover, the health care sector has become an important economic sector (within OECD 4-14% of GDP in 1997, compared to 2-5% in 1960), providing income and meaningful work to many (up to 10% of total employment)[6]. Besides, it should be stressed that health to many is valuable as such and worth protecting and paying for.

This document provides background information to Chapter 21 Human Health and the Environment of the OECD Environmental Outlook. Similar to Chapter 21, it starts with a brief overview of the socio-economic transitions within much of the OECD region and the accompanying transitions in health and environmental risks. Secondly, the concepts of (environmental) health and how it can be measured and monetarized are shortly explored. The next section describes how the environmental health impact in the OECD region has been estimated, using a burden of disease approach together with attributable risks. It also describes the efforts to provide a first indication of the costs of these environmental health effects. Subsequently a selection of pressing environmental concerns is presented, together with some studies on environmental costs and benefits from the literature. This document concludes with suggesting some tentative policy implications, based on the combined evidence of the previous sections.

2. Transitions in environmental risks and health

Patterns of environmental risks and their effect upon public health show considerable changes over time and place, and can be considered as the outcome of historic economic developments. Different stages in the socio-economic transition of societies from traditional to contemporary, also show differences in the nature and size of environmental challenges and corresponding health effects. Table 2.1 sketches the economic transition from agricultural societies to contemporary globalizing economy, together with the transitions in both environmental issues and health effects, and also identifies the sectors producing the environmental health threats, being of course potential intervention targets at the same time.

The transition from 19th century traditional, pre-industrial to 21st century (post)-modern societies has had and still has a major impact on population health status. For example, in Western Europe life expectancy has doubled from around 35 to over 75 years of age. This so-called health transition consists of two components: an epidemiological transition determining death rates, and a fertility transition determining birth rates. Together with the changes in both the environment and the organization of social and health-related services, these epidemiological and fertility transitions lead to effects on the population size and structure. This 'demographic transition' refers to a development from a pyramidal population structure to a situation with less children and more elderly. In most developing countries these transitions are clearly underway, while in the developed regions they have reached the stage in which chronic diseases -particularly from old age- have become predominant[7,8]. The economic development within the OECD has lead to longer and healthier lives for more people, although major health differences between high and low income groups still exist. An improved economic situation not only lead to changed nature and magnitude of environmental risks (as described in Table 2.1), but also significantly reduced other important risks and promoted improvements beneficiary for health, such as food amount and diversity, water management, better occupational circumstances, improved health care etc.

In traditional societies, environmental problems chiefly concern access to clean water, appropriate housing and protection against natural disasters, and are primarily related to infectious diseases, maternal and perinatal conditions and nutritional deficiencies. Although economic progress has provided the means to reduce these risks to acceptable minimum levels in much of the OECD region, it also lead to new risks, mostly linked to modern large scale rationalised production. Industrial and agricultural emissions of chemicals in water, air and food have been associated with respiratory diseases and various types of cancer, while (the possibilities of) large industrial accidents cause societal disruption and severe health effects and threaten basic trust. Within the established market economies or late-capitalist, post-modern societies, emphasis is now shifting from industrial production to escalated levels of consumption of goods and services from all over the world. Knowledge and tourism overruling all geographical and cultural divisions[9] are increasingly important economic factors[10,11]. Although the environmental risks of much of modern industry have largely been regulated, greatly increased transportation and energy use produce large scale transboundary air pollution (particulate matter, ozone). This results in increasing numbers of traffic accidents and noise pollution and reduces liveability in many urban areas, leading to e.g. higher levels of cardiopulmonary disease. Substantial environmental and health effects also occur in regions outside of the OECD, where much of the production of OECD-destined goods takes place.

The future health impact of climate change is as yet unknown, but expected to be significant. Still fast growing world population, the ageing of western populations and its effects upon the use of resources and energy, and the globalisation of western economic high consumption system can be expected to increasingly disrupt the biosphere’s life supporting systems, of which climate change and the loss of biodiversity are already observable signs. These unprecedented large-scale environmental changes might reshape human health risks, e.g. in adversely changing patterns of new and known infectious diseases (malaria, cholera, aids, Ebola etc) [12]. Since current levels of population health have been acquired through economic progress often detrimental for the environment, more sustainable development seems urgent and inevitable both within as well as outside the OECD, in order to sustain and enhance the world’s population health. Besides ‘greening’ technologies and decoupling economy and environmental pressure, this may also include a shift from produced assets and natural resources to human and social capital.

Finally, important changes may also occur in the field of governing and regulation. Up till now nation states have played an indispensable role in regulating polluting activities and cleaning up acknowledged sources of environmental health risks. Present risks and challenges however appear to be either supranational and global, or regional and even local. Noticeable changes can be expected in institutional structures and environmental actors, both at a global level (such as multinational corporations, international institutions and consumer organisations), as well as the local level (citizen committees, neighborhood watch groups and local governments fostering sustainable development).

Table 2.1. Transitions from traditional to (post-)modern economies.

Economic transition	***Agriculture and early industry*** →	***Industry and services (focus on production)*** →	***ICT and economic globalization (focus on consumption)*** →	The Future: ***Sustainable Development*** *or* ***Endangered Global Life Support Systems?***
Environmental issues	• Clean water scarcity • Food quantity and quality • Indoor air • Disease vectors	• Chemical emission and exposure in water, food and air (pesticides, heavy metals, POPs, VOCs, etc) • UV-radiation • Food (microb.)	• Transboundary air pollution (particulate matter, ozone, etc.) • Local urban air pollution • Urban noise • Urban liveability • Food (microb.) • Decreasing exposure to chemicals	• Global warming (disrupted carbon and nitrogen-cycles) • Natural disasters • Increased disease vector spread • Overpopulation • Land degradation • Water scarcity
Health effects	• Communicable diseases • Maternal and perinatal conditions • Nutritional deficiencies	• Various cancers • Respiratory diseases • Neurological disorders • Large accidents • Gastrointestinal disorders • Allergies • Reproductive disorders	• Respiratory diseases (acute and (aggrevation of) of chronic) • Gastrointestinal disorders • Mortality harvesting effects (cardiopulmonary disorders) • Psychosocial effects • Neurocognitive dysfunction • Reduced quality of life	• 'Return' of known and new communicable diseases (*eg*. malaria, aids, dengue) • Heat/coldstress • Natural disasters
Sectors (pollution sources and/or intervention opportunities)	• Public hygiene and sanitation • Housing • Land and water management	• Industrial processes • Agriculture (fertilizers and pesticides) • Waste disposal • Use of ozone depleting substances (cfc's)	• Transportation (mainly road and air) • Energy generation and use • Tourism	• World ecological system • Possible intervention areas: -technology (greening) -consumption (altered patterns) -population (size and composition)

3. Concepts and measures of health and environment

Nearly two centuries of successful preventive medicine and public health policy have stretched life expectancy in many developed societies almost to the limit[13]. Public health focus has gradually shifted from life expectancy to *health* expectancy. Or in other words: postponing as long as possible or mitigating the physical, mental or social limitations brought about by the chronic diseases of older age[14,15,16]. Within the framework of assessing the health impact of environmental factors, this chapter first discusses the concepts of (environmental) health together with a model of public health in orde to clarify the relation between health and the environment. The meaning of 'attributable fraction' is elaborated upon, after which a method to measure the environmental health impact in the OECD is proposed. The chapter concludes with suggesting methods to tentatively assess the environmental health costs in monetary terms.

As a result of the described epidemiological, health and demographic transitions, health impacts of environmental exposures no longer only involve clear mortality risks or loss of life expectancy, but also aspects of the quality of life in a broad sense[17]. Some examples of these aspects are aggravation of pre-existing disease symptoms (e.g. asthma, chronic bronchitis, cardiovascular or psychological disorders), severe annoyance, sleep disturbance, as well as a reduced ability to concentrate, communicate or perform normal daily tasks, and maybe even feelings of insecurity or alienation, unfavourable health perception and stress in relation to poor quality of the local environment and perceived danger of large fatal accidents[18]. There are also several indications that social responses to environmental interventions, such as the extension of an airport may lead to an increase of medical consumption, such as medication use, GP-visits or hospital admission[19,20,21]. Furthermore, several authors have pointed out the important role of socio-economic inequalities and social position within societies with regard to public health status. Independent of the absolute level of income, material insecurity, social exclusion, lack of self-esteem, loss of social cohesion may lead to a higher prevalence of health problems among the more deprived[22,23,24,25]. Obviously, health is not (anymore, if ever) a welldefined entity, and the same counts for environment. Both concepts may differ from era to era, from region to region, since they reflects changes or differences in social and cultural beliefs, knowledge and technology, and economic conditions. Key questions in any attempt to evaluate health impacts associated with environmental exposures are therefore 'what is health' and 'what is *environmental* health'?

3.1 What is health?

Several authors conceptualise health as an optimum dynamic equilibrium between individual capabilities and exogenous circumstances, enabling individuals to deal with external disturbances and pressures[13]. In such an approach health is looked upon as an individual's ability to cope with the demands of everyday life[26,27,28]. Successful adaptation to environmental circumstances in the broadest sense implies living an independent and productive life, maintaining optimal economic conditions and social interactions in all stages of life, and thus health may very well refer to well-adjusted people with physical handicaps[29]. In the context of environmental health impact assessment health problems may arise among those who lack the mental and physical resources to adapt to certain exposures, such as noise, air pollution, lack of open space, traffic density or the threat of a large accident[30].

Health as ‘a state of complete physical, mental and social well-being and not merely the absence of disease and infirmity’ is the far-reaching definition given by the World Health Organisation in its founding charter in 1946[31]. An important merit of this definition is the explicit appreciation of the subjective experience of health, and the inclusion of psychological and social dimensions. However, some argue that such a state of complete well-being corresponds much closer to happiness than to health[32,33]. As the quest for happiness is often regarded as essentially boundless, the quest for health becomes boundless as well. Alternatively health may be viewed as ‘a condition of being free of disease and infirmity and a basic and universal human right’, but at the same time be linked to appropriate indicators of mortality, morbidity and (health-related) quality of life[32].

Also, well-being and coping with everyday life requires much more than good health alone. It is not very likely that the contribution of public health policy would be the most efficient in such a broad field. This would limit the definition of health even more: ‘the absence of disease and other health problems of a physical or psychological nature’, as recently advocated by the Scientific Council for Governmental Policy in the Netherlands [34]. Of course, these views bear first and foremost on controlling the costs of health care and cure in ageing populations. However, in the field of environmental health protection one is confronted with similar needs for effective and efficient allocation of resources (including opportunity costs)[35,36].

Other conceptualisations of health, implicitly as well as explicitly, can be found in the large number of methods for measuring health status, either to be used at an individual level to compare quality of life after different options for medical intervention (e.g. quality adjusted life years: QALY's), or applied at the level of populations to measure the burden of disease, primarily to support the planning of public health programs (e.g. to assess the efficiency of different options)[26]. Some important concepts within these instruments are *opportunity* (cultural and socio-economic disadvantages, loss of resilience), *health perception* (expectations and satisfaction about health (and health care), reflecting of course the cultural images of health[37]), and *functional status* (physical, psychological and social functioning, for instance the ability to perform ‘activities of everyday life’)[38]. However, this again poses the question of what goes into health; does one take the perspective of the observer, the patient, and/or the effects upon society as a whole? [26,27].

Considering these points of view, we conclude here to a more or less conservative approach in which people are considered healthy until they are diagnosed not to be so (preferably by a medical doctor). The health status of specific (exposed) populations can then be assessed by means of a range of comparative population measures of mortality, morbidity, and impairment. One might rely on routinely available health statistics, such as mortality rates or the use of health services, or one might conduct surveys to reveal specific exposure-attributable response variables, such as lung function measurements or specific reported symptoms. But once again one will be confronted with the difficulty of defining ‘disease’ at the margins; the question remains whether a clear distinction can be made between clinical depression and anxiety on the one hand and anger, annoyance, irritation, or loss of morale on the other[30].

3.2 What is *environmental* health?

As with health, the question ‘what is environment’ can be approached from a number of different perspectives, such as biological, ecological, medical, social, chemical, economical etc. Within a human health perspective, defining environmental causes of disease based on the classic nature-nurture dichotomy would imply that all factors that are not genetic are to be regarded as environmental[39], or as Einstein put it: ‘environment is everything that isn’t me’. When the time scale is however taken large enough and evolutionary mechanisms are taken into account, even current genetic conditions might be seen as the result of past environments and therefore all diseases could be regarded as environmental. The common perception of environmental causes appears to emphasize another distinction, i.e. the extent to which exposure is voluntarily and subject to personal action. Behavioural and life-style factors are consequently not viewed as environmental, although the existence of a ‘social’ environment and resulting pressure may cast doubt on the voluntariness of such factors. Figure 3.1 sketches how various definitions of ‘environmental’ from a human health perspective may be related and emphasizes the overlap between the various groupings.

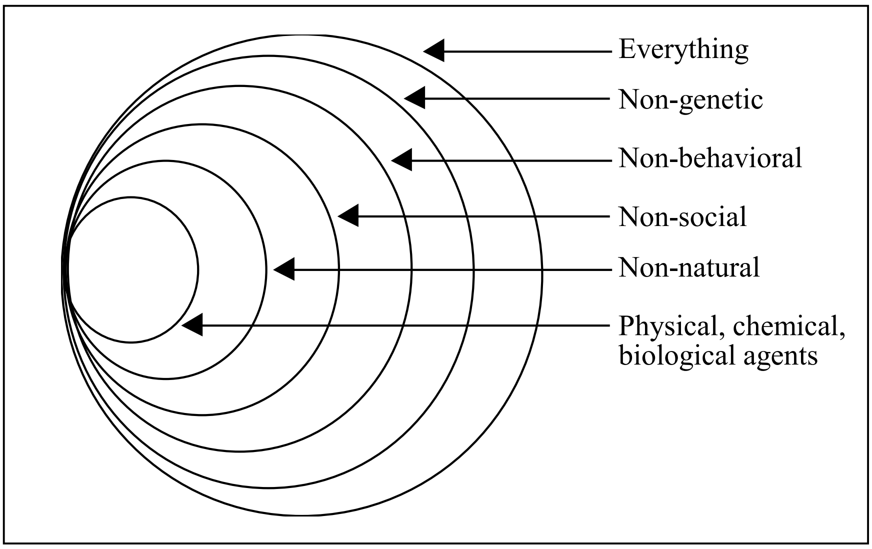

Figure 3.1 Different definitions of ‘Environmental Factors’ (Reproduced from Smith et al.[39]).

Up till now, environmental concerns in a health context have generally been with overt human-made hazards in the ambient environment. Today however, global environmental changes such as climate change and loss of biodiversity are increasingly requiring attention. Population growth, world wide mass urbanization together with high production and consumption levels are apparently affecting environmental quality and therefore human health and wellbeing[40]. To deal with these issues, concepts and attitudes concerning environmental influences on human population might need to be expanded. Instead of viewing the environment as a repository of potential hazards that have to be eliminated, the world around us might also be thought of and experienced as our habitat. This way health is not only a dearly-won asset to be protected against detrimental influences, but also a historically contingent state resulting from and supported by a number of complex and intertwined systems. A sustainable population health from an environmental perspective requires therefore a sustainable economic development protecting and maintaining a global life supporting environment and not only -though necessary- efforts to eliminate or control environmental risk factors[12].

Such an approach of environment and health corresponds to some extent to current economic thinking in e.g. the recent World Bank report ‘Expanding the Measure of Wealth: Indicators of Environmentally Sustainable Development [41]. This document is one of many in which an increasing emphasis on sustainable development takes shape, based on a concept of sustainability as opportunity. That would define sustainability as leaving future generations as many opportunities as, if not more than, we have had ourselves[5]. In economic terms one could use for opportunity the concept of capital, with its returns as income[4]. Income based on depletion of capital is not sustainable and should therefore not be considered as income. The wealth of a nation would then not only consist of the produced assets (economic capital) but also of natural capital (amongst which environmental conditions) and human resources (social and human capital, e.g. health and education); different types of capital might to a certain extent be complemetary. Again, environment may be regarded not only biologically as a risk factor of health and disease; it can also be approached economically as a (part of the natural) capital with health as one of its returns.

Other economists would take the position that environmental issues are those that occur to a group other than the decision-making group (resp. externalities vs. internalities). For example, outdoor air pollution would be environmental, but household indoor air pollution would be excluded, since it is under the influence of the affected individuals. This approach however assumes that the household can use all the necessary information (ie detect and understand the risks), makes rational decisions and is able to solve the problem of indoor air pollution by itself; clearly assumptions that are very seldom met in real life. Since the prevailing tradition in public health is to find and reduce all threats to health no matter where they occur and who bears responsibility for them, the externalities vs. internalities approach is hardly appropriate[39].

The definition of environmental health of the World Health Organization echoos this broad scope of the public health tradition: ‘Environmental health comprises those aspects of human health, including quality of life, that are determined by physical, chemical, biological, social, and psychosocial factors in the environment. It also refers to the theory and practice of assessing, correcting, controlling, and preventing those factors in the environment that can potentially affect adversely the health of present and future generations.’[42]. In practice, these factors have been classified into ‘targets’: air pollution, water pollution (both drinking and wastewater), hazardous waste, human ecology and settlements (incl. indoor air), food safety, monitoring, occupational health and safety[43].

For use in this document we propose that environmental health effects should focus primarily on outcomes that are significant to mortality, morbidity and health-related quality of life. Obviously this includes all clear intermediate risk indicators, such as lung function deficits, aggravation of asthma, or sleeping problems, as well as ‘derivative’ indicators like the use of medical services or self-medication. ‘Environmental’ refers to physical, chemical and biological human made or influenced exposures, excluding occupational health and safety, the majority of traffic, war etc. of which the ‘environmentalness’ is disputable. We also exclude important life-style determinants of health such as smoking behaviour and dietary patterns.

3.3 The relation between health and environment

3.3.1 Determinants of health: complex relations and interactions

To evaluate the manner in which environmental exposure may influence public health we consider a conceptual model that was developed in the framework of the Dutch Public Health

Status and Forecasts[13] report (see Figure 3.2; the model elaborates on previously published models, in particular the model proposed by the Canadian Minister of Health Lalonde in 1974).

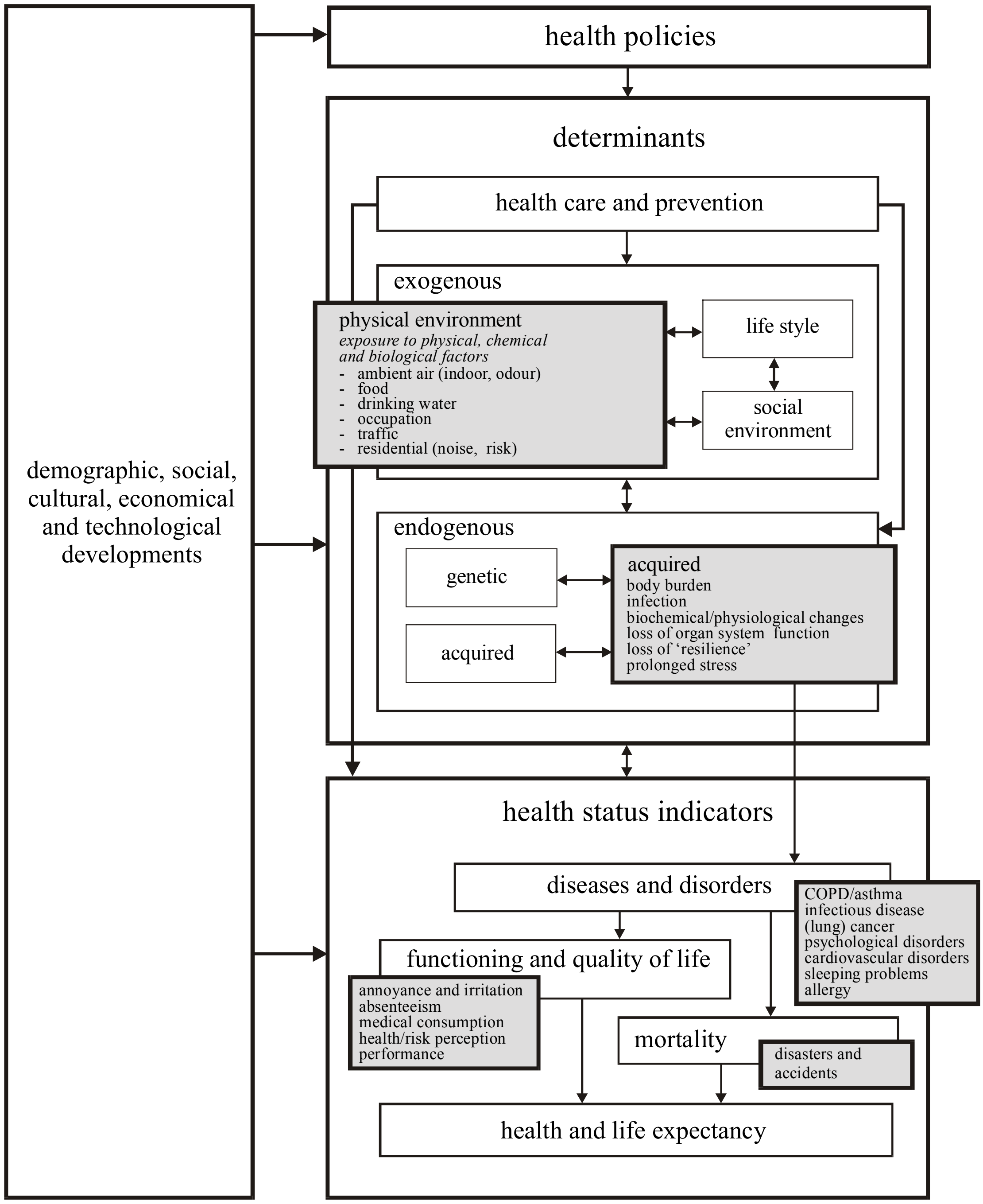

Figure 3.2 The Physical Environment as a determinant of Health Status.

The model illustrates that health status can be contemplated as a function of many (interacting) determinants (a complex of causality), including the quality of the physical environment. Endogenous as well as exogenous determinants are involved, which may explain why the response to environmental exposures may vary substantially from one individual to the other[19,33,44]. Furthermore it shows that health status may provide directions to health policy, which will in turn influence health status via determinants. This whole dynamic process is influenced by autonomous developments in demographic, socio-cultural, economic and technological areas.

Endogenous determinants may be genetic or acquired in the course of life. Gender, for example, is a genetic factor that may affect a person's state of health. In the Netherlands e.g. women live about 6 years longer; most of those extra years are however lived in reduced health as on average women suffer more from chronic diseases[45]. Genetic predisposition may involve clear abnormalities such as haemophilia or colour blindness. A particular feature in a population may nevertheless show a more complex genetically determined distribution, reflecting differences in susceptibility to pathogenic factors. Examples are variations in the ability to detoxify harmful substances, susceptibility to carcinogenic substances, or skin pigmentation in connection with damage caused by UV radiation (genetic polymorphism). Probably most endogenous determinants develop through interactions between genes and environmental factors and thus have both a genetic and an acquired component, for example length, blood pressure, blood lipoprotein composition (familial risk factors), and personal (psychological) attributes[46,47,48]. Acquired attributes are built up in the course of life, for instance immunity acquired through vaccination or prior infection, reduced lung function as a result of an earlier respiratory infection, many years of smoking or adverse occupational exposures. An important endogenous 'acquired' determinant of health is of course age. Many health problems occur later on in life, often in connection with the effect of exogenous determinants earlier in life.

Regarding exogenous determinants, a disctinction can be made between the physical environment, life-style factors and the social environment. The physical environment includes radiation, noise and heat (physical factors); oxygen supply, nutrients, hazardous substances in the outdoor and indoor environment, including the working environment (e.g. chemicals); bacteria, viruses and other (micro)organisms which may have both positive as well as negative effects on health status (biological factors). Life-style factors include diet, smoking, drug abuse, sexual habits, physical (in)activity and such. The social environment includes the pattern of social networks and socio-economic status.

A concept of health as a dynamic equilibrium emphasizes interaction between determinants, resulting in a particular state of health. While exogenous determinants act on endogenous ones, there are also many interactions within the group of exogenous determinants. Life-style for instance, is to a considerable extent determined by social environment (e.g. family situation). Aspects of lifestyle or behaviour, such as sunbathing, smoking and personal hygiene may on the other hand largely determine exposure to factors from the physical environment such as UV radiation, carcinogenic substances, or pathogenic organisms.

3.3.2 How much ill health can be attributed to the environment: 'attributable risk'

Environmental risk factors are often addressed as to their direct effect in causing disease. Maybe more importantly however, they also play a significant role in disease aggravation and prognosis by influencing other exogenous or endogenous determinants. In general, the extent to which a certain phenomenon causes diseases can be characterized by the 'attributable risk', indicating the percentage of a particular disease category that would be eliminated if the influence of this phenomenon were reduced to its lowest value [39,49]. Nearly every disease has multiple risk factors of which the environment is but one. Figure 3.3 shows how the various adverse health outcomes can be envisaged, with environmental (and most other) risk factors often forcing an upward movement of pre-existing cases towards more severe symptoms and disease stages, with some deaths as the top of the iceberg or pyramid. Only the more severe responses end up at a doctor's practice, in hospitals and thus in official health statistics (above the surface), while responses beneath the surface are only seen in special surveys. Moreover, apart from rare exceptions, responses are not specific for environmental exposures but often dominated by life-style, genetic and socio-demographic factors.

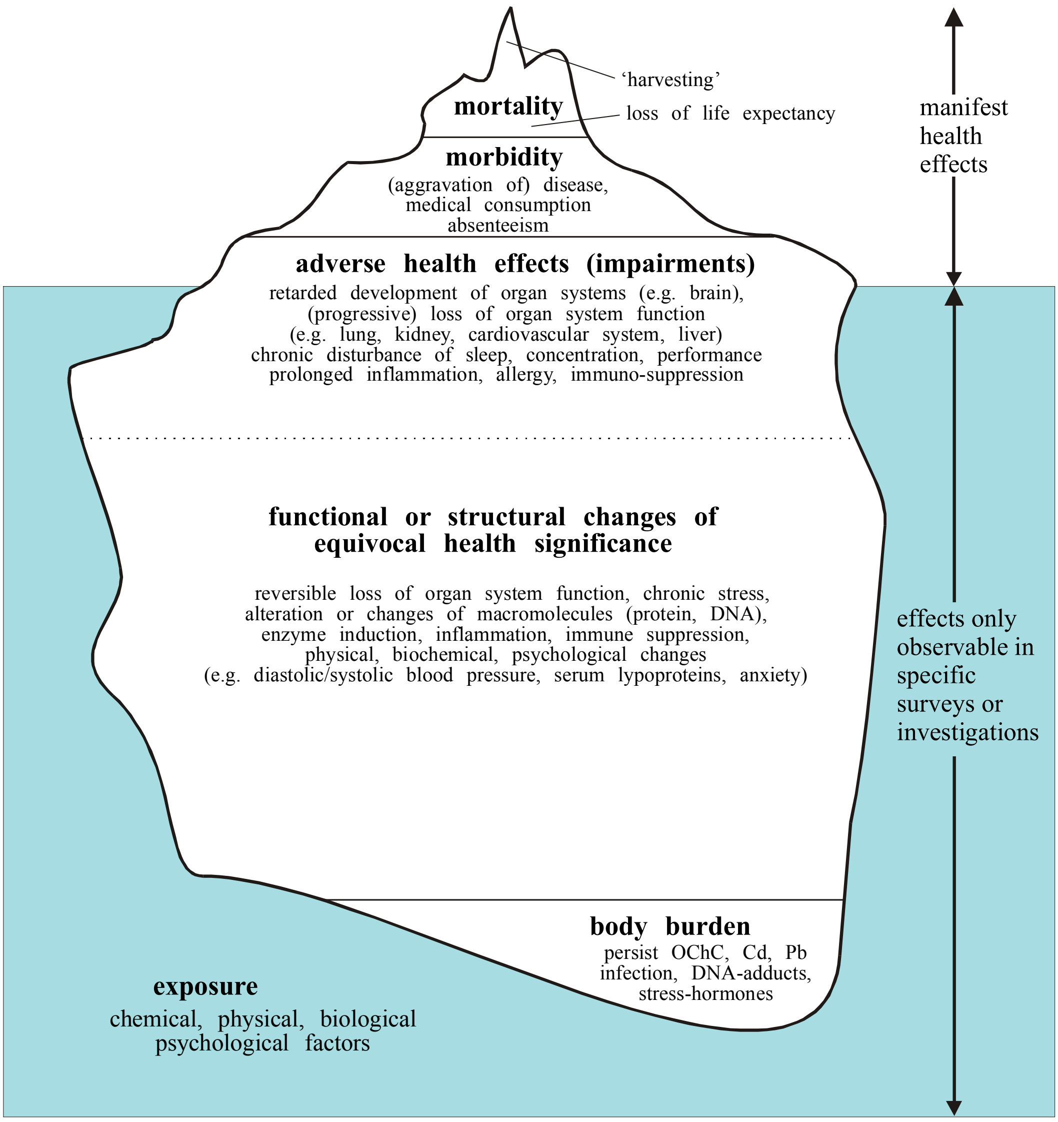

Figure 3.3 Diagram representing the Public Health relevance of disease end-points following various exposures (Reproduced from Hollander et al[50]).

Thus, most important risk factors do not directly create a certain number of new disease cases but merely enlarge the existing number; they are therefore not independent from each other and changes in one will affect others. Although this complicates understanding the disease web of causation, it also expands the number of possible intervention paths. Combining this with the above-mentioned definition of attributable risk implies that the percentages of attributable risk of each of the various risk factors of a disease may well add up to more than 100%[39]. For example, saying that large fractions of acute respiratory infections are attributable to air pollution, poor housing etc, is not incompatible with the statement that also large fractions may be due to e.g. malnutrition and lack of immunocompetence. Each risk factor must therefore be considered in the light of others and reducing one risk factor will influence the remaining attributable risk of others.

Whether a risk factor is defined as environmental also depends on the interdependent choices of time period and baseline. As discussed above, when a sufficiently long period is taken, all diseases can be regarded as environmental, while taking a rather short time horizon would exclude long term environmental health threats and effects, such as climate change effects and skincancer due to ozone layer reduction. Because humans have never lived without (environmental) risks, it can be argued that a certain level of risk and health effects is unavoidable, tolerable or even acceptable. A baseline of a zero exposure level might therefore be suitable for e.g. synthetic chemicals, but not for airborne particles, inonizing radiation etc. A baseline can also be seen as a 'counterfactual' or alternative scenario, to which the current level of risk factor is compared. Murray and Lopez (1999) distinguished three counterfactual scenarios[51]: the theoretical minimum represents a scenario where the exposure distribution is associated with the least population risk, the plausible minimum risk is described by the distribution with minimum population risk that is imagined to be plausible, while the feasible miniumum risk corresponds to the scenario with the minimal population risk that has been achieved somewhere in the world with current technologies and in optimal conditions.

3.4 Measuring environmental health impact

Previous paragraphs have dealt with definitions and concepts of (public) health, to what extent it may be 'environmental', and how the different risk factors and endogenous and exogenous determinants of health might be brought together into one model. The next step is to discuss how the impact of current environmental exposures upon health in existing populations can actually be measured or estimated.

As mentioned earlier, the impact of hazardous environmental exposures on human health can take numerous shapes of various severity and clinical significance. Among the many responses that have been attributed to environmental exposures are disturbed cognitive development in children, several types of cancer, reduced fertility, immune-suppression, severe noise annoyance and sleep disturbance[52,53,54]. During air pollution episodes well-studied human responses range from slight reversible lung function deficits in virtually everyone exposed, to aggravation of symptoms among asthmatics, and from hospital admission of patients with cardiopulmonary disease to the premature death of some of the very weak[55,56,57,58]. Some effects occur soon after the onset of exposure; others emerge after long term cumulative exposure, including a latency period. The public health significance of any biochemical, physiological or psychological response to an environmental insult depends on many endogenous and exogenous factors. Whether or not an environmentally induced change affects individual health may be a function of its reversibility, individual possibilities of compensation or level of resilience. At the population level, these effects are combined into possibly elevated rates of health status indicators such as morbidity and mortality, characterizing a population's health and the public health impact of environmental factors.

3.4.1 Indicators of morbidity

Functional or structural changes attributable to environmental exposures may (temporally) affect the normal function of organ systems or disturb mental or social functioning, in the end initiating disease or aggravating symptoms of pre-existing disease (frequency, intensity and duration). Whether disease indeed occurs depends largely on the individual vulnerability (genetic susceptibility, lifestyle, disease history, gender or age). Carcinogenesis may e.g. be initiated by environmental carcinogens in some unfortunate individuals, given an unfavourable genetic. Only when specific (not necessarily environmental) conditions for tumour promotion and progression are met in all stages the tumour might become clinically manifest. It is therefore often impossible to attribute individual cases to specific exposures. Wheteher the high exposure levels in occupational studies bear much significance to substantially lower everyday environmental levels is also subject of an ongoing debate[59,60]. Another example of disease prevalence affected by environmental exposure is asthma among young children, predominantly those who are constitutional atopic. There is an established association with exposure to indoor dampness, and associated bio-allergens (house mite excrements, compounds of bacteria or fungi)[61].

At the population level one would expect morbidity to be reflected in *absenteeism*, use of *health services*, and *medication* (including self-medication). In a recent survey of populations in the vicinity of Amsterdam Airport Schiphol for example, indications were found of increased use of medication for hypertension, cardiovascular disorders, allergy and asthma, tranquillisers and sedatives. (Self) perceived health is another 'aggregate' measure to evaluate a population's health status. In general perceived or self-rated health measures are not very specific, as many determinants are involved, among which social-demographic factors (age, gender, ethnicity), prevalence of chronic disease and functional limitations, as well as social-psychological well being.

Some examples of indicators to describe morbidity associated with environmental pollution are:

- exposure specific morbidity (e.g. prevalence of cardiovascular disease, sleep disturbance, asthma, lung cancer etc.)
- accelerated decrease in lung function, resulting in earlier onset of chronic obstructive pulmonary disease
- aggravation of respiratory or cardiovascular symptoms (resulting in absenteeism, medical consumption, see next)
- absenteeism from work or school
- medical consumption, such as GP- and emergency room visits, and hospital admission rates
- medication use, in particular with respect to disorders which can be related to a specific exposure (e.g. medication for cardiovascular disease, sleeping problems, sedatives and tranquillisers in relation to noise, or inhalers in relation to air pollution)
- disturbed intellectual development in children as a result of chronic lead poisoning
- self-rated health

3.4.2 Indicators of mortality

Mortality is the ultimate irreversible outcome of ageing or pathological processes. Age-specific overall mortality is an important and frequently used indicator to describe the public health status of the population. Since everybody dies at some point, the age at which death occurs or the years of life lost (reduction of life expectancy) are important attributes of mortality. 'Precipitated' mortality during particulate air pollution episodes involving predominantly the old and frail may cost up to several months of unhealthy life[62,63], while the impact associated with fatal accidents involving individuals with a 'random' age distribution may amount to a loss of many healthy years[64].

Regarding the case of large accidents, it is obvious that the general public does not perceive these risks, such as an aircraft crash in a residential area, simply in terms of annual death toll or even loss of life expectancy. For instance a calculated average so-called third party mortality risk of around 1 death annually is fairly insignificant compared to the total of annual deaths in a population or the deaths attributable to smoking. It is clearly not the public health burden per se, but the involvement of tens or hundreds of victims at the same time, the social disruption that results from large accidents and the involuntariness of exposure that might legitimate the high position of third party risk on the societal agenda[35,65].

To describe mortality in a population, age-, sex- and cause-specific figures are the indicators of choice, e.g.:

- annual respiratory and cardiovascular mortality associated with particulate air pollution;
- cancer mortality in relation to exposure to carcinogens (chemicals or radiation)
- loss of life expectancy (life table analysis).

3.4.3 An aggregate health impact indicator

Although common risk measures such as the previously mentioned morbidity and mortality indicators are informative and widely used, they often fail to adequately address the large diversity of environmental health impacts, since they are primarily geared to *probability* rather than to the *nature* and *magnitude* of adverse health consequences[66]. The annual mortality risk associated with a certain exposure for example appears unambiguous and easy to comprehend, but will in some instances be inadequate as it does not cover the full range of relevant health dimensions associated with a certain environmental health problem. It also gives no attention to e.g. age and previous health status of the deceased. Incorporating various relevant health attributes may therefore improve the quantitative risk assessment and subsequently the decision making process[67,68,69].

In recent years several integrative indicators have been constructed to aggregate health losses on the level of populations. An important one was developed within the World Health Organization - World Bank Global Burden of Disease project led by Murray and Lopez[70]. To assess the global disease burden and consequently the health policy priorities in different regions in the world, they applied disability-adjusted life years (DALYs). This health impact measure combines years of life lost and years lived with disability that are standardized by means of severity weights; it thus measures health using time as the metric.
The adaptation of the DALY-concept in this document was inspired by the notion that the multiform health loss due to environmental exposure is reasonably well characterized by three dominant aspects of public health, viz. *quantity* of life (measured by life expectancy and duration of disease), *quality* of life (expressed through a disease severity weight), and *social magnitude* (or number of people affected)[71]. Thus, environmental health loss is defined as time spent with reduced quality of life, aggregated over the population involved. The diagram in Figure 3.4 sketches the basic idea behind this and comparable approaches. Time is the unit of measurement. Public health loss is defined as time spent with reduced quality of life, aggregated over the individuals involved, and combining years of life lost (combining mortality and age of death data) and years lived with disability that are standardised by means of severity weights[70,72].

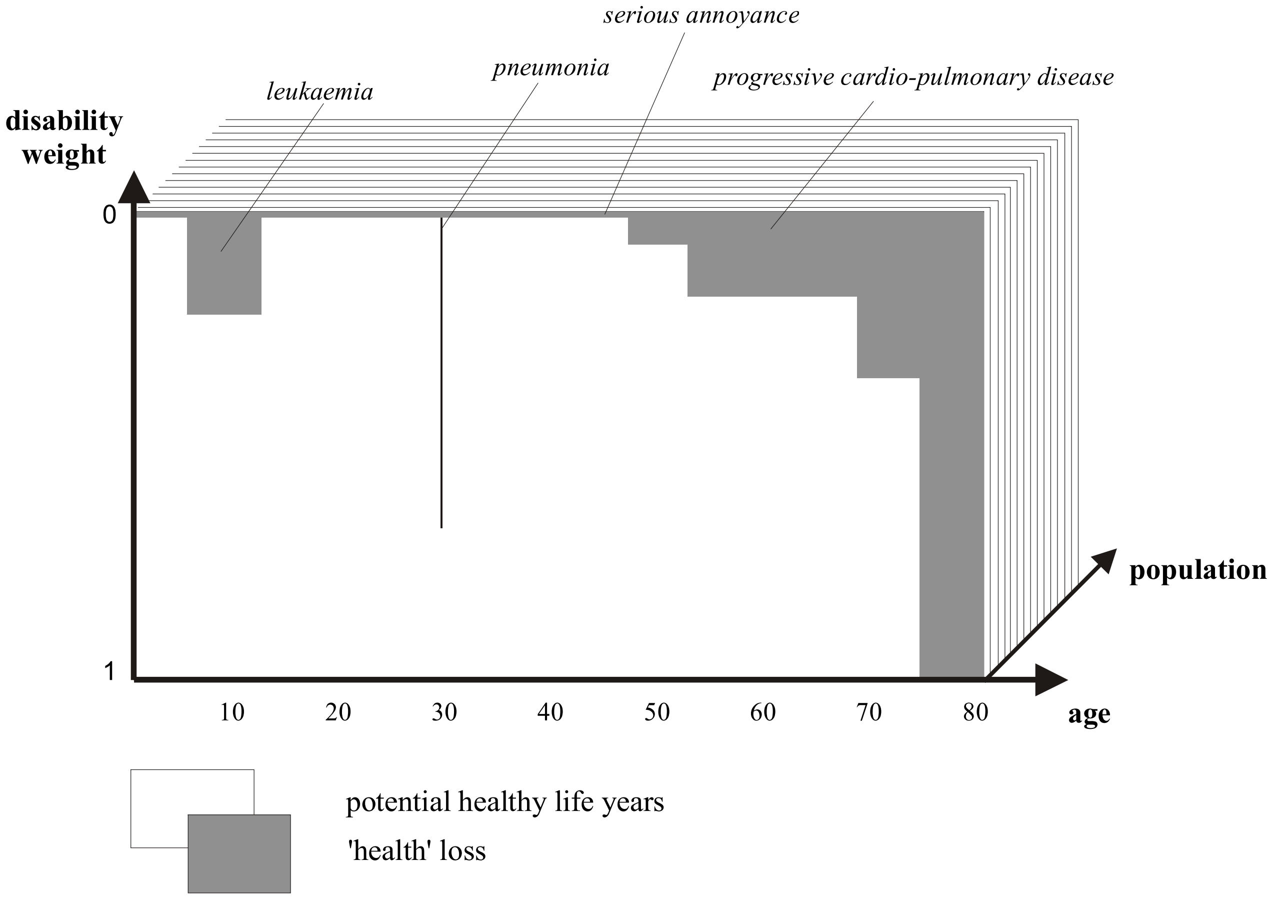

Figure 3.4 Diagram of the concept of Disability Adjusted Life Years (Reproduced from Hollander et al.[71]).

Important issues in a calculation of the burden of disease in DALYs are the estimation of the number of people affected, the duration of disease and the numbers of years of life lost through death, and the question of how to determine the severity weight for each disorder. To estimate the number of people affected, two basic approaches may be used: the exposure-based and the outcome-based approach[73]. The first assesses the exposure in the population and combines those data with dose-response relationships, resulting in the number of people showing an adverse health outcome. The second collects data on relevant disease outcomes and then determines which fraction of ill health can be attributed to certain environmental risk factors. Obviously the two methods require quite different sets of data. The duration of disease and the 'duration' of mortality can often be derived from clinical data, disease-specific mortality figures and life tables.

Weighting the severity of a disease condition or the reduction in quality of life caused by it has been the subject of much reasearch and debate. The Global Burden of Disease (GBD) project initially applied disability weight definitions which were primarily based on functionality, the (dis)ability to perform 'activities of everyday life' in four domains: procreation, occupation, education and recreation[15]. The approach was received with a fair amount of criticism, some involving the procedures of attributing weights, other the fact that the definitions did not fully comprise important dimensions of health such as pain, distress, discomfort, anxiety and depression. Aggregated scores would not adequately reflect preferences of various 'stakeholders'. To meet these objections in their revision of the DALY-approach Murray et al. applied the concept of 'indicator conditions'[74]. Using formal instruments to measure health preferences, 22 indicator conditions were given weights in series of consensus meetings involving physicians and public health scientists from different regions. These states reflected several distinct attributes of non-fatal health outcomes, such as large physical manifestations or limitations, psychological ands social limitations, pain, as well as disturbed sexual and reproductive functions. These indicator conditions were used subsequently to attribute disability weights to most other states. Recent Dutch (Environmental) Burden of Disease Studies[71,75] applied rather similar approaches for a different set of diseases and environment related health outcomes.

Two other -somewhat controversial[70,76]- features of the DALY measure as developed by Murray and Lopez in the Global Burden of Disease study are weighting for age and discounting of loss of healthy life in the future. Age weighting gives some ages more impact in the DALY estimates than others because of the economic and societal impact and justified by the idea that everyone may eventually pass through all ages. Applying a certain discount rate for future costs and benefits compared to present ones is common practice among economists -though not so much in the public health field-, because otherwise interventions would nearly always be postponed to the future.

Of course, there are many questions about concepts and methods underlying indicators such as the DALY, of which those concerning procedures and values for the weights for severity appear amongst the most pressing ones. The use of composite health outcome measures implies several normative choices, such as the reference life table to be used, the valuation procedures, etc. These choices have been extensively discussed in the literature[77,78,79,80,81]. However, key advantages of the DALY are its aggregate nature combining both quantity and quality of life, as well as its transparency and explicit appreciation of many of its assumptions, allowing for open discussion and trying out other other preferences. Well-established public health indicators such as mortality and morbidity on the other hand, also rest upon a number of rather implicit assumptions (e.g. implicitly valuing death at young and old ages equally), which however often go unnoticed.

3.5 Monetary valuation of environmental health impact

Using a burden of disease approach allows to express a wide range of health outcomes into one measure whatever their cause or nature is. Within economic thinking, money is the usual metric to express and compare both material and immaterial goods. Therefore, to be able to prioritize interventions and their expected benefit-cost ratios, health effects of both environmental problems and interventions should be compared on the same basis as financial costs and benefits in other areas. Since for environmental benefits such as health and clean air no markets exist or just very imperfect ones, these goods are not priced and their monetary values can not be readily observed. Monetary values of health effects have thus to be derived trough other means[82]. Two of the most widely applied approaches are: 1. measuring people's *willingness-to-pay* (WTP) for an environmental benefit (the welfare cost to an individual) or conversely their willingness to accept compensation for environmental degradation; 2. estimating the (avoided) *cost-of-illness* (CoI) related to environmental causes or interventions (costs for the society, e.g. health care costs, loss of productivity or income). WTP-measuring does not take into account costs borne collectively, while the CoI-approach excludes intangible costs such as disability and decreased quality of life borne by the individual, resulting in mostly much lower values compared to WTP. Willingness to pay values appear reasonably stable in Western societies, but CoI-values may vary largely since they depend on economic situation, the GDP share going to the health sector and the structure and size of the health system in that particular region.

A number of studies have collected data on people's willingness to pay for a reduction in their risk of death -it is important to note that it is not lives being valued, but a reduction in risk; observable also when someone e.g. accepts a riskier job but with higher wages- or other adverse health outcomes[83]. This integration of economics with health science requires matching as closely as possible the starting point of the valuation analysis to the health end point - such as a health response (e.g. a symptom day or an increase in mortality risk) or a health consequence (e.g. a hospitalization or bed-disability day). To provide an overview, Table 3.1 contains unit values for air pollution health outcomes as used in several major studies or models taken from Davis et al., who also offer a lucid and in depth discussion of the credibility and uncertainties of the willingness to pay methods within the framework greenhouse gas mitigation[83].

The values for mortality risk, chronic lung disease risk, and acute symptoms all are derived from a willingness-to-pay approach that may be thought of as measuring the full value to the individual of reducing the risk or the symptom. The other values are however only partial, mainly relying on cost of illness techniques. They are meant to capture the more severe manifestations of either acute events or chronic states and may, without proper adjustments, double count WTP benefits or provide significant underestimates of the WTP to reduce such effects. Although such CoI estimates are sometimes multiplied by a factor to bring them up to a WTP estimate so as to eliminate such underestimation, 'the evidentiary basis for the generality of this adjustment across endpoints is quite weak' [83].

Since within this document the primary focus is on the assessment of the environmental burden of disease, we will not deal here with all the conceptual and methodological issues and uncertainties involved in the monetary valuation of health impacts. However, we think it useful to provide at least a first indication of the environmental health costs in monetary terms and therefore of potential benefits of possible interventions. Because the environmental burden of disease has been expressed in DALYs, a monetary value per unit burden of disease would be required. Unfortunately, no WTP value for such an aggregate measure of health loss has yet been derived. Since a disease burden of one DALY is by definition equal to the full loss of one year of healthy life, the WTP value for one DALY might be tentatively estimated through deviding the WTP value for mortality by the average number of years lost with each death. The relation between DALYs and WTP methods remains to be studied and uncertainties such as differences in dimensions measured can not be ruled out. The same counts for the cost of illness approach. CoI values per unit burden of disease have not yet been studied. We assume that CoI-values based on health care costs might be correlated to some extent with the morbidity part of the burden of disease (the Years Lived with Disability), but much less so with the mortality part (Years of Life Lost). Since often only data on total DALYs are published, this causes an extra reason to regard calculating the environmental cost of illness as proposed above as rather tentative.

Table 3.1 Comparison of unit values used in several major studies or models (in $1990; reproduced from Davis et al[83]).

	US - EPA[a]			US - TAF[b]			Canada - AQVM[c]			Europe – ExternE[d]
	Low	*Central*	*High*	*Low*	*Central*	*High*	*Low*	*Central*	*High*	*Central*
Mortality	1560000	4800000	8040000	1584000	3100000	6148000	1680000	2870000	5740000	3031000
Chronic Bronchitis	-	260000	-	59400	260000	523100	122500	186200	325500	102700
Cardiac Hosp. Admissions	-	9500	-	-	9300	-	2940	5880	8820	7696
Resp. Hosp. Admissions	-	6900	-	-	6647	-	2310	4620	6860	7696
ER Visits	144	194	269	-	188	-	203	399	602	218
Work Loss Days	-	83	-	-	-	-	-	-	-	-
Acute Bronchitis	13	45	77	-	-	-	-	-	-	-
Restricted Activity Days	16	38	61	-	54	-	26	51	77	73
Resp. Symptoms	5	15	33	-	12	-	5	11	15	7
Shortness of Breath	0	5.3	10.60	-	-	-	-	-	-	7
Asthma	12	32	54	-	33	-	12	32	53	36
Child Bronchitis	-	-	-	-	45	-	105	217	322	-

Notes:

a. *Low and high estimates are estimated to be 1 standard deviation below and above the -mean of the Weibull distribution for mortality. For other health outcomes they are the minimums and maximums of a judgmental uniform distribution (US-Environmental Protection Agency. The benefits and costs of the clean air act1990 to 2010. USEPA Report nr. EPA-410-R-99-001).*

b. *Low, central, and high estimates are given respective probabilities of 33%, 34%, and 33% (Air Quality Valuation Model Documentation, Stratus Consulting for Health Canada).*

c. *Low and high estimates are the 5% and 95% tails of the distribution (Tracking and Analysis Framework, developed by a consortium of U.S. institutions, including RFF).*

d. *Uncertainty bounds are set by dividing (low) and multiplying (high) the mean by the geometric standard deviation (2) (ExternE. Externalities of energy, vol.7. EU,1999).*

4. Environmental health impact in the OECD

4.1 Estimating the environmental burden of disease

The burden of disease in a certain population, or the health status of a population, is often characterized through mortality, life expectancy, disease prevalence and incidence etc. As discussed in chapter 3, these measures do not provide an overall picture of a population's state of health. A recently developed composite measure of the burden of disease, the disability-adjusted life years (DALYs) however, expresses different diseases and their detrimental consequences to both quality and quantity of life into one measure – time[70,84]. One lost disability-adjusted life year (DALY) equals the complete loss of one healthy year of life. Because of its ability to combine different population health effects and dimensions, this approach appears also suitable to represent and quantify the large variety in severity and clinical significance of environmental health outcomes[71]. The following paragraphs first present estimates of the total burden of disease for the OECD and its income regions, then assess how much of the burden of disease might be attributed to environmental problems, and finally estimate the monetary costs of health lost to environmental exposures.

4.1.1 Burden of disease in the OECD

Burden of disease estimates in DALYs for 1998 were taken from the WHO World Health Report 1999[84]. This report provides DALYs (age-weighted and future-discounted only) for the world and by 11 geographical and income regions: the Americas (high and low/middle income), Africa, Europe (high and low/middle income), Eastern Mediterranean, South-East Asia (India, other low/middle income) and the Western Pacific (high income, China, other low/middle income). Causes of disease burden are divided in three major disease categories (communicable diseases, non-communicable diseases and injuries) with numerous disease subcategories. Burden of disease estimates in the World Health Report 1999 were derived trying different models dealing with missing data, a number of variables and various types of epidemiological data, resulting in a final model that produced results for 16 major (clusters of) causes of death (WHR Statistical annex p.87-88 [84]). Although these estimates are associated with many substantial uncertainties, without much doubt they represent the most comprehensive summary of health status available on a global scale. The applied DALY formula with age weights and future discount rate, and the age-specific disability/severity weights have been described in the Global Burden of Disease and Injury Series volume I[70].

Figures for OECD (high and middle income) and non-OECD were derived using the World Bank country income division[85] and OECD 1998 country population data, under the assumption that the country's or region's share in the burden of disease of its corresponding WHO and income subregion is equal to its share in the subregion's population. The total burden of disease in the OECD compared to non-OECD and the world is presented in Table 4.1. Contrasting more and less developed regions, both within the OECD and between OECD and non-OECD, clearly demonstrates that the burden of disease is considerably higher in the less developed countries, with non-OECD regions bearing nearly twice the burden of disease per capita compared to OECD countries. The health transition as described in chapter 2 can to some extent be observed when the diseases causing the loss of health are divided into three large groups, although differences between regions at a certain point in time should not be confused with historic changes and transitions occurring within the same region. The table shows that the burden of disease in less developed countries can be attributed to a larger extent to communicable (infectious, maternal, perinatal, nutritional) disorders, while in more prosperous regions health is lost primarily through the non-communicable (chronic, degenerative) diseases. At the same time, when compared in absolute terms per capita, the non-communicable diseases cause approximately the same burden of disease for all regions.

Table 4.1 (Environmental) Burden of Disease in OECD and the World

	OECD			non-OECD	World
	high income	*lower income*	total	total	total
Population in millions (%)	884 (80% of OECD)	224 (20% of OECD)	1 108 (19%)	4 797 (81%)	5 905 (100%)
Burden of Disease (in DALY/1000 cap)	120	190	134	258	235
Communicable diseases	*8 (7%)*	*41 (22%)*	*15 (11%)*	*115 (44%)*	*96 (41%)*
Non-communicable dis.	*97 (81%)*	*115 (60%)*	*101 (75%)*	*101 (39%)*	*101 (43%)*
Injuries	*14 (12%)*	*34 (18%)*	*18 (14%)*	*42 (16%)*	*38 (16%)*
Environmental Fraction	1.4-4.3%	3.7-6.7%	2.1-5%	8-12%	7.4-11%

Note: OECD lower income countries: Czech Republic, Hungary, Mexico, Poland, Turkey.
Sources: OECD[6], WHO [84], World Bank[85]; data edited by RIVM.

4.1.2 Estimating the environmental burden of disease in the OECD

Table 4.1 also presents by region the fraction (with lower and upper limits) of the burden of disease that might be attributed to unfavorable environmental conditions, based on the attributtable fraction for a number of assumedly environment related diseases (see below, Table 4.2 and Table 4.3). World-wide estimates can be up to 11% of the total burden of disease, while the environment related health losses within the lower income OECD region can still be as high as 6.7%. Differences in environmental fraction of the burden of disease between high and lower income areas are again substantial.

The following paragraphs describe in more detail how the environmental fractions of the burden of disease of selected diseases were derived, show the difference in size and nature between richer and poorer countries of the world and finally give the etimated environmental burden of disease within the OECD (Table 4.3)

The fraction of the total burden of disease that might be attributed to detrimental environmental exposures was estimated as follows. To give a robust indication of environmental disease burden on the level of the OECD, we used the World Health Report 1999[84] burden of disease estimates for the most important disease categories (causing more than 2% of burden of disease in developing countries). For each category of diseases we made an explicit assessment of the environmental attributable fraction. As briefly discussed in par. 3.3.2, attributable environmental risk refers to the fraction of disease that is eliminated if environmentally exposure was reduced to the lowest feasible level. Of course this lowest feasibly level can not always be defined very sharply as it may depend on available technology, degree of development etc[51]. Its limits are somewhere between plausible or conceivable and feasible defined as the most favourable level observed. We will avoid in depth discussions on whether attributable fraction refers to etiological, excess or rate fractions, future disease burden or past exposures. Our purpose is simply to come up with a rough estimate of the fraction of disease that will be avoided by feasible and conceivable reductions of environmental exposures[86]. We accept the fact that attributable fractions added up may account for an attributive percentage well above 100%, appreciating the multi-causal nature of disease aetiology, and the interaction (or interdependency) between different causes. We calculate the attributive fraction, presuming no other preventive measure have been taken (which would reduce the environmental attributable fraction).

Using GBD-estimates we implicitly assume that environmental exposure attributable cases are similar to general cases with respect to duration, survival and disease burden. In some cases, in particular exposure to air pollution and noise, the effect of environmental exposure on health is only measured in epidemiological studies as indicators of disease aggravation, such as hospital admission, daily mortality or medication use. Here we calculate two extreme possibilities: either we presume the environmental factor as causal (although from a medico-philosophical point of view difference between disease initiation and aggravation is difficult) or we only take years lived with disability into account (reflecting the aggravation of possibly pre-existing burden).

Whenever possible we used the epidemiological concept of attributable risk as a function of relative risk and exposure. Relative risks were taken from the literature, preferably recently published, adequate quantitative reviews. Exposure levels were derived from international reports, if relevant a distinction was made between levels in the less and the more developed world. Where good epidemiological data were non-existent we relied on published estimates, often based on geographical difference in disease prevalence.

Health impact assessment, especially regarding regional disease burden involves large uncertainties, quantitatively as well as qualitatively. Of many exposure response relationships even causality is still a topic of fierce discussion due to the many sources of (residual) confounding and bias in standard epidemiological research. Other uncertainties comprise:

- the transferability of risk ratios from one population to another (differences in the susceptibility of the populations, base-line risk, in some cases extrapolation of animal assay results to humans)
- the concentration and composition of pollutant mixtures (e.g. particle composition and size)
- differences in local behaviour, time activity patterns and (thus) exposures
- exposure measurement error (e.g. density, distribution of air pollutant monitors)[36].

To reflect these large uncertainties we define our AR-estimates in fairly broad classes with a lower and an upper estimate: <1%, 1-5%, 5-10% or 5-20%, etc. The next paragraphs briefly describe the current state of science with respect to the selected environment related diseases and come up with robust estimates of attributable fractions finally summarized in Table 4.2.

4.1.3 Disease specific estimates of environment attributable risk

Acute respiratory infections

Acute respiratory infections include infections of upper and lower respiratory tract, such as pneumonia, and Otitis media. On a global scale these diseases represent one of the largest proportions of total disease burden. Epidemiological studies on respiratory health of children show elevated outdoor air pollution levels may increase the prevalence of upper and lower respiratory symptoms fractions ranging from 1 to 3% per increase of 10 μ/m^3 PM_{10}[87,88,89,90]. An impressive series of time series analyses performed world-wide, show an increase in daily pneumonia mortality and morbidity (emergency hospital admission) associated with particulate as well as ozone air pollution ranging from 1 to 3% per 10 μ/m^3 PM_{10}. In dept statistical analysis of available data reveals this elevation of mortality is not just due to harvesting among the old and very weak, accelerating death with only a couple of days. In contrary, these findings probably reflect an influence of air pollution on airway susceptibility (infection risk) and disease progression and prognosis[91,92]. Analogously, epidemiological studies, primarily concerning young children have revealed an effect of indoor air pollution on respiratory health. Indoor air pollutants such as environmental tobacco smoke, NO_2 (from unvented heat appliances, solid fuels), dampness may increase prevalence and incidence of lower respiratory infections with 7-20%[93,94,95,96,97,98]. In the less developed world indoor pollution levels may be extremely high due to burning of unprocessed bio-mass. Therefore Smith and co-workers estimated indoor air pollution attributable fractions up to 50% of acute respiratory infections in regions of Asia and Africa[99,100,101,102].

Perinatal and maternal conditions, congenital abnormalities
Perinatal conditions linked with environmental factors may include low birth weight, associated with (indoor) air and noise pollution (<5%), sudden infant death syndrome due to ETS (10-25%)[103,104]. Poor housing conditions may affect the health of the mother and the new-born child. Furthermore, there are indications that intra-uterine and breast milk exposure to persistent organic pollutants, such as dioxin and PCB's, may affect neurological development of young children (e.g. mediated through thyroid metabolism). Maternal conditions are linked to environmental conditions through poor household conditions (crowding, chill, indoor air pollution, poor ventilation, drainage: 1-5%). Congenital anomalies are another environmental health concern, as a number of chemicals have been shown to induce teratogenic responses in experimental animals. However, similar responses in humans are not documented (apart from rubella infections, ≤ 1%). As low birth weight is an important factor in perinatal mortality we estimate the environmental fraction to be between 1 and 5%.

Diarrhoea
Dhiareal diseases primarily affect young children and are closely related to environmental factors of poor sanitation, public hygiene and access to clean water and safe food. Estimates of the fraction associated with environmental conditions are as high as 80-90%, based on variation between different regions in disease burden[39,105].

Sexually transmittable diseaes
Sexually transmittable diseases, such as HIV have no obvious relation with environmental factors. One might argue that land use developments, environmental disruptions and 'global village' travelling behaviour provide ample opportunities for microbes and viruses to switch from animal to human hosts.

Cancer
Lung cancer is by far the most important neoplasm in terms of disease burden, ranging from more than 10% of total cancer burden in low and middle-income countries to around 20% in the high-income countries)[84]. Most lung cancer is caused by tobacco smoking (AR: 80-90%)[106], there are several established relations with environmental factors, such as indoor radon (AR: 3-10%)[107], environmental tobacco smoke (1-5%)[108], indoor and outdoor air pollution (AR: fine particles, PAH, 4-10%)[71,109,110,111].

Especially in developing countries stomach cancer is the next most important neoplasm. There are weak toxicological indications that high nitrate concentrations in drinking water may affect gastrointestinal cancer risk as the may be converted into nitrosamines, a family of highly carcinogenic compounds. However, recently Heliobacter pyloris infection was identified as a very important risk factor, as it induces chronic superficial gastritis, which untreated will persist for decades, leading to ulcers and ultimately to stomach cancer. In developing countries H. pyloris infection is quite common. Infection is most probably facilitated by poor sanitation and crowding. As living conditions improved in the developed world, the rate of H. pylori infection has decreased substantially. In the same era stomach cancer incidence decreased and is now far down on the list. (AR: 20-50%)[112,113]. There are weak indications for associations between environmental exposure to radiation (including electromagnetic fields), and/or some widely used chemicals such as benzene and the incidence of leukaemia, and related neoplasms of the blood and lymph system[114,115,116]. However, epidemiological studies lack consistency. Furthermore, however tragic the individual cases, these neoplasm are very rare and from the public health perspective constitute only a very minor disease burden.

In the developed world breast cancer has gradually become one of the most important cancer in terms of health loss. Among the established risk factors are early menarche, late menopause, no pregnancy or late childbearing, prolonged hormone replacement therapy, higher socio-economic status and obesity. Most of these appear to be associated with hormone status, and long term internal exposure to estrogens and other (sex) hormones. Several authors have been pointing at persistent organic compounds (organochlorines), such as dioxins, PCB’s and certain pesticides, ubiquitously present in the environment to be involved in breast cancer genesis. These chemicals may interfere with hormone metabolism, for instance by mimicking estrogenic bioactivity. However, empirical evidence is scant and inconsistent. Furthermore the estrogenic potency of these POP’s appears to be much weaker than endogenous sex hormones, even weaker than constituents in normal vegetables[117,118,119]. The attributable risk would most probably not exceed 3%. The relation between exposure to (artificial) sunlight (UV) and skin cancer is probably causal. Of course exposure depends very much on life-style and contemporary fashion. Nevertheless a small proportion of skin cancer incidence, including the very fatal melanoma’s, can be attributed to ozone layer depletion increasing the amount of UV reaching our bare skin: 1-5%. It has to be noted that the most prevalent types of skin cancer (basal and squamous cell carcinomas) cause very little fatality and only relatively mild disease burden[120,121,122].

Child cluster
Most childhood infectious diseases, such as measles, neonatal tetanus, poliomyelitis, diphtheria and pertusis are preventable by vaccination. National immunisation programs will reduce the disease burden, which is still huge in the developing world (around 15% among children). However, transmission of these diseases, in particular measles, tetanus and pertusis, is largely associated with poor living conditions, crowding, safe drinking water and food. According to WHO improvement of housing and environmental conditions could contribute 5-10% to the reduction of disease burden associated with child cluster diseases[8,123].

Depression
Mental disorders, ranging from mild anxiety and depressive states to severe schizophrenia, are a growing public health concern. At this moment they account for more than 10% of total burden of disease, and projections suggest depression will become the second leading cause of disease burden in the next decades, right after ischaemic heart disease[39,124]. Although some chemical pollutants are known to interact with the psycho-neurological system (lead, mercury, carbon monoxide, toluene, organophosphorous pesticides), it is assumed here mental condition is primarily affected by the quality of the (local) environment, including noise and odour pollution, poor industrial safety, lack of social coherence and spatial quality (crime, population density, urban stress). Several spatial analyses on the level of neighbourhoods in large urban areas demonstrate a consistent association between poor spatial and environmental quality on the one hand and unfavourable perceived health and a negative perception of liveability in neighbourhoods. However empirical studies on the

association between high-level noise exposures around airports and hospital admission for psychological disorders are scant and inconclusive. Therefore, here we assume the attribution of environmental quality is modest (AR: 1-5%)[8].

Malnutrition

The disease burden estimate for malnutrition includes only disease associated with nutritional deficiencies, such as minerals (iron, iodine), proteins, and vitamins. The influence of malnutrition on incidence and prognosis of other diseases is not encompassed. Here it is assumed that environmental conditions, such as land degradation and soil pollution, have only a minor impact on availability and quality of foods (AR: 5-10%)[8].

Ischaemic heart disease

There is ample empirical evidence for an association between air pollution (e.g. particulates, ozone and indoor ETS) and ischaemic heart disease. Studies statistically analysing the association between day-to-day variations in air pollution levels and disease specific mortality and morbidity (hospital admission) show a consistent increase in disease manifestations ranging from 1 to 5% at higher pollution levels (roughly 1% (0.5-1.5) per 10 $\mu g/m^3$ increase). These air pollution attributable elevations in recorded morbidity and mortality may at least be interpreted as aggravation of pre-existing disease symptoms leading to (increased) medical consumption and, in some cases, death due to cardiac arrest. In other words, we may interpret these acute responses to air pollution as an indicator of increased, aggravated morbidity burden. However, recent analyses cast doubt on the initial assumption that day-to-day variations in mortality and morbidity events were merely the result of ‘harvesting’. Schwartz and co-workers revealed most of the cardiovascular mortality occurred out of hospital. Application of complex statistical techniques (‘distributed lag-times’) revealed the extent of lifetime lost would in general exceed three to four months. Furthermore, in several studies an association was found between high levels of $PM_{2.5}$ and reduced heart rate variability (a known risk factor for arrhythmia and sudden death), thus providing a biological mechanism linking cardiovascular mortality with air pollution[125,126,127]. Other study results suggest a systemic effect of particulate air pollution on immune status (inflammation) and blood dynamics (plasma coagulation)[91,92,128,129].

Results of three cohort studies in the US indicate the effect of outdoor air pollution (sulphates, particulates, ozone) on cardiopulmonary disease incidence might even be structural, affecting survival. Preliminary results of two European cohort studies in France and the Netherlands appear to confirm these results. Comparing most with least polluted cities, the US-studies indicate that the air pollution attributable fraction might range up to 5-10% for an increase of 10 $\mu g/m^3$ PM_{10}[130]. Indoor air pollution studies have shown that spousal exposure to environmental tobacco smoke leads to a similar increase of IHD risk. Ecological studies in less developed parts of India and Nepal have recorded very high IHD mortality rates, apparently due to high levels of indoor pollution associated with (unvented) burning of solid, unprocessed fuels[100]. Until new epidemiological insights emerge 15% is a reasonable upper estimate of attributable risk. A number of studies suggest an association between prolonged exposure to high levels of residential noise (traffic and aircrafts) and several manifestations of ischaemic heart disease (hypertension, hypertensive-use, GP-visits, Angina pectoris, Ischaemic heart disease diagnosis, cardiovascular accidents). Attributable fractions would be somewhere between 1-5%[131]. Considering these risk estimates (and a range of PM_{10} levels within the OECD from 20-60 $\mu g/m^3$) we propose an environmental AR for cardiovascular disease ranging from 5-15%.

Malaria
Malaria contributes significantly to global burden of disease, of course especially in the developing world (Africa). The disease burden associated with Malaria and a range of other vector-borne diseases is still increasing and might be unfavourably influenced by greenhouse-like climate changes. As nearly all malaria is related to environmental conditions, including land and water management, we apply an attributable fraction estimate of 70-80%[8].

Cerebrovascular disease
Reports of time series analysis indicate a link between air pollution and cerebrovascular morbidity and mortality. Based on analogy with risk actors such as smoking, and diet we assume the association to be roughly similar to time-series analysis with respect to ischaemic heart disease (AR: 5%).

Chronic respiratory cluster (COPD & asthma)
Chronic bronchitis and asthma cause the bulk of disease burden in this category. Asthma prevalence is highest among children and young adults and its incidence appears to be affected by indoor air quality (e.g. dampness, house dust mite and fungus allergen, AR: 20%). An association between outdoor (particulates) and indoor (e.g. ETS) air pollution and asthma morbidity is evident (symptoms, medicine use, GP and/or emergency room visits, hospital admission). Although it is unclear whether this concerns only aggravation of existing disease or initiation as well, most authors assume air pollution exposure affects susceptibility throughout life[88,90]. Chronic bronchitis is most prevalent among older people (often an asthma diagnosis eventually leads to chronic bronchitis at older ages). Cigarette smoking causes most chronic bronchitis, occupational exposures may also play an important role. However, among non-smokers chronic respiratory symptoms are clearly associated with high level of indoor and outdoor air pollution. The American cohort studies suggest a structural effect of long term exposures to air pollution on respiratory disease and survival (5-15%). Some studies in the developing world suggest an attributable risk of 50% among older women of lower socio-economic status due to the use of unvented wood-stoves. Furthermore, acute respiratory infections in earlier life, which are also associated with air pollution, may affect the risk of chronic bronchitis (AR: 5-15%).

Road traffic accidents
There is obviously some association between traffic accidents and environmental conditions, e.g. structure and density of urban areas (layout and hierarchy of road systems and residential areas), but good estimates are lacking (5-10%).

Tuberculosis
Tuberculosis may have important risk factors from the household environment, such as crowding, chilling and indoor air pollution. Of course these factors are very dependent on socio-economic factors, such as income and education (5-10%).

Estimates for disease burden and environment attributable risk in high and low and middle income countries are summarised in Table 4.2.

Table 4.2 Burden of Disease contribution and estimated Environment Attributable Fraction of environment related diseases in low and middle income and high income regions.

	% BoD low and middle income	environmental fraction (%)	% BoD high income	environmental fraction (%)
Acute respiratory infections	6.6	10-20	1.4	5-15
Perinatal conditions	6.2	1-5	1.9	1-5
Diarrhoea	5.7	80-90	0.3	80-90
STD/HIV	5.5	0-1	0.9	0-1
Cancer	5.1	1-5	15.0	1-5
Child cluster	4.4	5-10	0.4	1-5
Depression	4.0	1-5	6.5	1-5
Malnutrition	3.4	5-10	0.9	1-5
Ischaemic heart disease	3.3	5-20	8.8	5-15
Malaria	3.1	70-80	0.0	-
Cerebrovascular disease	2.9	1-5	4.8	1-5
Chronic respiratory disease	2.9	5-15	3.4	5-15
Road traffic accidents	2.7	5-10	4.2	5-10
Maternal conditions	2.5	1-5	0.4	1-5
Tuberculosis	2.2	5-10	0.1	5-10
Congenital anomalies	2.1	0-1	1.8	0-1

Using the estimated attributable fractions, Table 4.1 shows the differences between the richer and poorer regions of the world regarding health and (environmental) disease. The figure conveys several important messages. First, the upper axis shows that of the higher burden of disease in less developed regions a substantially larger proportion is affecting the very young. The percentage of the burden of disease borne by children below 5 years of age were based on data for the Established Market Economies vs non-EME [70]. Second, on the lower axis, it shows that the diseases causing most of the burden of disease in lower income countries often belong to the category of communicable and -to a large extent- potentially eradicable diseases. Finally, it shows that the environmental burden of disease in higher and lower income regions concerns a quite different set of diseases.

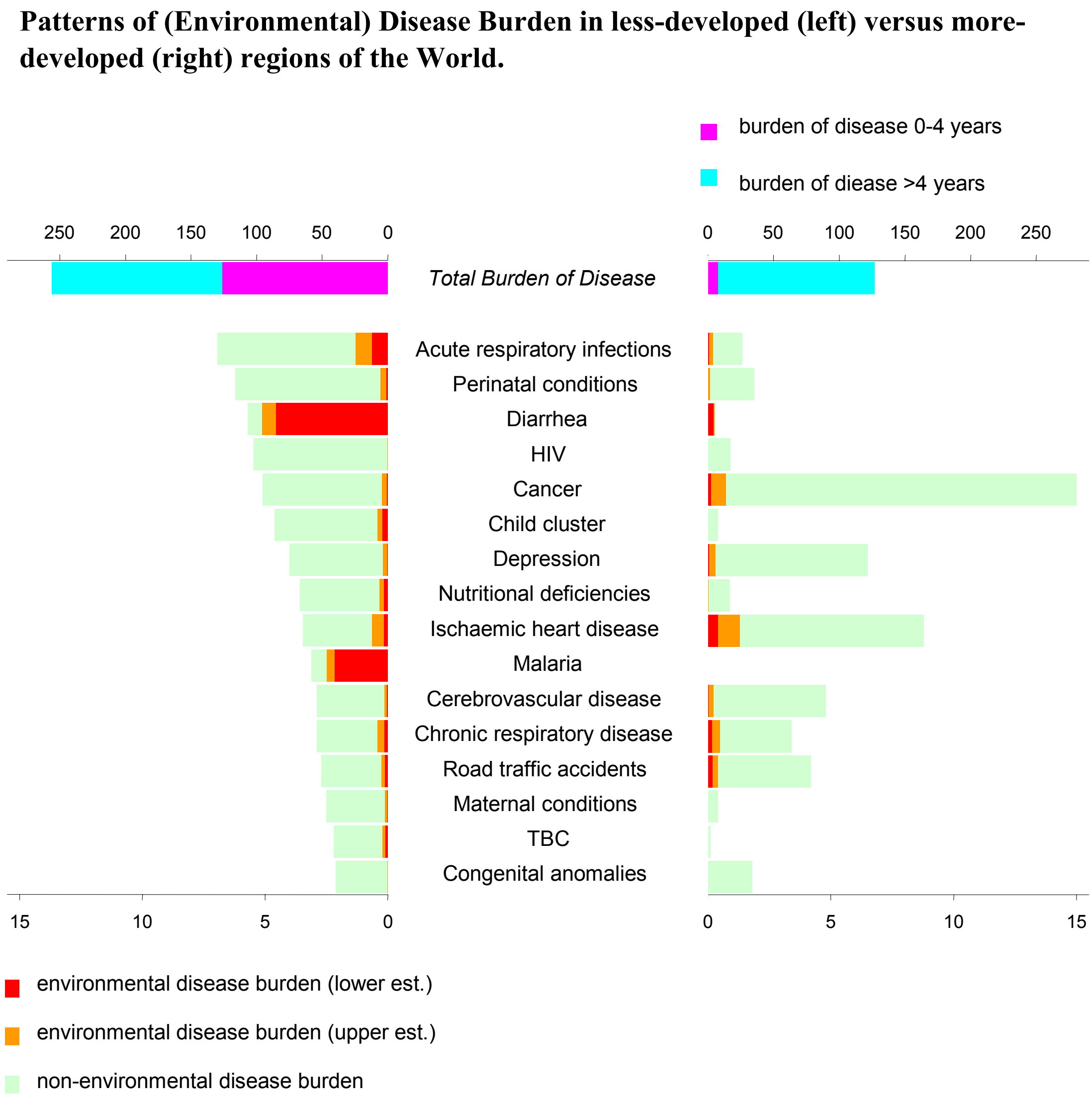

Figure 4.1 Patterns of (Environmental) Burden of Disease by Income.

Applying the environment attributable fractions from Table 4.2 to the OECD region and the corresponding burden of disease estimates for the selected environment related diseases based on the data in the World Health Report[84], finally produces Table 4.3. Fractions for the high income regions were used to avoid overestimation and because the OECD non-high income countries all belong to the higher middle income countries.

Table 4.3 Environmental Burden of Diseases in the OECD region (in thousand DALYs).

OECD	*high income*			*lower income*			*total*		
Environment related disease (category)	Burden of Disease	Environm. fraction		Burden of Disease	Environm. fraction		Burden of Disease	Environm. fraction	
		lower	*upper*		*lower*	*upper*		*lower*	*upper*
Acute respiratory infect.	1 400	70	210	1 500	75	230	2 900	150	440
Perinatal conditions	1 900	19	97	1 900	19	95	3 800	38	190
Diarrhea	290	230	260	1 300	1 000	1 200	1 600	1 300	1 400
HIV/AIDS	1 000	0	10	510	0	5	1 520	0	15
Cancer	16 900	170	840	3 400	34	170	20 200	200	1 000
Childhood diseases	340	3	17	540	5	27	880	9	44
Depression	8 600	86	430	2 800	28	140	11 400	110	570
Malnutrition	880	9	44	970	10	48	1 800	18	92
Ischaemic heart disease	9 310	470	1 400	3 100	150	460	12 400	620	1 900
Malaria	0	0	0	26	18	21	26	18	21
Cerebrovascular disease	5 100	51	260	2 000	20	99	7 100	71	360
Chronic respiratory dis.	3 600	180	540	990	49	150	4 600	230	690
Road traffic accidents	4 500	220	450	1 700	86	170	6 200	310	620
Maternal conditions	360	4	18	750	7	37	1 100	11	55
Tuberculosis	140	7	14	470	23	47	600	30	60
Congenital abnormalities	1 900	0	19	860	0	9	2 700	0	27
Sum	56 200	1 500	4 600	22 700	1 600	2 900	78 900	3 100	7 500
All diseases	106 000	1.4%	4.3%	42 600	3.7%	6.7%	148 400	2.1%	5.0%

4.2 Estimating environmental health costs

Using a burden of disease approach allows to express a wide range of health outcomes into one measure (the DALY) whatever their cause or nature is. As discussed in paragraph 3.5, to be able to prioritize interventions and estimate their expected benefit-cost ratios, health effects of both environmental degradation and interventions should be compared on the same basis as financial costs and benefits in other areas. Howevere, there is no simple way of attributing a monetary value to adverse health outcomes, since there is no proper market for goods like health. Some methods used here are estimating environmental health costs based on real expenditures on health, either the total expenditures or using disease-specific data; regarding loss of productivity as an estimate for the value of one year of lost life; and finally assesssing the environmental health costs by the amount people are willing to pay for avoiding unfavorable health outcomes.

4.2.1 Environmental burden of disease costs as estimated by total health expenditure

A first estimate of the environmental health costs -and therefore the potential benefits of environmental interventions- can be obtained by combining the previously estimated environmental burden of disease with data on the total expenditure on health for the OECD regions (from the OECD-database [6]). Total expenditure on health includes all medical costs: personal health care services, medical goods dispensed to out-patients, services of prevention and public health, health programme administration and health insurance, investments into medical facilities, education and training of health personnel and costs of health research and development. Since the environmental burden of disease has been expressed as a fraction of the total burden of disease, a crude estimate of the monetary costs of the environmental burden of disease can be achieved by applying this fraction to the total expenditure on health. Interventions reducing the environmental burden of disease might be assumed to lower these expenditures with a corresponding proportion. This can be interpreted as an estimate of the monetary value of the health benefits of the intervention. Table 4.4 displays the necessary data. The environmental burden of disease in for example the OECD high income region ranges up to 4.3% of the total burden of disease. This same percentage applied to the total expenditure on health (expressed as a percentage of the Gross Domestic Product) results in an upper limit of roughly a half percent of the GDP in the OECD high income region (4.3% of 10%) that may be attributed to environment induced health problems.

Table 4.4 Health Expenditure and Environmental Burden of Disease in the OECD.

OECD	*high income*	*lower income*	*total*
Burden of Disease (DALY/1000cap)	120	190	134
Environmental Fraction (% total BoD)	1.4-4.3%	3.7-6.7%	2.1-5%
GDP (PPP) - in billion US$	20 811	1 656	22 467
- $ per capita	23 700	7 700	20 500
Total expenditure on health (% GDP)	10%	4.9%	9.9%
Environm. Health Costs - billion US$	31-94	3-5	46-112
- $ per capita	35-106	13-24	42-101

Notes: PPP=Purchasing Power Parity. Economic data for 1997 [6], (environmental) burden of disease from Table 4.1.

Discussion

It is important to take into account some considerable flaws of this crude approximation when comparing the outcomes within the different regions and with monetary data concerning other sectors and issues. First, the environmental burden of disease is not evenly spread over all disease categories, but concentrates in a few. Since health expenditures may differ much between categories, applying a fixed percentage to estimate the environmental health costs may introduce considerable over- or underestimation. Second, expenditures on health hardly include the social and economic costs of mortality; within a burden of disease approach however mortality and subsequent lost years of life often comprise a substantial fraction. The environmental health costs as estimated here might therefore be seen as a lower limit. Finally, lower income countries combine a much higher burden of disease with much lower health expenditures and GDP. The approach as applied above results therefore in environmental health costs which are much lower than in high income countries, both per capita and in absolute terms. Likewise, a reduction of (environmental) burden of disease would yield much smaller benefits. This unwantedly suggests that investing in reduction policies in these countries is less worthwhile than in high-income regions. One way to interpret this might be to perceive the lower health expenditures as an undesirable gap in health care (expenditures). A reasonable estimate of the monetary benefits of reducing the (environmental) burden of disease in lower income countries should therefore also include otherwise necessary investments in the health care system. Besides that, when seen from an equity perspective the combination of significantly higher (environmental) burden of disease together with a considerably lower GDP and a lower percentage of GDP as health expenditure, may be enough to justify efforts aiming at improving the environmental conditions of the people living in these regions.

4.2.2 Estimating costs of environmental morbidity and mortality burden separately

When estimating environmental health costs using the total expenditure on health as above, mortality and morbidity are treated in the same way as they are combined into one measure for the total burden of disease. Separating morbidity and mortality with their contribution to the burden of disease (resp. YLD and YLL) allows for a more detailed assessments of the costs involved. Regarding morbidity, expenditures on health care may be assumed to be related to the morbidity fraction of the burden of disease in DALYs. Since health expenditures might vary significantly between disease categories, including data on disease-specific costs may lead to more appropriate estimates of the environmental costs and potential benefits. These data were however available for a number of high income OECD-countries only. For mortality costs no cause specific data were available. Therefore, lost productivity per year and published willingness-to-pay values were used to estimate the costs of environmental mortality.

Dividing DALYs into YLD and YLL

First, to be able to estimate the costs of environmental morbidity and mortality separately, the (environmental) burden of disease estimates must be separated into resp. Years Lived with Disability and Years of Life Lost. Since the currently used World Health Report[84] only contains DALYs, we applied the division into YLDs and YLLs as used in the Global Burden of Disease Study (volume 1, tables 7 and 8)[70], leading to Table 4.5.

Table 4.5 Division of the Total Burden of Disease of environment related diseases within the OECD high income region.

Disease	Burden of disease (in thousand DALYs)	Division of DALYs into YLD and YLL (based on the GBD-study[70])	
		YLD/DALY	YLL/DALY
Acute respiratory infections	1 400	0.11	0.89
Perinatal conditions	1 900	0.13	0.87
Diarrhea	290	0.90	0.10
HIV/AIDS	1 000	0.25	0.75
Cancer	16 900	0.13	0.87
Childhood diseases	340	0.76	0.24
Depression	8 600	1.00	0.00
Malnutrition	880	0.86	0.14
Ischaemic heart disease	9 300	0.09	0.91
Malaria	0	-	-
Cerebrovascular disease	5 100	0.31	0.69
Chronic respiratory diseases	3 600	0.70	0.30
Road traffic accidents	4 500	0.31	0.69
Maternal conditions	360	0.93	0.07
Tuberculosis	140	0.09	0.91
Congenital abnormalities	1 900	0.45	0.55
TOTAL	55 300	0.37	0.63

Environmental morbidity costs based on disease-specific costs of illness

Second, morbidity costs per environment-related disease had to be estimated. Unfortunately, the OECD-database[6] does not contain a disease-specific distribution of the above used total expenditure on health. Therefore data on direct costs of illness were used instead, which refer however only to the costs of health system activities to prevent, diagnose and treat health problems. Recent data on direct costs of illness (total and specified for all of the 17 main disease categories of the International Classification of Diseses (ICD); in local currencies) were available for 9 out of 29 OECD-countries for various years between 1990 and 1996[6]. Comparing for each country the calculated sum of the costs over all disease categories with the given total costs of illness and with the total expenditure on health, suggested important data anomalies and omissions for two countries, leaving the following to be included in the calculations: Australia (most recent data: 1993), Canada (1993), (West-) Germany (1990), Japan (1993), Netherlands (1994), Spain (1993) and Sweden (1991). All data were made comparable by expressing them as percentages of the national GDP (applying Purchasing Power Parity (PPP) factors) for the appropriate years. Inflation was not taken into account. The country estimates were then combined into one estimate for each ICD disease category by averaging. Since the total expenditure on health by definition includes more costs than direct costs of illness alone, the difference between the total expenditure on health and the sum of the disease-specific costs of illness -both averaged over the seven countries- was ascribed to all ICD disease category according to their contribution to the sum of the direct costs of illness. Combining the disease-specific health costs (estimated as a percentage of GDP) with the total GDP (PPP, in US$) of the OECD high income region, lead to an estimate of health costs per ICD disease category and, together with the data in Table 4.5, to health costs per YLD, as shown in Table 4.6. Health costs (and subsequently environmental health costs) have been calculated for the OECD high income region only, because all countries for which disease-specific health cost data were available belong to the high income category according to the World Bank division.

Table 4.6 Health costs per Years Lived with Disability (the morbidity fraction of burden of disease) for ICD-categories.

ICD-category	Burden of Disease (1000s)	YLD/DALY	Fraction of Health Costs	1000$/YLD
Infectious and parasitic diseases	4 200	0.34	0.024	36
Neoplasms	16 900	0.12	0.067	70
Endocrine, nutritional and metabolic diseases	5 200	0.70	0.042	25
Diseases of the blood and blood forming organs	-	-	0.006	-
Mental disorders	24 900	0.94	0.137	13
Diseases of nervous system and sense organs	142	0.98	0.065	990
Diseases of circulatory system	19 100	0.17	0.170	120
Diseases of respiratory system	7 910	0.63	0.085	37
Diseases of digestive system	5 190	0.56	0.085	64
Diseases of genitourinary system	1 170	0.46	0.050	200
Complications of pregnancy, childbirth and the puerperium	360	0.93	0.034	220
Diseases of the skin and subcutaneous tissue	134	0.00	0.024	-
Diseases of the musculoskeletal system and connective tissue	4 440	0.95	0.073	37
Congenital anomalies	1 870	0.45	0.007	17
Certain conditions originating in the perinatal period	1 940	0.13	0.007	56
Symptoms, signs and ill-defined conditions	-	-	0.056	-
External causes of injury and poisoning	12 400	0.33	0.069	37
All categories	*106 000*	*0.50*	*1*	*41*

Notes: Total expenditure on health in the OECD high income region 2153 billion US$ (Purchasing Power Parity, 1997). Burden of disease estimates for Diseases of the blood and for Symptoms etc. were not given in WHR 1999[84]. Burden of disease estimates for each ICD-category were calculated by slightly adjusting the WHR estimates, since the classification of diseases used in burden of disease calculations slightly differs from the ICD-approach. The high costs per YLD for 'Diseases of nervous system and sense organs' is possibly caused by the exclusion in the burden of disease estimate of a number of diseases each low in public health impact, but together leading to considerable expenditures.

The next step was to combine the calculated disease specific health expenditures per YLD with the estimated morbidity fractions (based on Table 4.5) of the environmental burden of disease caused by each of the selected environment related diseases (from Table 4.2). This results in a disease category specific estimate of morbidity related health costs, as shown in Table 4.7. Finally, total environmental morbidity costs were calculated by summing over the selected diseases, resulting in approximately 25 to 70 billion US$ for the OECD higher income region (appr. 1.2-3.4 % of total health expenditures within this region, see Table 4.4).

Table 4.7 Health costs for selected environment related diseases in the OECD high income region.

	Environmental Morbidity Costs (1000$)	
	lower estimate	upper estimate
Acute respiratory infections	290	870
Perinatal conditions	140	720
Diarrhea	7 500	8 400
HIV/AIDS	0	92
Cancer	1 500	7 400
Childhood diseases	90	470
Depression	1 100	5 400
Malnutrition	190	930
Ischaemic heart disease	4 600	14 000
Malaria	0	0
Cerebrovascular disease	1 800	9 200
Chronic respiratory diseases	4 600	14 000
Road traffic accidents	2 600	5 100
Maternal conditions	720	3 600
Tuberculosis	24	47
Congenital abnormalities	0	140
Total	*25 billion US$*	*70 billion US$*
Total per capita	*28 US$/capita*	*79 US$/capita*

Note: based on cost of illness data from the OECD-database[6]; Burden of disease estimates from WHR 1999[84]; division in morbidity and mortality fractions from GBD[70].

Environmental mortality costs

The costs of mortality related to environmental degradation were estimated in two ways. First, the economic value of a year of lost life may roughly be estimated as the contribution to the Gross Domestic Product during that year; a crude value of a year of (lost) life was therefore obtained by dividing the yearly GDP by the size of the population in that year. For the OECD richer region this lead to a value of 23,700 US$ (PPP, 1997) per year of life and multiplied by the environmental burden of mortality (in Years of Lost Life) to an estimate of environmental mortality costs of 22-71 billion US$ (25-80 US$/capita).

Alternatively, willingness-to-pay values may be used, incorporating indirect (eg. social) costs as well. Measuring people's *willingness-to-pay* (WTP) for an environmental benefit or avoiding an adverse outcome (the welfare cost to an individual) has provided a range of values for a number of environment-related health outcomes (see Table 3.1). WTP values for avoiding one death were available for mortality of persons younger than 65 years of age and for persons over 65, resp. ranging from 2.5-9 million US$ with 4.5 as the central value and from 1.9-6.8 with a central value of 3.4 million US$ (1994; based on various US and Western European studies, as summarised by Aunan et al.[132]).

To be able to estimate environmental mortality health costs based on the previously calculated environmental burden of disease and its mortality fraction, the WTP value for 1 death had to be reworked to a WTP value for 1 DALY (equal to 1 YLL, as discussed in paragraph 3.5). Since in the used burden of disease approach death is represented through the number of subsequently years of life lost, these years of lost life (YLL) of each death had to be calculated, using the remaining life expectancy at the time of death. Applying available Dutch life tables (1994[133]) as an approximation for the OECD high income region, average YLL per death were estimated at 46.7 and 10.9 years, resp. for persons dying below and over 65 years of age. The WTP value per death divided by the number of years of life lost per death results in a WTP value per YLL of 0.2 million US$ (with central WTP value and averaged over the values for death below and over 65 years of age; lower and upper WTP values give 0.11 and 0.41 million US$ per YLL resp.). Unlike the disease specific health costs approach above, this value per unit burden of disease is the same for all diseases, since it was based on a disease independent endpoint, *i.c.* death. This dollars per YLL value was then combined with the estimated mortality fraction of the environmental burden of disease in DALYs, resulting in an estimate of the environmental mortality health costs in the OECD higher income region, based on a willingness to pay approach.

Table 4.8 Environmental Mortality Costs (using a Willingness-to-Pay approach) in the OECD high income region.

Costs of environmental mortality burden	Applied willingness-to-pay value central	lower	upper
-billion US$	190-615	105-340	380-1230
-US$ per capita	215-695	120-390	430-1400

Table 4.9 finally combines the different approaches into one picture, showing the environmental health costs for the OECD high income region as estimated by the different methods. The lowest estimates were obtained while only taking into account the direct health costs. A somewhat higher estimate, valuing morbidity burden based on costs of illness and adding the valuation of the mortality burden with its loss of contribution to the GDP, includes more costs, but still only values economic aspects of lost health and life. The highest estimates were obtained again with valuing the morbidity burden with costs of illness, while for the mortality burden a willingness to pay method was applied, which can be thought of including all welfare costs, assumedly still excluding costs borne collectively[83,134]. Table 4.9 also indicates the potential benefits of environmental pollution reduction interventions; a rather small reduction of 5% of the environmental burden of disease could result in a benefit of 1.5 up to 35 billion US$ (1.7 - 40 US$/capita) in this region.

Table 4.9 Environmental Health Costs in OECD high income region by 3 methods (lower and upper estimates).

Approach	Environmental health costs		Potential benefits of a 5% reduction in environmental BoD	
based on:	*billion US$*	*US$ / capita*	*billion US$*	*US$ / capita*
Total Expenditure on Health	31 - 94	35 - 106	1.5 - 4.7	1.7 - 5.3
Disease-specific Costs of Illness *plus* GDP/capita	47 - 141	53 - 160	2.4 - 7.1	2.7 - 8
Disease-specific Costs of Illness *plus* Willingness To Pay (central)	215 - 684	243 - 774	10.7 - 34.2	12.2 - 38.7

Notes: For explanation of the approaches see text. Population OECD high income region 884 million.

Discussion

It has to be emphasized that such approximations of environmental health costs are based on a number of mostly implicit assumptions, of which the ones underlying the burden of disease methodology were discussed in an earlier chapter. Using costs of illness to estimate the costs of the environmental morbidity burden suggests that weights for disease severity or loss of quality of life and durations are related to the actual care costs of a disease; an assumption not implausible, but also not (well) studied. In addition, cost of illness figures refer to a certain year, while the DALY methodology ascribes all lost health and/or life to the year of incidence. For some diseases the relation between prevalence and incidence appears stable enough, but for others this may lead to extra estimation uncertainty (see also Melse et al. for a more thorough discussion of this point[75]). The same cautions count for estimating the costs of the environmental mortality burden. Economic productivity and willingness to pay each refer to a specific set of dimensions, of which it is not clear or well studied how these are covered by the estimation of Years of Yife Yost in the DALY or similar methods[134]. Willingness to pay methods imply that there is more to life than economic productivity. Such methods appear to embrace the individual utility as the ultimate good and finally aggregate these individual values into value for the society as a whole. A public health impact approach on the other hand emphasizes the perspective of the policymaker allocating public resources, ideally following outcomes from political and societal discussion in which the value for the society is not by definition the same as the aggregated individual values. The DALY indeed aggregates from the individual to the societal level, but applies rather welldefined and transparent methodology, open for discussion. The question what is measured (*ic*. health) and how, and whether that is what is desired and necessary, appears therefore easier to answer to a larger extent than with WTP-methods and the like. The results of the monetary valuations as presented here are for these reasons only meant as a first indication and should be used prudently; more adequate estimates require much work to be done.

5. Selected environmental health issues and monetary studies

5.1 Selected environmental health issues

The following paragraphs highlight some issues concerning environment and health that have gained considerable scientific and public attention.

5.1.1 Chemicals

Exposure to chemicals has often been associated with unfavorable effects upon human health, assumedly causing various types of cancer and other severe health effects. Marked by Rachel Carson's early *Silent spring*[135] the seventies and early eighties were an era of great concern about the 'chemical world' among politicians and scientists as well as the general public. Emerging highly sensitive analytic techniques revealed that rapid post-war industrial developments had caused the omnipresence of a myriad of man-made (or processed) chemical compounds in the environment and the food chain. Toxicologists have been developing sensitive tests to investigate potentially adverse properties of chemicals, initially primarily aiming at detecting carcinogenicity. Conservative mathematic models predicted that exposure to environmental chemicals might contribute significantly to cancer disease burden[136].

In the nineties the initial 'chemophobia' has faded. Governmental regulations forced down emissions of many hazardous substances. Even the very persistent organochlorines, such as dioxins and PCB's, are now slowly disappearing from the food chain in Europe, as shown by multi-centre breast milk analyses[137]. New chemicals or applications are thoroughly evaluated before bringing them to the market. In general exposure levels of most potentially hazardous chemicals are falling in the US and EU, although pesticide and fertiliser use remain high, especially in the US [11,138]. Furthermore, the validity of many sensitive toxicological assays with respect to low real-life environmental exposures was challenged on pathological grounds, especially as many human studies, even in extreme conditions, often failed to demonstrate clear health responses[59,139]. However, there is still some cause for alertness e.g. with respect to mixtures or very specific physiological action, such as hormone disruption, interference with the immune system, reproduction or development. The enhanced susceptibility in ageing populations may also become an important issue[140,141].

5.1.2 Specific groups

Differences in (environmental) health within populations can be vast. Even in a relatively egalitarian society as the Netherlands, individuals from the highest socio-economic groups live around 3.5 years longer compared to the lowest group, while their healthy life expectancy is even almost twelve years higher[13]. Geographical differences in health status are highest on the level of residential neighbourhoods, in particular in large cities[25]. Deprived urban areas in high income countries share high unemployment levels, low incomes, unfavourable working and living conditions together with lower health status. Within Europe, the number of such urban neighbourhoods with an accumulation of conditions detrimental to health has increased since 1989[142], while in Northern America poor or racially-distinct communities appear disproportionally affected by pollution and resource degradation and many rural and indigenous populations experience water quality problems[11]. Life-style factors, such as smoking, alcohol abuse and intake of fat, fruits and vegetables also appear to be unequally distributed across socio-economic groups. Environmental risk factors often aggrevate existing disease conditions; the already ill and weak such as the elderly are therefore especially vulnerable groups with the latter showing 'harvesting' mortality related to episodes of air pollution[143].

Social-demographic health differences may in part also be due to selection processes, as people in poor health are excluded from education and employment, in particular with respect to geographically determined health differences. In the last decades people from higher-income groups have in many cases moved out of the older neighbourhoods (often in the vicinity of industrial zones) to suburbias and dormitory towns with better housing, working and transport conditions and a higher quality of the local environment, leaving the more socially disadvantaged groups behind[144]. There are also indications of a more direct influence on health status from socio-economic status, since mortality rates tend to be lowest in countries that have smaller income inequalities and thus lower levels of relative deprivation[145,146].

Within the less-developed countries children under five are still amongst the most vulnerable groups. Communicable diseases, which are strongly related to environmental conditions such as clean water supply, sewage disposal systems etc., cause 85% of infant deaths in developing countries, while an under-five child in a low income country has a 12 times higher chance of dying from these than a child in developed countries[7]. Of the total burden of disease, in the established market economies about 10% falls within the 0-4 years, compared to 50% in the rest of the world[84].

5.1.3 Changing global environment and effects upon human health

Mean annual earth temperature have increased since 1990 by 0.4-0.7 °C, most likely caused by the emissions of greenhouse gases (mainly CO_2, CH_4 and N_2O) expected to increase even much further in the near future[147]. Although such a rise in temperature of less than a degree may not sound alarming, it is appearently changing the earth's climate and major health effects are to be expected. Direct effects would include altered mortality and morbidity composition from a change in exposure to thermal extremes and the physical hazards of a changed pattern of floods, storms and droughts. Indirect health effects include an increase in the spectrum and incidence of infectious diseases, such as malaria and dengue fever. Climate change may also foster the spread of cholera via the warming-induced proliferation of coastal and estuarine planktonic organisms within which the cholera vibrio naturally shelters and multiplies[12]. Other indirect effects concern a declining agricultural production because of changes in growth season length with the worst consequences expected in the southern hemisphere, while increased variability in temperature and rainfall will enlarge harvest failure risks. Although there is much uncertainty and hotly debated -recent multivariate malaria modelling eg. suggested only minute changes due to counteracting effects of temperature, humidity etc.[148]- when applying the so-called 'precautionary principle', ample attention is required. Besides these global environmental health effects, economic globalization also increasingly interconnects populations everywhere in many ways and enlarges human mobility enormously in speed and volume. This might enhance a fast dissemination and geographical redistribution of pests and pathogens, such as HIV, the rat-borne hanta-viruses and new strains of bacterial meningitis[12].

The global rise in temperature has lead to international concern mainly aiming at reducing greenhouse gas emissions through policies such as the Kyoto-protocol, which is however still largely unratified by the industrialized countries. Some argue that from a public health protection point of view, it might be more effective and efficient though to invest in more conventional technologies and measures such as improved sanitatation, greater dissemination of anti-mosquito nets, vaccination programs etc.[43]. Seen in a larger perspective however, disrupted carbon and nitrogencycles may be the first signs of destabilisation of global life supporting systems, caused by the unprecedented consumption of energy and materials increasing the risk for a 'planetary overload'[12]. Proposed reductions of greenhouse gas emissions and improved public health protection within this perspective are therefore necessary but short-term steps on the road to a more sustainable, equitable and healthy development.

5.2 Selected studies concerning environmental health costs and benefits

5.2.1 Health costs due to road traffic-related air pollution

Road traffic related air pollution is at present a major environmental risk factor, especially in OECD high income countries. Health costs related to this type of pollution have recently been studied for three OECD countries in preparation for the 1999 WHO Ministerial Conference on Environment and Health, as summarized by Seethaler et al.[149]. This study provides numbers of adverse health outcomes for total and road transport particulate air pollution and applies a willingness-to-pay approach. With these data, we calculated the burden of disease by multiplying the number of cases with duration and severity weights as used in Hollander et al.[71] and in Melse et al.[75]. Depending on whether it is assumed that premature death following small particulate matter (PM_{10}) exposure is a matter of assumed harvesting effects of the already severely ill and weakened or an independent cause of death, estimates of duration and severity weight can range from 0.5 to 7.5 years and from 0.7 to 1 [71,134]. Burden of disease estimates therefore also show a considerable range. A hypothetical reduction in particulate matter exhaust due to road transport is here assumed to result in an equal reduction of disease burden in DALYs, and thus the same percentage reduction in monetary costs and potential benefits. Table 5.1 shows that a 5% reduction in road transport particulate reduction could then result in a benefit of 1.5 billion US$ or 21 US$ per capita (in this study equal to over 1000 premature deaths and 1250 bronchitis cases averted).

Table 5.1 Health Costs due to Particulate Matter Air Pollution in 3 OECD-countries.

	Austria, France and Switzerland combined	
	total particulate pollution	*road transport*
Specific adverse health outcomes		
Premature death (% of total)	6.1 %	3.3 %
Chronic bronchitis cases (% of total)	9.0 %	4.9 %
Burden of Disease (% of Total BoD)	1.4-4.5 %	0.7-2.4 %
Monetary WTP-valued environmental health costs		
In billion US$ (% of GDP)	56 (3.5 %)	30 (1.9 %)
Per capita (US$)	765	411
Benefits if PM_{10} air pollution were reduced with 5%		
Total in billion US$	2.8	1.5
Per capita (US$)	38	21

Notes: This study applied a relatively low WTP-value for a prevented death (appr. 1 mill. US$). Average PM_{10}-exposure levels (ug/m^2) total 23.6, of which due to road transport 8.7 (37%). Combined population 73.4 million. Burden of Disease calculation based on Hollander[71] and Melse[75]. Results originally in Euro (1.13 US$ 1997).

5.2.2 Costs and benefits of environmental interventions

Making an environmental intervention economically worthwhile depends not only on the benefits but of course also on the costs involved. Evidence from some recently implemented or planned interventions suggest that environmental interventions can be financially sound. A reduction of particulate matter air pollution in Santiago, Chile for instance showed an overall benefit-cost ratio of 1.7 (1.2-2.4; see Table 5.2) with health effects valued by averted costs of health care[150]. The benefit estimate is even a lower bound estimate since it only includes benefits from reduced particulate emissions, and because it only values avoided health care costs benefits, omitting possible productivity, ecosystem and aesthetic benefits. Another example is given by an energy saving program in Hungary, expected to produce benefits in various sectors exceeding costs by 3 up to 16 times, while applying a rather low WTP-value[132].

Table 5.2 Benefits (avoided Health Care Costs) and Costs of controlling Particulate Matter Pollution in Santiago, Chile (in million US$).

Pollution Source	*Benefits*	*Costs*	*B/C Ratio*
Fixed Sources	27	12	2.4
Gasoline Vehicles	33	14	2.4
Buses	37	30	1.2
Trucks	8	4	1.8
Control Strategy (total)	105	60	1.7

In two recent comprehensive studies funded by respectively the United Nations (1998)[151] and the European Commission (1999)[152], costs and benefits were analysed of various scenarios for the reduction of long-range transboundary air pollution, one of the largest environmental challenges in (late-)modern OECD. Both studies included the region of the European Union (15 countries) region and incorporated effects upon health (morbidity and mortality), besides effects on materials, crops and ecosystems. Estimates of health benefits were derived through various methods of willingness to pay.

The UN report states that ‘health effects are dominated by the chronic impact of fine particulates on mortality’ (p. 5). Becaue of uncertainties and debate concerning the quantification of these effects, three different estimates of health benefits were provided. Air pollution effects on mortality due to acute short-term exposure were estimated with lower and upper limits, and also as the combination of the acute mortality high estimates with the estimates for effects on mortality due to chronic exposure. Table 5.3 shows that for the EU

Table 5.3 Benefits and Costs (in million US$) of moving from emission reductions under the current reduction plan/legislation scenario to those for the maximum technically feasible reduction scenario.

	Benefits			*Costs*
	crops + materials + morbidity +:			
	acute mortality		acute mortality (high)	total
	low	high	+ chronic mortality	
EU15	36 551	57 207	202 006	34 714
non-EU15	20 538	33 315	176 666	39 017
Total Europe	57 089	90 522	378 672	73 730

Note: Two different willingness to pay methods were used: VOSL (value of a statistical life) for acute mortality, VOLY (value of a life year) for chronic mortality. Results originally in ECU (1.13 US$ 1997).

benefits exceed costs already at the lowest estimates of health effects, while for the whole of Europe this is the case for the upper estimate of acute mortality, still excluding disputable chronic mortality effects.

The study funded by the European Union investigated annual cost and benefits up to 2010 of moving from the stricter of current legislation and reduction plans to low, central and high ambition scenarios for the reduction of acidification, eutrophication and ground level ozone. Instead of the three different health benefits estimates as used in the UN study, here impacts were divided into five types, based on the results of a confidence ranking exercise: group I: materials damage (excl. paint damage), N-fertilisation on crops, acute effects on mortality, morbidity (excl. restricted activity days and chronic bronchitis); group II: restricted activity days, paint damage, ozone and SO_2 effects on crops; group III: acute effects on mortality, chronic effects on bronchitis; groupIV: ozone effects on forests, chronic effects on mortality; and group V: chronic effects on mortality, changes in visibility. Benefits were expressed cumulatively, seqentially adding together results for the five groups. Table 5.4 compares annual costs and benefits for each scenario using the more conservative monetary valuation method, showing that for all scenarios the least certain of the quantified effects are not needed for benefits to exceed costs.

*Table 5.4 Comparison of A*nnual *Benefits and Costs (in million US$) for scenarios reducing Acidification, Eutrophication and ground level Ozone*[152]

Scenario	*Cumulative annual benefits*					*Annual costs*
	Group I	+II	+III	+IV	+V	
low ambition	520	2 710	3 840	12 400	13 600	4 750
central ambition	723	3 390	5 090	19 200	19 200	8 480
high ambition	1 040	4 630	7 570	30 500	32 800	18 100

Notes: Two different willingness to pay methods were proposed (VOSL-value of a statistical life, and VOLY-value of a life year), the authors preferring the more conservative VOLY-approach. Results originally in Euro (1.13 US$ 1997).

Table 5.5 summarizes the results of both studies -although differing in a number of aspects- suggesting that large scale environmental policies can be economically worthwhile, with benefits generally exceeding costs.

Table 5.5 Benefits and Costs of Air Pollution Reduction Scenarios in the European Union.

From current reduction plans and legislation to:	Benefits	Costs	B/C-ratio
♦ *maximum* technically feasible reduction, *total* figures [151]			
- in billion US$	47-202	35	1.4-5.8
- in US$/capita	125-540	93	
♦ central ambition scenario reducing acidification, eutrophication and ground level ozone, *annual* figures [152]			
- in billion US$	11-35	8.5	1.4-2.3
- in US$/capita	32-51	23	

Notes: Lower benefits estimates: first row: average of 'acute mortality' estimates; second row: average of impact groupings III and IV (see text). Both studies use a form of WTP to monetary value health effects (UN[151] *uses VOLY and VOSL, EU*[152] *uses VOLY). EU population appr. 375 million, GDP (PPP) 7690 billion US$. Results originally in ECU/Euro (1.13 US$ 1997).*

6. Implications for environmental health policy

Combining insights and evidence from previous chapters, Table 6.1 presents a tentative and schematic picture of how within higher income OECD regions, the current environmental burden of disease might be attributed to major environmental exposures and to corresponding sectors. Such connecting of environmental issues with accompanying health losses to economic sectors promises a better understanding of the relation between economic trends and developments and health, but only as far as the environment is the intermediary variable; as mentioned earlier, the relations between health and economy are numerous and complex. Moreover, sectors often overlap to some extent and not all of the environmental health losses can be unequivocally assigned to a certain sector.

Table 6.1 Schematic and tentative presentation of the relative contribution of issues and sectors to the Environmental Burden of Disease in higher income OECD.

Environmental issue	Contribution to environmental BoD	Contribution to each issue by sectors				
		Transport	Energy use	Industry	Agriculture	Housing
Air pollution	♦♦♦♦	++	+			
Noise	♦♦♦	+++		+		
Indoor environment	♦♦			+		++
Food- and waterborne	♦♦			+	+	
Road traffic accidents	♦♦	+				
Chemicals	♦			+	+	
UV-radiation	♦			+		
Climate change	as yet unknown, expected very high	++	++	+	++	+

Notes: The number of 'plusses' is only meaningful within each row..

Important environmental causes of lost health in developed countries are air pollution and noise problems, to which mainly the transport and the energy production sectors contribute. While the future health impacts of climate change are as yet unknown, they are expected to be significant through the advent of new and known infectious diseases (malaria, cholera, aids, Ebola etc), loss of life through increased extreme weather conditions, etc. (see 5.1.3). Still fast growing world population, the ageing of western populations and its effects upon the use of resources and energy, and the globalisation of western economic high consumption system can be expected to increasingly disrupt the biosphere's life supporting systems, of which climate change and the loss of biodiversity are already observable signs. It appears that unprecedented large-scale environmental changes are reshaping human health risks[12,40]. Current levels of population health have been acquired through economic progress often detrimental for the environment. More sustainable development seems therefore urgent and inevitable both within as well as outside the OECD, in order to sustain and enhance the world's population health. Besides 'greening' technologies and decoupling economy and environmental pressure, this may also include a shift from produced assets and natural resources to human and social capital[5].

Since within the burden of disease approach different health effects are expressed into one measure comparison between the various outcomes appears possible. Hence estimations of burden of disease can be utilized in setting intervention priorities and assessing intervention efficacy. Expanding Table 6.1 to the whole of the OECD and adding related adverse health outcomes, Table 6.2 tries to prioritize diseases, issues and sectors, based on the previously estimated amounts of burden of disease attributed to these.

Table 6.2 Tentative prioritization of diseases, issues and sectors from an Environmental Burden of Disease perspective.

	OECD	
	high income	*lower income*
Diseases	cardiopulmonary diseases cancer depression	communicable diseases cardiopulmonary diseases cancer
Issues	air pollution chemicals noise/liveability	sanitation/food/housing air pollution chemicals
Sectors	transport industry/agriculture housing	public hygiene/housing transport/energy industry/agriculture

Within the OECD's more developed regions diseases such as cancer, supposedly showing a rather direct cause-effect relationship with the modern industrial era chemicals, are still important. Others however have gained significance or are on the way. The burden of disease attributed to the group of cardiopulmonary diseases and depression primarily concerns aggrevation of pre-existing disorders through complex and multicausal mechanisms, instead of more directly causing disease. Related environmental issues are both global (transboundary air pollution) and local (noise and urban liveability), pointing to the transportation sector as the first target for intervention. The group of communicable diseases is still important issues in the OECD's lower income countries, pressing for further improvement of social and living conditions. The prevalence of cancers calls for continuing regulation efforts of environmental risks related to industry and agriculture, while the cardiopulmonary diseases are primarily related to the transportation as well as the energy production sector.

Obviously prioritisation of environmental issues and interventions not only depends on the size of the (health) impacts, but on a number of other inputs as well, such as feasibility, monetary costs, expected benefit-cost ratios and necessarily involves political deliberation. A first indication of environmental monetary health cost has been given, but this should not be used for disease-specific recommendations due to its tentative nature. Although the avoided direct costs of environmental illness approach almost certainly underestimates real intervention profits, even from this point of view considerable opportunities for benefits exceeding costs can be envisaged. As shown in previous chapters, there is sufficient evidence from other studies to believe that the potential monetary benefits of environmental interventions are substantial. Benefits may often exceed costs, sometimes even without including the monetary valuing of the health benefits. Benefit-cost ratios however depend on the shape of benefit and cost functions, which may differ considerably between phases in the health and risk transition and between regions and environmental issues. Vaccination against child diseases will for instance show benefits easily exceeding costs in developing countries with low vaccination levels and high diseases numbers, but may not be economically worthwhile in developed countries with opposite patterns.

Finally, although data on (environmental) burden of disease, health costs and potential benefits are often associated with many substantial uncertainties, all evidence rather strongly suggests that measures to improve the environmental situation can be very worthwhile investments. This holds not only because of the intrinsic value of the environment and human health, but is also valid when expressed in monetary terms.

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